UNEP

UNEP RISØ CENTRE
ENERGY, CLIMATE AND SUSTAINABLE DEVELOPMENT

PROMOTING LOW CARBON TRANSPORT IN INDIA

Assessment of Motor Vehicle Use Characteristics in Three Indian Cities

PROMOTING LOW CARBON TRANSPORT IN INDIA

Assessment of Motor Vehicle Use Characteristics in Three Indian Cities

Authors

Prof. Dinesh Mohan
Transportation Research & Injury Prevention Programme
Indian Institute of Technology, Delhi

Mr. Rahul Goel
Indian Institute of Technology, Delhi

Dr. Sarath Guttikunda
Division of Atmospheric Sciences, Desert Research Institute, Reno, USA

Prof. Geetam Tiwari
Indian Institute of Technology, Delhi

June 2014

UNEP Risø Centre on Energy, Climate and Sustainable Development
Technical University of Denmark

This publication is part of the 'Promoting Low Carbon Transport in India' project

Supported by:

Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

based on a decision of the Parliament
of the Federal Republic of Germany

ISBN: 978-87-93130-15-9

Design and production:

Magnum Custom Publishing
New Delhi, India
info@magnumbooks.org

Photo acknowledgement:

Photo credit: Yann
http://commons.wikimedia.org/wiki/File:Road_traffic,_Gwalior.jpg

Back cover photo credit: Biswarup Ganguly
http://commons.wikimedia.org/wiki/File:Traffic_Jam_-_Amir_Ali_Avenue_-_Kolkata_2012-09-18_1069.JPG

Acknowledgements

We would like to acknowledge the support received from Dr. Subash Dhar and Dr. Sudhir Sharma from the UNEP Risø Centre, and Ms. Kamala Ernest and Mr. Bert Fabian from the UNEP, at various stages of the study as well as during the project workshops and in preparation of the final report.

We would also like to acknowledge the support from Mr. Mahesh Rajput, Mr. Vijay Prajapati, Mr. Digvijay Singh, Mr. Dheeraj Swaroop, Mr. Karan Vir, and Mahesh Gaur (Indian Institute of Technology Delhi), Mr. Ravi Gadepally (iTrans Pvt. Ltd.), Ms. Kalgi Shah and Dr. Talat Munshi (CEPT Ahmedabad), and PURGE." A special thanks is also due to Ms.Surabhi Goswami for proof reading and finalising the layout of this report.

Authors

Photo credit: Biswarup Ganguly
http://commons.wikimedia.org/wiki/File:John_Burdon_Sanderson_Haldane_Avenue_-_Kolkata_2007-02-28_07232.JPG

Contents

Abbreviations

APSRTC	Andhra Pradesh State Road Transport Corporation
BS	Bharat Stage
CNG	Compressed Natural Gas
CO	Carbon Monoxide
EU	European Union
gCO2/km	Grams carbon dioxide per kilometres
GFEI	Global Fuel Economy Initiative
GHG	Greenhouse gas
km	Kilometres
km/L	Kilometres per litre
L/100km	Litres per 100 km
LGV	Light Goods Vehicles
LPG	Liquefied Petroleum Gas
mpg	Miles per gallon
MTW	Motorised two wheelers
OECD	Organisation for Economic Cooperation and Development
ppm	Parts per million
R&D	Research and Development
rpm	Revolutions per minute
sq. km	Square kilometres
UNEP	United Nations Environment Programme
US	United States
VOC	Volatile Organic Compounds

Photo credit: Biswarup Ganguly
http://commons.wikimedia.org/wiki/File:John_Burdon_Sanderson_Haldane_Avenue_-_Kolkata_2007-02-28_07231.JPG

Executive Summary

Globally, fuel efficiency of vehicles is taking centre stage within the context of climate change, public health, and reducing dependence on oil. In India, efforts are underway to formulate fuel efficiency standards for cars. In this regard, this report gives an account of fuel efficiency and other vehicular characteristics of the existing fleet in India. This information forms an integral part of understanding the status of the current fleet, as a base case. This report presents case studies of three cities in India – Delhi (the capital city), Visakhapatnam in Andhra Pradesh, and Rajkot in Gujarat. Vehicular characteristics estimated include age distribution, annual mileage driven and number of in-use vehicles. For this, surveys have been carried out at fuel stations in the three cities. Age distribution of cars and motorised two-wheelers (MTWs) in the three cities show that more than two-thirds of the vehicles are less than 5 years old, and almost all of the vehicles are up to 15 years old– with an average age of less than 5 years. Estimates of average annual mileage show that they are different for the three cities. The estimated average annual mileage (± 95% confidence interval) of cars in Delhi is 12,199 ± 435 km, and the average annual mileage of MTWs in Delhi, Visakhapatnam and Rajkot are 12,804 ± 349 km, 9,238 ± 576 km and 7,255 ± 325 km, respectively. When classified by model years, data from the three cities show that the annual mileage of cars and MTWs reduce non-linearly with increasing age, following a logarithmic or exponential function. In the case of cars, the average annual mileage reduces by 42% in the initial 10 years, and in the case of MTWs, it reduces by 30-45%. Average fuel efficiency of petrol cars in the three cities varies from 14.9 to 16.2 km/L. For diesel cars, the fuel efficiency varies from 16.3 to 17.4 km/L for engine displacement less than 1,600 cubic centimetres (cc), and 10.8 to 11.9 km/L for engine sizes greater than 1,600 cc. For MTWs, the range of fuel efficiency is 48.5 to 52.3 km/L. It is estimated that the actual number of in-use cars in Delhi lies in the range of 51-59%, while for MTWs the range is 40-45% of the total registered vehicles in their respective categories in year 2012. The proportions of in-use MTWs in Visakhapatnam and Rajkot are 44%and 51%, respectively. The vehicular fleet in Indian cities is much younger than in richer nations of the European Union and in the US, where the average age of cars is 8 years and 11 years, respectively. Data from Delhi and Rajkot indicate that average fuel efficiency of MTWs is reducing for the newer model years, possibly due to the induction of high-powered motorcycles in the fleet. In the case of cars, the data shows that the penetration of bigger cars is reducing the fuel efficiency of the diesel car fleet. Estimates of in-use vehicles from the three cities show that the cumulative registration number of

vehicles from government sources overestimates the existing fleet of cars and MTWs by 100% and 150%, respectively. The fuel efficiency of new cars in India is up to 20-30% more than the global average, owing to its high share of small cars. In addition, India has the lowest average weight of vehicles in the world, based on a study by Global Fuel Economy Initiative. The high growth rate of vehicles, in Indian cities, with a comparatively smaller existing fleet means that fuel efficiency standards will have their desired effect at a much faster rate than most developed economies of the world. It is estimated that, due to the high growth rate of vehicles, the replacement rate of fleet is also high. As a result, when implemented in India, new fuel standards will lead to 90% of vehicles conforming to those standards within 15 years.

1. Background

1.1 Context

This study is part of a larger research project on "Promoting Low-Carbon Transport in India", a major initiative of the United Nations Environment Programme (UNEP), hereafter referred to as the Low Carbon Transport (LCT) project in this document. The overall context in which the LCT project has been undertaken is the critical role of the transport sector in reducing greenhouse gas (GHG) emissions. India is currently the fourth largest GHG emitter in the world, although its per capita emissions are less than half of the world's average. Further, India's transport sector accounts for 13% of the country's energy related CO_2 emissions. It is evident that opportunities exist to make India's transport growth more sustainable by aligning development and climate change agendas.

The key objectives for the LCT project are as follows:

1. Delineating an enabling environment for coordinating policies at the national level to achieve a sustainable transport system

2. Enhancing capacity of cities to improve mobility with lower CO_2 emissions

The LCT project has been endorsed by the Ministry of Environment and Forests (MoEF), Government of India. It is being jointly implemented by the UNEP Risø Centre, Denmark (URC); Indian Institute of Technology, Delhi (IIT-D); Indian Institute of Management, Ahmedabad (IIM-A); and CEPT University, Ahmedabad.

Assessment of Motor Vehicle Use Characteristics in Three Indian Cities is one of the case studies being carried out under the LCT project. This report gives an account of fuel efficiency and other vehicular characteristics of the existing fleet in India.

1.2 Case study

Globally, fuel efficiency of vehicles is taking centre stage within the context of climate change, public health, and reducing dependence on oil. In India, efforts are underway to formulate fuel efficiency standards for cars. In this regard, this report gives an account of fuel efficiency and other vehicular characteristics of the existing fleet in India. This information forms an integral part of understanding the status of the current fleet, as a base case. This report presents case studies of three cities in India – Delhi (the capital city), Visakhapatnam in Andhra Pradesh, and Rajkot in Gujarat.

Purpose

In order to set standards for fuel efficiency, there needs to be assessments of it in the current fleet, as a base case. Since the final objective is to reduce total fuel consumed, to estimate the total consumption there is also a need to estimate vehicular usage and share of fuel type (petrol, diesel, CNG, LPG). In

India, the only sources for obtaining fuel efficiency values for vehicles are the figures published by auto manufacturers. These are based on estimates using laboratory-based standard driving cycles, which do not necessarily reflect the real-world values. Studies from around the world have established that there is a significant gap between real-world and laboratory values of fuel efficiency of vehicles, which can be more than 30%, expressed as percentage of real-world value. The gap varies over different settings, which is due to differences between laboratory and on-road conditions such as driving patterns and use of vehicle accessories. There are currently no studies available in India to estimate fuel efficiency of in-use fleet and respective vehicle usage. This study was conducted to determine on-road values of fuel efficiency for private motorized vehicles, along with other vehicular characteristics, which are necessary for obtaining estimates of fuel consumption by different vehicle types. At present it is not possible to obtain details of the vehicle fleet in use as owners are only required to pay a life-time tax when they buy a vehicle. Therefore, most vehicles remain on the register even after they have been scrapped. The official registration numbers give an idea of the cumulative number of vehicle sold over a long period of time and not hose in use at present.

Scope

The issue of fuel efficiency (expressed as kilometres per litre, unless otherwise noted) of vehicular fleet in a setting can be largely classified in two parts. First is the fuel efficiency of new vehicles, which are being added to the existing fleet. Fuel efficiency of such vehicles will depend on the availability of the latest technology in the market, the prevailing preference of vehicle characteristics by the consumers, and other vehicle standards applicable for a setting. Second is the average fuel efficiency of in-use fleet, which is a more complex estimate as it is dependent on the characteristics of vehicle models sold in the past. This also needs to account for the degradation in fuel efficiency, which occurs due to the usage of vehicles over a period of time. In this study we have used different methods to obtain estimates of the numbers and age of vehicles in use. The work involved in this study focuses on real-world fuel efficiency as per information obtained from vehicle users.

1.3 Future fuel efficiency standards

A high growth rate of vehicles in Indian cities with a comparatively smaller existing fleet means that fuel efficiency standards will have their desired effect at a much faster rate than most developed economies of the world. It is estimated that fuel standards, when implemented in India, will lead to 90% of vehicles conforming to those standards within the next 15 years. There is an urgent need to carry out user surveys in Indian cities, in order to take stock of the current fleet – in terms of fuel efficiency and vehicle usage. While most countries have studies quantifying the gap, efforts in this direction are pending in India. In order to be able to ascertain efficacy of standards, these efforts need to be carried out and repeated at regular intervals.

2. Introduction

The number of cars sold in India during the period of 2001-2011 was three times that of the 1991-2001 period. Consequently, household ownership of cars has increased from ~6% in 2001 to ~10% in 2011, (Census-India, 2012) which is still low compared to other high-income settings in the world. In India, the national import dependence for petroleum has reached more than 70%, which leads to a heavy economic burden, and vulnerability to international economics. According to the World Health Organization (WHO, 2011), India has 27 of the 100 most polluted cities in the world, of which 4 are in the top 10. Similar economic burdens and climate change issues are being experienced by many countries around the world, due to automobile use, especially those with high motorization rates. Since emissions are directly influenced by the fuel efficiency of vehicles, it has a central role in climate change mitigation strategies and reducing health effects, as well as economic burdens on national economies. In this context, the issue of fuel efficiency standards has been gaining increased attention in various settings around the world.

Internationally, many countries (including the four largest automobile markets–the United States, European Union, China and Japan) have adopted more stringent fuel efficiency standards to promote fuel-efficient vehicles, and India has started the process of doing so. In order to set standards for fuel efficiency, there needs to be assessments of it in the current fleet, as a base case. Since the final objective is to reduce total fuel consumed, to estimate the total consumption there is also a need to estimate vehicular usage and share of fuel type (petrol, diesel, CNG, LPG). In India, the only sources for obtaining fuel efficiency values for vehicles are the figures published by auto manufacturers. These are based on estimates using laboratory-based standard driving cycles, which do not necessarily reflect the real-world values. Studies from around the world have established that there is a significant gap between real-world and laboratory values of fuel efficiency of vehicles, which can be more than30%, expressed as percentage of real-world value. The gap varies over different settings, which is due to differences between laboratory and on-road conditions such as driving patterns and use of vehicle accessories. There are currently no studies available in India to estimate fuel efficiency of in-use fleet and respective vehicle usage. This study was conducted to determine on-road values of fuel efficiency for private motorized vehicles, along with other vehicular characteristics, which are necessary for obtaining estimates of fuel consumption by different vehicle types.

3. Fuel quality and vehicle emission standards in India

In the absence of mandatory fuel efficiency standards in India, other measures have been introduced to reduce vehicular air pollution over the past two decades. Table 1 shows those measures in chronological order. Between 2000 and 2010, emission standards improved from Bharat Stage I (BSI) to BSIII and up to IV in a few major cities. During the same period, the sulphur content in petrol fell from 2,000 ppm to 150 ppm, and for diesel from 10,000 ppm to 350 ppm. Cities mandating Bharat IV standards have a sulphur content of 50 ppm, even lower than the national standards. However, most measures have been implemented in a phased manner, starting from major cities followed by national level implementation.

Table 1. Chronology of vehicle emission norms and fuel quality standards in India

Year	Description
1990	First set of emission norms
1994	0.15 g/L lead in petrol (four metros)
1995	Emission norms for catalytic vehicles Unleaded petrol (four metros)
1996	Second set of emission norms 5% benzene content in petrol 0.5% sulphur in diesel (four metros and Taj, Agra)
1997	Low leaded petrol (India) 0.25% sulphur in diesel (Delhi and Taj, Agra)
1998	0.25% sulphur in diesel (metros)
1999	Unleaded petrol (NCR)
2000-2001	Euro-I equivalent (India) Euro-II equivalent for cars (four metros) Unleaded petrol (India) 3% benzene content in petrol (metro cities) 1% benzene content in petrol (Delhi and Mumbai) 0.25% sulphur in diesel (India) 0.05% sulphur in diesel (Mumbai) 0.05% sulphur in diesel (NCR) 0.05% sulphur in diesel (Chennai and Kolkata)
2005	Euro-II equivalent (India) Euro-III equivalent (seven megacities)
2010	Euro-III equivalent (India) Euro-IV equivalent (metros)

In Asia, India is lagging behind other countries in setting fuel standards for reducing the sulphur content of diesel. For instance, Hong Kong, Japan, Singapore, South Korea and Thailand have already implemented nationwide use of diesel with sulphur content of 50 ppm or less. Aside from Asian countries, the European Union has adopted Ultra Low Sulphur Diesel and the USA has mandated sulphur content of 15 ppm. Figures A1 and A2 in Appendix A show the fuel quality and emission standards in India, against global standards. One of the major barriers to India adopting more stringent emission standards (Euro V or higher) is the high sulphur content in the diesel and petrol, which is 350 ppm and 150 ppm, respectively. This is because high sulphur content in fuel gives rise to other technological constraints for reducing vehicular emissions. At such levels, sulphur inhibits the proper functioning of advanced after-treatment technologies, ranging from diesel particulate filters to lean NO_X traps that could reduce vehicle emissions by more than 90% (ICCT, 2013). Due to the prevailing regime of two parallel emission standards in India, Bharat Stage (BS) IV in major cities and BS-III in others, benefits achieved from higher emission standards are negated to some extent. This is because BS-IV vehicles requiring low sulphur fuels may fill their tanks with fuel that has higher sulphur contents, which is available outside all major cities. In addition, all the heavy vehicles plying across multiple states still only meet BS-III (ICCT, 2013).

4. International Policies

Given the rapidly increasing demand for fuel, and GHG emissions resulting from the high rate of motorisation, countries around the world have addressed this issue by establishing fuel efficiency programmes and GHG emission targets. The experience with such programmes in various settings has shown them to be among the most cost-effective tools for controlling oil demand and GHG emissions. Fuel efficiency programmes include both fuel standards and fiscal incentives to improve the energy efficiency of individual vehicles per unit of distance travelled. Fiscal incentive programmes have improved fuel economy, especially when implemented in combination with fuel efficiency standards. Incentives can be directed at improving the efficiency of the vehicular fleet, through variable registration fees or taxes, or by limiting vehicle use, through fuel taxes and road use fees. Table 2 shows such programmes from different countries (ICET, 2011).

Table 2. Measures to promote fuel-efficient vehicles

Approach		Measures/forms	Country/ region
Standards	Fuel Economy	Numeric standard averaged over fleets or based on vehicle weight-bins or sub-classes	US, Japan, Canada, Australia, China, Republic of Korea
	GHG Emissions	Grams/km or grams/mile	EU, California (US)
Consumer Awareness	Fuel Economy/GHG Emission Labels	mpg, km/L, L/100 km, gCO_2/km	Brazil, Chile, Republic of Korea, US and others
Fiscal Incentives	High Fuel Taxes	Fuel taxes at least 50% greater than crude price	EU, Japan
	Differential vehicle fees and taxes	Tax or registration fee based on engine size, efficiency & CO_2 emissions	EU, Japan, China
	Economic Penalties	Gas guzzler tax	US
Support for new technologies	R&D programs	Funding for advanced technology research	US, Japan, EU, China
	Technology mandates and targets	Sales requirement for Zero Emission Vehicles (ZEVs), PHEVs and EVs	California (US), China
Traffic Control Measures	Incentives	Allowing hybrids to use high occupancy vehicle (HOV) lanes	California, Virginia and other states in the US
	Disincentives	Banning SUVs on city streets, inner city congestion charges	Paris, London

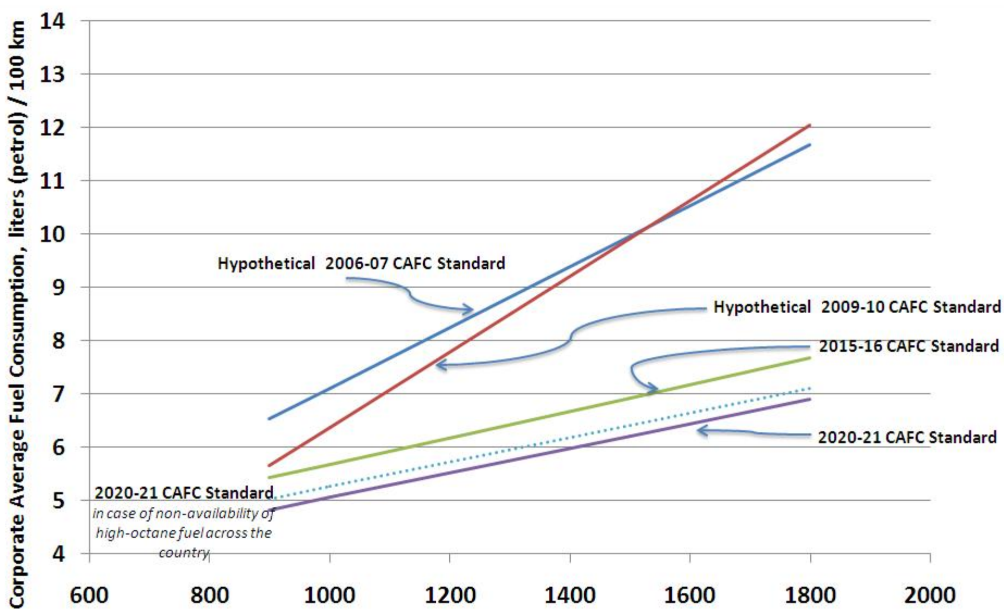
Source : ICET, 2011

China implemented the first-ever fuel consumption standards for passenger vehicles in 2004. The standards were weight-based, specifying a fuel-consumption rate limit for vehicles of a certain range of weights, and have been implemented in phases. The first phase of the standards took effect in 2005 and 2006, and the second phase in 2008 and 2009. These standards were designed to bring about fuel-economy improvements and technology-pushing effects. Auto manufacturers applied a combination of relatively low-cost technologies to their products to meet the fuel-economy requirements. As a result of the standards, the sales-weighted average fuel efficiency in China improved from 10.97 km/L in 2002 to 12.4 km/Lin 2006, representing an increment of 13% in four years. The country implemented the second phase of the standards in 2008, which led to a further increment of 3% in fuel efficiency. The slower rate of increment is attributed to the already implemented stricter standards at the end of the first phase. With the recent shift of the auto market towards heavier vehicles in China, the fuel efficiency benefits achieved from previous standards are being nullified. The third phase of the standards aims to remedy it by introducing corporate average fuel-consumption (CAFE) targets similar to those in the USA. The third phase, which has been finalized and will soon be adopted, is expected to improve fuel efficiency by another 15% by 2015 (Huo et al., 2012).

5. National Policies

In the absence of fuel efficiency standards, India has also proposed to introduce measures to provide a regulatory signal to manufacturers to continuously reduce the average fuel consumption of cars sold by them, over the next 10-year period. These measures have been proposed by the Bureau of Energy Efficiency (BEE, 2011). A two-pronged approach has been proposed for these measures: medium and long-term fuel consumption standards. The approach also introduces the labelling of all new cars that are sold in the market, with labels providing consumers information on the fuel consumption of a car model, and the relative fuel consumption of the model compared to others in the same weight.

Figure 1. Progressive evolution of corporate average fuel consumption standards



Source: BEE, 2011

The standards specify the fuel consumption norms to be met by manufacturers. Compliance with these standards would require manufacturers to invest in new technology and production lines. Consequently, they would need adequate time to redesign and retool in order to meet the standards. Therefore, the standards are being specified for the sales that occur in the fiscal years 2015-16 and 2020-21. It is anticipated that the 2015-16 standards could be met through the fine-tuning and optimization of current designs, whereas the 2020-21 standards would require complete redesigning and retooling. Figure 1 shows the hypothetical CAFC standard lines for 2006-07 and 2009-10, and the mandatory CAFC standard lines for 2015-16 and 2020-21(BEE, 2011).

Figure 2. Estimated fleet replacement curves at 5% and 10% growth in car sales for new standards introduced in 2015 and 2020

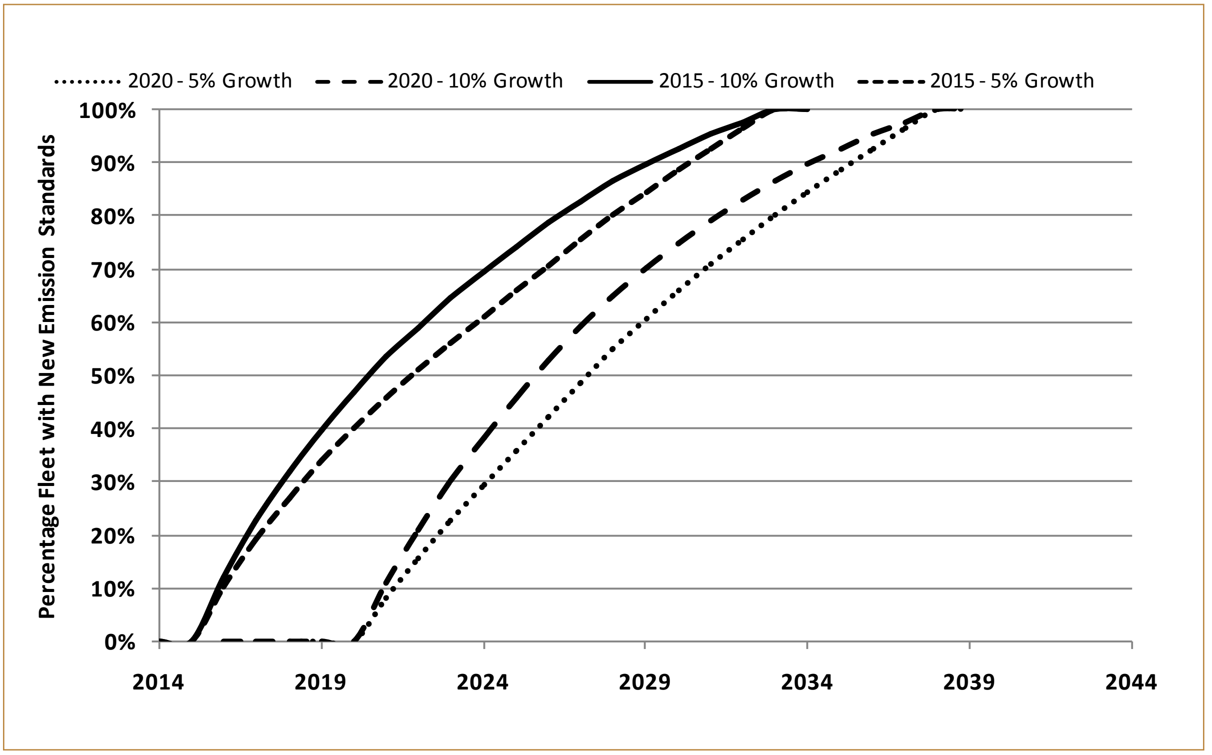


Figure 2 shows fleet replacement levels at a 5% and 10% growth rate in car sales if new standards are introduced in 2015 or 2020. These estimates indicate that fleet replacement occurs faster at higher growth rates. If new fuel efficiency standards will be introduced in 2015, then 70% of the fleet would be cleaner by 2024 at a 10% sales growth, and at a 5% sales growth in 2026. If the standards would be introduced in 2020, then the corresponding years would be 2029 and 2031. This indicates the importance of introducing more stringent standards when the growth rates are higher.

6. Factors Influencing Fuel Efficiency

The issue of fuel efficiency (expressed as kilometres per litre, unless otherwise noted) of vehicular fleet in a setting can be largely classified in two parts. First is the fuel efficiency of new vehicles, which are being added to the existing fleet. Fuel efficiency of such vehicles will depend on the availability of the latest technology in the market, the prevailing preference of vehicle characteristics by the consumers, and other vehicle standards applicable for a setting. Second is the average fuel efficiency of in-use fleet, which is a more complex estimate as it is dependent on the characteristics of vehicle models sold in the past. This also needs to account for the degradation in fuel efficiency, which occurs due to the usage of vehicles over a period of time. In terms of available information, the former is much easier to obtain, and will be discussed later. This information is readily available (though highly inaccurate) from sources like auto manufacturers or other regular publications, such as *Autocar* and web-based sources like *Carwale.com*. By weighing the fuel efficiency values with the sales share of different models, an estimate of fuel efficiency can be obtained for new fleet. By contrast, information for the latter is much more difficult to acquire, and needs to be estimated using user surveys or laboratory tests of a representative sample of vehicles in the existing fleet.

6.1. Fuel Efficiency of New Vehicles

The following are the major factors that influence the fuel efficiency of new vehicles (Brink and Wee, 2001; GFEI, 2011):

a) Power train characteristics such as engine displacement, transmission type, fuel type, engine power

b) Vehicle size, which affects air drag

c) Vehicle weight, which affects acceleration resistance

d) Driving pattern characterised by acceleration, deceleration and driving speed

e) Other factors such as use of heating, ventilation, air conditioning, and other vehicle accessories

It could be argued that fuel efficiency standards maybe one of the factors influencing the fuel efficiency of a new fleet. However, to conform to the standards, auto manufacturers will eventually make changes in one of the above-mentioned factors. In order to estimate the fuel efficiency of new fleet, it is a common practice to use values provided by auto manufacturers and weigh those values by the respective sales shares of vehicle models. However, numerous studies from around the world have shown that values provided by manufacturers, which are essentially the values obtained from laboratories using a designated driving cycle, are significantly higher than the real-world fuel efficiency experienced by in-use vehicles. For settings such as the US, Canada and Western Europe, Schipper and Tax (1994) estimated the gap to be up to 30% of the actual value during the late 1980s. Dutch and German studies estimated this gap to

be 10% and 17%, respectively, in the late 1990s (Zachariadis, 2006). Among the latest studies is the one from China (Huo et al., 2011), which compared the laboratory and real-world fuel efficiency (expressed as litres per 100 km) of 153 car models with a sample of more than 60,000 vehicles, and found that 80% of car models have a gap of 0–30%, and that 66% have a gap of 5–25%. The study also found that the gap grows with increasing difference between the average real-world speed and speed of driving cycle. It is noteworthy that, when expressed in kilometres per litre, the fuel efficiency gap, as a percentage, is higher than when it is expressed in litres per 100 km. Schipper and Tax (1994) discussed five different factors which may be responsible for the difference between laboratory and on-road actual values of fuel efficiency. They are as follows:

a) Formulae used to represent the real driving cycle under represent real-world congestion

b) Actual conditions in all parts of the cycle, such as weather and road surface, are not represented

c) Driver behaviour such as acceleration, deceleration and average speed in the real-world conditions

d) Lack of vehicle maintenance in the real-world

e) Test values fail to represent cars actually sold because tested cars are optimized for testing, and also contain more fuel intensive features (larger engines, turbo charging, etc.), which is not shown in the tests or sales weightings.

The issue of the gap between laboratory and real-world fuel efficiency values is an important one. The presence of such discrepancies will lead to highly exaggerated estimates of the fuel efficiency improvement of the fleet, attributed to fuel efficiency standards, while ground realities may be far from expectations.

6.2. Fuel Efficiency of In-use Fleet

The work involved in this study focuses on real-world fuel efficiency as per information obtained from vehicle users. Some of the major factors influencing the fuel efficiency of the existing fleet are:

a) Fuel efficiency of vehicle models of different ages

b) Fuel-mix – petrol, diesel, CNG, LPG

c) Car sales per year and retirement age of vehicles, which, together, determine the age distribution of existing fleet

d) Distance travelled by vehicles, classified by their fuel type and age

It should be understood that for a given fleet, fuel efficiency alone is not sufficient to understand the complete picture. This is because the measurement of fuel efficiency is eventually used to estimate demand of automobile fuels. To forecast this demand, there is a need to assess various vehicular characteristics, which either influence fuel efficiency or the estimate of total fuel consumption. Currently, passenger cars use four different fuels (petrol, diesel, CNG and a small share of LPG), while two-wheelers are mostly petrol driven – and both cars and two-wheelers have an almost negligible share of electric vehicles. Based

on the fuel used, the fuel efficiency of different vehicles varies significantly from one another, and the shares of fuels are changing rapidly over time due to the changing prices and preferences of consumers, and the availability of CNG. Age is another major factor that influences fuel efficiency of vehicles – which reduces with increasing age. Total distance travelled, usually expressed as the distance travelled per year and referred to as annual mileage in this study, is directly related to total fuel consumption. To understand the energy intensity of distance travelled and the effectiveness of fuel efficiency standards, the annual mileage should also be classified by the age of the vehicles as well as the fuel type.

Photo credit: Varun Shiv Kapur
http://commons.wikimedia.org/wiki/File:Delhi_Metro_and_CNG_Buses_in_Azadpur_Neighborhood.jpg

7. Three Cities' Study

This report presents vehicular characteristics from three cities in India. Table 3 gives the background statistics for the three study cities: Delhi, Rajkot and Vishakhapatnam. Delhi is one of three cities in India with a population of more than 10 million (the others are Mumbai and Kolkata), while Visakhapatnam and Rajkot are of the 34 cities with a population between 1 to 2 million (Census of India, 2011). In Rajkot and Delhi, CNG is used by passengers, as well as freight based three-wheeled scooter rickshaws and other public transport vehicles, while both types run on diesel in Visakhapatnam. Of the three cities, Visakhapatnam has no CNG vehicles.

Table 3. Characteristics of three case-study cities

City	Population (2011)	Area (sq. km.)	Per cent households owning cars (Census, 2011)	Per cent households owning MTWs (Census, 2011)+
Delhi	16,787,941	1,483	21	38
Visakhapatnam	1,730,320	534**	8*	36*
Rajkot	1,478,265	257***	10*	60*

+MTW: Motorised two-wheeler, * District level data, ** Greater Visakhapatnam Municipal Corporation

***Rajkot Urban Development Authority

+ MTW – motorised two-wheelers for urban areas at district level since city-level data is not yet published

In order to estimate the existing patterns of vehicle use in the three cities, there needs to be estimations of fuel efficiency, distance travelled (in terms of annual mileage), age distribution, as well as an estimate of the number of in-use vehicles in each city. The number of registered vehicles in Indian cities is reported to be an overestimation, as it does not take into account vehicles that have been retired or are not in use. The following is a description of the transportation scenario in the three cities.

7.1. Delhi

Delhi is the capital of India and the second most populated city in the country. Of all the major metropolitan cities in India, it has the highest motor vehicle ownership. According to Census 2011, 21% of households own at least one car, and 30% own at least one motorised two-wheeler (MTW). Bus-based public transport caters to ~27% of the total trips (RITES, 2008), most of which are served by a state-run bus system with a fleet of about 6,000 buses plying on up to ~650 routes (DIMTS, 2009). In addition, a significant proportion of road-based public transportation trips in Delhi are served by contract carriage buses operated by private owners, auto-rickshaws (both contract-based as well as stage-carriage) and mini-buses. Rail-based public transportation consists of a ~190 km metro network. Travel demand in

Delhi is not only intra-city but also has a significant share of inter-city travel because of the growth of satellite cities around it. During the last three decades, the population of its satellite cities – Ghaziabad, Faridabad, Gurgaon and Noida – grew seven times, reaching 5.3 million in 2011. This region has expanded to become one large agglomeration with a total population of ~22 million, giving rise to a high demand for travel in between these cities.

7.2. Visakhapatnam

Visakhapatnam is a coastal city on the eastern coast of India. It is the second largest agglomeration in the state of Andhra Pradesh. Apart from being a major port city, it is primarily an industrial hub (steel, petroleum refining and fertilizer) providing a significant share of the city's employment in this sector. Public transportation in the city is provided by the state-run APSRTC, which runs buses within the city as well as to surrounding areas. In addition, public transportation in the city is served by para-transit modes, constituting mainly of auto-rickshaws.

7.3. Rajkot

Rajkot is the fourth largest city in the state of Gujarat. Within the city, travel is largely dominated by private vehicles, while public transportation is provided by para-transit modes – auto-rickshaws – operated by private owners.

7.4 Data Collection

In this study, a combination of primary surveys has been utilized as well as secondary sources available in the public domain of the cities. For Delhi, Visakhapatnam and Rajkot, the results are presented from the fuel station surveys. Moreover, for Delhi, results from the pollution check centres database are also presented.

Fuel Station Surveys

In Delhi, 10 fuel stations were randomly selected from a total of 150, from a list of stations supplied by a major fuel retailer in the city. Three fuel stations located in the southern, northern and north-western parts of Delhi were selected, where the surveys were carried out between May and August 2012. The 3stations were located on different land-use types – residential, mixed, and one on a major arterial corridor. The vehicle owners/drivers were asked the following five questions, which took approximately 2-3 minutes on average to record:

(1) Type of fuel used; (2) Registration number; (3) Year of manufacture and model; (4) Fuel efficiency, km/L (number reported by the owner/driver based on their experience); and (5) Odometer reading (total km travelled) at the time of the survey.

Statistical tests were carried out to compare the age distribution of vehicles from the samples collected at the stations. Table 4 shows the age distribution of vehicles for the three fuel stations. An F-test was carried out in order to test the variance of age distribution over the three stations. It shows that the locations have no statistically significant difference in the age distribution of the sampled cars. Therefore, it was assumed that the data from these stations was representative of the fleet in Delhi and, consequently, further data collection was discontinued. A similar procedure was adopted for Visakhapatnam and Rajkot.

Pollution Check Centres

In Delhi, vehicles over a year old are required to undergo a pollution check every three months under the Pollution under Control (PUC) programme. There are ~500 pollution checking centres in Delhi, which are mostly located at fuel stations and some mobile stations along the major corridors and highways, for convenience. For every vehicle tested at these centres, the operator records the: (a) make and model of the vehicle; (b) fuel type – petrol/diesel/compressed natural gas (CNG); (c) category of the vehicle (two-wheeler, three-wheeler, four-wheeler, bus, and truck); (d) vehicle manufacturing date; (e) vehicle emission test date; (f) tailpipe emission rates for CO and VOCs, measured at engine idle speed and at high idle speed of 2,000 rpm (lambda testing).

The emission data of all the vehicles is available at http://delhitransportpuc.in, which is operated by the Transport Department of Delhi. The data (referred to as PUC data) was utilised from 300 centres for the year 2010, with a total of 700,000 vehicles –passenger cars, motorized two-wheeled vehicles (MTWs), buses, and three-wheeled auto-rickshaws running on a mix of petrol, diesel and CNG. It should be noted that of the three cities, this data was only available for Delhi.

7.5. Age Profile of Vehicles

Age distributions of the vehicular fleet in the three cities have been obtained using fuel station surveys. In the case of Delhi, age distribution has been estimated using PUC data as well (Tables 4 and 5).

Table 4. Age profile from fuel station surveys

	Delhi		Visakhapatnam		Rajkot		
Age Bins (%) (Years)	Cars	MTWs	MTWs	Three-Wheelers (Diesel)	MTWs	Auto Rickshaws (CNG)-Passengers	Three-Wheelers (Diesel)-Freight
0-5	68	73	64	75	69	71	39
6-10	26	23	27	24	25	29	40
11-15	6	3	6	1	6	0	21
15+	1	1	3	0	0	0	0
All age	100	100	100	100	100	100	100
Total Sample	2,231	1,570	1,001	203	1,251	156	220
Average Age (years)	4.4	4.7	4.8	3.2	3.6	3.2	6.5

The average age of MTWs in Rajkot is the lowest of the three cities. This can be explained using vehicle registration data and census data, which show that Rajkot has a much higher rate of new vehicles added to the fleet every year. Compared to Vishakhapatnam, which has similar population level (see Table 3), Rajkot has an average of ~59,000 MTWs registered every year from 2006-2010, while Visakhapatnam only has ~29,000 – half that of Rajkot. This is also reflected in the ownership levels of MTWs in the two cities. According to census 2011, 60% of urban households in the Rajkot district have at least one MTW; while in the Visakhapatnam district only 36% of households have an MTW.

Table 5. Age profile of non-private vehicles from PUC centres in Delhi

Age Bins (Years)	Delhi				
	Passenger		Freight		
	Buses (CNG)	Auto Rickshaws (CNG)	LGV (CNG)*	Tempos (Diesel)	Trucks (Diesel)
0-5	22	39	84	54	49
6-10	70	56	13	31	35
11-15	8	5	3	15	17
15+	0	0	0	0	0
All age	100	100	100	100	100
Total Observations	8,645	42,633	24,187	9,598	3,945

*Light goods vehicles with gross vehicle weight <7,500 kg

7.6. Estimation of In-use Vehicle Fleet

One of the problems faced in Indian cities is that the vehicle registration data is an overestimation of the actual number of vehicles on the road. This was confirmed in a study done by Central Road Research Institute in 2007 (CRRI, 2002). This is because private vehicle owners pay a lifetime tax on the purchase of the vehicle and do not have to register their vehicle annually[1]. It appears that most vehicles are not taken off the official register once they are retired. In the case of Delhi, two different methods have been used to estimate the in-use vehicles and express them as the percentage of cumulative number of vehicles registered in the year 2011. One method used the PUC data (method 1), while the other used age distribution from fuel station surveys (method 2). The details of the two methods have been described in Appendix B. In the case of Visakhapatnam and Rajkot, only method 2 was used, due to the unavailability of PUC data from the two settings. Due to the inadequate sample size for cars from Vishakhapatnam and Rajkot, the in-use number for cars was not estimated. The estimates of in-use proportions of vehicles for the three settings are shown in Table 6. The in-use proportions for cars and two-wheelers show that use of cumulative registration numbers may overestimate actual in-use fleet by 100%.

Table 6. Percent in-use vehicles of the total registered vehicles until 2012

City	MTWs	Cars
Delhi	40, 45*	51, 59*
Visakhapatnam	44	–
Rajkot	51	–

*Two values correspond to two different methods

1 Vehicles in India are required to re-register after 15 years

7.7. Average Annual Mileage

Table 7 shows the annual mileage estimates from the three settings. Figures A3 to A6 in Appendix C show the plot of average annual mileage of cars and MTWs with their model years, with the lower and upper bounds for 95% confidence intervals (CI) from the three settings. In order to model the relationship between the variables – total mileage and vehicle age –various non-linear curves have been fitted. For cars as well as MTWs, a log-log relationship has been found between two variables to describe the greatest variance – 59% in both cases. Since the variance explained by such models is very low, a logarithmic function has been fitted for the average values of annual mileage for each model year. As shown in the plots, the model also helps in smoothing the data. The models for cars and MTWs explain a variance of ~90% and ~83%, respectively, and are given as:

$$MAnnualAvg_{Cars,k} = -3873\ ln(k) + 18315$$

$$MAnnualAvg_{MTWs,k} = -3915\ ln(k) + 18602$$

Here, $MAnnualAvg_{Cars,k}$ and $MAnnualAvg_{MTWs,k}$ are the average annual mileage (in km) of cars and MTWs, respectively, and k =(2012-Model year +1). For both cars and MTWs, the annual mileage reduces by 27%, 42% and 52% after 5 years, 10 years and 15 years, with a reference model year of 2011.

Table 7. Average annual mileage of cars and MTWs in three settings

City	MTWs (km)	Cars (km)
Delhi	12,804 ± 349	12,199 ± 435
Visakhapatnam	9,238 ± 576	–
Rajkot	7,255 ± 325	–

The three cities have significantly different mileage values for MTWs. The explanation for this can be given by looking at the spatial structure of these cities. Compared to Visakhapatnam and Rajkot, Delhi is a larger urban agglomeration with contiguous growth of its neighbouring cities (Ghaziabad and Noida in the east, Faridabad in the south-east and Gurgaon in the south), leading to a significant proportion of inter-city travel. Moreover, the spatial structure of Visakhapatnam and Rajkot differs significantly. While the latter is circular and has contiguous built-up areas, the former is linear and has discontinuous built-up areas due to the high penetration of green areas within the city. The built-up areas in Greater Visakhapatnam are less than one-third of the total area. It is important to note here that although the population of Delhi is almost 10times that of Vishakhapatnam, the annual distance travelled by MTWs is only about 35% greater in Delhi. The annual distance covered by cars and MTWs in Delhi is similar.

7.8. Fuel Efficiency

The drivers at the fuel stations were asked to report fuel consumption rates for their cars and MTWs. Some of the survey respondents also mentioned that, depending on whether they operate their air-conditioner or not, their fuel efficiency varies. Therefore, most survey respondents mentioned a range

in their vehicle's fuel efficiency. Among the cars, fuel efficiency values have been classified by fuel type – diesel and petrol. Moreover, diesel cars were further segregated into two categories based on their engine displacement – ≤1,600 cubic centimetre (cc) and >1,600 cc. Tables 8 to 10 show the average values of fuel efficiency for different vehicle types. Figures A7 to A12 in Appendix C show the variation of lower and upper values of fuel efficiency of cars (all types) and MTWs, with their 95% CI for each model year from the three settings. In the case of MTWs, average fuel efficiency is lower for newer models than their older counterparts – this is most pronounced in Delhi and Rajkot. This phenomenon is possibly due to an increase in the share of motorcycles with higher engine displacement and lower fuel efficiency. However, with the given sample sizes and confidence intervals of the average numbers, no conclusive argument can be made.

Table 8. Fuel efficiency of vehicles from fuel station surveys in Delhi

Type of Vehicle	Lower Value* (km/L)	Sample Size	Upper Value (km/L)	Sample Size
Diesel Cars (all engine sizes)	14.0 ± 0.3	528	15.3 ± 0.5	235
Diesel Cars (<=1,600 cc)	16.1 ± 0.3	322	17.4 ± 0.5	145
Diesel Cars (>1,600 cc)	10.8 ± 0.3	206	11.9 ± 0.5	90
Petrol Cars	15.3 ± 0.1	1672	16.2 ± 0.2	664
MTWs	48.5 ± 0.5	1565	52.3 ± 0.8	704

*In the case of Delhi, survey respondents mentioned a range of fuel efficiency values. Lower and upper values correspond to this range

Table 9. Fuel efficiency of vehicles from fuel station surveys in Rajkot

Type of Vehicle	Fuel Efficiency (km/L)	Sample Size
Diesel Cars (all engine sizes)	13.6 ± 0.5	258
Diesel Cars (<=1,600 cc)	17.1 ± 0.7	102
Diesel Cars (>1,600 cc)	11.4 ± 0.5	156
Petrol Cars	15.8 ± 0.4	149
Petrol MTWs	51.5 ± 0.5	1,251
CNG Three-Wheelers (converted from petrol)	33.9 ± 1.0	293
Diesel Three-Wheelers	23.8 ± 1.3	156

Table 10. Fuel efficiency of vehicles from fuel station surveys in Visakhapatnam

Type of Vehicle	Fuel Efficiency (km/L)	Sample Size
Diesel Cars (all engine sizes)	16.1 ± 0.3	484
Diesel Cars (<=1,600 cc)	16.3 ± 0.4	438
Diesel Cars (>1,600 cc)	13.5 ± 0.8	46
Petrol Cars (all engine sizes)	14.9 ± 0.3	517
Petrol MTWs	48.5 ± 0.5	992
Diesel Three-Wheelers	29.3 ± 0.7	205

Age distribution of cars and MTWs in the three cities – Delhi, Visakhapatnam and Rajkot – show that more than two-thirds of the vehicles are less than 5 years old, and almost all are within 15 years of age. This is a result of a high growth rate of vehicles in the Indian cities during the last decade. During the 1990s, in Delhi, on average, ~70,000 cars and ~100,000 MTWs were registered every year, which has almost doubled to ~130,000 cars and ~220,000 MTWs per year during the current decade (2002-2012). Similarly, Rajkot had ~22,000 MTWs registered every year from 1991-2001, and more than 58,000 during 2001-2011. The age distribution of the vehicular fleet in Indian cities is in complete contrast with those in the developed world – which is experiencing the ageing of its vehicular fleet. The average age of cars in the European Union[2] was 8.2 years for the year 2008 (ACEA, 2010), and 11.1 years in the US for the year 2011 (Polk, 2011). According to 2008 data, the proportions of cars in Europe and the US older than 10 years are 35% and 37%, respectively (ACEA, 2010; NHTS, 2009[3]), which is more than four times that of Delhi, for cars older than 10 years. This indicates that fleet replacement is occurring in a short time in India. Therefore, the early introduction of stricter standards for emissions will have a much greater effect in a shorter time in India than in richer nations.

The annual mileage of cars and MTWs shows a decreasing trend with increasing age, and a similar rate of reduction for both vehicle types. The reduction of annual mileage with the increasing age of vehicles has also been observed internationally. Similar observations have been reported from European countries (Van Wee et al., 2000; Zachariadis et al., 2001), USA (ORNL, 2011), Japan (Nishimura, 2011) and New Zealand (MOT, 2011).From the plots given by Zachariadis et al. (2001), it can be observed that the reduction rate of annual mileage with increasing age of cars varies significantly from country to country. However, a direct comparison of the two is not completely valid, as this study reports data at the city level, while those mentioned by Zachariadis et al. (2001) are country level estimates. The reduction of mileage indicates that as vehicles become older they tend to be used less. Van Wee et al. (2000) hypothesized that those with older cars, foreseeing greater use of their vehicles in the near future, tend to buy newer ones that are more comfortable and energy-efficient. In addition, being more fuel-efficient and less costly per kilometre driven, newer cars tend to be driven even more. In the context of Indian cities, and more so in Delhi, the change in mileage may also be due to changing travel patterns. For instance, during the last two decades (1991-2011), contiguous satellite cities around Delhi (Ghaziabad, Noida, Faridabad and Gurgaon) have almost quadrupled in population, along with the growth of employment avenues. This may have resulted in a large number of people commuting between these cities.

2 Austria, Belgium, Estonia, Finland, France, Germany, Greece, Latvia, Portugal, Slovakia, Sweden and the UK

3 http://nhts.ornl.gov/briefs/Changes%20in%20the%20Vehicle%20Fleet.pdf

For fuel efficiency data, with the given sample size in each model year, the confidence intervals are large and, therefore, any statistically significant variation of fuel efficiency with the age of the vehicles cannot be concluded. However, it may be possible to obtain conclusive results with a bigger sample size. Fuel efficiency of vehicles is largely determined by factors such as driving pattern (gear change, average speed, and trip length), vehicle weight, and engine type (fuel type and engine capacity). It is known that diesel cars, for a given engine size, are more efficient than petrol cars (Van den Brink and Van Wee, 2001). When segregated by engine size, the fuel efficiency of diesel cars with an engine size less than 1,600cc have higher efficiency than those with an engine size greater than 1,600 cc (16.1 and 14.0 km/L, respectively). An overall average of all the diesel cars (all engine sizes) is even lesser than their petrol counterparts (10.8 and 15.3 km/L, respectively). These findings show that the penetration of large engine cars in the fleet reduce the effects of increased efficiency with diesel cars. Since manufacturers in India do not publish car sales information by state/city, it cannot be said with certainty whether the penetration of large engine size diesel cars is equally high in other Indian cities. A study of vehicle sales data shows that diesel cars in India currently have the major share in the large engine (>1,600 cc) categories. According to the study, during 2009-2011, only 13% of the petrol cars sold in India were above 1,200 cc, while this proportion was 92% in the case of diesel cars (CSE, 2012).

8. International comparison

An international study (GFEI, 2011) reported the fuel economy of light-duty vehicles around the world. This study consisted of the EU as well as 21 other countries, and included both OECD[4] and non-OECD[5] countries. These countries, combined, represented 85% of total vehicle registrations in the world in the year 2005. The study analysed fuel economy and other vehicular characteristics for new vehicle registrations in these countries, for the years 2005 and 2008. Comparing the data for the two years, globally, there has been an improvement of ~5% in the fuel efficiency of cars, from 2005 to 2008 (see Table 11). The improvement, however, was in large part brought about by improvements within the OECD countries. By contrast, the fuel efficiency in non-OECD countries (which includes India) had in fact reduced.

Table 11. Fuel efficiency of cars for new registrations in 2005 and 2008 (GFEI, 2011)

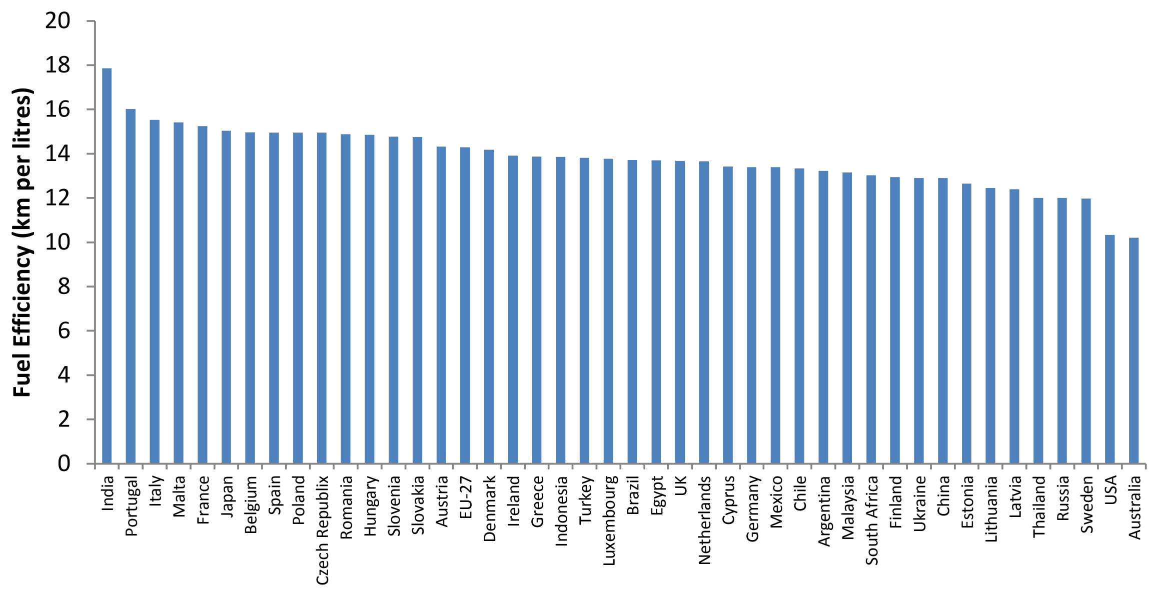
	2005	2008	% Improvement
OECD Average	12.2	13.1	7.4%
Non-OECDAverage	13.4	13.0	-2.9%
Global Average	12.4	13.0	4.8%

Of all the countries studied, India had the best average fleet fuel efficiency (Figure 3). However, it appears that this study used fuel efficiency values as reported by car manufacturers. Thus, it may not reflect actual on-road conditions which lead to reduction in fuel efficiency of vehicles. While the fuel efficiency values in this study can only be seen as indicative of the actual values, it, nevertheless, shows that the car fleet in India was the most fuel-efficient in the world. It should be noted that the GFEI study took into account only the new registrations, for the years 2005 and 2008, and did not include the overall vehicular population in use.

4 Australia, Chile, France, Germany, Italy, Japan, Mexico, Portugal, Spain, Turkey, UK, USA, the EU

5 Argentina, Brazil, China, Russia, Egypt, India, Indonesia, Malaysia, South Africa, Thailand, Ukraine

Figure 3. Fuel efficiency of new registrations for the year 2005 (Data Source: GFEI, 2011)



In order to understand the different factors that contribute to the higher fuel efficiency of Indian cars, compared to global trends, it is important to look at the characteristics of the cars sold in India vis-à-vis global cars. For instance, fuel type, vehicle size, engine displacement and vehicle weight strongly affect the fuel efficiency of cars. Of all the countries considered in GFEI (2011), India had the highest share of small cars in new registrations. For the year 2008, India had up to 70% of the cars in the small size segment, while this share was~25% for the global fleet. Vehicle size is a key factor influencing fuel economy, and is closely linked to vehicle weight and engine cylinder capacity. As a result, the car fleet in India also had the highest share (~60%) of cars with engine displacement less than 1,200 cc. Moreover, it was one of the four countries that had up to 80% share of cars with engine displacement less than 1,600cc;the other three being Indonesia, Chile and Malaysia. Additionally, India had the lowest average vehicle weight (< 1,000 kg). This shows that consumer choices in India, and possibly the pricing of cars owing to taxation policies, have resulted in the most fuel-efficient fleet in the world.

9. Conclusions

1. A high growth rate of vehicles in Indian cities with a comparatively smaller existing fleet means that fuel efficiency standards will have their desired effect at a much faster rate than most developed economies of the world. It is estimated that fuel standards, when implemented in India, will lead to 90%of vehicles conforming to those standards within the next 15 years.

2. Various studies from different parts of the world (none available from India) have found a wide gap between the real-world and laboratory-based values of fuel efficiency of vehicles. The reported gap reaches up to 30%of the real-world value. With such a gap, the use of laboratory-based values, provided by auto manufacturers to estimate the baseline fuel efficiency of vehicular fleet, will overestimate the actual fuel efficiency. Therefore, there is an urgent need to carry out user surveys in Indian cities, in order to take stock of the current fleet – in terms of fuel efficiency and vehicle usage. While most countries have studies quantifying the gap, efforts in this direction are pending in India. In order to be able to ascertain efficacy of standards, these efforts need to be carried out and repeated at regular intervals.

3. Technological advances for internal combustion engines are promising to bring about a significant change in the fuel efficiency of vehicles in the near future. A list of such technologies and their estimated effects on fuel efficiency is shown in Appendix E.

Photo credit: Amityadav8
http://commons.wikimedia.org/wiki/File:Pune_Traffic_Two_Wheelers.jpg

References

ACEA (2010) The Automobile Industry Pocket Guide. Accessed online from <http://www.acea.be/images/uploads/files/20100520_2010_KEY_FIGURES_4_Vehicles_in_Use.pdf> European Automobile Manufacturers' Association, Brussels

BEE (2011) Consultation Paper, Bureau of Energy Efficiency, India

Booz & Company (2011) Alternative Powertrains and Challenges for Next Decade, SIAM Annual General Meeting, Discussion Document, Booz & Company, New Delhi

Census-India (2012) Census of India 2011, The Government of India, New Delhi, India.

CRRI (2002) "Urban Road Traffic and Air Pollution in Major Cities", Volume 1, Government of India, New Delhi.

CSE (2012) Proposal for additional excise duty on diesel cars to reduce public revenue losses and public health costs, Centre for Science and Environment, New Delhi.

DIMTS (2009) 'Financing for city bus service under JnNURM', Delhi Integrated Multimodal Transportation Systems, <http://www.slideshare.net/jaaaspal/jnnurm-bus-financing-delhi-experience#btnNext> accessed on July 26, 2012.

DSH (2012). Delhi Statistical Handbook 2012. Directorate of Economics and Statistics, the Government of National Capital Territory of Delhi, New Delhi, India.

GFEI (2011) International comparison of light-duty vehicle fuel economy and related characteristics, Working Paper 5/10. Global Fuel Economy Initiative, International Energy Agency, Paris, France.

Huo, H., He, K., Wang, M. & Yao, Z. (2012) Vehicle technologies, fuel-economy policies, and fuel-consumption rates of Chinese vehicles. Energy Policy, 43, 30-36.

Huo, H., Yao, Z., He, K., & Yu, X. (2011) Fuel consumption rates of passenger cars in China: Labels versus real-world. Energy Policy, 39(11), 7130-7135.

ICCT (2012) The Potential of Lower Vehicular Emissions in Indian Cities, Briefing, The International Council on Clean Transportation.

ICCT (2013) Policy Summary: India's Vehicle Emissions Control Program, Briefing, The International Council on Clean Transportation.

ICET (2011) Global overview on fuel efficiency and motor vehicle emission standards: policy options and perspectives for international cooperation, The Innovations Center for Energy and Transportation, United Nations Background Paper, (3).

MOT (2011) Aging of the Light Vehicle Fleet, Ministry of Transport, New Zealand, New Zealand.

NHTS (2009) Changes in the U.S. Household Vehicle Fleet, National Household Travel Survey 2009, Federal Highway Adminstration, US.

Nishimura, E. (2011) Assessing the Fuel Use and Greenhouse Gas Emissions of Future Light-Duty Vehicles in Japan.Master of Science in Technology and PolicyEngineering System Division, Massachusetts Institute of Technology.

ORNL (2011) Developing a Best Estimate of Annual Vehicle Mileage for 2009 NHTS Vehicles , Federal Highway Adminstration, National Household Travel Survey.

Polk (2012) Average age of vehicles reaches record high, according to Polk. Accessed online from <https://www.polk.com/company/news/average_age_of_vehicles_reaches_record_high_according_to_polk>,Polk, Southfield, Michigan, US.

RITES (2008) Travel Characteristics, Household Interview Survey Report – December 2008, Transport Demand Forecast Study and Development of an Integrated Road cum Multi-modal Public Transport Network for NCT of Delhi, RITES Ltd., New Delhi, India.

Schipper, L. & Tax, W. (1994) New car test and actual fuel economy: yet another gap? Transport Policy, 1, 257-265.

SIAM (2011) National Hybrid/Electric Mobility Study, Society of Indian Automobile Manufacturers, New Delhi.

Van den Brink, R. M., & Van Wee, B. (2001) Why has car-fleet specific fuel consumption not shown any decrease since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption. Transportation Research Part D: Transport and Environment, 6(2), 75-93.

Van Wee, B., Moll, H. C., & Dirks, J. (2000) Environmental impact of scrapping old cars. Transportation Research Part D: Transport and Environment, 5(2), 137-143.

WHO (2011) Outdoor Air Pollution in the World Cities. World Health Organization, Geneva, Switzerland.

Zachariadis, T. (2006) On the baseline evolution of automobile fuel economy in Europe. Energy Policy, 34, 1773-1785.

Zachariadis, T., Ntziachristos, L., & Samaras, Z. (2001) The effect of age and technological change on motor vehicle emissions. Transportation Research Part D: Transport and Environment, 6, (3) 221-227.

Appendices

A. International Fuel Standards

Figure A1. Levels of sulphur in diesel

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Bangladesh							5000										
Cambodia					2000				1500								
Hong Kong,		500					50					10[a]					
India (nationwide)	5000				2500					500					350		
India (metros)	5000				2500	500				350[a]					50[a]		
Indonesia	5000										3500				350		
Japan [b]	500									50		10					
Malaysia	5000		3000				500[c]			500[d]							50[a]
Pakistan	10000						7000[c]										
Philippines	5000					2000			500								
PRC (nationwide) [e,f]	5000						2000			2000 & 500							
PRC - Beijing	5000						2000		500	350			50				
Singapore	3000		500								50						
South Korea	500							430	100		30	15(10)[f]					
Sri Lanka	10000							5000[d]			500						
Taipei,	3000			500			350		100				50				
Thailand	2500			500					350		150				50		
Viet Nam	10000											500					
European Union					500					50(10)[f]			10				
United States	500										15						

Source: CAI-Asia, 2008

> 500 ppm   51 – 500 ppm   < 50 ppm

Figure A2. Timeline of emission standards

Country	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
European Union	E1	Euro 2					Euro 3				Euro 4			Euro 5					Euro 6	
Bangladesh[a]											Euro 2									
Bangladesh[b]											Euro 1									
Hong Kong, China	Euro 1		Euro 2				Euro 3					Euro 4			*Euro 5*					
India[c]							Euro 1				Euro 2					Euro 3				
India[d]					E1	Euro 2					Euro 3					Euro 4				
Indonesia											Euro 2									
Malaysia			Euro 1												*Euro 2*				*Euro 4*	
Nepal						Euro 1														
Pakistan	No conclusive information available																			
Philippines									Euro 1				Euro 2					*Euro 4*		
PRC[a]							Euro 1			Euro 2			Euro 3			Euro 4				
PRC[e]							Euro 1		Euro 2			Euro 3		Euro 4 Beijing only						
Singapore[a]	Euro 1						Euro 2													
Singapore[b]	Euro 1						Euro 2					Euro 4								
Sri Lanka									Euro 1				*Euro 2[f]*							
South Korea												Euro 4			Euro 5					
Taipei,					US Tier 1								US Tier 2 Bin 7[g]							
Thailand	Euro 1						Euro 2			Euro 3								Euro 4		
Viet Nam													Euro 2							

Source: CAI-Asia. 2008, Emission standards for new vehicles (light duty). Available: http://www.cleanairnet.org/caiasia/1412/articles-58969_resource_1.pdf

B. Methods for Estimation of In-use Vehicle Fleet

Method 1: From PUC Data

From the PUC data, there are the total number of cars and MTWs that were tested at different centres in Delhi. Since vehicles are required to undergo pollution checks4times a year, the total number of tested vehicles is more than the number of unique vehicles which had undergone pollution checks. Using the average number of times each vehicle undergoes pollution check in a year, the number of unique vehicles tested at PUC centres can be estimated as:

$$N_{i,test,unique} = \frac{N_{i,test,all}}{f_{i,test}}$$

Here, $f_{i,test}$ is the average number of times a vehicle of type i (cars/MTWs) goes for pollution checks per year. $N_{i,test,all}$ is the total number of vehicle type i tested, and $N_{i,test,unique}$ is the total number of unique vehicles tested in the reference year.

From the fuel station survey, the PUC certification history has been checked, from PUC data, for a sample of 858 cars and 437 MTWs, using their registration numbers. Among passenger cars, only 16% appeared for tests 4 times per year (as per the requirement), while the rest appeared fewer than 4 times. The overall average is 2.1 times per year. Among MTWs, only 14% appeared 4 times a year, and the overall average for all MTWs is 2.4 times per year. In 2011, a total of 2,068,500 cars were tested at different PUC centres in Delhi. For an average frequency of 2.1times per year by each car, the total

number of unique cars tested at PUC centres is 985,000. It has been established from the surveys that only 73% of the total on-road vehicles go for pollution checks at least once a year.

Using this, the total number of in-use vehicles can be expressed as:

$$N_{i,in-use} = \frac{N_{i,test,unique}}{\Phi_{i,compliance}}$$

While the proportion of total registered vehicles on-road and in-use can be expressed as:

$$\alpha_{i,in-use} = \frac{N_{i,in-use}}{N_{i,total}}$$

Here, $N_{i,in-use}$ is the total number of in-use vehicles in the reference year, $\Phi_{i,compliance}$ (73%) is the proportion of total on-road vehicles with at least one PUC certificate each year, and N_{total} is the total number of registered vehicles up to the reference year.

According to the official numbers provided by the Transport Department of Delhi (DSH, 2012), the total number of cars and motorcycles registered in Delhi at the end of 2011 were 2,300,000 and 4,600,000. This resulted in 59% of the registered cars and 42% of the registered MTWs as being on-road and in-use in 2011.

Method 2: Using Age Profile from Fuel Station Surveys

An additional method of estimating the actual number of in-use vehicles is by using the age profile of the vehicles from the fuel station surveys. Using the number of vehicles registered in the last 5 years (2007 through 2012) and the proportion of vehicles within 5 years of age, the total number of in-use vehicles can be expressed as:

$$\mathbf{N_{i,in-use}} = \frac{\sum_{k=2007}^{2012} \mathbf{VehReg_{i,k}}}{\mathbf{f_{i,5}}}$$

Here, $VehReg_{i,k}$ is the number of vehicle type i registered in year k, and $f_{i,5}$ is the proportion of vehicles within 5 years of age. An important piece of information required, besides the age profile from the surveys, is the number of vehicles registered on an annual basis – assuming that all the vehicles younger than 5 years are in-use.

From the fuel station surveys, it can be estimated that 68% ($f_{car,5}$) of cars are 5 years or younger. Moreover, the total number of vehicles registered in the previous 5 years (2007 through 2012) is 826,500 ($\sum_{k=2007}^{2012} \mathbf{VehReg_{i,k}}$).This indicates that the total number of in-use cars is 1,215,500($N_{car,in-use}$), which is 51% ($\alpha_{car,in-use}$) of the total registered cars in 2012. From the fuel station surveys, there are 71% ($f_{MTW,5}$) of MTWs within the age of 5 years, and the total registered MTWs in the previous 5 years is 1,479,000. Thus, the total in-use MTWs are estimated to be 45% ($\alpha_{MTW,in-use}$) of the total registered MTWs. It is important to note that the number of in-use vehicles using this method may be an overestimation, as it assumes that all the vehicles registered within the previous 5 years are in-use, which may not be the case.

C. Annual Mileage and Fuel Efficiency

Figure A3. Annual mileage of cars from fuel station surveys in Delhi (n=2,220)

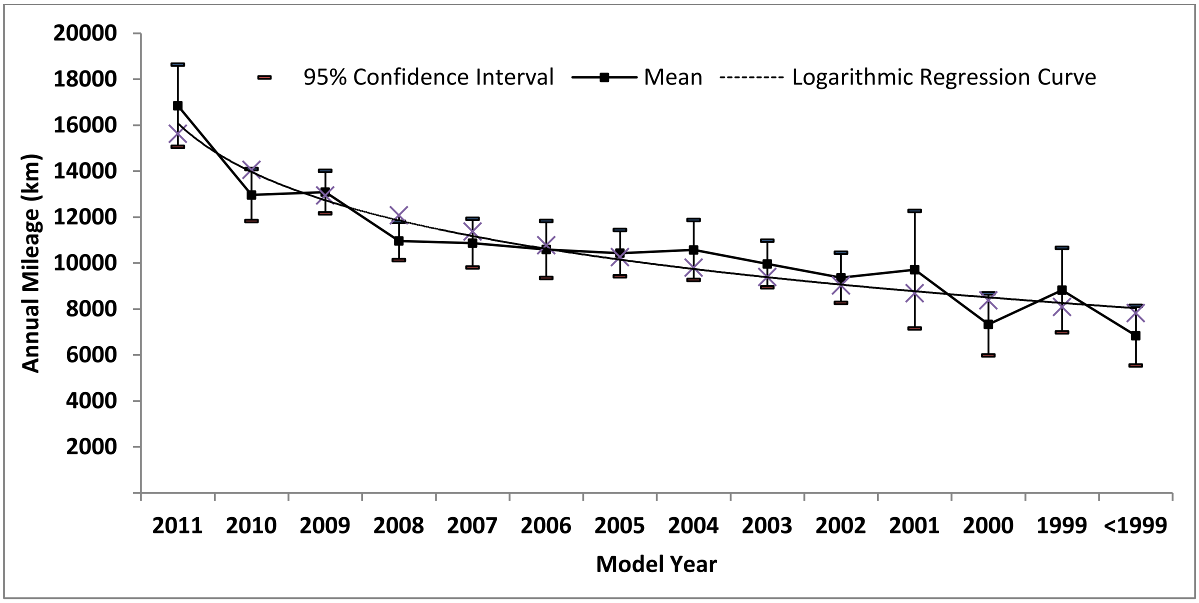


Figure A4. Annual mileage of MTWs from fuel station surveys in Delhi (n= 1,565)

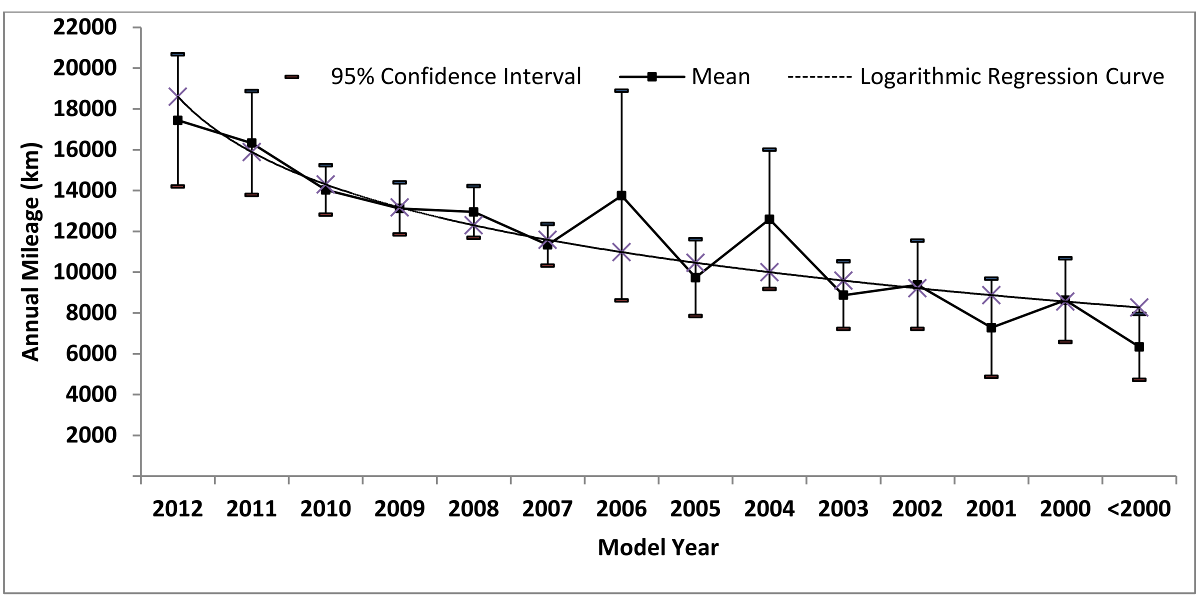


Figure A5. Annual mileage of MTWs from fuel station surveys in Rajkot (n=1,251)

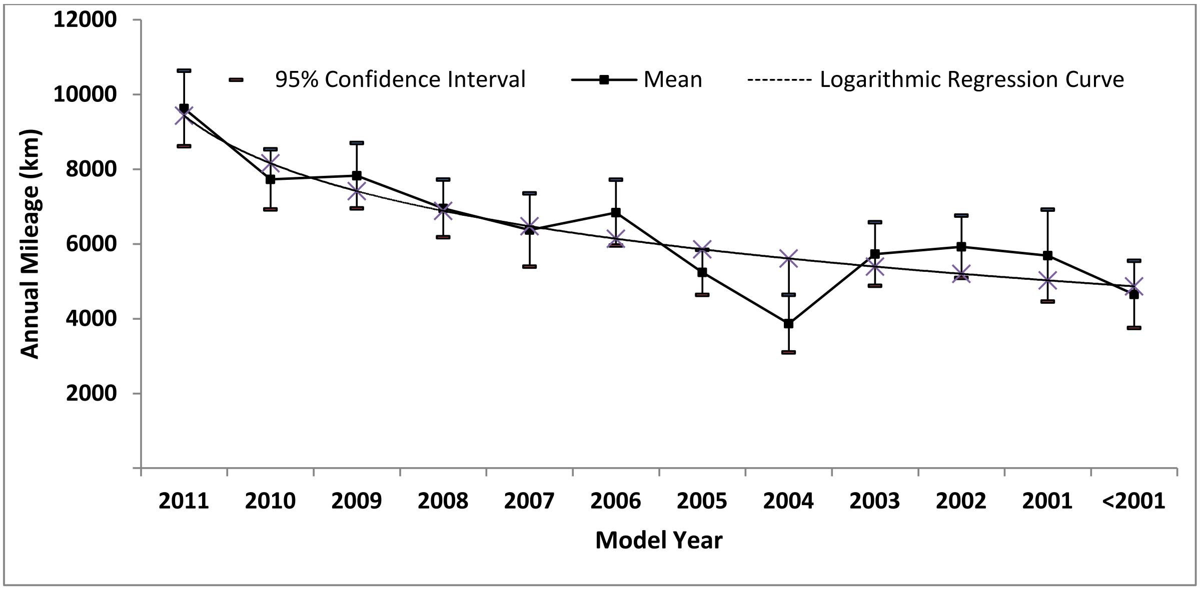


Figure A6. Annual mileage of MTWs from fuel station surveys in Visakhapatnam (n=922)

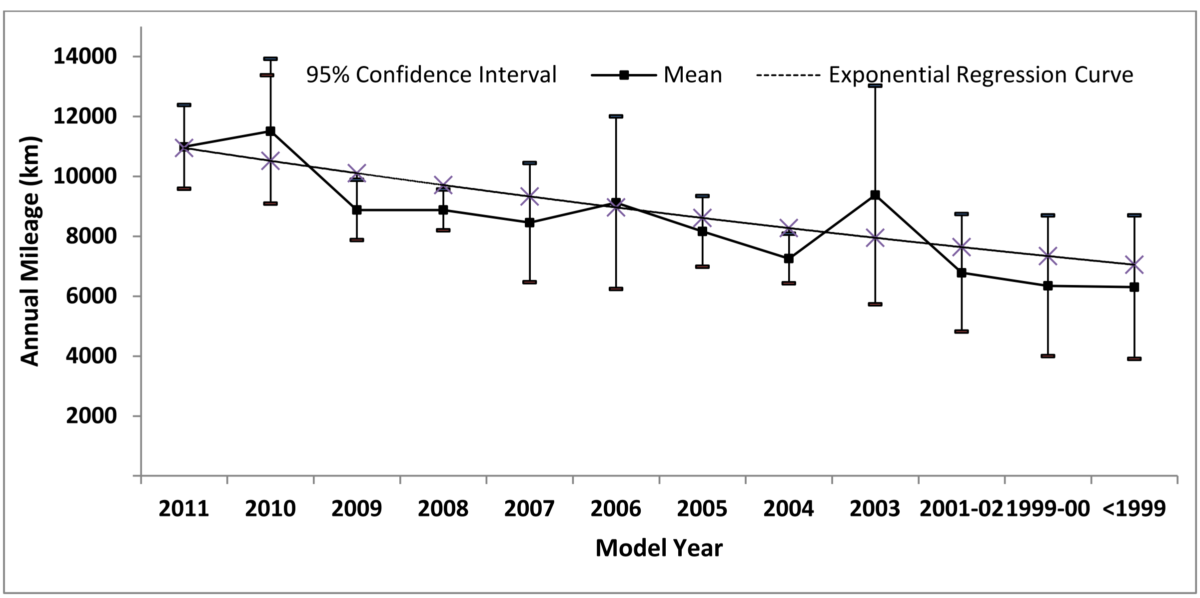


Figure A7. Lower value of fuel efficiency of cars from fuel station surveys in Delhi (n=2,196)

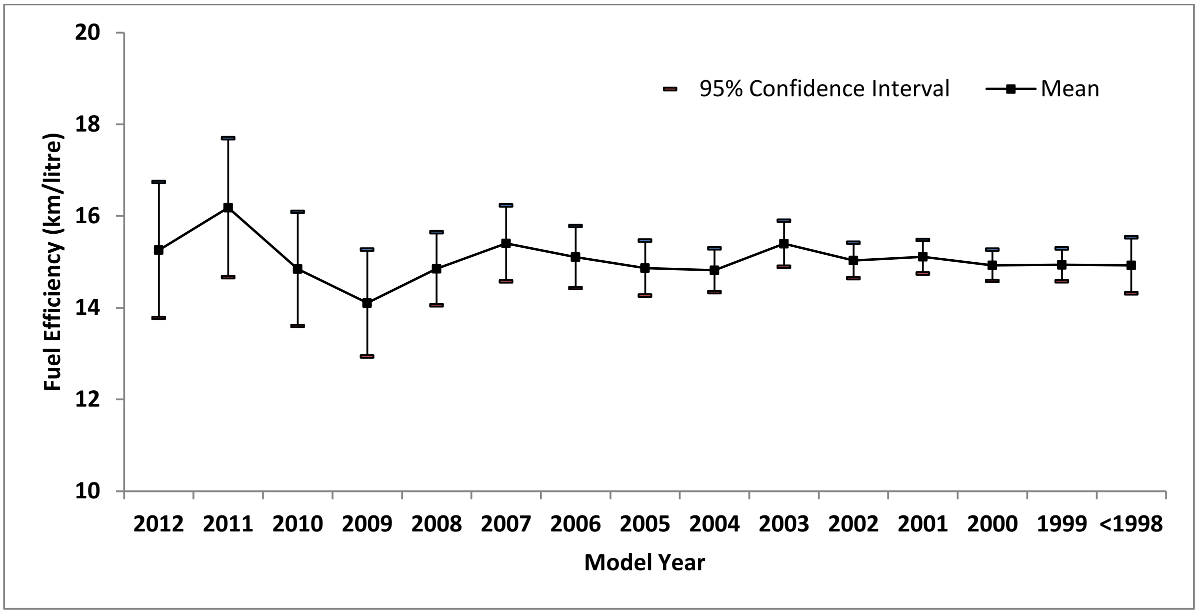


Figure A8. Upper value of fuel efficiency of cars from fuel station surveys in Delhi (n=902)

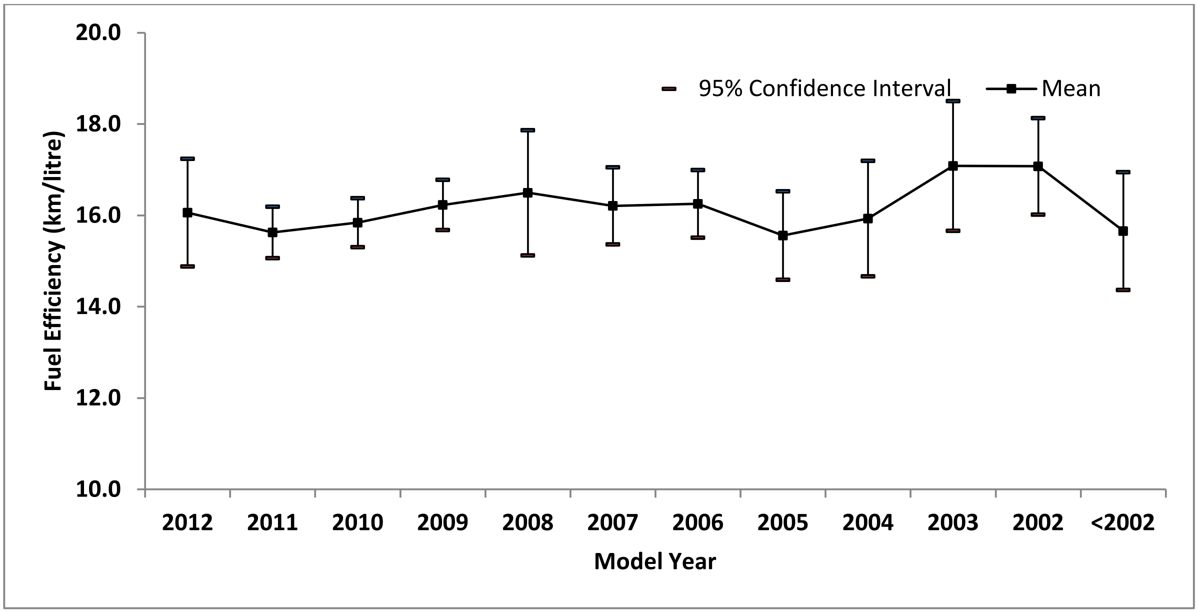


Figure A9. Lower range of fuel efficiency of MTWs from fuel station surveys in Delhi (n= 1,570)

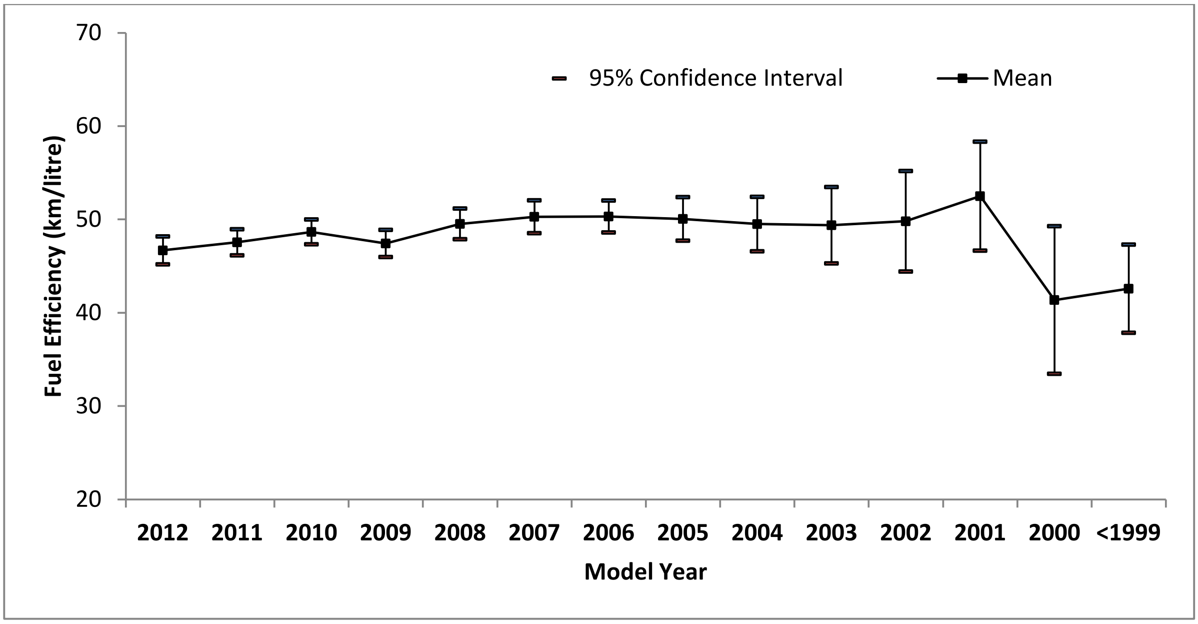


Figure A10. Upper range of fuel efficiency of MTWs from fuel station surveys in Delhi (n=702)

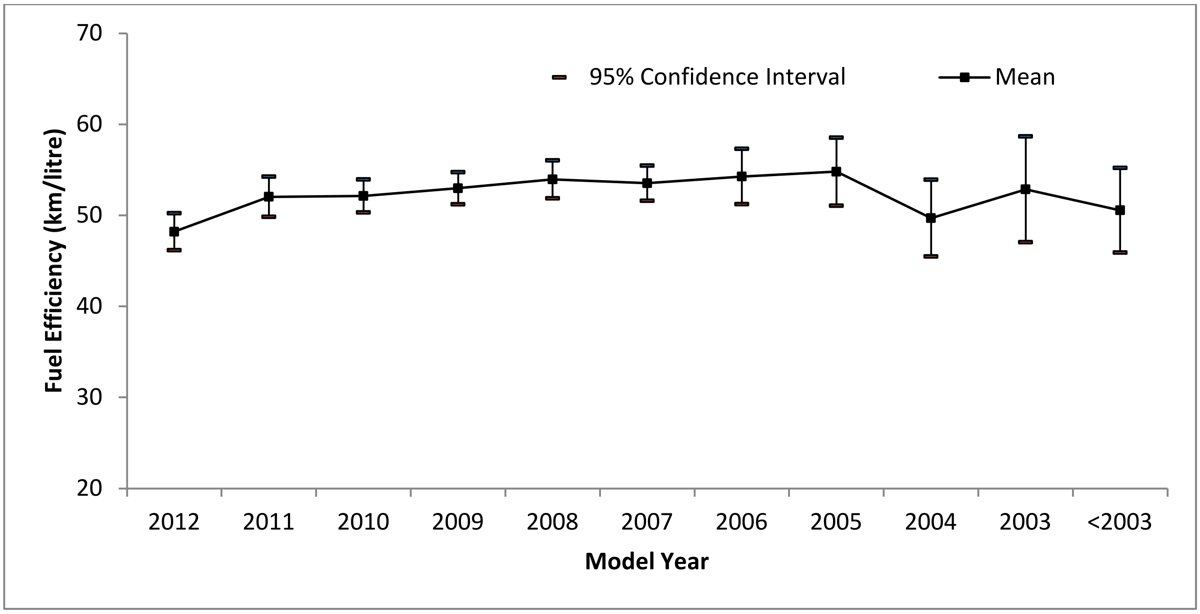


Figure A11. Fuel efficiency of MTWs from fuel station surveys in Rajkot (n=1,251)

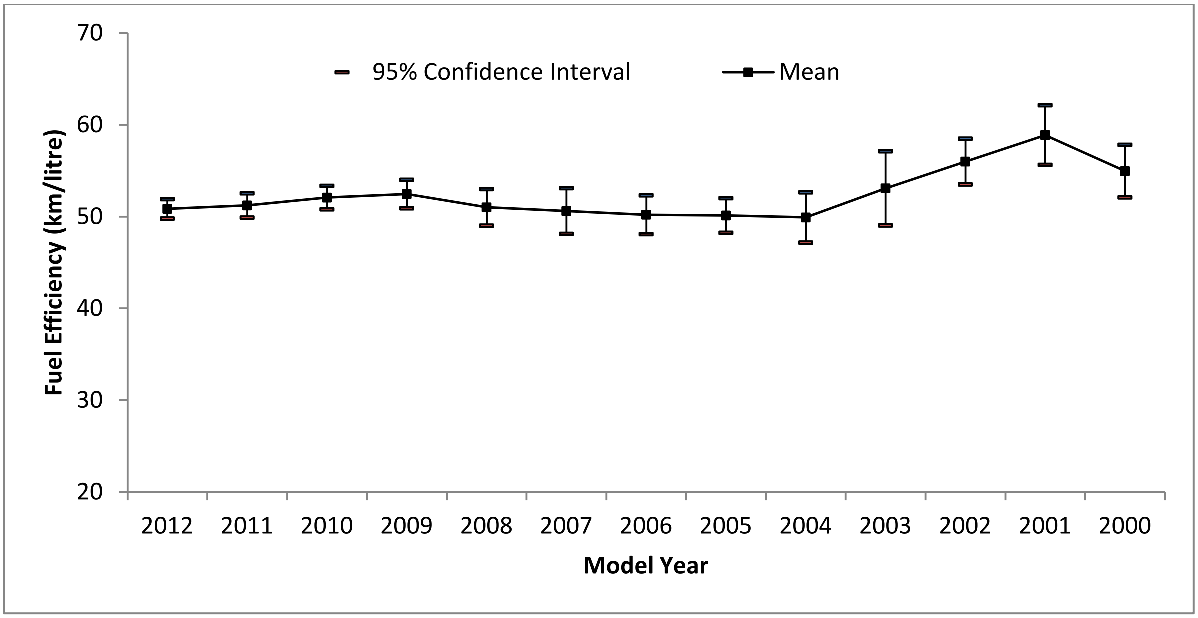
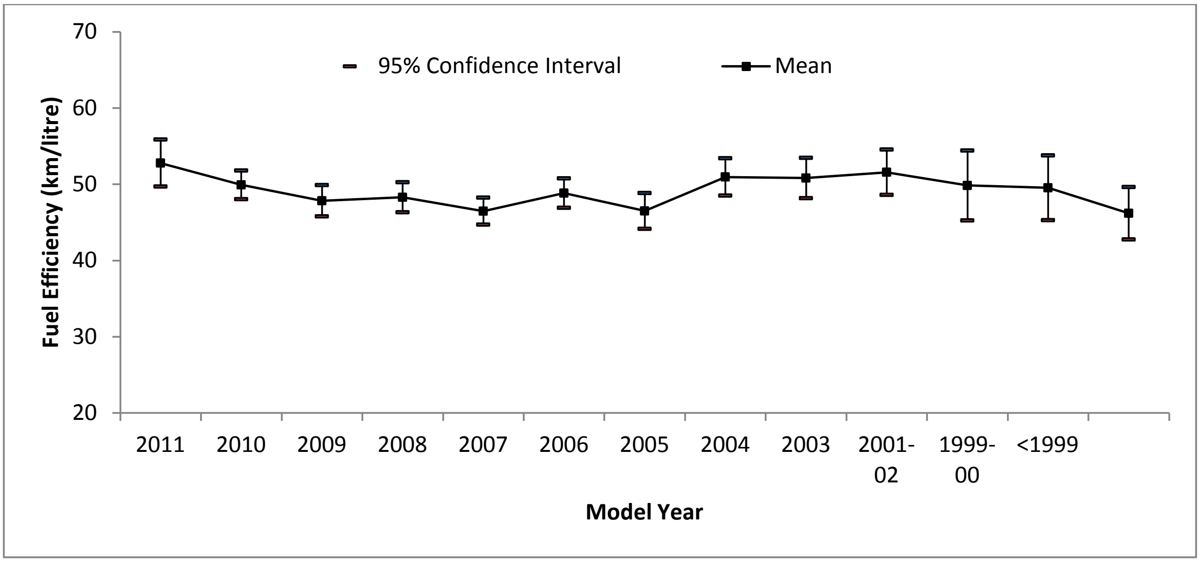


Figure A12. Fuel efficiency of MTWs from fuel station surveys in Visakhapatnam (n=978)



D. ICCT Recommendations for Improving Fuel Efficiency in India

Box 1. Policy Recommendations to Reduce Vehicular Emissions in India – International Council for Clean Transportation (ICCT)

1. At present, the 20 major cities are receiving Bharat IV fuel supply, and the Ministry of Petroleum and Natural Gas (MoPNG) has announced plans to supply BS IV fuels to a total of 50 cities, shortly. This program could be expedited since it has major benefits for emission reductions from both existing and new vehicles, and, therefore, has the potential to immediately impact PM and NOx emission levels in these cities. The move to Bharat IV fuels in these cities needs to be quickly followed up by the move towards ultra low sulphur fuels (ULSFs). The ULSFs, which contain 10-15 ppm of sulphur, will not only further bring down emissions from all on-road vehicles, but they will also enable the emission control technology associated with Bharat VI emission standards to perform at the most efficient level.

2. India should adopt a "one country, one fuel" policy. This will ensure that vehicular emissions are not out of compliance with standards behind because of fuels. It will also ensure all vehicles plying the roads of India's most polluted cities are not refuelling with lower quality fuels (ICCT, 2012).

3. Indian policy should ensure that vehicles already on the road are operating to their design specifications, and not emitting excess pollutants. This means enhancing, or perhaps replacing, the current Pollution under Control (PUC) programme with an in-use emissions testing program that selects vehicles off the road and tests them according to their original emission standards.

4. Durability requirements should also be toughened, as Indian vehicles are frequently kept in service for much longer than the assumptions concerning the typical length of service on which emission control standards are currently based. A strong inspection and maintenance (I/M) programme could encourage earlier retirement of older vehicles, as the costs of maintaining older vehicles could increase significantly.

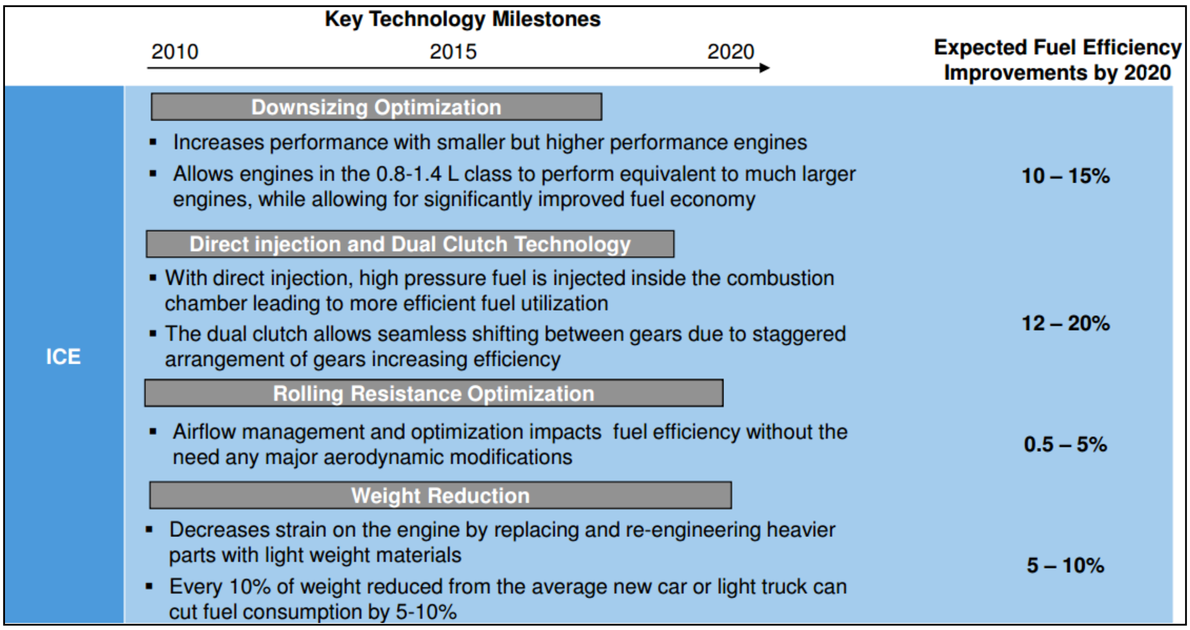
5. Currently, private vehicles need only be registered 15 years after their initial purchase. There should be mandatory annual vehicle registration for all vehicle types across the country. This can be linked with PUC testing and proof of insurance. This will provide India more comprehensive data on its vehicle fleet, which is difficult to estimate in the current regime, and enable the government to streamline vehicle regulations.

6. India currently has no regulations for evaporative emissions, which are a health hazard to those refuelling vehicles as well as those living near fuelling stations because they contain benzene. The volatile organic compounds (VOCs) in fuel vapours also exacerbate ozone formation. The control of such emissions needs to be done at two stages – first, when delivering gasoline fuel to underground storage tanks at retail filling stations, and second, during vehicle refuelling (ICCT, 2013).

E. Fuel Efficiency Gains Through Innovations in Internal Combustion Engine (ICE)

A significant improvement in fuel efficiency (up to 20%) can be achieved through innovations in ICE technology. The figure below shows technological milestones and their potential timeline.

Figure A13. Technology roadmap



Source: Booz & Company, 2011

Potential of Electric Vehicles in India

In 2011, the Ministry of Heavy Industries and Public Enterprises, and the Society of Indian Automobile Manufacturers sponsored a study on the potential of electric vehicles in India (SIAM, 2011). According to the study, India has the potential to reach an overall annual sales figure of 6-7 million electric vehicles (xEVs) by 2020. The major share of these sales would be contributed by battery electric two-wheelers, which would contribute to 4.8 million annual sales in 2020. Hybrid cars, buses and LCVs could also reach 1.3–1.6 million unit sales in 2020, contributing significantly to xEV penetration. The majority of the liquid fuel savings would also come from the large-scale electrification of 2 wheelers, accounting for 1.4 million tonnes of liquid fuel savings (~USD 1,700 million). An estimated benefit of 1.5% reduction in CO_2 emissions would be possible, due to the penetration of electric vehicles leading up to 2020.

However, in order to help induce the penetration of electric vehicles, there is a need for a clear roadmap. The market is unlikely to reach the potential on its own, owing to several barriers hindering the process. The government and industry need to support a clear long-term roadmap in order to realize this potential for India. There is a requirement for investments in infrastructure and incentives. The table below shows investments and benefits achieved from potential electric vehicle penetration by the year 2020 (SIAM, 2011).

Table A1. Summary of investments and benefits- 2020

		2 W	3 W	4 W	Bus	LCV	Total
Incremental sales of electric vehicles ('000)		4,800	20-30	1,300-1,600	2.3-2.7	150-170	6,000-7,000
Liquid Fuel Savings[6]	MT	1.4	0.06-0.09	0.4-0.65	0.16-0.19	0.09-0.16	2.2-2.5
	USD[7] million	1,700	70-100	520-720	190-210	110-180	2,600-2,800
CO_2 Reduction (%)		2.7%	-0.9%	0.6%-1%	1.8%-2.1%	1.5%	1.3%-1.5%
Investment (USD million)	Demand/Supply	1,040	86-142	1,000-1,130	100-110	260-300	2,500-2,700
	Others	1,000	22-36	450-610	120-126	30-50	1,600-1,800
Return on investment (USD million)		5,600	240-340	960-1420	660-740	300-540	7,800-8,600

Current Government Schemes for Electric Vehicles

Realizing the possible impact of hybridization/electrification, the government of India has come up with a set of initiatives to facilitate xEV penetration in the country. The Alternative Fuels for Surface Transportation Programme by the Ministry of New and Renewable Energy (MNRE) has given a jumpstart to the Indian EV industry. Following this initiative, a number of other government entities have also started incentivizing xEVs.

The Alternative Fuels for Surface Transportation Programme guarantees demand incentives for all xEVs, amounting to a total of USD 19 million between 2010 and 2012. This is, however, subject to manufacturers giving at least a 1-year warranty and setting up 15 service stations across India. The programme also provides support for research, design, development and demonstration projects on a partnership basis with the stakeholders involved.

There is a push for the introduction of electric buses under the JnNURM programme. Under this scheme, electric trolleybuses will be introduced in Mysore and Bengaluru. Furthermore, certain state governments, such as that of Delhi, are providing demand side subsidies in addition to VAT and road tax waivers.

As is evident, most of these initiatives are largely fragmented and short-term. In order to achieve the potential laid out, a more systematic and collaborative approach is required from the government and industry, supporting a clear long-term roadmap. Currently, the solutions available in the market do not meet consumer expectations, and, hence, the market is at the infeasible stage (specifically for xEV 3W,

6 Well-to-wheel savings

7 1$= USD 1 = 50 Indian Rupees

4W, buses and LCVs). To achieve the tipping point for the market, the first step is to bridge this price–performance gap for consumers, and bring acceptable products into the market through demand side and supply side interventions. In parallel, the industry also needs to invest in building manufacturing and technology development capabilities. Along with this, power and charging infrastructure investments need to be made to facilitate adoption. This will lead to the development of viable solutions in the market for consumers, at acceptable price-points. OEMs should be incentivized for local manufacturing. Self-sustainability will be achieved with increasing penetration, beyond which incentives will not be required (SIAM, 2011).

Information about the project:

UNEP Transport Unit in Kenya, UNEP Risø Centre in Denmark and partners in India have embarked on a new initiative to support a low carbon transport pathway in India. The three-year 2.49 million Euro project is funded under the International Climate Initiative of the German Government, and is designed in line with India's National Action Plan on Climate Change (NAPCC). This project aims to address transportation growth, development agenda and climate change issues in an integrated manner by catalyzing the development of a Transport Action Plan at national level and Low Carbon Mobility plans at cities level.

Key local partners include the Indian Institute of Management, Ahmedabad, the Indian Institute of Technology, Delhi and CEPT University, Ahmedabad. The cooperation between the Government of India, Indian institutions, UNEP, and the Government of Germany will assist in the development of a low carbon transport system and showcase best practices within India, and for other developing countries.

Homepage : www.unep.org/transport/lowcarbon

FOR MORE INFORMATION, CONTACT:

United Nations Environment Programme (UNEP)
Division of Technology, Industry and Economics (DTIE)
Transport Unit
P.O Box 30552
Nairobi, Kenya
Tel : +254 20 762 4184
Email : lowcarbon@unep.org
www.unep.org/transport/lowcarbon

DTU