ANALYSIS OF TECHNICAL OPTIONS FOR MITIGATING ENVIRONMENTAL EMISSIONS FROM THE URBAN TRANSPORT SYSTEM IN SELECTED ASIAN COUNTRIES

Case Study of Delhi and Mumbai

Sudhakar Yedla

Jyoti K. Parikh

Anjana Das

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Indira Gandhi Institute of Development Research
Mumbai 400 065, India

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Asian Institute of Technology

For any further information or comments please contact -

Dr. Sudhakar Yedla
Assistant Professor
Indira Gandhi Institute of Development Research
Goregaon (E), Mumbai 400 065, India
Email: sudhakar@igidr.ac.in
Home: http://www.igidr.ac.in

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Preface

We now present a summary of research carried out by Indira Gandhi Institute of Development Research (IGIDR), Mumbai, which addressed the dynamics of transport and energy demands and the resulting environmental emissions in Delhi and Mumbai. Forecasting is done for a planning period of 20 years (1998-2020). The following issues have been addressed -

Issue I: Projection of demand for urban transport services and associated energy requirements and the resulting environmental emissions. Here, dynamics of travel needs and energy demands in Delhi and Mumbai are examined under various optimistic and pessimistic economic growth assumptions along with the business-as-usual (BAU) scenario. Environmental emissions (Green house gases and other harmful emissions) are also examined with the changing travel and energy needs under various scenarios considered.

Issue II: Analysis and selection of technical options for the energy efficiency improvement and mitigation of GHGs and other harmful emissions from urban transport systems. Various potential alternatives in controlling GHG and other harmful emissions are selected based on the criteria of energy saving potential, emission reduction potential and economic feasibility. Selection of options is specific to transport systems in Delhi and Mumbai. Optimal mix of different travel modes in sharing travel demands is determined for Delhi and Mumbai transport systems for a period of 20 years (1998-2020). This was done by minimizing the total transportation cost over the time period. Optimal mix of vehicles was obtained for various GHG mitigation targets ranging between 5% to 25%. Marginal CO_2 abatement cost was determined under each scenario for Delhi and Mumbai transport systems.

Issue III: Identification and ranking of barriers to the introduction of selected technical options to mitigate environmental emissions from the urban transport system. Barriers for the implementation of alternative transportation option chosen by the optimization model are identified both for Delhi and Mumbai. Barriers identified are ranked with respect to important qualitative criteria along with a set of quantitative criteria like energy efficiency, emission reduction potential and cost. Ranking exercise was done by adapting multi-criteria approach involving all actor groups from transport systems by accounting for their opinion in terms of qualitative criteria.

This report deals comprehensively with various aspects of the urban transport system for two major metropolitan cities. Starting with the forecasting of demands and emissions under assumptions of possible changes in economic activities, it further identifies a set of alternative transportation options based on detailed analysis of feasibility and potential in Mumbai and Delhi to obtain optimal mix of modes under various scenarios of GHG reduction levels. Identification and ranking of barriers completes the analysis, which help to formulate policies for transportation of Delhi and Mumbai.

The Asian Regional Research Program in Energy, Environment and Climate – Phase II (ARRPEEC II) involved a number of sectors viz. Transport, Biomass, Power and Small Scale Industries sector (SMI). "Analysis of Technical Options for the Mitigation of Environmental Emissions from Urban Transport Systems in Selected Asian Countries" is a transport sector project involving eight Asian cities namely Beijing, Hangzhou, Delhi, Mumbai, Bandung, Jakarta, Manila and Ho Chi Minh representing China, India, Indonesia, Philippines and Vietnam. This project is coordinated by Asian Institute of Technology (AIT) in collaboration with National Research Institutes (NRIs) from the participating countries.

We thank Swedish International Development Cooperation Agency (Sida) for supporting this interesting project on urban transportation in Delhi and Mumbai carried out at the Indira Gandhi Institute of Development Research (IGIDR), Mumbai, India. We also thank Mr. Sudhir Raghunath Kasbekar for his kind help in editing and proof reading this report.

Jyoti K. Parikh
Sudhakar Yedla

PROJECT SUMMARY

1. Introduction

India has been facing rapid urbanization. There is a two-fold increase in urban population during 1971-2001, registering a compounded annual growth rate (CAGR) of 3.8%. According to 2001 census there are 40 metropolitan cities, each with over 1 million people accounting for roughly one-third of urban population. Over 50% of the urban population lives in the five major metros of Bangalore, Kolkata, Chennai, Delhi and Mumbai. Among all the problems caused by urbanization, urban transport is considered to be one of the most severe. In many cities, population is doubling in a decade or little more. In contrast, roads and other transport infrastructure is growing at a much slower pace. Lack of effective policies and investments along with unplanned urbanization growth has resulted in increasing gap between supply and demand of transport services. Tremendous increase in personalized vehicles due to inadequate public transport system coupled with lack of corresponding expansion in road space has led to problems of congestion, longer travel time, increasing travel cost, more energy consumption and pollution. Thus, quality of life, productivity, environment and economic efficiency suffer due to problems in the transport sector.

Fossil fuels used in the transport sector cause pollution, which has reached alarming levels in all Indian metros. In the mid 90’s Delhi was the fourth most polluted city in the world, while a number of other Indian cities are following closely behind. A massive increase in the number of vehicles together with the existence of a large number of old, inefficient, ill-maintained and obsolete vehicles, result in emissions of hundreds of thousand tons of pollutants annually in gaseous and particulate form into the atmosphere. The use of poor quality fuel, poor road conditions and congestion further contribute to it. Around 67% of air pollution in Delhi was caused by motor vehicles in 1996. In 1994, the share of automobiles in total pollutant load was 52% in Mumbai. What is most disturbing is that, this share is growing.

Thus, a sustained mitigation approach needs to be developed by identifying the right set of alternative options/choices to achieve an environmentally sustainable urban transport system. With this objective, Swedish International Development Cooperation Agency (Sida) has started ARRPEEC project involving Asian Institute of Technology (AIT) and five National Research Institutes (NRIs) to identify and assess the potential of a set of alternative transportation options in major Asian cities. Indira Gandhi Institute of Development Research (IGIDR) was chosen as Indian NRI to analyze alternative transportation options for Delhi and Mumbai transport systems with the objective of achieving energy efficiency and less pollution.

The overall objective of the study is to analyze the technical options for mitigation of green house gases (GHG) and other harmful emissions from the urban transport systems. The specific objectives of the project are as follows:

(i) to analyze and project the demand for urban transport services and associated energy demand and environmental emissions for a planning period of 20 years;

(ii) to analyze and select the technical options for energy efficiency improvement and mitigation of GHGs and other harmful emissions from the urban transport systems; and

(iii) to identify and rank the barriers to the introduction of selected technical options to mitigate environmental emissions from the urban transport systems.

2. Analysis of Urban Transport Energy Demand and Emissions

Scenario Definitions: Business as Usual (BAU) scenario considers a uniform annual GDP growth rate of 5% in Delhi and 6.6% in Mumbai, till 2020. Four Alternative Scenarios are constructed based on different GDP growth rates. Alternative scenarios 1 and 2, consider 50% and 25% higher annual GDP growth rates respectively while alternative scenario 3 and 4 considers 50% and 25% lower annual GDP growth rates respectively compared to the growth rates considered under BAU scenario.

2.1 Travel Demand

2.1.1 Delhi

BAU Scenario: Population growth and growing economic activities lead to manifold increase in travel demand and vehicular stock. Per capita travel demand is expected to grow from 17 km to 31 km during the planning horizon. Despite assumptions on the implementation of Mass Rapid Transit System (MRTS) with carrying capacity of 6.4 million passengers by 2015, about 8.85 million vehicles are expected to roll down on Delhi roads by 2020. Significant growth in personalized transport modes viz. cars and 2-wheelers is expected. Due to growing income, ownership of these two transportation modes is expected to double by 2020. A similar trend is expected in the case of Mumbai also. Share of motorized travel demand met by personalized mode of transport is expected to increase from about 40% to 45% over the time period. The share of bus in the total travel demand, on the other hand, would decline from 53% to 48%.

Alternative Scenarios: In Alternative Scenario 1 with high economic growth there is a 10-fold increase in vehicle stock during 1997-2020. While annual growth rate in vehicle stock is 5.8% in BAU Scenario, in this scenario, it is about 10.4% per annum. In Alternative Scenario 2, total number of vehicles in 2020 is estimated to be 14.7 million, as compared to 8.85 million in BAU Scenario.

With the assumptions of pessimistic economic growth rate (alternative scenario 3), total vehicular stock, declines from 2.38 million to 1.54 million over the time period. In Alternative Scenario 4, vehicle stock is expected to grow gradually from 2.38 million to 4.5 million by 2020.

Vehicular mix similar to BAU scenario is observed in all alternative scenarios. Personalized mode of transport dominates the total vehicle stock heavily. As expected, due to higher economic growth, there is many fold increase in ownership of vehicles in first two alternative scenarios. In Alternative Scenario 3 and 4, lower economic growth limits ownership of personalized vehicles. Number of 2-wheelers per 1000 persons would decline from the existing 134 to 21 in 2015. However, it is expected to grow to 43 in 2020. Due to the same reason, the number of cars per 1,000 persons would drop from 58 to 9 in 2015 and then increase to 18 by 2020.

Per capita per day travel need is expected to increase heavily from 17.5 km in 1998 to about 75 km and 47 km in 2020, respectively under the two optimistic scenarios. Under alternative scenario 3, low economic growth and implementation of MRTS would pull down the demand for motorized transport from 73 billion p-km to 37 billion p-km by 2020. Per capita per day transportation requirement shows a drastic fall from 17.5 km in 1998 to about 3 km in 2015. Demand for freight is expected to fall gradually from 2.6 billion t-km to 2.0 billion t-km by 2015. However, it would increase to 2.3 billion t-km afterwards. Under alternative scenario 4, on the whole, passenger travel demand would increase from 73 billion p-km in 1998 to 112 billion p-km by 2020. Travel demand per capita per day declines from 17.5 km to about 14 km by 2020.

2.1.2 Mumbai

BAU Scenario: As in the case of Delhi, population growth and growing economic activities lead to a manifold increase in travel demand and vehicular stock. Per capita travel demand is expected to grow from 8.2 km to 26 km in Mumbai during the planning horizon. In Mumbai, bus continues to be the dominant mode of passenger transport.

Alternative Scenarios: Under alternative scenario 1 with high economic growth, a 14-fold increase in vehicle stock is expected during 1998-2020 in Mumbai. While annual growth rate in vehicle stock is 7.7% under BAU scenario, in this optimistic scenario it is about 12.8% per annum. Vehicles stock in Mumbai increases about 8.7 times under alternative scenario II compared to that of 5 times increase under BAU scenario. With the assumption of pessimistic economic growth rate, alternative scenario 3 and alternative scenario 4, total vehicle stocks in Mumbai, increases by 1.4 and 2.38 times, respectively by 2020.

Vehicular mix under all alternative scenarios is similar to that under BAU scenario. Personalized mode of transport dominates the total vehicle stock heavily. Under alternative scenario 3, while cars per 1,000 persons remain same as the base case (14), number of 2-wheelers per 1,000 persons is expected to grow marginally from 22 to 27 by 2020. Under alternative scenario 4, 2-wheelers and cars per 1000 persons increase from 14 and 22 to 26 and 58, respectively during the planning period.

In Mumbai, about 10-fold increase in passenger travel demand is expected under alternative scenario 1. A similar trend is observed under alternative scenario 2. Low economic growth under alternative scenario 3, results in very low growth in travel demand for both 2-wheelers and cars. Under alternative scenario 4, travel demand of both types doubles over a period 1998-2020. In the alternative scenario 1 and 2, both types of travel demand showed higher annual rate of growth during 1998-2020 than assumed annual GDP growth rate. Per capita per day passenger travel demand is expected to increase by almost 8 times and 5 times respectively between 1998 and 2020 under alternative scenario 1 and 2. However, under alternative scenario 3 during the same period, it declines from 8.16 km to 7.68 km. Under alternative scenario 4, it almost doubles.

2.2 Energy demand

2.2.1 Delhi

BAU Scenario: Growth in transport energy demand is expected to be significant. However, assumptions on MRTS, curbs the energy demand for motorized transport to some extent. It is expected to grow 2.3 times during 1997-2020. The annual growth rate is worked out to be 4.4% against the assumed economic growth rate of 5.6%. The total energy demand from transport services in 1998 was 42.2 million GJ and is expected to increases many fold to reach 137.4 million GJ by 2020.

Energy intensity for passenger transport falls over the years due to higher penetration of more energy efficient CNG and battery operated vehicles. However, energy intensity for freight transport increases during the same period, due to increase in share of LCV in total freight transport, which is relatively energy inefficient. Passenger transport dominates the energy demand, though its share is expected to fall from 84% to 81% by 2020.

As far as individual fuel is concerned, the demand for natural gas is expected to reach 1 billion cubic meters by 2020. This will call for an elaborate CNG supply network. Replacement of diesel driven passenger vehicles such as buses, taxis etc. by CNG driven vehicles, would lead to a fall in demand for diesel. In the latter periods only goods vehicles would demand diesel. Because of higher share of personalized mode of transport, the growth in demand for gasoline will be 2.35 times the base year consumption.

Alternative Scenarios: In Delhi, with the assumption of 50% higher annual GDP growth rate over BAU scenario, the transport system is expected to demand about 2.6 times more energy in 2020 than the same in the BAU scenario. In alternative scenario 2, the travel demand is 1.65 times more than under the BAU scenario. The estimated annual growth rate in energy demand during 1997-2020, in these two scenarios is 8.9% and 6.8%, respectively. In the case of pessimistic GDP growth rate assumptions, the urban transport system in Delhi is expected to demand only 20% of the energy demand under BAU scenario. This is about 50% of the energy consumption in 1997.

2.2.2 Mumbai

BAU Scenario: In Mumbai, a 3-fold increase is expected during 1998-2020. The annual growth rate works out to be 4.4% and 5.1%, respectively for Delhi and Mumbai, as against assumed economic growth rates of 5.6% and 6.6% respectively. The total energy demand from transport services in 1998 was 19.1 million GJ and is expected to reach 60.3 million GJ by 2020.

As in the case of Delhi, the energy intensity of passenger transport decreases over the planning horizon due to penetration of more energy efficient CNG and battery operated vehicles. Passenger transport dominates the energy demand. However, its share is expected to fall from 94% to 92% by 2020. Natural gas demand of about 1 billion cubic meters by the year 2020 suggests the need for an elaborate CNG supply network. Replacement of diesel driven passenger vehicles like buses, taxis etc. by CNG driven vehicles, leads to a fall in demand for diesel.

Alternative Scenarios: Under optimistic assumptions of GDP growth rate, energy demand is expected to grow annually at a rate of 9.7% per annum (alternative scenario I) and 7.4% per annum (alternative scenario II) during 1998-2020. Energy demand in 2020, in absolute terms, is expected to be about 2.5 times higher than the same under the BAU Scenario. In pessimistic assumption of GDP growth scenario, urban transport system demands about 18 million GJ, which is 87% of energy that is actually consumed in 1998.

2.3 Environmental Emissions

2.3.1 Delhi

BAU Scenario: Despite moderate economic and population growth, measures such as fuel substitution, supply of clean fuel, implementation of strict emission norms and MRTS will help Delhi reduce pollution load (local) from 412,000 thousand tons to 328,000 tons by 2020, about 20% decrease from the base year. Use of low lead gasoline reduces lead emissions substantially. Similarly, use of low sulfur diesel, stricter emission norms and substitution of diesel in passenger transport, is expected to reduce sulfur emissions from 4,600 tons to 2,700 tons by 2015. However, it would increase marginally by 2020, due to growth in freight travel demand. Stricter emission norms and introduction of CNG driven bus is expected to reduce NO_x emissions as well.

Cars and 2- wheelers put together contribute about 80% of HC emissions in Delhi. 2-wheelers alone contribute about 70% of total CO emissions. Therefore, in Delhi, there is further scope of reduction in CO and HC by reducing the use of personalized transport. Phasing out of diesel driven bus system would limit the growth in particulate emissions.

Delhi is expected to experience 2.57 times more CO_2 emission by 2020. CO_2 emission from the Delhi transport system is 2.4 times higher than that of Mumbai at any given time.

Alternative Scenarios: The total pollution load under alternative scenario 1 is expected to get doubled by 2020 from the present level of 412,000 tons. Therefore, in terms of pollution, this economic growth scenario is unsustainable unless some even stricter abatement rules and measures are adopted. Under alternative scenario 2, the pollution load is initially expected to decline to 344,000 tons by 2010 and then increase again to 542,000 tons by 2020. Under pessimistic economic growth scenarios, pollution declines to 66,000 tons from the base level of 412,000 tons in 1997. Pollution load under alternative scenario 4 is expected to reduce to 150,000 tons by 2015 and subsequently rise to 167,000 tons by 2020.

As far as individual pollutants are concerned, under alternative scenario 1 and 2, CO_2 emissions are expected to increase significantly from 3620 thousand tons in 1997 to 24,200 thousand tons and 15,400 thousand tons by 2020, respectively. Under alternative scenario 3, the pessimistic assumptions cut down the emissions by 2020 almost by 50%. Under alternative scenario 4, CO_2 emissions increase by 36% from the base level over the planning horizon. All other pollutants show similar trends.

2.3.2 Mumbai

BAU Scenario: Pollution levels are relatively better in Mumbai. Implementation of strict emissions norms and introduction of clean fuel and fuel substitution along with heavy dependence on public transport helps Mumbai to remain relatively clean. Pollution load is expected to decline by about 40%, from 135,000 tons in 1998 to 84,000 tons in 2020. CO and HC continue to be the main pollutants, emitted mostly by gasoline driven vehicles. Particulates, SO_x and NO_x emissions are expected to go down considerably during 1998-2020 because of reduced use of diesel driven vehicles, low sulphur diesel and stricter emission norms. Mumbai is expected to register 2.7 times more CO_2 emissions by 2020 compared to the base year.

Alternative Scenarios: Under alternative scenario 1, pollution level would increase by 66% by 2020. It is almost three times the pollution load in 2020 under BAU Scenario. Pollution load in a lesser optimistic GDP growth scenario shows a decline initially and reaches 86,000 tons by 2010. However, it is expected to increase after that to reach almost the base level by 2020. In pessimistic GDP growth scenario emission levels go down abnormally from the base level of 136,000 tons, because of the expected fall in the transportation activities.

Under alternative scenario 1 and 2, CO_2 emissions would increase significantly from 1,500 thousand tons to 9,960 thousand tons and 6,500 thousand tons by 2020, respectively. Under alternative scenario 3, the pessimistic assumption cuts down the emissions by 23% by the end of planning horizon. Under alternative scenario 4, CO_2 emissions in 2020 are expected to increase by 53% from the base level. All other pollutants follow similar trends.

3. Technical Options to Mitigate Environmental Emission

This section presents the technological and economic potential of a set of selected alternative transportation options for Delhi and Mumbai transport systems.

3.1 Options Considered

From the two categories of alternative options to reduce GHG and other harmful emissions, the following alternatives are selected based on various criteria and also the existing trends of growth in vehicle stock. In the case of Delhi, use of CNG for buses and cars, shift from 2-stroke 2-wheelers to 4-stroke 2-wheelers and battery operated buses (BOV) are the four options considered. With due consideration to the characteristics of Mumbai transport system, use of CNG for buses and cars, shift from 2-stroke 2-wheelers to 4-stroke 2-wheelers and use of CNG for 3-wheelers and BOV 3-wheelers are selected for further analysis.

3.2 Emission Reduction Potential of the Selected Options

Potential of each selected alternative option in reducing emission of various pollutants is determined by means of emission reduction potential (ERP).

In the case of Delhi, all chosen options showed better ERP. However, the technology is difficult to adapt for BOV and it is yet to prove its impact at the policy level. Thus, it was not considered for further analysis. Two wheelers showed moderate ERP in comparison to other alternative options. But due to the fact that Delhi traffic is dominated by 2-wheelers, this option was selected for further scrutiny. Use of CNG for bus and car showed slight rise in CO_2 emissions.

In the case of Mumbai, it was found that except the option of shifting from 2-stroke 2-wheelers to 4-stroke 2-wheelers, all other options fared relatively well in controlling emissions. This trend could be due to the fact that 2-wheelers are not the dominating mode of transport in Mumbai and hence failed to show better ERP. Use of CNG for bus and 3-wheeler contributes to marginal rise in CO_2 emissions. BOV 3-wheelers shows high ERP potential with much better adaptability.

3.3 Pollution Abatement Cost (PAC)

All selected options for Delhi and Mumbai are tested for economic feasibility. Life cycle operating costs are used to compare the feasibility of various technical options.

Abatement cost !

Difference of the life cycle operating cost of the technological alternative and the existing technology to be replaced divided by the emission mitigation potential of the option

In the case of Delhi, CNG cars proved to be much better option with a better PAC (Rs. -104.4 /kg pollutant)[1]. There is a considerable difference of 70% between the PAC of CNG cars and 4-stroke 2-wheelers. It is quite interesting to observe that, in case of Mumbai, CNG buses proved uneconomical (PAC of Rs. 0.34/Kg pollutant) in terms of unit pollution abatement cost. Among the other three options considered for Mumbai, CNG cars proved economical for pollution reduction with a PAC of Rs. – 83.9/Kg pollutant. Battery operated 3-wheelers are not only efficient in reducing pollution but are also cost effective. In spite of their high initial capitol cost, BOV 3-Wheelers proved economical, may be due to the advantages it has in terms of fuel and other costs.

4. Least-cost Options to Mitigate CO_2 Emissions

This section presents minimization of cost in mitigating global and local environmental emissions with a given set of constraints. An optimal mix of vehicles from different modes was determined to cater the travel demands over the planning horizon driven by emission constraints. In the case of Delhi, alternative options viz. 4-stroke 2-wheelers, CNG cars and CNG buses are more prominent and, in the case of Mumbai, CNG 3-wheelers, BOV 3-wheelers, CNG cars and CNG buses are more prominent. Determination of the optimal vehicular mix for minimized total cost of transportation is done by developing different scenarios based on the level of emission mitigation targets viz. 5%, 10%, 15%, 20%, 25% and 30% reduction in CO_2 emissions, vis-à-vis the base case of no emission mitigation targets.

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[1] Negative value of PAC indicate that the option under consideration has lesser LCC vis-à-vis the base case

4.1 Selected Least Cost Options

4.1.1 Delhi

Table 1 presents the vehicular-mix at selected CO_2 emission reduction targets in selected years. According to the least cost model results, among the alternative options considered, CNG buses supply the highest share of transport services supplied in p-km. Total discounted cost of the transport system over the planning period under base case (without CO_2 mitigation constraint) is 15.1 billion US$ (in 2000 prices). The transport system in Delhi emits a cumulative total of 30 million tons of CO_2 over the planning horizon.

In the Delhi transport system, efforts to mitigate CO_2 are expected to reduce the use of diesel cars. The travel demand would be catered by gasoline cars with the share of CNG cars remaining uniform. However, diesel cars also have a major share in catering to the travel demand during the initial period of the time frame, which diminishes gradually. Cars are targeted more than buses for emission mitigation. The change in vehicular mix is observed predominantly in the later phase of the time horizon.

Table 1: Vehicular-mix at selected CO_2 emission reduction targets in Delhi (Percentage)

Vehicle Type	Technology	0% Reduction			10% Reduction			20% Reduction			25% Reduction		
		2005	2010	2020	2005	2010	2020	2005	2010	2020	2005	2010	2020
Car	Gasoline	12.5	9.0	22.4	12.5	9.0	24.3	26.2	22.7	24.8	16.0	24.0	24.8
	Diesel	16.0	15.0	2.4	16.0	15.0	0.5	2.3	1.3	0.0	0.0	0.0	0.0
	CNG	1.2	2.0	4.6	1.2	2.0	4.6	1.2	2.0	4.6	1.2	2.0	4.6
Bus	Diesel	10.2	11.9	11.6	10.2	11.9	11.6	10.2	11.9	11.6	22.6	11.9	11.6
	CNG	44.3	44.8	39.8	44.3	44.8	39.8	44.3	44.8	39.8	44.3	44.8	39.8
2W	2S	8.7	6.3	1.9	8.7	6.3	1.9	8.7	6.3	1.8	8.7	6.3	1.8
	4S	7.2	10.9	17.2	7.2	10.9	17.2	7.2	10.9	17.3	7.2	10.9	17.3

Source: IGIDR (2001)

Ten per cent mitigation scenario shows some rise in gasoline cars by reducing the share of diesel cars. And this was found happening in the later part of the time horizon. The bus population is expected to remain almost unchanged from the base case of no emission targets and the same is observed in the case with 2 wheelers. The emission target of 20% results in considerable rise on gasoline cars (increased share) over the middle band of the time horizon. During the same period drastic fall is expected in the share of diesel cars. A further increase in emission targets to 25% shows some increase in share of CNG buses but in the later part of the planning horizon.

4.1.2 Mumbai

Table 2 presents the vehicular-mix at selected CO_2 emission reduction targets in selected years in Mumbai. According to the least cost model results, among the alternatives considered, diesel buses supply the highest share of the transport services supplied in p-km. The total discounted cost of the transport system over planning horizon under the base case is 4.0 billion US$ (in 2000 prices). The transport system in Mumbai emits a cumulative of 12 million tons of CO_2 over the planning horizon.

Table 2: Vehicular-mix at selected CO_2 emission reduction targets in Mumbai (Percentage)

Vehicle Type	Technology	0% Reduction			5% Reduction			15 % Reduction			30% Reduction		
		2005	2010	2020	2005	2010	2020	2005	2010	2020	2005	2010	2020
Car	Gasoline	8.4	13.0	10.5	12.9	13.0	12.4	12.9	13.0	12.6	12.9	13.0	12.6
	Diesel	5.5	0.6	2.3	1.0	0.6	0.4	1.0	0.6	0.2	1.0	0.6	0.2
	CNG	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
Bus	Diesel	75.2	60.2	74.1	75.2	48.7	74.1	75.2	37.2	70.4	43.6	16.7	19.3
	CNG	0.0	16.1	0.0	0.0	27.6	0.0	0.0	39.1	3.7	31.6	59.6	54.9
3-W	Diesel	8.0	2.8	8.5	8.0	2.8	8.5	7.6	2.8	6.0	5.7	0.9	6.0
	CNG	2.4	4.2	2.5	2.4	4.2	2.5	2.4	4.2	2.5	2.4	4.2	2.5
	BOV	0.0	2.2	0.0	0.0	2.2	0.0	0.5	2.2	2.5	2.4	4.1	2.5

Source: IGIDR (2001)

In Mumbai, unlike Delhi, the change in vehicular mix due to emission mitigation strategies was found happening from the initial phase of the time horizon. BOV 3-wheelers were chosen against the conventional 3-wheelers and this option made the choice very easy. Change from diesel to CNG buses was observed in Mumbai. Unlike Delhi, shift to clean fuel in the case of bus is significant compared to that of cars, which demonstrates the dominance of efficient bus network in Mumbai.

Ten percent emission reduction target results in slight rise in gasoline cars evenly spread over the entire time horizon. This is further expected to result in considerable fall in the share of diesel cars. It is interesting to see the CNG cars share remain almost unchanged. Unlike in the case of Delhi, the share of diesel bus in Mumbai reduces considerably giving a jump to the CNG buses during the middle band of the time period. An expected rise in emission mitigation to 20% shows a similar trend of shifting to gasoline cars where the change of share in the case of CNG buses took a big leap uniformly all over the time horizon. CNG buses are expected to replace diesel buses considerably. This contrasting result of increased CNG buses against the CO_2 mitigation target is explained below.

At this level of emission mitigation (20%), the share of gasoline/diesel 3-wheelers reduces considerably with an increased share of BOV 3 wheelers. A similar trend is observed at 25% reduction levels as well. High emission mitigation achieved by this option results in choosing CNG buses over diesel buses, which are cost effective and less polluting (for local pollutants). And also it is interesting to observe that the model chooses CNG buses over CNG 3 wheelers, with the share of 3 wheelers remaining more or less unchanged over the time period.

4.2 Local Emissions

Different scenarios of CO_2 emission mitigation levels gave different responses in terms of local pollutants. Table 3 presents the local emission level under selected CO_2 reduction targets in Delhi. Among all local pollutants TSP showed considerable change under different

CO_2 mitigation scenarios. In Delhi, the changes in TSP levels are in the range of 2% to 24% for the CO_2 mitigation of 5% to 25%.

Table 3: Emission levels of local pollutants at selected CO_2 emission reduction targets in Delhi, 10^3 tons *

Pollutants	0% CO_2 reduction			10% CO_2 reduction		20% CO_2 reduction		25% CO_2 reduction	
	1997	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
CO	263.0	316.3	659.5	316.3	901.7	504.2	913.5	522.8	913.5
NOx	49.0	27.7	53.5	27.7	58.6	31.7	58.9	32.1	58.9
TSP	7.2	11.6	14.9	11.6	12.9	10.1	12.8	9.9	12.8
SOx	4.6	9.3	13.4	9.3	7.8	4.9	7.5	4.4	7.5

*1997 figures are the actual emission level

Table 4 presents the local emission level under selected CO_2 reduction targets in Mumbai. Among all local pollutants TSP showed considerable change in different CO_2 mitigation scenarios. In Mumbai, the changes in TSP levels are in the range of 5% to 36% for the CO_2 mitigation of 5% to 25%.

Table 4: Emission levels of local pollutants at selected CO_2 emission reduction targets in Mumbai, 10^3 tons *

Pollutants	0% CO_2 reduction			10% CO_2 reduction		20% CO_2 reduction		25% CO_2 reduction	
	1998	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
CO	83.0	130.8	244.9	125.5	248.6	118.9	234.4	110.7	228.5
NOx	18.5	9.6	16.2	9.0	16.4	8.4	14.7	8.4	14.0
TSP	2.6.	4.1	9.8	3.2	8.4	2.4	6.3	2.1	5.3
Sox	1.9	4.0	9.3	2.9	7.9	1.9	5.2	1.7	3.9

*1998 figures are the actual emission level

CO_2 mitigation strategies showed their potential in controlling local pollutant with considerable precision. This presents an interesting interaction of global mitigation strategies vis-à-vis local emission mitigation strategies. This could be a trend setting result in light of the increasing emphasis on global issues in urban transportation sector and possibilities of bringing it under CDM purview.

Mumbai shows more potential than Delhi in controlling local pollutants under GHG mitigation strategies.

4.3 Marginal CO_2 Abatement Cost

Marginal CO_2 abatement cost in Delhi is double the cost in Mumbai. MAC in Delhi ranges from 36 to 116 USD for the CO_2 reduction of 5% to 25% over the planning period. For Mumbai, it is in the range of 17 to 24 USD for the same level of emission mitigation. In Delhi, where significant efforts have been made already to combat the ever increasing emissions, further efforts to mitigate CO_2 are expensive. Where as, in cities like Mumbai where pollution is on the rise but yet to reach the threshold levels, mitigation of CO_2 would be much cheaper. Combating green house gas emissions over a period of 20 years is found to be less expensive in Mumbai compared to Delhi. MAC values for CO_2 in Delhi and Mumbai are significantly lower than many other Asian countries. Marginal abatement costs at different levels of emission mitigation both in the cases of Delhi and Mumbai are given in the table below.

Table 5: Marginal CO_2 Abatement Costs (US$/ton of CO_2)

CO_2 Reduction level (% of the base case emission)	Delhi	Mumbai
5	35.68	17.48
10	44.59	--
15	49.08	19.51
20	66.94	21.44
25	115.87	24.12
30	--	47.51

5. Identification and Ranking of Barriers to the Adoption of Selected Options

Delhi

Conversion of conventionally fueled buses to CNG buses (Option – I), conversion of conventionally fueled cars to CNG cars (Option – II) and replacing 2-stroke 2-wheelers by 4-

stroke 2-wheelers (Option – III) are chosen as alternative options to achieve energy efficiency and emission reduction from Delhi transport system. Identification of barriers was done by personal consultation with all actor groups involved either directly or indirectly in transportation systems. Ranking of barriers is carried out by applying Analytic Hierarchy Process (AHP), a multi-criteria decision making tool based on quantitative as well as qualitative criteria. Group aggregation by standard AHP methodology is used to arrive at final opinion matrix. Following are the identified barriers and their ranking:

Rank	**Barriers**		
	Option I – CNG Bus	**Option II – CNG Car**	**Option III – 4-S 2-W**
1	Lack of resources and infrastructure	Lack of resources and infrastructure	Additional costs
2	Additional costs	Additional costs	Lack of enforcing mechanism
3	Lack of enforcing mechanism	Availability of efficient technology/conversion kits	Lack of awareness
4	Availability of efficient technology/conversion kits	Lack of awareness	Availability of alternative technology

The biggest barriers for the implementation of option I and II are resource availability and lack of sufficient infrastructure. This is largely so because both are CNG based options. CNG options are riddled with problems of resource and infrastructure availability. Hence, the implementation of CNG option -- whether for CNG buses or CNG cars – faces the bottleneck of lack of resources and infrastructure. Therefore, adequate policy measures need to be taken to remove these barriers for better implementation of this potential transportation option in Delhi.

Additional cost is expected to be a major barrier in the case of 4-stroke 2-wheelers. Hence, by bringing down the additional cost burden on users, 4-stroke 2-wheelers can be made more prominent on Delhi roads. Additional cost is the second important barrier for the implementation of CNG option. It is very clearly observed that cost of CNG kits has not come down considerably over the last 10 years. Hence, measures are needed to bring down the additional cost on the user to make this option more penetrating in Delhi transport system.

Lack of enforcing mechanism as a barrier is expected to catch more attention compared to the availability of technology as a barrier. It clearly indicates that in the opinion of various actors involved in the Delhi transport system, availability of technology is no more a problem for the implementation of various alternative options. However, availability of technology may show some influence on cost as well as the safety of the alternative options. It is only the resources and infrastructure along with enforcing mechanism, which needs to be focused upon for better implementation of these alternative options. Removing the additional cost burden on users would also make alternative options more adaptable.

Mumbai

Conversion of conventional fuel cars to CNG cars (Option – I), conversion of conventional fuel 3-Wheelers to CNG 3-Wheelers (Option – II) and conversion of conventional fuel 3-Wheelers to BOV 3-Wheelers (Option – III) are the chosen alternative options to achieve energy efficiency and emission reduction from the Mumbai transport system.

Availability of efficient technology/conversion kits, additional costs, lack of resources and infrastructure, lack of enforcing mechanism and lack of awareness are the barriers for these options. This was concluded based on various influencing factors like traffic conditions, vehicle stock, information on modes that are dominating the road and geographical conditions. Following is the list of barriers for each option and their ranking.

Rank	**Barriers**		
	Option I – CNG Car	**Option II – CNG 3-Wheeler**	**Option III – BOV 3-Wheeler**
1	Lack of resources and infrastructure	Lack of resources and infrastructure	Additional costs
2	Lack of enforcing mechanism	Availability of efficient technology/conversion kits	Availability of alternative technology
3	Additional cost	Additional costs	Lack of enforcing mechanism
4	Availability of efficient technology/conversion kits	Lack of awareness	Lack of awareness

Lack of resources and infrastructure is expected to be a dominating barrier for the implementation of CNG cars and CNG 3-wheelers in Mumbai. CNG conversion had been initiated in Mumbai in the late 90's and till now there has been only a marginal conversion achieved. Hence, for the implementation of CNG option -- whether it is CNG car or CNG 3-wheeler -- lack of resources and infrastructure is a major bottleneck and policy measures need to be taken to remove these barriers for better implementation of CNG option in the Mumbai transport system.

Additional cost is expected to be a major barrier for the implementation of BOV 3-wheelers and, to some extent, in the case of CNG 3-wheelers as well. Additional cost appeared to be the second important barrier for the implementation of CNG option. Availability of technology is the second major barrier for the implementation of BOV 3-wheelers. Hence, measures need to be taken to overcome this barrier to make BOV 3-wheelers more penetrating in the Mumbai transport system. 3-wheelers showed some concern about the cost as a barrier. This was not observed in the case of CNG cars. This could be due to the ownership constraint. 3-wheelers are used for public transport and most of them are for their livelihood. Unlike cars, any capital investment in 3-wheelers calls for some financing and that certainly lessens the burden on the user. Removing the additional cost burden on the user would also make the options more adaptable.

6. Conclusions

The analysis assumes a declining emissions factor due to stricter emission norms and supply of cleaner fuel. It also assumes MRTS of capacity 3.4 million passenger by 2005 in Delhi and doubling its capacity by 2015. Furthermore, it assumes the policy of replacement of diesel bus system by CNG and introduction of electricity driven intermediate mode of transport. Therefore, unless the following measures are implemented, emissions level will go up many folds than the estimated one.

- Implementation of strict emission norms is extremely necessary
- Supply of clean fuel (low lead gasoline, low sulphur) should be made mandatory
- Implementation of MRTS in Delhi
- Supply of CNG should be ensured
- Large scale CNG driven and battery operated vehicle manufacturing capacity

From the scenario analysis, the study concludes that in terms of pollution, high economic growth scenarios are unsustainable unless some even stricter abatement rules and measures than that assumed in BAU scenario are adopted.

From the analysis of various options for energy saving and emission reduction potential, the study concludes that replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers, CNG cars and buses are better alternatives for Delhi, where as in Mumbai, the options are biased mostly towards public transport. CNG cars and 3-wheelers and BOV 3-wheelers showed more potential.

The analysis of transportation and energy demands over the time horizon and also techno-economic analysis of alternative options indicates that Mumbai remains dominated by the public transport system, despite a growing demand for personal mode of transport.

In the case of Delhi, an optimal mix of alternative options for emission mitigation is expected to target the emission control over the later years on the time horizon, which is in contrast to the case of Mumbai. This could be due to the fact that CNG vehicles dominate in Delhi, hence the reduction in emission is more attempted by replacing diesel cars in later part of the planning horizon. Where as in Mumbai, induction of BOV 3-wheelers showed better potential and hence the emission reduction is targeted right from the beginning of the time period.

CO_2 mitigation efforts appeared to be less expensive in Mumbai compared to Delhi. Marginal abatement cost under the 15% reduction target is expected to cost 40 USD and 20 USD (approx.) in Delhi and Mumbai, respectively.

CO_2 mitigation strategies resulted in control of local pollutants considerably. In Mumbai, reduction levels of local pollutants are expected to be higher than the target CO_2 reduction levels. This indicates that the environmental management and pollution control efforts in Mumbai yield better benefits.

Lack of resources and infrastructure is expected to be a major barrier in the way of implementation of CNG technology. Additional cost is the second biggest barrier to the implementation of CNG technology. This barrier is particularly significant in Mumbai in the case of CNG 3-wheelers. The interesting finding from Delhi, in the light of the Supreme Court directives, is that availability of technology in the case of CNG is no more a barrier but implementation difficulties (lack of enforcing mechanism) are ranked higher. This clearly explains the CNG paradox in the Delhi transport system.

The Mumbai transport system is expected to continue its reliance on the public transport system and CNG 3-wheelers are going to be the main target. Additional cost and technology availability are expected to be the major barriers to this environmental friendly option and policy makers have a major role in augmenting its penetration in the system by implementing appropriate policy measures.

1. INTRODUCTION

Rapid urbanization has often been described as a feature of developing countries regions., India is no exception as it has witnessed tremendous growth in urbanization since independence. There has been a two-fold increase in urban population during 1971-1991, registering a compounded annual growth rate (CAGR) of 3.8% (Figure 1). The share of urban population in total population has gone up from 20% in 1971 to 28% in 1991 and is projected to grow respectively at 34.5% and 41.7% in 2001 and 2011.

As per the 1991 census, India had 93 cities with population above 0.2 million and 73 cities with population above 0.3 million each. There are 23 metropolitan cities (each with over 1 million people) accounting for roughly one-third of urban population and one-twelfth of total population. Over 50% of the metropolitan population lives in five giant metros- Calcutta (11.86 million), Mumbai (9.93 million), Delhi (9.42 million), Madras (5.36 million) and Bangalore (4.1 million).

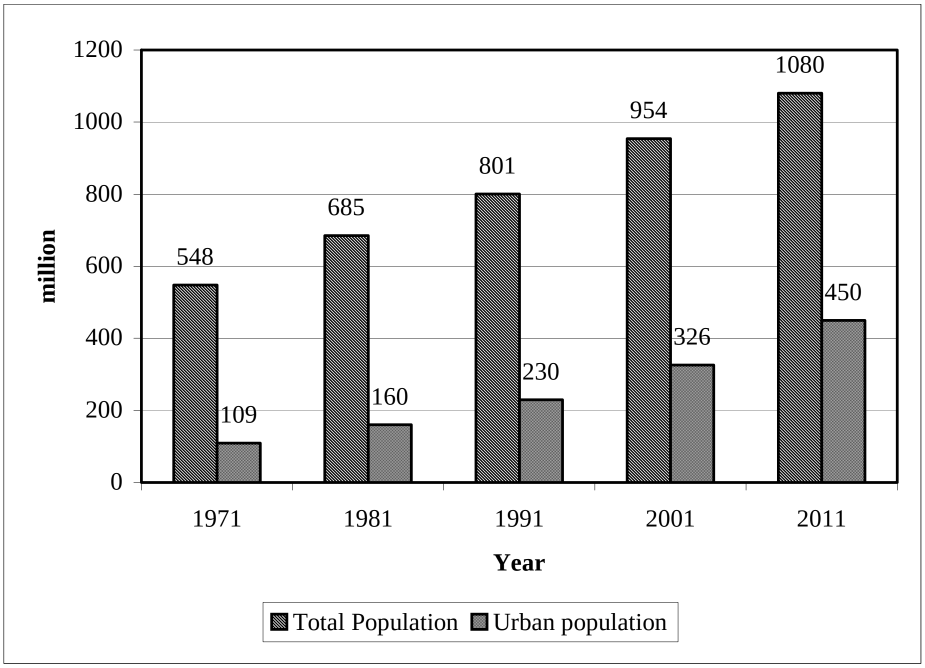

Figure 1 Urbanization trend in India

Although, urbanization is a vital ingredient of economic progress, it has caused a number of problems. Indian cities contribute nearly 60% of the national income, at the same time, they have become unsustainable due to lack of basic amenities such as water, sewerage system, housing facility, transport etc. Overflowing population has led to a number of problems such as proliferating slums, congestion, waste generation and pollution.

Urban transport is considered as one of the most serious problems. Despite years of planning, India has been unable to address the serious inefficiencies prevailing in urban transportation. In many of the cities in India, population is doubling in a decade or little more. In contrast, roads and other transport infrastructure have grown at a much slower pace. Heavy investments to the tune of 12-15% of national outlay have been made in the transport sector. Unfortunately, much of the central plan expenditure is diverted towards construction of national highways and augmenting capacity in the railways. That leaves very little for the needs of urban transportation.

Lack of effective policy and investment along with the uncontrolled urbanization growth has resulted in gross discrepancies between supply and demand of transport services. Inadequate public transport system has led to a tremendous growth in personalized vehicles on the one hand, and at the same time road space has not grown proportionately leading to congestion, longer travel time, more energy consumption, increasing cost of travel and pollution. Failure to provide adequate transport facilities also greatly increases trip duration and costs both for passenger and goods traffic, lowering productive efficiency and placing a particularly heavy burden on poorer groups of the population living in peripheral and other areas with very limited access. There are people who either spend hours in commuting for work or sleep at their workplace and go home at weekends, or for lack of transport cannot work at all. The annual loss caused by the poor traffic and transportation in urban India is estimated to be of the order of Rs 200 billion (Ramanathan, 1999).

Transportation has serious implications for pollution caused by fuel burning. Diesel driven buses contribute significantly to particulate, nitrogen dioxide and sulfur di-oxide emissions. Gasoline burning automobiles probably contribute most of the CO pollution and a significant share of the volatile organic compounds (VOCs) and NOx.

Pollution levels in all Indian metros have reached alarming levels and the growing incidence of respiratory and cardiac ailments and cancer is a direct consequence of the deteriorating air quality. Delhi has the dubious distinction of being the fourth most polluted city in the world, while a number of other cities in the country are following closely behind. A World Bank study on the health effects of air pollution in Delhi revealed that SPM in Delhi alone led to premature death of 7,491persons in 1991/92. The study when repeated for the year 1995 showed an increase to about 10,000 persons in just three years (Brandon and Homman, 1995).

According to the World Resources Report (1996), motor vehicles were responsible for 90% of the carbon monoxide emissions, 85% of hydrocarbon emissions, 59% of the emission of nitrogen oxides (NO_x), 13% of sulphur dioxide (SO_2) emissions and 37% of emissions of suspended particulate matter (SPM) in Delhi during 1987. According to the same study, automobiles caused about 52% of the total NO_x emissions, 5% SO_2 emissions and 24% of SPM emissions in Mumbai city during 1992. In the year 1993-94, the share of automobiles in total pollutant load was as high as 64% in Delhi and 52% in Mumbai. The share of automobiles in total air pollution in Delhi has increased further to 70% (Sreedharan, 1998).

A massive increase in the number of vehicles and a large number of old, in-efficient, ill-maintained and obsolete vehicles, results into emission of a stupendous quantity of pollutants about millions of tons annually in gaseous and particulate forms into the atmosphere. Use of poor quality fuel, bad road conditions, and congestion further contribute into it.

The present study carried out by IGIDR in collaboration with Asian Institute of Technology, Thailand examines the following three issues:

Issue 1:	Analysis of urban transport energy demand
Issue 2:	Energy efficiency improvement of urban transport system and mitigation of GHG and other harmful emissions
Issue 3:	Barriers to energy efficiency improvement of urban transport system.

The analysis is confined to two cities in India, namely, Delhi and Mumbai. This report is presented in three different sections focusing on each of the above issues.

2. CITY CHARACTERISTICS AND TRANSPORT SECTOR PROFILE

2.1 Delhi

2.1.1 Geography

Delhi is situated in North India, on the banks of the river Yamuna. The national capital sprawls over 1,483 square kilometers, 47% of which is urban and the remaining 53% is rural.

2.1.2 Population

Since 1912, after it became the capital of India Delhi has emerged as a multi-dimensional and multi-functional urban center. The city's population grew by about 53 percent between 1971 to 1981 and by another 52 percent between 1981 to 1991. The compound annual growth is around 4.3 percent since 1951, which is twice the country's average population growth rate. By 2001 population in Delhi has reached 14.19 million (Table 1).

Table 1 Delhi population

Census Year	Population (millions)	Compound annual growth rate for the	Percentage of all India
1951	1.74	-	0.48
1961	2.66	4.31	0.61
1971	4.07	4.34	0.74
1981	6.22	4.34	0.91
1991	9.42	4.24	1.11
2001	14.19	4.23	1.47

Source: District Census handbooks, Directorate of Census operations, Delhi

In 2001, average population density was 6,352 persons per km^2 with maximum population density being 16,833 in the Municipal Corporation of Delhi (MCD), followed by 7,050 in New Delhi Municipal Committee (NDMC), and the least being in Delhi Cantonment area 2,197 persons per km^2. However, in rural areas of Delhi the population density reads at 1,190 persons per km^2 only (*WWF-India*, 1995).

2.1.3 Economic activity

Commercial and economic activities are intensive in the capital city. Several Central Government offices, Public sector undertakings, commercial traders and industries are operating in the city. Consequently, Delhi is a relatively affluent city. The city's economy has grown at a rate of 6.2% annually during 1985/86-1996/97. Per capita income in 1996/97 was Rs 5,614 (at 1980/81 constant prices) (Table 2), as compared to the national average of Rs 3,124.

Table 2 City Domestic Product (CDP) and Income/capita of Delhi (at 1980/81 constant prices)

Year	SDP (in Rs crores)	Income/ capita (Rs)
1980/81	2,455	4,030
1985/86	3,302	4,376
1990/91	4,489	4,846
1996/97	6,432	5,615

Source: (GOI, 1990; GOI 1997)

2.1.4 Road Network

The transportation network is predominantly road based. The city has a ring railway. But its role is minimal in meeting travel demand. Delhi has a ring road, which is a major facilitator for the traffic to move in different directions. However, with the rapid increase in the vehicles and traffic levels, all the major traffic junctions along the ring road are congested posing severe traffic problems.

Table 3 presents some important indicators of road traffic in Delhi. Delhi has the longest road length of 1284 km per 100 km^2 of area among cities in India. The road network in the city is 22,487 km long. Average annual growth rate of road length from 1981 to 1997 was 3.4%, which is much less than the average annual growth rate of vehicles' registration for the same period, 16%. As a result, traffic density has increased from 39 vehicles per km to 119 vehicles per km from 1981 to 1997, causing serious congestion problems. As far as road quality is concerned, roads in the capital do not last longer than five years, whereas experts say a good quality road should sustain the load of vehicles for at least fifteen years.

Since 1970, an integrated Mass Rapid Transport System (MRTS) with a proposed length of 144 km surface rail corridor, which would utilize the existing railway corridors in Delhi, and an under ground / elevated metro rail system of 41 km consist of two corridors the East-West (24 km) and the North-South (17 km) is under consideration/construction. Recently, Phase I of the project consisting of 2 surface corridors for a total length of 44.3 km and one under ground corridor for a length of 11 km has been cleared for implementation and fast approaching its completion. According to the original planning the whole project, in parts, is expected to be commissioned by March 2005. The first phase of the project will generate substantial benefits by shifting off 3.2 million commuter trips per day from the roads, which would mean (Sreedharan, 1999):

- 3,500 less buses on the road
- Increase in average speed of road buses from 10.5 km/h to 14 km/h
- Saving of 2.6 million man hours per day due to reduced journey time
- Saving in fuel cost worth Rs. 500 crores (5000 million) per year
- Reduction in pollution and accidents

Table 3 Select indicators of road traffic in Delhi

	1971	1981	1991	1997
Road length (in km)	8231	14316	21564	24402
Total registered motor vehicles (‘000)	204	561	1923	2895
Number of vehicles per km of road length	25	39	89	119
Number of personnel controlling traffic	1068	1602	1846	2925

Source: Action Plan for Streamlining Traffic in Delhi Published by *PHD Chamber of commerce and industry*

2.1.5 Vehicle stocks and its growth

Delhi has faced a tremendous motorization. The number of registered motor vehicles rose from 0.56 million in 1981 to 3 million in 1998 – a five fold increase (Table 4). There has been tremendous growth in the demand for motor vehicles after partial liberalization of the automobile sector in 1983-84. Between the period March 1988 and March 1998, the average annual growth rate of registered motor vehicle was around 9%.

The growth in motor vehicle population, however, has not been even across all categories – personalized modes of transport have dominated this growth. This category, consisting of two wheelers and cars/jeeps accounts more than 90 percent of Delhi’s motor vehicles (Figure 2). During 1985/86-1996/97, number of 2-wheeler and cars per 1000 persons have grown from 88 and 23 to 160 and 59 respectively, more than double. On the other hand, the share of buses – the primary mode of public transport in Delhi – is just around one percent in recent years. The number of buses per 1000 persons has grown from 1.86 to 2.58 during 1985-1997. Yet, buses currently meet about 53 percent of total passenger travel demand. It is estimated that only 27,000 of buses move more than 9.8 million commuters daily (Dass, 1999). In contrast, 2.4 million personalised vehicles provide mobility to only 7.1 million people. Even the percentage share of the intermediate mode of public transport (three wheelers and taxis), accounted for 4.6 percent of all motor vehicles in 1984-85 but this figure had decreased to 3.1 percent by 1997-98. So, there is a shift towards personalized mode of transport. This has made traffic management more difficult since availability of road space has not increased proportionally. This results in congestion, which reduces vehicle speed and causing extra fuel consumption and pollution.

Table 4 Registered motor vehicles in Delhi

Year	Total no. of vehicles (million)	Compound annual growth rate since the previous period (%)
1970-71	0.20	-
1980-81	0.56	10.56
1990-91	1.80	12.47
1994-95	2.43	10.46
1997-98	3.03	11.67

Source: SIAM

While majority of the increase in motor vehicles is accounted by petrol driven two-wheelers and cars, there has also been more than proportionate increase in the consumption of diesel (Table 5 and Table 6).

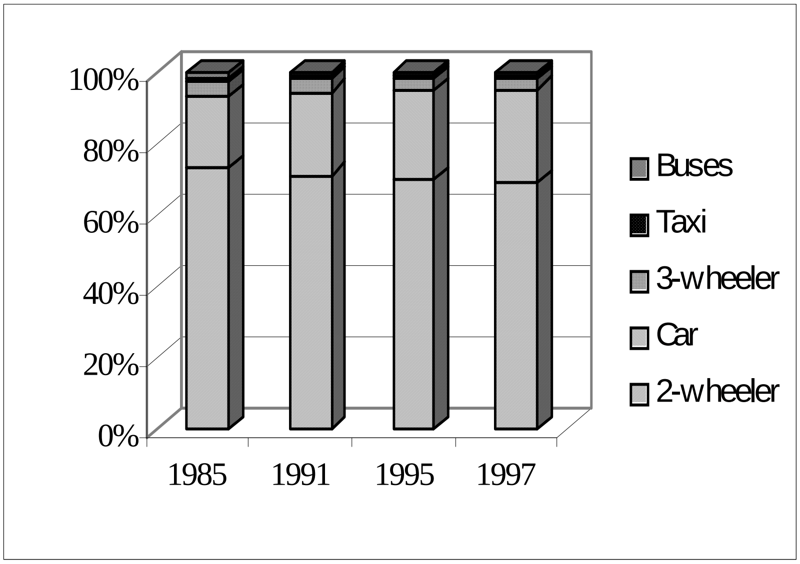

Figure 2 Composition (%) of passenger vehicles in Delhi

Table 5 Registered petrol and diesel vehicles in Delhi

Year	Petrol	Diesel	Petrol to diesel vehicle ratio
1970/71	163776	16658	9.8
1980/81	491368	44643	11.0
1990/91	1692281	120686	14.0
1993/94	2098413	149590	14.0
31.12.1996	2590830	202776	12.8

Source: UNEP, 1999

Table 6 Fuel consumption in Delhi (‘000 tons)

Year	Petrol	Diesel	Petrol to diesel consumption ratio
1980-81	133	377	0.35
1989-90	330	718	0.46
1992-93	363	810	0.45
1994-95	408	929	0.44
1995-96	436	1153	0.38
1996-97*	476	1242	0.38
1997-98**	585	1199	0.49

Source: Delhi Statistical Handbook, various issues, * Ministry of Petroleum and Natural Gas

** Oil Co-ordination committee

2.1.6 Pollution

Central Pollution Control Board (CPCB) has been monitoring air quality in major cities since 1984 under the National Ambient Quality Monitoring Network. The pollutants which are conventionally measured to estimate pollution load, are Carbon Monoxide (CO), Hydrocarbons (HC), Oxides of Nitrogen (NO_x), Sulphur Dioxide (SO_2), Lead (Pb), and Particulates (SPM or PM_{10}). CPCB has also specified National Ambient Air Quality Standards (NAAQS) for CO, NO_x, SO_2, lead and particulates[1]. These standards are differentiated by three types of location -industrial, residential, and sensitive areas. The

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[1] An ambient concentration level is a measure of the average density of pollutants usually specified in terms of pollutant mass per unit volume of air. They are expressed in units micrograms per cubic metre (mg/m^3) or in terms of relative volume of pollutants per unit volume of air (parts per million (ppm)).

NAAQS, however, are for overall air quality and are to be met after aggregating emissions from transport, power, industry and domestic sources (Table 7).

Table 7 National ambient air quality standards (mg/m^3)

Pollutant	Averaging time	WHO recommended limits by type of areas Sensitive	Residential	Industrial	Averaging time
CO	1 hour	2000	4000	10000	30000
	8 hours	1000	2000	5000	10000
NOx	24 hours	30	80	120	150
	Annual	15	60	80	-
SO2	24 hours	30	80	120	100-150
	Annual	15	60	80	40-60
Lead	24 hours	0.75	1.00	1.5	-
	Annual	0.5	0.75	1.0	-
SPM	24 hours	100	200	500	150-230
	Annual	70	140	360	60-90

Table 8 presents data on air quality for Delhi, which indicates high values of suspended particulate matter (SPM) at all monitoring stations.

Table 8 National ambient air quality standards (mg/m^3)

	SO_2		NO_2		SPM	
Year	Annual mean	Variation (%) (base 1989)	Annual mean	Variation (%) (base 1989)	Annual mean	Variation (%) (base 1989)
1989	8.7		18.5		373	
1992	18.4	111	30.4	64	377	1.0
1995	19.0	118	34.1	84	407	9.0
1996	19.0	109	33.7	82	387	4.0

Source: White paper on Pollution in Delhi

Daily air pollution load in the city has doubled from 1,450 tons to 3,000 tons during 1991-96, causing a serious cause of concern (Figure 3). In a study on “Urban Air Pollution in Mega cities of the World” by WHO/UNEP in 1992, Delhi was reported to be the fourth most polluted city in the world and as having a serious particulate pollution. According to CPCB officials, 40% of the total SPM is of size 10 micron or lower, and is respirable. A World Bank study estimated the health costs of ambient air pollution in Delhi alone as US $ 100-400 million (Brandon and Hommann 1996).

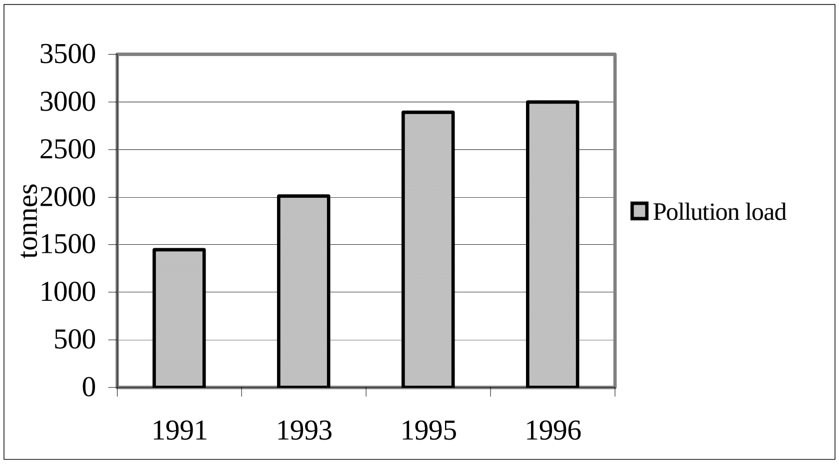


Figure 3 Daily air pollution load in Delhi (in tons)

Excessive growth in motorized vehicles, especially, two wheelers, cars, and jeeps are primarily responsible for acute air pollution problem in Delhi. It is estimated that around 67 percent of air pollution was caused by motor vehicles in 1996 (Figure 4). Vehicles account for 97% of the HC emissions in the air, 48% of NO_x, and 76% of CO emissions (CPCB, 1995). Gasoline run vehicles contribute most of the CO, HC and lead (Pb), while diesel vehicles are the main source of particulates and SO_2. 67% of the vehicles in Delhi are the most polluting kind, that is, two and three wheelers, powered by 2 stroke engines and responsible for most of the HC emissions.

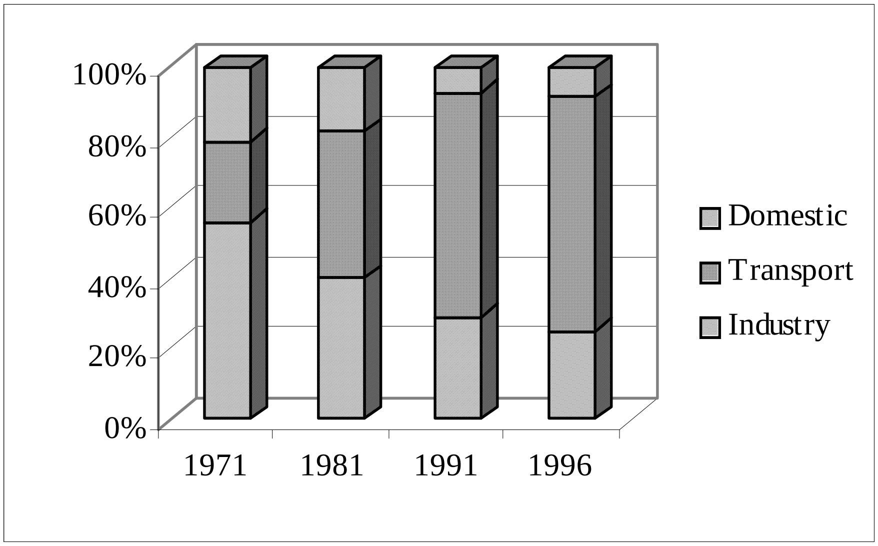


Figure 4 Air pollution in Delhi by sources (percentage)

Table 9. Vehicular emissions 1994 (tons/day)

City	Particulates	SO_2	NO_x	HC	CO	Total
Delhi	10.3	8.96	126.46	249.57	651.01	1046.3
Mumbai	5.59	4.03	70.82	108.21	469.9	659.5
Calcutta	3.25	3.65	54.69	43.88	188.24	293.7

Source: CPCB (1995)

This is because a large part of unburned fuel escapes with the exhaust due to the simple design of the engine. The CPCB estimates that roughly 2,000 tons of air pollutants were emitted everyday by motor vehicles in Delhi in 1996. This is an increase of over 100% from the 1991 levels. The pollution load from motor vehicles shows an increasing trend both in terms of absolute amounts as well as a proportion of total air pollution.

Centre for Science and Environment (CSE) has identified following four major causes behind vehicular pollution (CSE, 1996):

- outdated vehicle technology arising from vehicle manufacturers’ unwillingness to keep abreast of clean technologies and their successful attempts at getting away with as little design upgradation as they can;
- poor fuel quality produced by public sector refineries that can do as they please because they set their own quality standards;
- poor vehicle maintenance by indifferent consumers and economic compulsions that keep vehicles on the road long after they should have been junked;
- poor traffic planning that fails to foresee the oncoming crisis and take firm corrective steps, including discouraging the suicidal rate of growth of privately -owned motorized vehicles.

About 25 to 40% of the fuel supplied to small two-stroke gasoline engines in two and three wheelers is wasted without being burned due to 'short circuiting' of the fresh fuel-air mixture to the engine exhaust. This inherent weakness in the existing design of two-stroke engines is a large contributor of HC mentioned above. In fact, two and three wheelers contribute over 70% of HC emissions. On the contrary, the emission rate for NO_x is higher in diesel fuelled heavy vehicles because of lower combustion temperatures than gasoline fuelled vehicles. This is why commercial vehicles contribute the bulk of NO_x emissions. Emission rate for SO_2 are also higher for diesel vehicles, with commercial vehicles contributing more than 50% of total SO_2 emissions. The gasoline vehicles contribute to the major lead emissions whereas the diesel vehicles are responsible for particulates emissions. 30% of the problem of vehicular emissions is due to bad fuel quality (CSE, 1996).

Standards for controlling emission levels of new vehicles were incorporated into the Motor Vehicles Act (1989) only as late as 1991, enforcing some quality control on the automobile industry. The mass emissions standards refer to gm/km of pollutants emitted by the vehicles during mass emission tests conducted under specified driving conditions , are notified by Ministry of Surface Transport and enforced by State Transport Department. Exhaust emissions standards of Indian vehicles as specified in 1991 is given in Table 10.

Table 10 Exhaust emission standards for Indian vehicles

Category of vehicles/exhaust emissions	Unit	Standard effective (April 1991)	Standard effective, April 1996	EURO I
Gasoline				
Passenger cars				
CO	gm/Km	14.3-27.1	8.68-12.4	2.72
HC	gm/km	2.0-2.9		
(HC + Nox)	gm/km		3-4.36	0.97
Diesel vehicles				
Gross vehicle weight > 3.5 tons				
CO	gm/kWh	14.0	11.2	4.5
HC	gm/kWh	3.5	2.4	1.1
Nox	gm/kWh	18.0	14.4	8.0
PM	gm/kWh			0.36
Gross vehicle weight <3.5 ton				
CO	gm/kWh	14.3-27.1	5.0-9.0	4.5
HC + NO_x	gm/kWh	2.7-6.9	2.0-4.0	
HC	gm/kWh			1.1
NO_x	gm/kWh			8.0
PM (engines with power > 85 KW)	gm/kWh			0.36
<85 KW	gm/kWh			0.61

Source: GOI (1990), GOI(1996), GOI(1997b)

The existing Bureau of Indian Standards (BIS) for fuel started incorporating emission parameters during the same period. But in both cases, the standards were set according to the terms and conditions dictated by the industry. Both the regulatory authorities and the manufacturers pleaded incapacity to make any drastic improvements, and so the standards they followed were far too lax compared to those elsewhere in the world. In 1996, government came up with mass emissions standards for vehicles, which are stricter than earlier (Table 10). Other measures during 1994-96 include the use of unleaded petrol and fitting of catalytic converters in the car. Fitting catalytic converters to cars has reduced emissions of CO.

Poor maintenance of vehicles adversely affects their emission efficiency. The role of maintenance in combating vehicular pollution was reflected in government policy for the first time in 1989, which made the certificate of fitness as mandatory for registration of public vehicles, commercial vehicles and personal vehicles older than 15 years. The 1990 vehicular emission rules required all motor vehicles to comply with the laid down exhaust emission standards. Delhi State Transport Department issues Pollution Under Control (PUC) certificates to vehicles. Vehicle owners are required to check the emissions level of their vehicles every three months and obtain a PUC certificate. Vehicles failing to meet the standards are required to rectify the fault and obtain the certificate. The State Transport Authority fines vehicles not possessing a PUC certificate. This is a step towards minimizing vehicular pollution by regular checks. This system, however, has come under severe public criticism due to the existing lacunae in the issue of certificates and the discrepancies in pollution readings from one station to another. For example, though it is necessary for all vehicles to have a valid PUC at all times, according to statistics maintained by transport department, percentage of vehicles with valid PUC was highest at 23% in 1997 since the introduction of this legislation. This it appears, was the result of the special PUC enforcement drive launched by the transport department in 1996/97.

There is a provision to levy a monetary fine of Rs 1000 on motorists who falls abide by the law. However, enforcement of the law has been poor. For instance, since the introduction of the law in 1991, vehicles fined, as a percent of those without PUC was highest at 1.07 in 1997. Statistics maintained by Automobile Association of Upper India reveals that more than 50% of vehicles in Delhi in May 1995, failed to comply with the prescribed standards. What is more alarming is that nearly 44% of the new vehicles checked were found to be not in compliance with the standards. This shows that PUC despite being a potentially powerful instrument in controlling pollution from vehicles has failed to make an impact on vehicular pollution.

The failure of the administration to enforce environmental regulations, has led to judicial interventions. The Supreme Court has come up with several guidelines in last few years. The Court has urged the government to accept the emissions standards EURO I, II etc. for the vehicles as adopted by European Commissions. Table 11A and 11B present the emissions standards as specified. In last few years, The Supreme Court issued the following directives aimed to control the impacts of transportation on air quality:

- Elimination of leaded petrol from NCT of Delhi by September 1, 1998
- Phasing out of all commercial vehicles, which are more than 15 years old by October 2, 1998.
- From June 1, 1999, Euro I norm was made effective for all private vehicles.
- No 8-year old buses to ply except on CNG or other clean fuels by April 1, 2000.
- Entire city bus fleet to be steadily converted to single fuel mode on CNG by March 31, 2001.
- Replacement of all Pre -1990 auto and taxis with new vehicles on clean fuels by March 31, 2000.
- From April 1, 2000, no vehicles will be registered in the National Capital Region, unless it conforms to EURO II norms.
- Supply diesel with 0.05% sulphur content in the NCR from May 2002
- Supply petrol with 1% benzene content in the NCR from October 31, 2001
- Supply of only pre-mix petrol in filling stations to two stroke engines by December 31, 1998.
- Ban on registering two stroke vehicles from July 2000
- All in-use vehicles with two stroke engines will have to be fitted with catalytic converter

Mass emission standards (EURO II)

Table 11A. For motor cars with seating capacity of and upto 6 persons and gross vehicle mass not exceeding 2,500 Kg

	CO	(HC + NOx)	PM
Gasoline engine	2.2	0.5	
Diesel engine	1.0	0.7	0.08

Source: GOI(2000)

Table 11B. Four wheeler passenger vehicles with GVW equal to or less than 3,500 kg and designed to carry more than 6 persons (including driver) or maximum mass of which exceeds 2500 kg

	Mass of CO (g/km)		Mass of (CO + Nox) (gm/km)		Mass of PM (gm/km)
	Gasoline	Diesel	Gasoline	Diesel	Diesel
Ref Mass (rw) in kg					
< 1250	2.2	1.0	0.5	0.7	0.08
1250< rw<1700	4.0	1.25	0.6	1.0	0.12
1700 < rw	5.0	1.5	0.7	1.2	0.17

Source: GOI(2000)

Some results are visible. For example, about 3,000 taxis and 9,000 three-wheelers which were old, were scrapped by 1999. Oil companies have started supplying petrol and diesel with less than 0.05% sulphur content from April 1, 2000 (Box 1). From February 2000, they have started supplying HSD with less than 0.25% sulphur content. Also they have started supplying lead free petrol. Reduction in vehicular emission load and improvement in ambient air quality can be observed from tables 12 and 13, respectively.

Box 1

Gasoline lead phase out programme in India

Phase I	June 1994	Low leaded (0.15 g/l)	Cities of Delhi, Mumbai, Calcutta and Chennai
Phase II	1.4.1995	Unleaded (0.013g/l)	
Phase III	1.1.1997	Low leaded (0.15g/l)	Entire country
Phase IV	1.9.1998	Ban on leaded fuel	NCT of Delhi
Phase V	31.12.1998	Unleaded (0.013g/l)	All other capitals of states/UT and other major cities
Phase VI	1.1.1999	Unleaded only	NCR
Phase VII	1.4.2000	Unleaded	Entire country

Diesel Sulphur phase out programme in India

Phase I	April 1996	Low sulphur (0.5%)	Four metros and Taj Trapezium
Phase II	August 1997	Low sulphur (0.25%)	Delhi and Taj Trapezium
Phase III	April 1998	Low sulphur (0.25%)	Metro cities
Phase IV	April 1999	Low Sulphur (0.25%)	Entire country

Source: CPCB (1999)

Table 12 Estimated vehicular emission load in Delhi

Pollutant	Pollution load (000 tons)		Reduction (%) over 1995
	1995	1998	
SO_2	15	25	27
NO_2	207	63	12
SPM	28	426	25
Lead	0.36	136	97
CO	351	337	4
HC	113	115	+2

Source: CPCB (1999)

Table 13 Improvement in ambient air quality in Delhi (Traffic intersections)

Pollutant	1995	1998	Reduction (%) over 1995
SO_2	42	25	40
NO_2	66	63	5
SPM	452	426	6
Lead	335	136	60
CO	5587	5450	3

All units are in microgramme/m^3 except lead, which is in nano-gramme/ m^3

Source: CPCB (1999)

2.2 Mumbai

2.2.1 Geography

Mumbai on the western coast of India is one of the world's largest and most crowded cities. The Bombay Metropolitan Region (BMR) extends over an area of 4,355 km^2 and comprises Municipal Corporation of Greater Bombay (MCGM), Thane, Kalyan and Navi Mumbai. Its administrative limits cover Bombay city and Bombay Suburban Districts and parts of Thane and Raigad Districts.

Bombay is located on the western edge of the region separated from the main island by Thane Creek and Vasai Creek. The city is located on Bombay Island whilst the suburbs occupy the majority of the area of Salsette Island. These two islands are separated by Mahim creek, which has largely been reclaimed at its eastern end. The Municipal Corporation of Greater Mumbai occupies some 465 km^2 on these two islands. Mumbai Island is about 18 km long and 4.75 km wide narrowing to little more than 1.3 km width at the southern tip of the island where the CBD is located around the old Fort area. Study area for this study is limited to the Municipal Corporation of Greater Mumbai (MCGM).

Mumbai's peculiar geography - a narrow wedge - shaped land surrounded by waters on three sides - has for decades dictated its spatial growth. While the early growth of Mumbai took place in the south near the port, it spread northwards along the suburban rail corridors. Till 1968, most of the region's urban growth was confined to Greater Bombay's municipal limits though it had began to occur in Thane, Kalyan and surrounding areas beyond Greater Bombay.

Since 1975 the Bombay Metropolitan Region Development Authority (BMRDA) has been co-ordinating planning and development in BMR. One of the principal concerns of BMRDA is to secure an orderly decentralisation of economic growth and of development away from the BMC area and in particular away from the Island City of Bombay.

The proposed New Bombay was a counteragent to reduce pressures in Bombay itself. The regional plan envisaged a population of 2 million in New Bombay by 1991. However, development of New Bombay has been slow.

2.2.2 Population

Table 14 presents the population growth in the Greater Mumbai. Mumbai is the world's most crowded city (WS, 1994). The employment opportunities it offers have served as a major attraction for migrants from the rural hinterland. Till 1981, migration had supplemented a high rate of natural population growth. As a result, population growth was more than 3%. However, due to acute space shortage, the population of Greater Mumbai has started showing a declining growth rate during 1981-91. The population is expected to be 12.9 million in 2011. This takes into account the probability that both the rate of migration and natural increase will tend to stabilize. Population density in the island city was 44,100 persons per km^2 whilst in the suburbs the densities were 16,000 in the eastern suburbs and about 16,600 in the western suburbs (AS, 1994).

Table 14 Population in Greater Mumbai

Census Year	Population (millions)	Compound annual growth rate for the preceding decade
1951	2.99	-
1961	4.15	3.32
1971	5.97	3.70
1981	8.24	3.28
1991	9.92	1.87

2.2.3 Economic Activity

Mumbai is the country's leading port and commercial centre. It is considered as the financial capital of India. While the state economy grew by 5.8% per annum in real terms during 1980-1989, Greater Mumbai's economy increased by about 4.7% per annum. In 1989/90, the city contributed about 22% in of the State economy. Per capita income increased from Rs 4,389 to Rs 5,525 during 1980-90, registering a growth rate of 2.7% per annum (Table 15).

Table 15 City Domestic Product (CDP) and income/capita (1980/81 prices)

	CDP (Rs. crores*)	Income/capita (Rs.)
1980	3,480	4,359
1984	3,861	4,431
1989	5,282	5,525

Source: BMRDA (1995); * one crore is equal to 10 million

2.2.4 Road Network and Transport

In transportation terms, Mumbai has become a victim of its own success. Fourfold growth of population since 1951 has been largely accommodated in the suburbs, while the highest concentration of jobs has taken place in the Island City. As a result, of the two million daily commuters more than half a million commute across Mahim Creek into the Island city. Moreover, the physical characteristics of the city are such that the suburbs have been constrained to spread northwards only, and all transport facilities are concentrated within three narrow corridors. This has put tremendous stress on all modes operating in these corridors.

The urban transport in Mumbai is based on suburban railway services provided by the Western and Central Railways, Buses, taxis, three-wheelers, and personalized vehicles. Public transport accounts for more than 80% of the journeys or trips with the rail system and buses having almost equal share between them. However, in terms of passenger kilometers, railways carry nearly four times traffic carried by the buses because of longer average lead.

Suburban rail network, which has served the needs of the metro well is also ably, supported by an efficient bus service under BEST (Brihan Mumbai Electricity and Surface Transport) Undertaking. Suburban rail services operating along a network of some 300 km of electrified broad gauge provided by two zones of the Indian Railways transporting about 5.2 million suburban passengers per day through some 2000 daily electric motive unit (EMU) services. This is different story that the passengers already travel like sardines inside carriages and like sacrificial lambs on top of the carriages. The problems are expected to be even more acute in the commercial capital of India with the city's population estimated at around 22 million by the end of the decade and other mega trends in the growth of passenger and traffic within and outside its horizons.

The road network in BMR predominantly runs in the north-south direction due to the linear expansion of the city. Currently traffic movements are concentrated in three main corridors i.e., western, central and eastern. There are very few continuous east-west cross routes across the Island, due to limited crossings of the railway lines and the density of development. As a result of this there is heavy concentration of traffic along these few routes. The eastern side of the island is close to the port facilities and is congested with heavy truck traffic. The western corridor is mainly congested with private car traffic.

Table 16 presents the growth in road length in Greater Mumbai. Between 1984 and 1997, road length has increased by 321 km, on an average, about only 24 km has been added annually. In contrast, during 1985-98, annual growth rate in number of registered vehicles was 4.6%. Obviously, there is increasing congestion. Number of vehicles per km of road has increased from 278 in 1984 to 416 in 1997.

Table 16 Growth in road network in Greater Mumbai

Year	Road length (km)	Vehicles/km
1984	1,431	278
1992	1,584	417
1996	1,738	406
1997	1,752	416

Table 17 shows the vehicular growth in Mumbai. Between 1980 and 1998, number of registered vehicles has almost tripled. As far as passenger vehicles are considered, personalized vehicles (2-wheelers and cars) dominate the total vehicle population. However, while share of car has declined from 48% to 37%, same for two wheelers has increased from 35% to 45% during the same period (Figure 5). In absolute number the 2-whleers grew by more than two times in the same period, while cars grew by one and half times. Number of cars and two-wheelers per 1,000 persons has grown from 21 to 25 and 15 to 30, respectively (Table 18). On the other hand, number of buses per 1,000 persons increased from 0.7 to 1.2 only.

Table 17 Number of registered vehicles in Greater Mumbai

Year	Cars/jeeps	2-wheelers	3 -wheeler	Taxis	Buses	Goods vehicles	Total
1980	1,43,581	68,983	1,559	28,270	4,073	35,221	2,81,687
1985	1,90,546	1,37,410	24,577	34,338	6,180	42,544	4,35,595
1990	2,58,315	2,31,932	39,350	34,340	7,520	47,268	6,18,725
1998	2,75,563	3,28,940	72,007	48,646	13,138	47,058	7,85,352

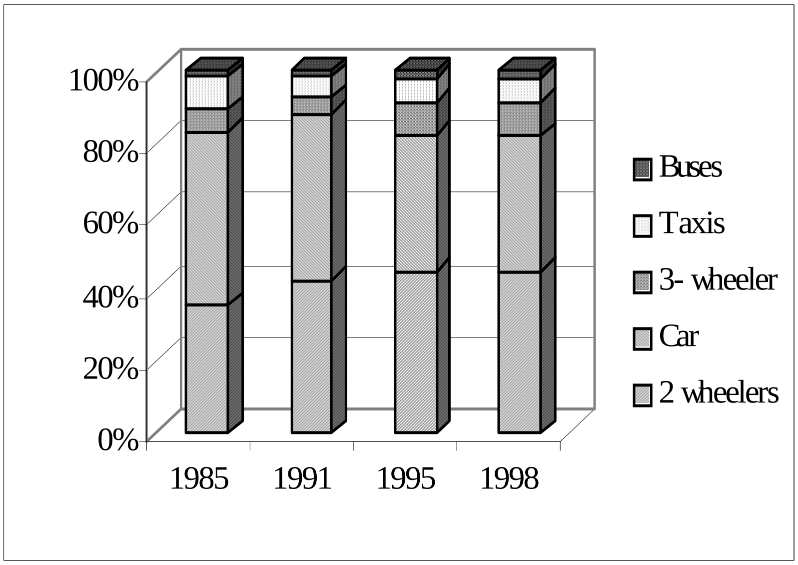


Figure 5 Composition of percentage share of passenger vehicles

Table 18 Number of vehicles per 1,000 persons

Year	Car/jeeps	2- wheelers	3 wheeler	Taxis	Buses
1980	17..99	8.64	0.20	3.54	0.51
1985	21.46	15.48	2.77	3.87	0.70
1990	26..52	23.81	4.04	3.53	0.77
1998	25.15	30.02	6.57	4.44	1.20

Out of 55,000 taxis running in Mumbai in March 2000, about 11,000 operate on CNG and the entire remaining lot on diesel. About 12% of total vehicles operate on diesel. Trends in consumption of transport related fuels like gasoline and diesel are presented in Table 19. Multi-fold increase in consumption of both fuels is observed. While, gasoline consumption increased from 0.29 million ton in 1985/86 to 1 million ton in 1997/98, diesel consumption grew from 0.44 to 2.22 million ton.

Table 19 Consumption of gasoline and diesel in Mumbai (million tons)

Year	MS	Diesel
1985/86	0.29	0.44
1990/91	0.36	0.56
1996/97	1.02	2.24
1997/98	1	2.22

Source: WB, 1997

2.2.5 Pollution

Municipal Corporation of Greater Bombay (MCGB) has a network of 22 measurement stations in commercial, industrial and resident areas. Levels of TSP, SO_2, NO_x, and ammonia are measured as 8-hour averages per month.

Air pollution measurement programs over the last decade show a definite increase in average total suspended particles (TSP) and nitrogen oxides (NO_x) concentrations, while sulphur dioxide ($SO_{2)}$) concentration have decreased (WB, 1997). TSP concentrations (annual average, and maximum of 24 hours) are much higher than WHO Air quality guidelines of 90 mg/m^3 at many measuring sites. At certain times WHO air quality guideline for SO_2 is also exceeded. Bombay has a substantial particle pollution problem, with frequent and widespread exceeding of TSP and PM_{10} air quality guidelines (WB, 1997). According to the measurements, the SO_2 pollution problem seems less pronounced although guidelines are sometimes exceeded. NO_x concentrations are presently within WHO guidelines.

Traffic emissions are a clear and major source of air pollution exposure. Lead is a significant pollutant in Bombay. Annual average levels ranged from 0.5 mg/m^3 to 1.3 mg/m^3. These exceed the WHO guideline annual average (0.5-1 mg/m^3, long term) and the Bombay guideline (1.0 mg/m^3, annual average and 1.5 mg/m^3 24-hour average) at all locations. From 1980 to 1987, average lead concentration in the air nearly doubled.

The annual average SO_2 concentration in Bombay has decreased since the 1980 average of about 45 µg/m^3 to 25 µg/m^3 in 1992/93. The summary of measurements in 1992/93 indicates that long-term average SO_2 concentrations are fairly low and less than WHO and Bombay guidelines at all sites (WB, 1997). Table 2.20 presents the TERI estimates on vehicular emissions in Mumbai. Table 21 presents the vehicular emissions vis-a-vis total emissions in 1992/93. Transport is responsible for more than 50% of NO_x emissions.

Table 20 Vehicular emissions (000 tons/year) in Mumbai

Year	CO	HC	Lead	NOx	Sox	Particulates
1991	54	20	25.6	18	2.4	2.9
1996	56	22	26	21.5	3.1	3.6

Source: TERI, 1997

Table 21 Vehicular emissions vis-à-vis total emissions in Greater Bombay in 1992/93 (tons/year)

	Vehicles	TSP	SO_2	NO_x
Gasoline	Cars	492	160	6643
	2/3 wheelers	737	250	179
Diesel	Cars	765	395	1783
	Buses	445	566	2891
	Trucks	1234	2120	8024
Transport sector		3673	3490	19520
From all sectors		22143	79264	37547

Source: WB, 1997

To combat the vehicular pollution in Mumbai, almost similar measures as in Delhi are expected to be adopted. Similar to Delhi, in Mumbai also, the High Court took an active part to provide guidelines to reduce pollution in the city. Mumbai High Court had set up a Committee on December 1999, headed by the Transport Commissioner to examine the entire matter and to come up with directions for the future.

The Committee has come up with its recommendations and submitted the report in April 2000. Some of the recommendations made by the Committee are listed below:

- The sulfur content in the entire diesel to be supplied in Mumbai city at all the petrol pumps should be reduced to 0.05% by October 1st, 2000. It should be further reduced to 0.035% by April 1, 2003 and to 0.005% by April 1, 2005.

- The benzene content in all the petrol supplied in Mumbai city at all the petrol pumps should be reduced from the present level of 3% to less than 1% by October 1, 2000.

- With effect from May 1, 2000, all new buses to be purchased by BEST, should be CNG operated until EURO II compliant engines become available in these new vehicles. BEST may exercise an option either to have CNG operated buses or EURO II or higher version diesel engine buses in such a manner that by April 1, 2005 at least 1000 buses are operated on CNG.

- Engines of all the existing BEST buses, which are not even EURO I compliant must be changed to EURO II compliant engines by October 1, 2002.

- With effect from January 1, 2001, all taxis above the age of 15 years must be converted to CNG or any other clean fuel. Further with effect from January 1, 2002, all diesel taxis above the age of 8 years should be converted to clean fuel.

- With effect from January 1, 2001, all 3 wheelers above the age of 10 years should be converted on CNG or any other clean fuel. Further with effect from January 1, 2002, all 3 wheelers above the age of 8 years should run on clean fuel.

- The present permissible limit of 4.5% CO emission in respect of 2 and 3 wheelers should be reduced to 3% with effect from October 1, 2000 for Mumbai city to bring it at par with the CO emission level of 4 wheelers.

- All heavy commercial vehicles as well as light good vehicles to be registered in the Mumbai Metropolitan Region from April 1, 2000 must be EURO II compliant.

- With effect from January 1, 2001, all 2 wheelers registered in Mumbai Metropolitan Region and which are more than 15 years old shall be scrapped and their registration deemed to have been cancelled.

- With effect from January 1, 2001, all 3 wheelers registered in Mumbai Metropolitan Region and which are more than 10 years old shall be scrapped unless converted to clean fuel.

- With effect from January 1, 2001, all transport vehicles other than 3 wheelers and BEST buses over the age of 15 years shall be scrapped unless converted to clean fuel.

- All two stroke two and three wheelers in use vehicles in Mumbai should be fitted with Catalytic converter by July 1, 2001.

- All petrol driven vehicles registered in Mumbai prior to April 1, 1995 should fit catalytic converter by 1st July 2001.

- All catalytic converters supplied by the manufacturers for 2 wheelers will carry a warranty of effective working of the catalytic converter over a distance of 30,000 km.

Section I

Urban Transport Energy Demand and Emission Analysis

1. FRAMEWORK FOR ANALYSIS

1.1 Methodology

The methodology adopted in projecting energy demand and emissions from the transport system is presented in Figure 1.1. It includes the following three components:

1. An Econometric model to project vehicle stock

2. Spread -sheet model to estimate travel demand met by different vehicle type

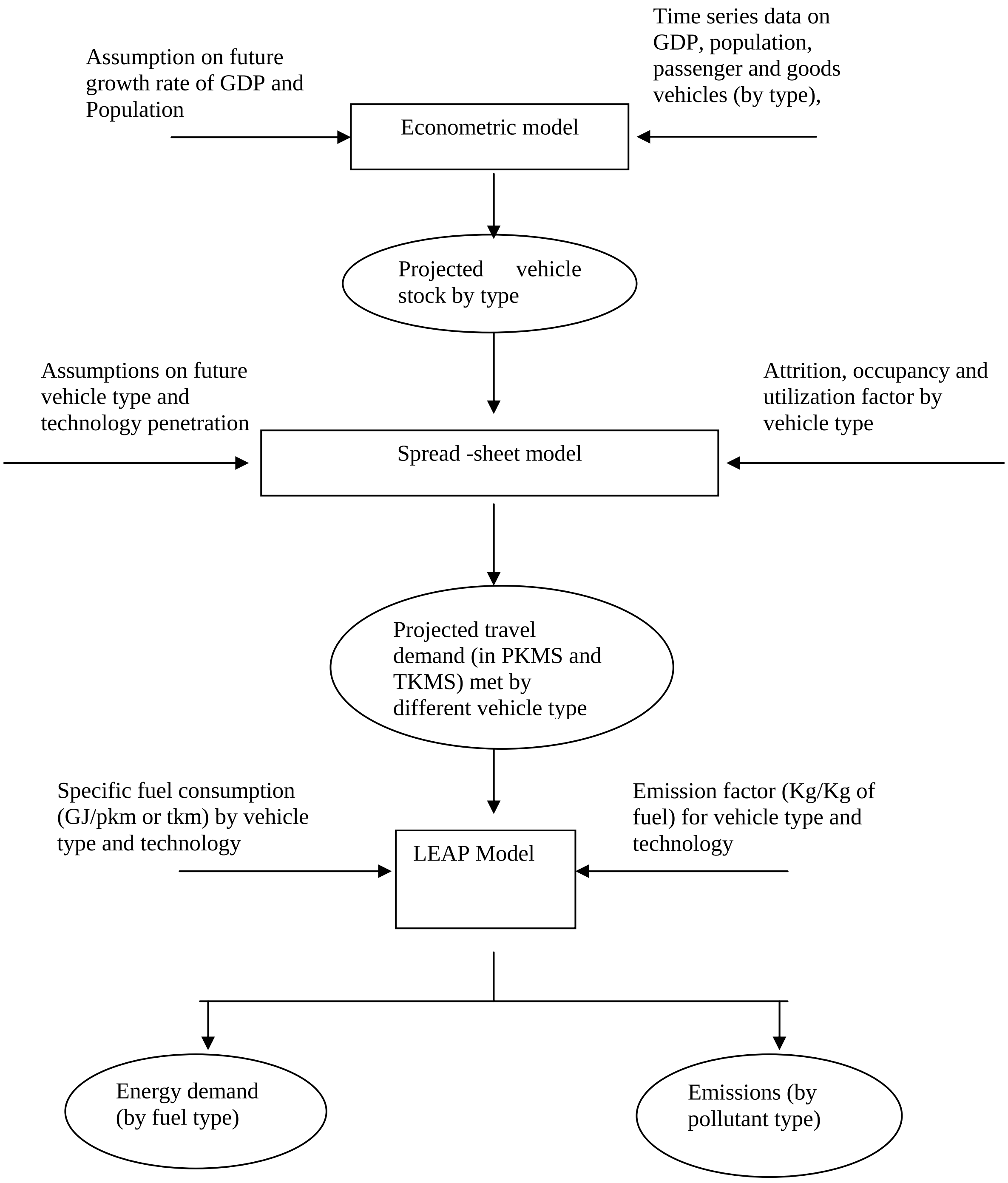
3. LEAP model to estimate energy demand and emissions from the transport system

The following sections discuss each of these components in detail.

1.1.1 Econometric model to project vehicle stock

An Econometric model was used to project the vehicular stock. Separate equations were estimated for each vehicle type (2-wheeler, car/jeep, 3-wheeler, taxi, bus and good vehicles) since the determinants for acquiring a vehicle are different. While, to project the private vehicles like, 2-wheeler and car/jeep, number of vehicle per capita has been correlated with income per capita, in case of public/commercial vehicles, number of total registered vehicles per year has been regressed over the GDP of the city in that year. The choice of these variables and equations (linear/log etc.) is determined by by the statistical significance of the various estimated relationships (t-statistic, R^2 etc.). While for Delhi time series data for the period 1980-1997 have been used, in the case of Mumbai, data was adapted to the time period 1980-1998.Therefore, base years of the projection are 1997 and 1998 for Delhi and Mumbai, respectively. BMRDA (Bombay Metropolitan Region Development Authority) has estimated domestic product of Mumbai for three years viz., 1981, 1985 and 1990 (BMRDA, 1995). For all these three years, it has shown that Mumbai accounts for about 23% of the total state domestic product of Maharashtra. The same share has been applied on state domestic product to generate domestic product of Mumbai for other years. Various issues of Economic Survey (GOI, 1997) were used as data source for the domestic product of Delhi. Projections have been made for the years 2005, 2010, 2015 and 2020. Equations for different vehicles obtained from the exercise that are used for future projections are given below for Delhi as well Mumbai.

Figure 1.1. Projecting energy demand and emissions for urban transport system



Delhi

2-wheeler

$(2Wh/Cap)_t = -0.13 + 0.0000526\ (Inc/Cap)_t,\ R^2 = 0.87$

(-5.31)   (9.96)

Car

$(Car/Cap)_t = -0.0666 + 0.0000223\ (Inc/Cap)_t,\ R^2 = 0.93$

(-9.51)   (14.8)

3-Wheeler

$3Wh_t = -14696 + 15.97\ GDP_t,\ R^2 = 0.95$

(-3.74)   (17.36)

Taxi

$Taxi_t = 3133.7 + 1.67\ GDP_t,\ R^2 = 0.93$

(6.27)   (14.31)

Bus

$Bus_t = -1524.7 + 4.76\ GDP_t,\ R^2 = 0.96$

(-1.50)   (20.0)

Truck

$Truck_t = -18704 + 25.456\ GDP_t,\ R^2 = 0.98$

(-4.41)   (25.60)

Mumbai

2-wheeler

$\log (2Wh/Cap)_t = -15.277 + 1.308 \log(Inc/Cap)_t,\ R^2 = 0.67$

(-8.09)   (5.98)

Car

$\log (Car/Cap)_t = -12.38 + 0.956 \log(Inc/Cap)_t,\ R^2 = 0.92$

(-11.33) (7.86)

3-Wheeler

$3Wh_t = -18854 + 8.21\ GDP_t,\ R^2 = 0.83$

(-2.65)   (7.20)

Taxi

$Taxi_t = 23821 + 1.87\ GDP_t,\ R^2 = 0.69$

(8.88)   (4.48)

Bus

$$\log(Bus_t) = -15.17 + 0.97 \log GDP_t \,,\ R^2 = 0.94$$
$$(-10.27)\quad (16.31)$$

Truck

$$Truck_t = 27658 + 3.34\, GDP_t \,,\ R^2 = 0.86$$
$$(14.47)\quad (8.92)$$

where,

$(2Wh/Cap)_t$ = Number of 2-wheelers per capita in the year t

$(Inc/Cap)_t$ = Income (Rs) per capita in the year t (at 1980/81 constant prices)

$(Car/Cap)_t$ = Number of cars per capita in the year t

$3Wh_t$ = Number of 3-wheelers in the year t

GDP_t = GDP (in Rs crore, 1 crore = 10^7) of the city in the year t at 1980/81 constant prices

$Taxi_t$ = Number of taxi in the year t

Bus_t = Number of buses in the year t

$Truck_t$ = Number of trucks in the year t

Figures in the brackets are t-statistic.

1.1.2 Spread -sheet model to estimate travel demand met by different vehicle type

Once number of vehicle stocks for a particular year has been determined from the above equations, an attrition factor is applied to arrive at the number of vehicles that actually exist in that year. Penetration of different vehicle type and technology as planned by the concerned City Planning Agency or the Government (as discussed in the pollution section of the individual city) for the future transport system of the corresponding city has been taken into account. Travel demand in a year that would be met by a particular vehicle type and technology has been estimated by multiplying the number of that vehicle type that exists in that year with

i) occupancy factors (persons or tons carried per vehicle in each trip)(Table 1.1),

ii) utilization factor (km traveled by the vehicle in a day) (Table 1.1) and

iii) 365 (number of days in the year).

Total passenger or freight travel demand in a year has been arrived at by summing up the travel demand met by all the vehicles type used for passenger or freight movement.

Equation 1.1 is used to estimate the total passenger or freight travel demand in a year t for city I.

$$PKM_{it} or TKM_{it} = \sum V_{jit} O_{jit} U_{jit} * 365 \qquad (1.1)$$

where,

PKM_{it} = Passenger travel demand in the year t in the city i (measured in passeger kilometer)

TKM_{it} = Freight travel demand in the year t in the city i (measured in ton kilometer)

V_{jit} = Number of vehicles of type/technology j in the year t in the city i

O_{jit} = Occupancy factor (measured in number of persons per vehicle per trip) for the vehicle of type j

U_{jit} = Utilisation factor (km traveled by a vehicle per day) for the vehicle of type j

i = Mumbai and Delhi, t = 2005, 2010, 2015, 2020

1.1.3 LEAP model to estimate energy demand and emissions from the transport system

Long Range Energy Alternative Planning (LEAP) model is a computer based accounting tool, used widely to estimate the energy demand and emissions levels under different policy scenario (for detail see (TERI, 1997)). Travel demand by vehicle type and technology that has been estimated in Component 2, is fed to the LAEP model along with vehicle-wise energy efficiency (fuel consumption/passenger kilometer or ton kilometer) and emission factor, to analyse the energy demand and pollution from the city transport system. Pollutants considered are CO, HC, NO_x, SO_2, Lead and particulates. LEAP uses following equations to estimate energy demand and emissions:

Energy demand

$$F_{kt} = (PKM_{it} \text{ or } TKM_{it}) \text{ x } S_{jk} \text{ x } E_k \qquad (1.2)$$

where, F_{kt} demand for fuel k in the year t. S_{jk} denotes the percentage share of vehicle type j (operated on fuel k) in total passenger or freight kilometer demand. E_{jk} is the energy intensity of the vehicle j expressed in fuel consumption (GJ) per pkm or tkm. Total fuel demand is obtained by aggregating fuel demand across different modes and technologies.

Emissions

$$P_{jt} = F_{kt} \text{ x } EF_{kjt} \qquad (1.3)$$

where, P_t represents emissions in tons and EF_{kjt} is the emission from vehicle j operated on fuel k and expressed in kg per kg of fuel used.

1.2 Scenarios and Assumptions

Five scenarios are constructed based on different GDP growth rates. They are:

1. Business as Usual Scenario (BAU)
2. Alternate Scenario 1
3. Alternate Scenario 2
4. Alternate Scenario 3
5. Alternate Scenario 4

Assumptions in BAU Scenario are as follows:

India has achieved a high rate of economic growth after introduction of economic reform in 1991. Projections for long term economic growth of Delhi are not available. Therefore, for Delhi, the same annual GDP growth rate of 5.6% as observed during 1992-97, after introduction of economic reform in 1991, has been assumed for the entire time horizon of 1998-2020. Annual growth rate of population has been taken as 3.8% for the period 1998-2006, and 2% for the rest of the time horizon (GOI, 1996). For the same reason as in Delhi, for Mumbai also, actual GDP growth rate of 6.6% that has been registered during 1992-97, has been assumed to continue till 2020. For the entire time horizon, present analysis assumed the same population growth rate of 1.2% as estimated by BMRDA for the period 1996-2021 for the Greater Mumbai (BMRDA, 1995).

Table 1.1. Attrition factor by vehicle type

	Base year	2005	2010	2015	2020
2-wheeler	15	15	15	15	15
Car	25	20	15	15	15
3-wheeler	15	15	15	15	15
Taxi	25	10	15	15	15
Bus	10	10	10	10	10
HCV/LCV	15	15	15	15	15

Source: TERI (1997)

Table 1.2. Penetration of technology by vehicle type (Share (%) of the technology in new vehicles added during the period)

	Vehicle type	Technology	Fuel used	2000-05	2006-10	2011-15	2016-20
Passenger	2-wheeler	2-stroke	Gasoline	50	30	-	-
		4-stroke	Gasoline	50	70	100	100
	Car	Gasoline	Gasoline	87	90	85	80
		Diesel	Diesel	8	-	-	-
		CNG	Natural Gas	5	10	15	20
	3-wheeler	Gasoline	Gasoline	50			
		CNG	Natural Gas	25	50	50	50
		Battery	Electricity	25	50	50	50
	Taxi	Gasoline	Gasoline	50	50	50	50
		Diesel	Diesel	-	-	-	-
		CNG	Natural gas	50	50	50	50
	Bus	Diesel	Diesel	-	-	-	-
		CNG	Natural gas	100	100	100	100
Freight	LCV		Diesel	100	100	100	100
	HCV		Diesel	100	100	100	100

As mentioned in the methodology (component 2), once vehicle stock is projected, an attrition factor has been applied for each vehicle type to arrive at the number of vehicle exists in a particular year. Assumptions on attrition factor are listed in Table 1.1. Penetration of new technology in future years as considered for different vehicle types is given in Table 1.2. We have used a constant set of figures (Table 1.3) for vehicle occupancy factor and utilisation rate obtained from an earlier study carried out by TERI (TERI, 1997).

Table 1.3. Occupancy and utilization of vehicles

	Delhi		Mumbai	
	Occupancy (persons or tons/vehicle/trip)	Utilization (km/day)	Occupancy (persons or tons/vehicle/trip)	Utilization (km/day
2-wheeler	1.5	13.5	1.5	13.5
3-wheeler	1.76	120	1.8	100
Car	2.68	27	2.68	27
Taxi	1.57	85	1.6	85
Bus	37	186	38	245
LCV	0.7	25	0.7	20
HCV	5	25.00	5.28	20

LCV: Light Commercial vehicle, HCV: Heavy Commercial Vehicle

Source: (TERI, 1997)

However, we recognize that these two parameters have a significant bearing on travel demand and emissions.

In the case of Delhi, we consider the implementation of first phase of MRTS by 2005, which will carry 3.2 million of passengers per day. We have assumed that 75% of the 3.2 million of passengers will shift from bus to MRTS and the rest will shift from the use of personalised mode with 12.5% each from 2-wheeler and car respectively. In addition, we have assumed completion of second phase with additional capacity of 3.2 million of passengers per day in 2015. A similar pattern of passenger shift as in case of Phase I of MRTS has been assumed for Phase II. Reduction in number of buses, cars and 2-wheelers due to the Phase I and II of MRTS has been presented in Table 1.4. It should be noted that the present study limits the energy demand and emission analysis for motorized transport system only and does not include the MRTS.

Table 1.4. Replacement of 2-wheelers, cars and buses by MRTS

MRTS	2-wheeler	Car	Bus
Phase I	194098	54318	3427
Phase II	499218	139706	8814

Table 1.5 and 1.6 present the energy efficiency and emissions factors by vehicle type and technology those are used for the analysis. Gradual reductions in emissions factors over time, reflects the emissions norms that have been specified in different points of time. With the introduction of low lead petrol from 1994 and unleaded petrol from 1995, emission factors for lead came down. Further, emissions factors include impact of the implementation of EURO I in 1999 and EURO II in 2000 (UNEP, 1999). Further improvement in emission standards has been considered for the period 2000-05. Due to paucity of further information, it has been assumed that same emission standards will continue beyond 2005.

Table 1.5. Energy efficiency by vehicle type/technology

Technology		Fuel	Km/GJ	PKM or TKM/GJ	MJ/PKM or TKM
2-wheeler	2 stroke	gasoline	1233.38	1850.07	0.54052
2-wheeler	4 stroke	gasoline	1804	2706	0.369549
2-wheeler	4stroke/CC	gasoline	1804	2706	0.369549
3-wheeler	2stroke	gasoline	566	996.16	1.003855
Car(pre 84 model)		gasoline	261.7	701.356	1.425809
Car (post 84 model)		gasoline	393.5	1054.58	0.948245
Car	CC	gasoline	410.8	1100.944	0.908311
Car		diesel	232.4	622.832	1.605569
Taxi		gasoline	261.7	410.869	2.433866
Taxi		diesel	232.4	364.868	2.740717
Bus		diesel	86.57	3203.09	0.312199
3-wheeler	CC	CNG	833	1466.08	0.682091
Car		CNG	579	1551.72	0.644446
Taxi		CNG	385	604.45	1.654397
Bus		CNG	89.5	3311.5	0.301978
3-wheeler		electricity	2785.5	4902.48	0.203978
Car		electricity	1739.1	4660.788	0.214556
Bus		electricity	358.2	13253.4	0.075452
LCV		diesel	147.55	103.285	9.681948
HCV		diesel	93.05	491.304	2.0354

CC: Catalytic Converter; Source: Bose, 1998

Table 1.6. Emission factors by vehicle type (gm/km)

Type of vehicle	Year	CO	HC	NOx	SO_2	Particulates	Pb
Cars and Jeeps	Up to 1991	25	5.00	2.00	0.053	-	0.030
	1991-94	19.8	2.73	2.00	0.053	-	0.030
	1994-95	19.8	2.73	2.00	0.053	-	0.008
	1995-99	6.45	1.14	1.14	0.053	-	0.003
	1999-2000	3.16	0.56	0.56	0.053	-	0.003
	2000-05	2.2	0.25	0.25	0.053	-	0.003
Two Wheelers	Up to 1991	8.30	5.18	0.1	0.023	-	0.008
	1991-1994	6.49	4.5	0.1	0.023	-	0.008
	1994-96	6.49	4.5	0.1	0.023	-	0.002
	1996-2000	5.00	4.32	0.1	0.023	-	0.002
	2000-2005	2.4	2.4	0.1	0.023	-	0.0002
Three Wheelers	Up to 1991	12.0	7.0	0.26	0.029	-	0.019
	1991-94	12.0	7.0	0.26	0.029	-	0.019
	1994-95	12.0	7.0	0.26	0.029	-	0.005
	1996-2000	8.1	6.48	0.26	0.029	-	0.005
	2000-2005	4.8	2.4	0.26	0.029	-	0.0004
Commercial	Up to 1991	12.7	2.1	21.0	1.5	3	-
	1991-96	12.7	2.1	21.0	1.5	3	-
	1996-2000	9.96	1.44	16.8	0.75	2.4	-
	2000-2005	5.35	0.66	9.34	0.37	2.4	-

Source: Indian Institute of Petroleum (IIP), Automotive Research Association of India (ARAI)

Alternate Scenarios: Alternate scenarios have been constructed; based on different GDP growth rates as suggested by Asian Institute of Technology (AIT). While Alternative Scenario 1 and 2 assume respectively 50% and 25% higher annual rate of GDP than the BAU Scenario, other two scenarios assume GDP growth rates, which are respectively 50% and 25% lower than the BAU Scenario (Table 1.7). Other assumptions in all the alternate scenarios remain the same as in BAU Scenario.

Table 1.7. GDP growth rates (%) per annum in alternate scenarios

	Alt. Scenario 1	Alt. Scenario 2	Alt. Scenario 3	Alt. Scenario 4
Delhi	8.4	7	2.8	4.2
Mumbai	9.9	8.25	3.3	4.95

2. RESULTS AND ANALYSIS

Results and analysis have been divided into three components, 1) travel demand, 2) energy demand and 3) emissions from the transport system. These are discussed separately for BAU Scenario and Alternate Scenarios. The discussion follow:

2.1 BAU Scenario

2.1.1 Travel Demand

Tables 2.1 and 2.2 present the projected SDP, population and vehicle stocks for Delhi and Mumbai during the time horizon of the analysis in the BAU Scenario. It can be observed that, during 1997-2000, while population in Delhi is expected to grow 1.9 times, both SDP and vehicle stocks would increase 3.7 times. It should be noted further that, despite implementation of MRTS with carrying capacity of 6.4 million passengers by 2020, about 8.85 million of vehicles are expected to ply on Delhi roads. In the case of Mumbai, during the same time period, while GDP and population will increase 4.3 and 1.3 times respectively, total vehicle stock is expected to go up 5 times. Therefore, while vehicle stock -GDP elasticity is about one in case the of Delhi, it is greater than one for Mumbai.

Table 2.1: Projected SDP, population and total vehicle stock for Delhi

Year	SDP (Rs crores)	Population (million)	Total Vehicles
1997	6,432	11.46	23,87,996
2005	10,532	16.03	35,08,371
2010	13,850	18.02	47,96,766
2015	18,214	19.92	63,40,340
2020	23,953	22.01	88,54,421

1 crore = 10^7, Source: Estimated by the project team at IGIDR

Table 2.2 : Projected SDP, population and total vehicle stock for Mumbai

Year	GDP (Rs crore)	Population (million)	Total vehicle
1998	9,015	10.8	4,95,308
2005	14,988	11.9	8,75,772
2010	20,593	12.6	12,06,312
2015	28,294	13.4	18,24,725
2020	38,874	14.3	25,19,447

Source: Estimated by the project team at IGIDR

Tables 2.3 and 2.4 present the growth by vehicle type for Delhi and Mumbai. In both the cities, a steep growth is expected in personalized vehicles. Though MRTS would replace about 0.5 million of 2-wheelers and 0.13 million of cars by 2020, in Delhi, the number of 2-wheeler and car will grow from the present level of 1.5 million and 0.66 million to 5.78 million and 2.4 million respectively in 2020. Respective annual growth rates are estimated as 5.9% and 5.8% during 1997-2020. Similarly two wheeler vehicles in Mumbai will grow from 0.23 million and 0.15 million in 1998 to 1.5 million and 0.6 million respectively in 2020. Although, car-GDP elasticity is less than one (0.96), 2-wheeler-GDP elasticity is about 1.31. Personalized vehicles continue to dominate the total vehicle stock. In Delhi, the share of personalized mode (car and two-wheeler) continues to be as high as 96%. In fact, there will be a marginal growth in the share, from 96.1% to 96.7% (Figure 2.1). The share of buses in total vehicle stock, on the other hand, will decline from 0.68% to 0.46%. This can be explained by the fact that we have assumed about 75% of 6.4 million of MRTS passengers will shift from bus to MRTS.

Due to the government's policy on phasing out of taxis, which are more than 15 years old, the number of taxis in Delhi declines during 1997-2005, however, it grows thereafter. For the same reason, growth rate of three wheeler stock is only 2.1% during 1997-05, however, it increases at the rates of 12%, 7% and 5% in the latter three periods.

In Mumbai, share of personalized mode (car and 2 wheeler) will go up from present level of 81% to 88%, share of bus in total vehicle population, on the other hand, will marginally decline from 1.32% in 1998 to 1.12% in 2020 (Figure 7). The government's policy on phasing out old 3-wheelers and taxis as in Delhi, explains the growth patterns of these two vehicles.

There is respectively 3-fold and 4-fold growth in good vehicle stocks in Delhi and Mumbai, during the time horizon of the analysis.

Table 2.3: Projected vehicles stock in Delhi

	2-Wh	3-wh	Taxi	Car	Buses	Total	LCV	HCV	Goods vehicle
1997	1530944	59831	12802	664564	15532	2283673	57378	46945	104323
2005	2148893	70692	9313	1103407	19455	3351765	95530	61076	156606
2010	3130580	123685	14855	1292449	26411	4587980	135711	73075	208786
2015	4170067	169799	17756	1695175	27754	6080550	168864	90927	259790
2020	5782376	214334	22413	2454375	39275	8512774	222070	119576	341646

Table 2.4: Projected vehicles stock in Mumbai

Year	Car	2-wheelers	3- wheeler	Taxis	Buses	Total passenger vehicles	LCV	HCV	Total Goods vehicles
1998	154865	233530	54757	26961	6309	476422	11037	7849	18886
2005	267882	451017.59	91610	25101	12745	848355	16999	10419	27418
2010	342271	668921.76	104103	35582	16675	1167552	24806	13953	38759
2015	476778	1087894.8	148246	33766	19974	1766658	37163	20904	58066
2020	623113	1534209.2	210407	44667	27269	2439667	51059	28721	79780

Source: Estimated by the project team at IGIDR

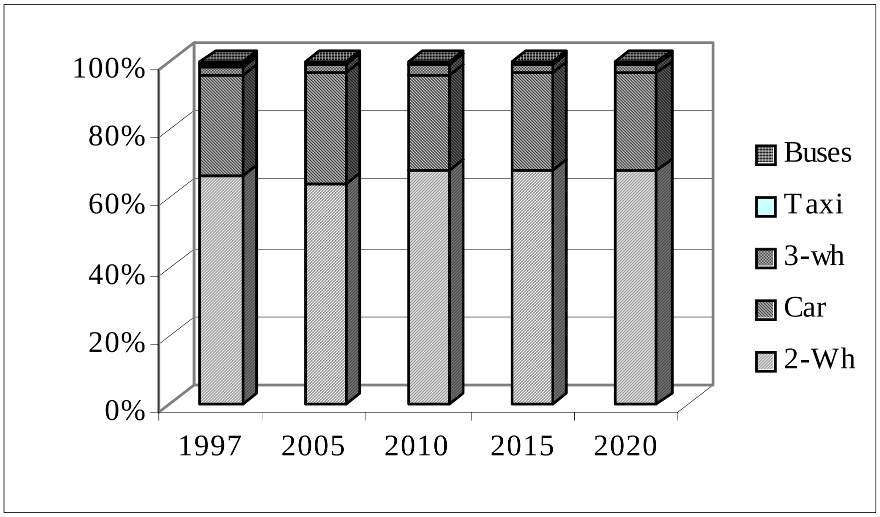


Figure 2.1: Composition (%) of passenger vehicles stock in Delhi

In Delhi, while share of car and 2-wheeler in total vehicle population, will remain the same at about 29% and 68% respectively, in Mumbai, there will be a steep growth in the share of 2-wheeler in total vehicle from 49% to 63%. The share of cars in Mumbai, however, will fall from 32% to 25%.

While per capita income nearly doubles from Rs 5,614 to Rs 10,880 during 1997-2020, number of cars and 2-wheelers per 1,000 persons in Delhi increase almost in the same rate, from 58 and 133 respectively today to 111 and 263 in 2020 (Table 2.5). Number of buses per 1,000 persons is expected to increase from 1.4 to 1.8.

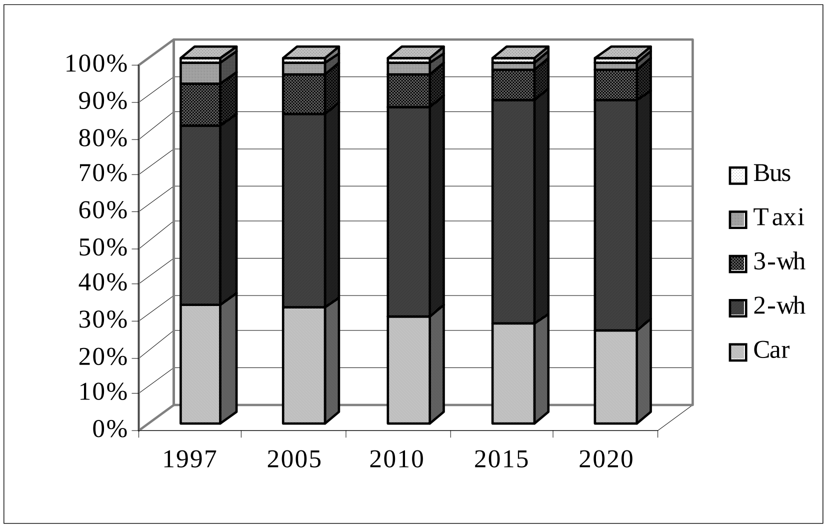


Figure 2.2: Composition (%) of passenger vehicles stock in Mumbai

Table 2.5: Vehicle per 1000 persons in Delhi

Year	Car	2-wheeler	3-wheeler	Taxi	Bus
1997	58	133	5	1	1.4
2005	69	134	4	0.6	1.2
2010	72	174	7	0.8	1.5
2015	85	209	8	0.9	1.4
2020	111	263	9	1.0	1.8

Source: Estimated by the project team at IGIDR

Table 2.6: Vehicle per 1000 persons in Mumbai

Year	Car	2- wheelers	3- wheeler	Taxi	Bus
1998	14	22	5	2	0.6
2005	22	38	8	2	1.1
2010	27	53	8	3	1.3
2015	35	81	11	3	1.5
2020	44	107	15	3	1.9

Source: Estimated by the project team at IGIDR

A similar trend is observed in Mumbai as well. While, cars and 2-wheelers per 1,000 persons will go up from 14 and 22 to 44 and 107 respectively, that for buses will increase from 0.6 in 1998 to 1.9 in 2020 (Table 2.6).

Total passenger travel demand in Delhi will increase from 73 billion passenger kilometer (pkms) in 1997 to 253 billion pkms in 2020, registering an annual growth rate of 5.3% per annum (Table 2.7). However, during 2005 and 2010, passenger travel demand of 11.49 billion pkms will be met by MRTS, based on the assumption of completion of MRTS with carrying capacity of 3.2 million passengers by 2005. This figure will further go up to 29.52 billion pkms in 2015 and 2020 due to enhancement of MRTS carrying capacity to 6.4 million passengers by 2015. MRTS will respectively meet 10%, 7.9%, 15.7% and 11.6% of total passenger travel demand in 2005, 2010, 2015 and 2020. Passenger travel demand of 99.8 billion pkms, 133.88 billion pkms, 159 billion pkms, 224 billion pkms will be met by motorized transport. Freight travel demand is expected to increase from 2.63 billion tonne kilometer (tkms) to 7.18 billion tkms in 2020. Annual growth rate of freight demand during 1997-2020 is estimated as 4.3%, as against assumed GDP growth rate of 5.6% during the same period.

Total passenger travel demand for Mumbai has been estimated as 32 billion pkms, 61 billion pkms, 79 billion pkms, 100 billion pkms, 137 billion pkms respectively for the years 1998, 2005, 2010, 2015 and 2020 (Table 2.8). Annual growth is worked out as 6.8% which is higher than Delhi may be because of assumption on higher GDP growth rate for Mumbai. Fright travel demand has been estimated as 0.36 billion tkms, 0.49 billion tkms, 0.66 billion tkms, 0.99 billion tkms, 1.37 billion tkms respectively for the years 1998, 2005, 2010, 2015 and 2020. Freight demand is expected to grow at a rate of 6% annually during 1998-2020, as against annual GDP growth rate of 6.6% during the same period.

Per capita passenger travel demand has been estimated as 19 km, 22 km, 26 km and 31 km respectively in 2005, 2010, 2015 and 2020, as against estimated 17 km in 1997 (Table 2.7). TERI estimates of per capita passenger travel demand for Delhi are 23 km and 27 km respectively for the years 2005 and 2010 (TERI, 1997). Per capita travel demand in Mumbai is low as compared to Delhi. Respective figures are 8.2 km, 14 km, 17.1 km, 20.4 km and 26.2 km for the years 1998, 2005, 2010, 2015 and 2015 (Table 2.8). TERI estimates on per capita travel demand in Mumbai are 11.8 km and 13.2 km for 2005 and 2010 (TERI, 1997).

Share of motorized travel demand met by personalized mode of transport is expected to increase in Delhi from about 40% (car - 24%, 2-wheeler -15.5%) in 1997 to 45% (car 27%, 2-wheeler -18%) in 2020 (Table 2.7). Share of bus in total travel demand, on the other hand, will decline from 53% to 48%. While share of 3-wheeler will remain constant at about 6% (except for the year 2010, when it will decline to 5%), share of travel demand met by taxi will decline marginally.

Table 2.7: Projection of passenger and freight demand met by different mode in Delhi

	Passenger kilometer demand in billion passenger km							Per capita travel demand (km) per day	Freight demand in billion tonne kilometer		
	by motorized transport						MRTS				
	Car	2-Wh	3-wh	Taxi	Buses	Total			LCV	HCV	Total
1997	17.55	11.32	4.61	0.62	39.02	73.12		17.48	0.37	2.26	2.63
2005	29.14	15.88	5.45	0.45	48.87	99.80	11.48	19.02	0.61	2.94	3.55
2010	34.14	23.14	9.53	0.72	66.34	133.88	11.48	22.09	0.87	3.52	4.39
2015	44.77	30.82	13.09	0.86	69.72	159.26	29.52	25.97	1.08	4.38	5.46
2020	64.82	42.74	16.52	1.09	98.66	223.83	29.52	31.53	1.42	5.76	7.18

	Distribution of travel demand in different mode (%)						
	Passenger demand					Freight demand	
	Car	2-Wh	3-wh	Taxi	Buses	LCV	HCV
1997	24.00	15.48	6.31	0.85	53.36	13.9	86.1
2005	29.20	15.92	5.46	0.45	48.97	17.2	82.8
2010	25.50	17.28	7.12	0.54	49.56	19.7	80.3
2015	28.10	19.35	8.22	0.54	43.77	19.8	80.2
2020	28.90	19.09	7.38	0.49	44.08	19.7	80.3

Source: Estimated by the project team at IGIDR

Table 2.8: Projection of passenger and freight demand met by different mode in Mumbai

	Passenger kilometer demand in billion kilometers						Per capital/day travel demand in km	Freight demand in billion tonne kilometers		
	Cars	2wh	3wh	Taxis	Buses	Total		LCV	HCV	Total
1998	4.1	1.7	3.6	1.3	21.4	32	8.16	0.056	0.303	0.359
2005	7.1	3.3	6.0	1.2	43.3	61	14.02	0.087	0.402	0.488
2010	9.0	4.9	6.8	1.8	56.7	79	17.16	0.127	0.538	0.665
2015	12.6	8.0	9.7	1.7	67.9	100	20.37	0.190	0.806	0.996
2020	16.5	11.3	13.8	2.2	92.7	137	26.21	0.261	1.107	1.368
	Distribution of travel demand in different mode (%)									
	Passenger demand							Freight demand		
	Cars	2wh	3wh	Taxis	Buses			LCV	HCV	
1998	12.71	5.36	11.18	4.16	66.60			15.71	84.29	
2005	12.04	5.47	9.87	2.04	71.0			17.78	82.22	
2010	11.60	6.24	8.63	2.23	71.5			19.07	80.93	
2015	12.60	8.05	9,75	1.68	67.9			19.07	80.93	
2020	12.10	8.31	10.13	1.62	67.9			19.07	80.93	

Source: Estimated by the project team at IGIDR

In Mumbai, bus continues to be the dominant mode of passenger transport (Table 2.8). The share of travel demand met by bus goes up to 71.5% in 2010 and then declines to 68% in 2020. Share of 2-wheeler will increase from 5.4% to 8.3%, while share of cars continues to be about 12% during 1998-2020. The share of taxi will decline from 4.2% to 1.7%.

2.1.2 Energy Demand

Total energy demand for the transport sector in Delhi and Mumbai is presented in Table 2.9. Transport energy demand (motorized) in Delhi has grown 2-3 times during 1997-2020, from 50.6 million GJ to 137 million GJ. In Mumbai, during the same period, it has grown three fold from 20 million GJ to 60 million GJ. Annual growth rates are worked out to be 4.4% and 5.1% respectively for Delhi and Mumbai, as against assumed economic growth rates of 5.6% and 6.6% respectively. Lower growth in energy demand for motorized transport in Delhi can be attributed to the introduction of MRTS. In both the cities, transport energy-GDP elasticity remains lower than one. Other than MRTS in Delhi, introduction of CNG and electricity driven vehicles in both the cities which are more energy efficient would attribute to low energy-GDP elasticity.

Table 2.9: Total transport energy demand (million GJ) in Delhi and Mumbai

City	1997*	2005	2010	2015	2020
Delhi	50.6	68.9	85.5	102	137
Mumbai	20	29.9	36	45	60

- 1998 for Mumbai

Source: Estimated by the project team at IGIDR

Tables 2.10 and 2.11 present the estimated energy demand by passenger and freight transport and their energy intensity. In Delhi, energy intensity for passenger transport has fallen gradually from 0.58 GJ/1000 pkms in 1997 to 0.5 GJ/1000 pkms in 2020, altogether a 14% decrease. This decline can be attributed to penetration of more energy efficient CNG and battery operated vehicles. For freight transport, energy intensity, on the other hand, increases from 3.08 GJ/1000 tkms to 3.55 GJ/1000 tkms, during the same period, due to increase in share of LCV in total freight transport which is relatively energy inefficient. For Mumbai, energy intensity for passenger transport falls significantly from 0.6 GJ/1000 pkms in 1998 to 0.4 GJ/1000 pkms in 2020. This is due to a marginal increase in share of bus to meet passenger travel demand and introduction of more energy efficient CNG and battery operated vehicles. Lower share of private transport explains the low energy intensity for passenger transport in Mumbai as compared to Delhi. For freight transport, energy intensity, on the other hand, increases from 3.22 GJ/1000 tkms to 3.50 GJ/1000 tkms, during the same period, due to increase in share of LCV in total freight transport. Figures 2.5 and 2.6 present the share of passenger and freight transport in total energy demand. Passenger transport dominates the energy consumption. However, its shares in Delhi has fallen from 84% in 1997 to 81% in 2020. Consequently, share of freight transport, has increased from 16% to 18.5% during the same period. In 1998, 94% of total transport energy in Mumbai was used to transport passenger, while remaining 6% by the freight movement. However, share of energy demand for passenger transport is expected to decline marginally over the years, from 94% to 92% in 2020.

Table 2.12 and 2.13 present the fuel-wise energy demand for the two cities. Penetration of natural gas and electricity reflects the government policy of introduction of clean fuel for the city transport system. Natural gas demand of about 1 billion cubic meters in both the cities suggests the need of an elaborate gas supply network. Replacement of diesel driven passenger vehicles like buses, taxis etc. by CNG driven vehicles, lead to fall in demand for diesel. In the later period only good vehicles demand it. Because of higher share of personalized model of transport, growth in gasoline demand is 2.35 times of the present consumption figure in Delhi .

Table 2.10: Energy demand and intensity by mode (Delhi)

Year	Energy demand (Million GJ)		Travel demand		Energy intensity	
	Passenger	Freight	Passenger (billion pkms)	Freight (billion tkms)	Passenger (GJ/ 1000 pkms)	Freight (GJ/ 1000 tkms)
1996	42.5	8.12	73.1	2.63	0.581	3.087
2005	57	11.88	99.8	3.55	0.571	3.346
2010	69.95	15.5	133.9	4.39	0.522	3.531
2015	82.7	19.35	159.3	5.46	0.519	3.544
2020	111.9	25.45	223.8	7.18	0.500	3.545

Source: Estimated by the project team at IGIDR

Table 2.11: Energy demand and intensity by mode (Mumbai)

Year	Energy demand (Million GJ)		Travel demand		Energy intensity	
	Passenger	Freight	Passenger (billion pkms)	Freight (billion tkms)	Passenger (GJ/ 1000 pkms)	Freight (GJ/ 1000 tkms)
1996	19.1	1.16	32	0.36	0.597	3.22
2005	28.2	1.66	61	0.49	0.462	3.39
2010	33.8	2.3	79	0.66	0.428	3.48
2015	41.5	3.5	100	0.996	0.415	3.51
2020	55.5	4.8	137	1.37	0.405	3.50

Source: Estimated by the project team at IGIDR

Table 2.12: Projected energy demand for transport sector in Delhi

	Unit	1997	2005	2010	2015	2020
Electricity	Mill kWh	0	41.67	155.56	319	458
Natural gas	Bill m3	0	0.43	0.64	0.77	1.16
Gasoline	Mill tonne	0.61	0.81	0.92	1.10	1.44
Diesel	Mill tonne	0.48	0.33	0.40	0.46	0.57

Table 2.13: Projected energy demand for transport sector in Mumbai

	Unit	1998	2005	2010	2015	2020
Electricity	Mill kWh	0	61.11	144.44	261	383
Natural gas	Bill m3	0.02	0.25	0.55	0.72	1.0
Gasoline	Mill tonne	0.20	0.24	0.24	0.29	0.36
Diesel	Mill tonne	0.22	0.2	0.09	0.9	0.11

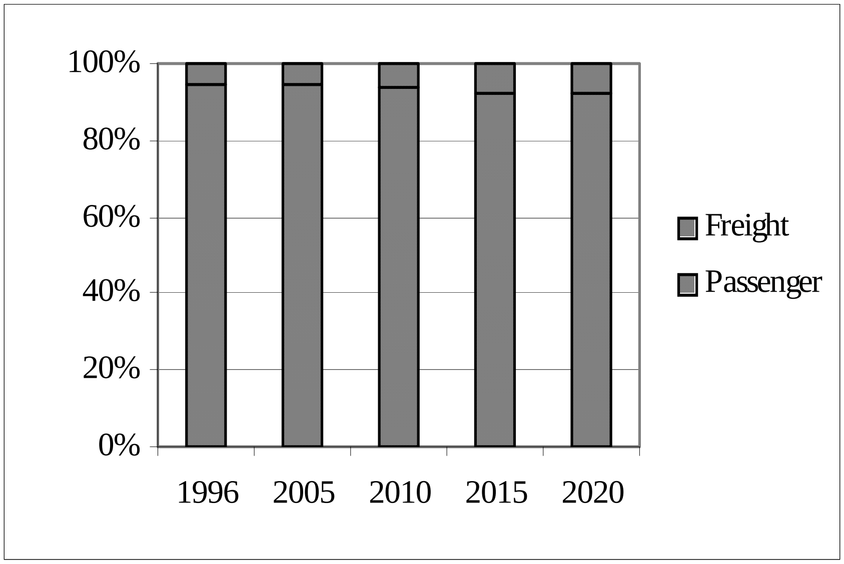


Figure 2.3: Share of passenger and freight travel mode in total energy demand (Delhi)

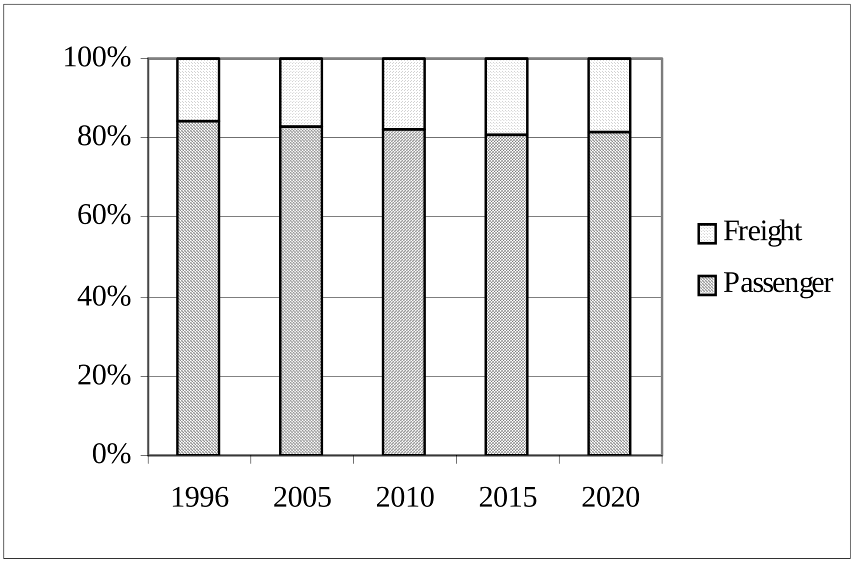


Figure 2.4: Share of passenger and freight travel mode in total energy demand (Mumbai)

Table 2.14: Share (%) of different passenger travel mode in total energy consumption (Delhi)

Travel mode	1997	2005	2010	2015	2020
2-wheeler	14.2	15.6	15.1	15.6	14.8
Car	42.9	49.1	45.3	48.9	50.2
3-wheeler	10.8	8.1	9.1	8.8	6.5
taxi	3.8	1.4	2.0	2.1	2.0
bus	28.3	25.8	28.4	24.6	26.5
Total energy demand (mill GJ)	42.43	56.99	69.96	81.8	111.9

Table 2.15: Share (%) of different passenger travel mode in total energy demand (Mumbai)

	1998	2005	2010	2015	2020
2 wheeler	4.7	5.8	6.6	8.0	7.9
car	27.0	23.5	24.8	27.1	25.9
3-wheeler	18.8	17.0	11.5	10.8	11.0
taxi	16.0	8.6	8.6	6.7	6.6
bus	33.5	45.2	48.5	47.4	48.6
Total energy demand by passenger travel (Mill GJ)	19.09	28.23	33.85	41.54	55.54

As far as different passenger travel mode is concerned, cars in Delhi accounted for the highest share in total energy consumption, about 43% in 1997 (Table 2.14). This share is expected to further increase to 50% in 2020. Bus is the second largest consumer and continues to remain so till 2020. The share of 2-wheeler in total passenger related energy consumption remains same at about 15% throughout 1997-2020.

In Mumbai, bus is the largest consumer of energy, accounting for 33.5% in 1998(Table 2.15). There is a sharp increase in its share to 45% in 2005. After that its share remains at about 48% till 2020. Car is the second largest consumer of energy with a share ranging from 24-27% throughout the time horizon of the analysis. 3-wheeler is the third largest consumer, however, its share falls from 19% in 1998 to 11% in 2020.

2.1.3 Emissions

Implementation of strict emissions norms, introduction of clean fuel, and MRTS, would help Delhi to reduce the pollution load (local) from 412,000 thousand tonnes to 242, 000 tonnes in 2015, however, it would increase to 328,000 tonnes in 2020, due to demand growth (Table 2.16). Use of low lead gasoline reduces the lead emissions drastically. Similarly, use of low sulfur diesel, stricter emission norms and reduction in diesel use, reduces the sulfur emissions from 4,600 tonnes to 2,700 tonnes in 2015, however, it increases marginally in 2020, due to growth in freight travel demand. Stricter emission norms and introduction of CNG driven bus, reduce NO_x emissions as well. Car and 2-wheeler together contribute about 80% of HC emissions in Delhi. 2-wheeler alone contribute about 70% of total CO emissions. Similarly car and 2-wheeler together contribute about 83% of CO in 2005, however, it declines to 70% in the latter years. Phasing out of diesel driven bus system would limit the growth in particulate emissions. Because of assumptions on introduction of MRTS, declining emission factors over the years, our estimations on pollutants are lower than TERI estimates (figures within the brackets).

Table 2.16: Projected emissions (000 t) from the transport sector in Delhi

	1996	2005	2010	2015	2020
CO_2	3646	4665	5796	7011	9364
CO	263	203 (198)	127 (206)	129	182
HC	88	76 (81)	66 (82)	63	81
Lead	0.26	0.16 (0.1)	0.05 (0.098)	0.05	0.07
NO_x	49	39 (61)	40 (74)	40	52
SO_x	4.6	3.5(8.9)	2.8(11)	2.7	3.2
Particulates	7.2	5.4(12)	6.6 (14)	7.9	10.2
Total of local pollutants	412	327	242	242	328

Figures in the brackets are TERI estimates

The situation in Mumbai would be better than that in Delhi. Implementation of strict emissions norms and introduction of clean fuel along with heavy dependence on public transport would help Mumbai to remain relatively clean. Pollution load declines by about 50%, from 135,000 tonnes in 1998 to 61 000 tonnes in 2015, however, after that, it increases to 84,000 tonnes along with the increase in travel demand (Table 2.17). CO and HC continue to be the main pollutants, emitted by mainly the gasoline driven vehicles. Particulates, SO_x and NO_x emissions go down considerable during 1998-2020 because of lesser use of diesel driven vehicles, low sulphur diesel and stricter emissions norm.

Table 2.17: Projected emissions (000 t) from the transport sector in Mumbai

	1997	2005	2010	2015	2020
CO_2	1461	2010	2310	2950	3950
CO	83	55 (71)	32 (80)	33	46
HC	29	26 (30)	17 (34)	16	22
Lead	0.08	0.03 (0.03)	0.015(0.03)	0.014	0.017
NO_x	18.5	16 (30)	10.1(35)	9.9	13.2
SO_x	1.9	1.2 (4.7)	0.7(5.7)	0.64	0.7
Particulates	2.6	2.2 (5.2)	1.3 (6.3)	1.4	1.9
Total of local pollutants	135	101	61	61	84

Figures in the brackets are TERI estimates

Tables 2.18 and 2.19 present the share of passenger transport in the total pollution. In both the cities, bulk of the emissions comes from the passenger transport. However, its share will decline over time. Presently, passenger transport is responsible for respectively 84% and 97% CO_2 emissions in Delhi and Mumbai. Its share will fall to respectively 80% and 90% in 2020. It remains responsible for 100% lead emissions throughout the time horizon. Similarly, it emits about 90% and 97% of CO and HC in 2020. However, its shares in NO_x, SO_x and particulate emissions fall drastically over the time horizon. On the whole, share of passenger transport in total pollution load (non-CO_2) will decline from 92% to 77% in Delhi during 1997-2020. In case of Mumbai, it falls from 96% to 82%.

Table 2.18: Share (%) of passenger transport in total pollution (Delhi)

Pollutant	1997	2005	2010	2015	2020
CO_2	84.3	81.3	80.3	79.7	80.1
CO	94.3	92.1	87.2	87.7	87.9
HC	97.7	97.4	96.6	97.0	97.2
Lead	100.0	100.0	100.0	100.0	100.0
NO_x	76.7	42.8	27.3	23.9	23.8
SO_x	67.4	61.4	58.9	60.7	57.2
Particulate	48.2	8.3	5.5	2.3	0.0
Total local pollutants	91.8	85.8	77.3	76.5	77.0

Source: Estimated by the project team at IGIDR

Table 2.19: Share (%) of passenger transport in total pollution (Mumbai)

Pollutant	1998	2005	2010	2015	2020
CO_2	97.14	94.28	92.68	90.03	89.75
CO	97.24	96.36	93.75	90.91	90.65
HC	99.66	98.85	98.27	100.63	96.82
Lead	100.00	100.00	100.00	100.00	100.00
NO_x	91.35	79.88	56.86	44.44	43.18
SO_x	84.21	83.33	71.43	70.31	67.14
Particulate	76.92	68.18	23.08	4.29	0.00
Total local pollutant	96.38	93.55	87.16	83.71	82.55

Source: Estimated by the project team at IGIDR

2.2 Alternate Scenarios

2.2.1 Travel Demand

Tables 2.20 and 2.21 present the projected SDP for Delhi and Mumbai in different scenarios. Alternate Scenario 1 which assumes a GDP growth rate of 8.4% in Delhi throughout the entire time horizon, SDP grows about seven times in 1997-2020. In this scenario, SDP in 2020 is almost double that of BAU Scenario. In the same scenario, there is more than an 8-fold increase in SDP in Mumbai between 1998 and 2020. SDP in 2020 in this scenario is even more than double the figure in BAU Scenario. In Alternate Scenario 2, SDP in Delhi grows from Rs 6,432 crore in 1997 to Rs 32,628 crore in 2020, while in Mumbai, SDP increases about six fold over the time horizon of the analysis as compared to the base year. Alternate Scenario 3, which assumes a pessimistic annual growth rate of 2.8% and 3.3% respectively for Delhi and Mumbai, during the entire time horizon, SDP only doubles by 2020. SDP in Delhi, in Alternate Scenario 4, grows from Rs 6,432 crore in 1997 to Rs 17,266 crore in 2020, whereas in Mumbai, where economic growth rate is 4.95%, SDP increases three times over 1998-2020.

Table 2.20: Projected economic product (Rs crore, at 1980/81 prices) in different scenarios for Delhi

Year	BAU Scenario	Alt. Scenario 1	Alt. Scenario 2	Alt. Scenario 3	Alt. Scenario 4
1997	6432	6432	6432	6432	6432
2005	10532	13328	11826	8247	9315
2010	13850	19976	16586	9468	11443
2015	18214	29942	23263	10870	14056
2020	23953	44879	32628	12480	17266

Table 2.21: Projected economic product (Rs crore at 1980/81 prices) in different scenarios for Mumbai

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	9016	9016	9016	9016	9016
2005	14988	19186	16999	11690	13270
2010	20593	30759	25268	13750	16896
2015	28294	49313	37558	16174	21512
2020	38875	79058	55827	19024	27390

Source: Estimated by the project team at IGIDR

Estimated per capita annual income for Delhi and Mumbai is shown in Tables 2.22 and 2.23. Per capita annual income in Delhi grows about 4 times in 2020 in Alternative Scenario 1. Income per capita is Rs 20,390 in 2020, which is almost double that of BAU Scenario. In the same scenario, the per capita income of a Mumbaite would go up from Rs 8,346 to Rs 55,384 in 2020, an increase of more than six times. In the Alternate Scenario 2, per capita income of a resident in Delhi grows from Rs 5,613 to Rs 14,824 during 1997-2020, whereas, in Mumbai, during the same period, it increases about more than four times. In Alternate Scenario 3, which assumes a pessimistic growth rate of 2.8%, per capita income in Delhi, falls from Rs 5,613 to Rs 5,145 in 2005, however, after that, it increases marginally to reach Rs 5,670 in 2020, which is almost the same as in 1997. Thus 2.8% GDP growth rate coupled with population growth, would result in a decline in per capita income till 2015. Unlike Delhi where per capita income falls, in Mumbai it increases over the period in Alternate Scenario 3 despite much lower economic growth, to reach s

Rs 13,327 in 2020 up from Rs 8,346 in 1998. In Alternate Scenario 4, while in Delhi, per capita income grows 1.39 times during 1997-2020, it becomes slightly more than double in Mumbai.

Table 2.22: Projected income per capita (Rs at 1980/81 prices) in Delhi

Year	BAU Scenario	Alt. Scenario 1	Alt. Scenario 2	Alt. Scenario 3	Alt. Scenario 4
1997	5613	5613	5613	5613	5613
2005	6570	8314	7377	5145	5811
2010	7686	11085	9204	5254	6350
2015	9144	15031	11678	5457	7056
2020	10883	20390	14824	5670	7845

Table 2.23: Projected income per capita (Rs at 1980/81 prices) for Mumbai

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	8346	8346	8346	8346	8346
2005	12576	16098	14263	9808	11134
2010	16271	24302	19964	10864	13349
2015	21050	36687	27942	12033	16004
2020	27234	55384	39109	13327	19188

Source: Estimated by us

Table 2.24: Projected vehicle stocks in different scenarios (Delhi)

Year	BAU Scenario	Alt. Scenario 1	Alt. Scenario 2	Alt. Scenario 3	Alt. Scenario 4
1997	2387996	2387996	2387996	2387996	2387996
2005	3508371	5736391	4539674	1688185	2538995
2010	4796766	9675684	6975828	1308235	2879936
2015	6340340	14868200	9841780	778620	3055453
2020	8854421	23285822	14728956	1542463	4501461

Source: Estimated by the project team at IGIDR

Table 2.25: Projected vehicle stock in different scenarios (Mumbai)

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	495308	495308	495308	495308	495308
2005	875772	1288940	1071445	564761	712075
2010	1206312	2272208	1686834	538054	839468
2015	1824725	4222410	2845357	606111	1123267
2020	2519447	7045517	4325743	692869	1413586

Source: Estimated by the project team at IGIDR

Tables 2.24 and 2.25 present the projected vehicle stock in Delhi and Mumbai respectively under different scenarios. In Alternate Scenario 1, there is expected to be an explosion in vehicle stock in both the cities. While in Delhi, there is 10-fold increase in vehicle stocks during 1997-2020, in Mumbai, it goes up 14 times from the present level. In Delhi, while annual growth rate in vehicle stock was 5.8% in BAU Scenario, in this scenario, it would be about 10.4% per annum. The annual vehicular growth rate in Alternate Scenario1 is even higher in Mumbai at 12.8%, than 7.7% in BAU Scenario.

In Alternate Scenario 2, total number of vehicles in 2020 is projected as 14.7 million in Delhi, as compared to 8.85 million in BAU Scenario. Vehicles stocks in Mumbai in 2020 increases about 8.7 times from 1998 level, as against 5 times increase under the BAU scenario.

Alternate Scenario 3, which assumes a pessimistic economic growth rate, along with fall in per capita income, and addition of MRTS, total vehicle stocks in Delhi, declines from 2.38 million in 1997, to 1.69 million in 2005, and further falls to 0.78 million in 2015 due to expansion of MRTS, however, increases to 1.54 million in 2020. Overall, number of vehicles fall by about 0.8 million during 1997-2020. In Alternate Scenario 4, vehicle stocks grow gradually from 2.38 million to 4.5 million in 2020. Annual growth rate is only about 2.8%, as against 5.8% in BAU Scenario.

In Alternate Scenario 2 and 3, only 1.4 and 2.8 fold increase in vehicle stock is expected in Mumbai, during the same period. While in Alternate Scenario 3, annual vehicular growth during 1998-2020 has been estimated as much lower than GDP growth rate, in Alternate Scenario 4, it grows annually almost at the same rate as GDP.

Figures 2.5 to 2.8 depict the passenger vehicle mix for Delhi in all the alternate scenarios. In both the cities, similar vehicular mix as in BAU Scenario is observed in all alternate scenarios. In Delhi, excepting in Alternate Scenario 3, car and 2-wheeler together account for about 96% of total vehicles. In Alternate Scenario 3, due to a fall in personal income, share of personalized transport declines to 89% in 2015, however, it again increases to 94% in 2020. 2-wheeler alone accounts for about 65% of the total vehicles. Share of bus is negligible, not even one percent and declines to about 0.46% in 2020.

In Mumbai, also, personalized mode of transport dominates heavily in the total vehicle stock in all the alternate scenarios (Figure 2.9 to Figure 2.12). However, there is a marginal variation in its share. While, in BAU Scenario, share increases from 81.5% in 1998 to 88.4% in 2020, in Alternate Scenario 1 and 2, it goes up to respectively to 89.65 and 89% respectively because of assumption of higher income. In the Alternate Scenario 3 and 4, on the other hand, the figures are marginally low at 87.1% and 87.8% respectively. Share of 2-wheeler in total vehicle stock grows from 49% to 67% and 65% respectively in 2020 in first two alternate scenarios, as compared to 62.9% in BAU Scenario. However, in other two scenarios, share of 2-wheeler in 2020 is respectively 57% and 60.5%, slightly lower than in BAU Scenario. Similar to BAU Scenario, share of cars in total vehicle stocks falls over time in all the alternate scenarios. While share of bus remains almost the same over the entire time horizon of the analysis in all scenarios, even as share of intermediate transport like taxi and 3-wheeler declines.

As expected, due to higher economic growth, there is many fold increase in ownership of vehicles in both the cities, in first two alternative scenarios (Table 2.26). In Alternate Scenario 1, along with 4-fold growth in per capita income in Delhi, 2 wheelers per 1000 persons grows from 134 in 1997 to 696 in 2020. During the same period, cars per 1,000 persons grows from 58 to 295. In this scenario, even, number of buses per 1000 persons grows from 1 to 5, while it is expected to grow from 1 to 2 in BAU Scenario.

While, there is only marginal growth in number of taxis per 1,000 persons, number of 3-wheelers grew from 5 to 23 per 1,000 persons. Alternate Scenario 2 also showed a significant growth in ownership in personalized vehicles. Numbers of 2-whleers and cars per 1000 persons are expected to grow from respectively 134 and 58 in 1997 to 439 and 186 in 2020. While, numbers of 3-wheelers per 1000 persons grows from 5 to 15, same figure grows from 1 to 3 for buses. In Alternate Scenario 3, lower economic growth limits the ownership in personalized vehicles. Number of 2-wheelers per 1,000 persons declines from existing 134 to 21 in 2015, however, it grows to 43 in 2020. For the same reason, number of cars per 1000 persons drops from 58 to 9 in 2015 and then increases to 18 in 2020. Number of other vehicles per 1,000 persons also falls. For example, number of buses per 1,000 persons falls from 1.36 to 0.25. Number of 2-wheelers per 1,000 persons falls from 134 in 1997 to 94 in 2005 because of lower economic growth and introduction of MRTS that would lead to shifting in some passengers from 2-wheelers mode to the MRTS. The number again falls from 103 in 2010 to 98 in 2015 due to the expansion of MRTS and it increases thereafter to 132 in 2020. Number of cars per 1,000 persons falls gradually from existing 58 to 41 in 2015 and thereafter it increases to 56 in 2020.

Table 2.26: Passenger vehicles per 1000 persons in Delhi in different scenarios

	Car	2-wheeler	3-wheeler	Taxi	Buses
			Alternate Scenario 1		
1997	58	134	5	1	1
2005	108	226	7	1	2
2010	148	353	12	1	3
2015	204	493	17	2	4
2020	295	696	23	2	5
			Alternate Scenario 2		
1997	58	134	5	1	1
2005	87	177	6	1	2
2010	106	254	9	1	2
2015	134	325	12	1	2
2020	186	439	15	2	3
			Alternate Scenario 3		
1997	58	134	5	1.1	1.4
2005	37	59	2	0.3	0.5
2010	18	46	3	0.4	0.5
2015	9	21	3	0.3	0.2
2020	18	43	3	0.3	0.3
			Alternate Scenario 4		
1997	58	134	5	1.1	1
2005	52	94	3	0.5	1
2010	42	103	5	0.6	1
2015	41	98	5	0.6	1
2020	56	132	6	0.6	1

Source: Estimated by the project team at IGIDR

Table 2.27 presents the different vehicle per 1000 persons in Mumbai. In Mumbai, number of 2-wheelers and car per 1,000 persons go up from respectively 22 and 14 in 1998 to 323 and 106 in Alternate Scenario 1 and 192 and 70 in Alternate Scenario 2. In Alt Scenario 3, on the other hand, while cars per 1,000 persons remain the same at 14 as in 1998, number of 2-wheelers per 1,000 persons would grow marginally from 22 in 1998 to 27 in 2020. In Alternate Scenario 4, 2-wheelers and cars per 1,000 persons increases from 14 and 22 to 26 and 58 respectively in 1998-2020.

Table 2.27: Passenger vehicles per 1000 persons in Mumbai in different scenarios

	Cars	2-wheeler	3-wheeler	Taxi	Bus
			Alternate Scenario 1		
1998	14	22	5	2	1
2005	32	58	10	3	2
2010	48	105	15	4	2
2015	74	199	23	5	3
2020	106	323	37	8	5
			Alternate Scenario 2		
1998	14	22	5	2	1
2005	27	47	9	2	1
2010	37	76	11	3	2
2015	52	130	16	4	2
2020	70	192	24	5	3
			Alternate Scenario 3		
1998	14	22	5	2	1
2005	15	23	6	2	1
2010	13	22	4	2	1
2015	13	25	4	1	1
2020	14	27	5	1	1
			Alternate Scenario 4		
1998	14	22	5	2	1
2005	19	30	7	2	1
2010	19	36	6	2	1
2015	23	48	7	2	1
2020	26	58	9	2	1

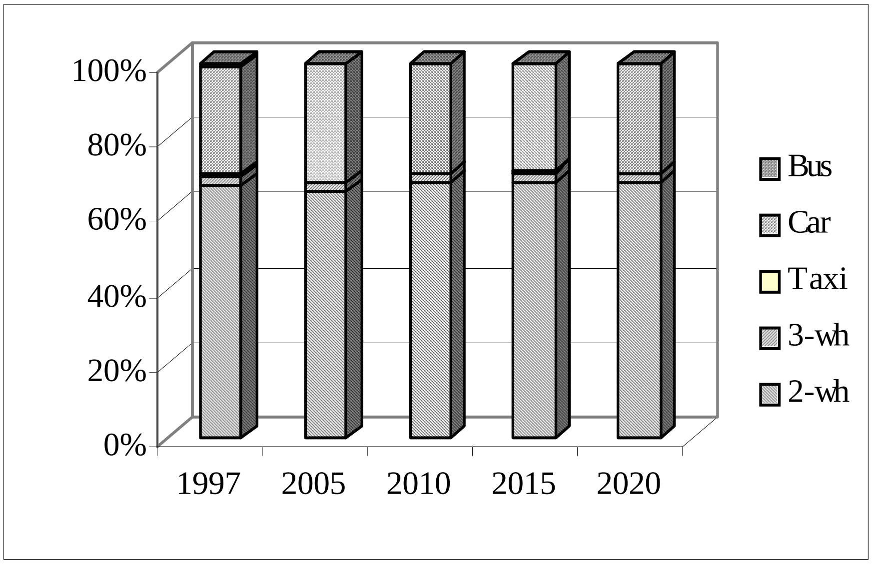


Figure 2.5: Passenger vehicle mix (%) in Alternate Scenario 1 (Delhi)

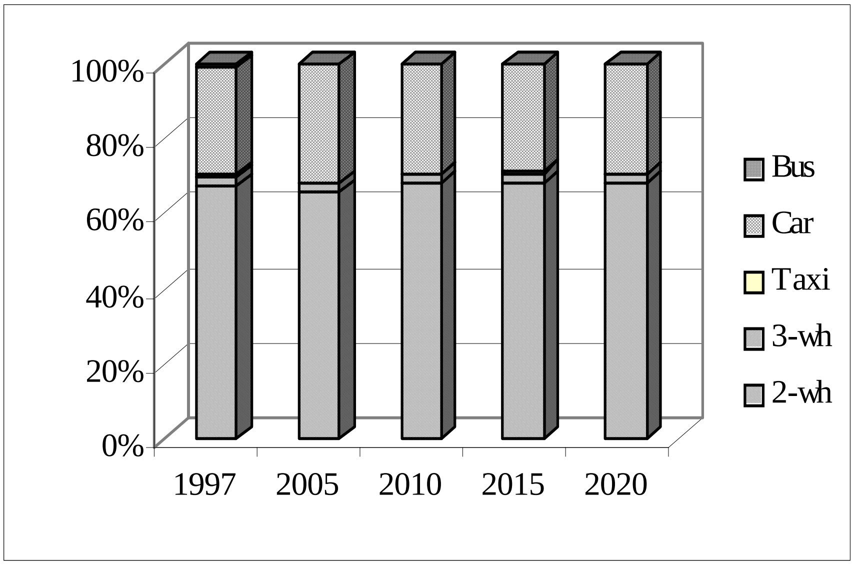


Figure 2.6: Passenger vehicle mix (%) in Alternate Scenario 2 (Delhi)

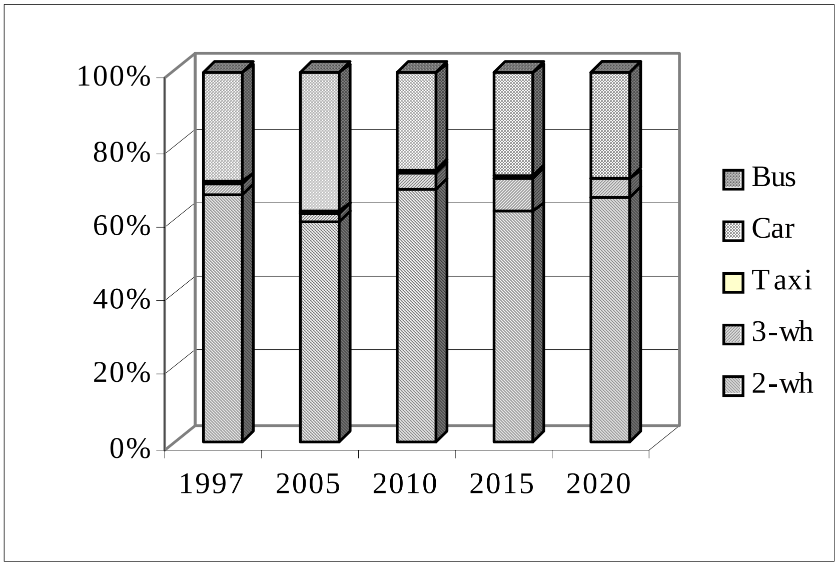


Figure 2.7: Passenger vehicle mix (%) in Alternate Scenario 3(Delhi)

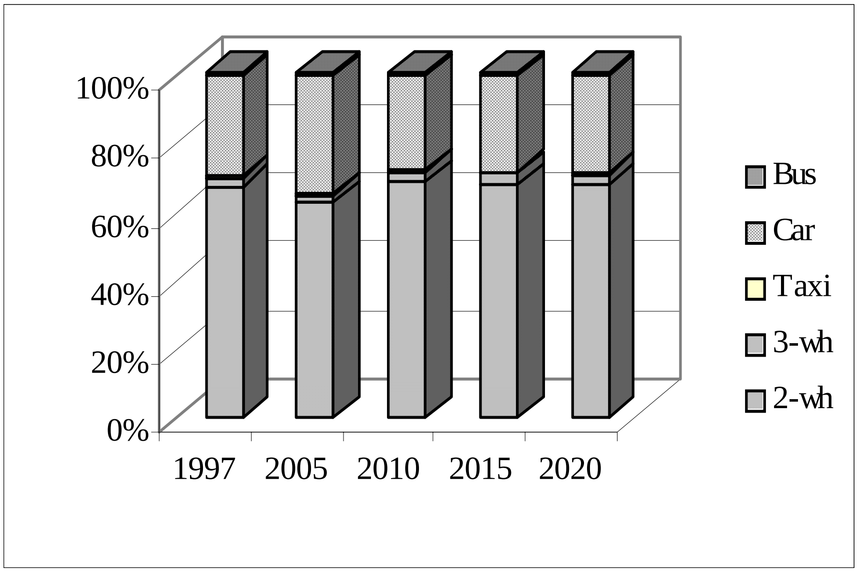


Figure 2.8: Passenger Vehicle mix (%) in Alternate Scenario 4 (Delhi)

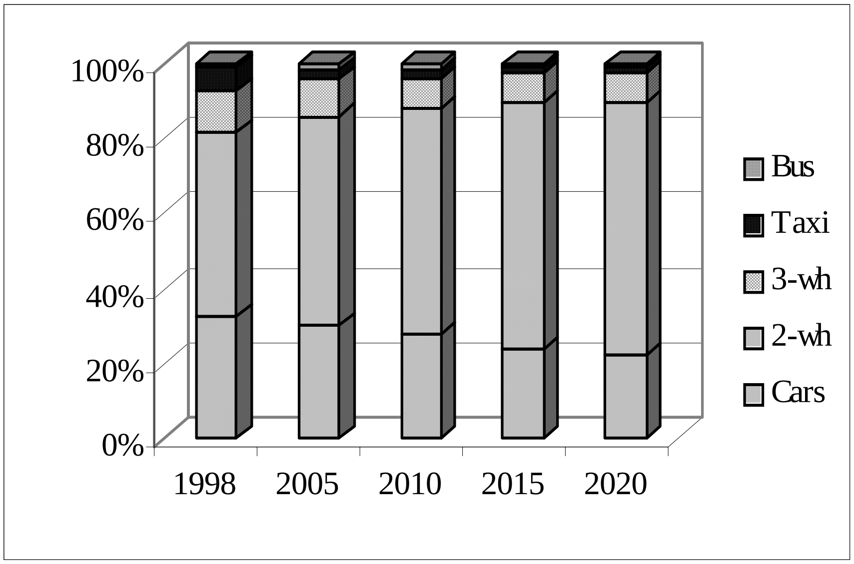


Figure2.9: Passenger vehicle mix (%) in Alternate Scenario 1(Mumbai)

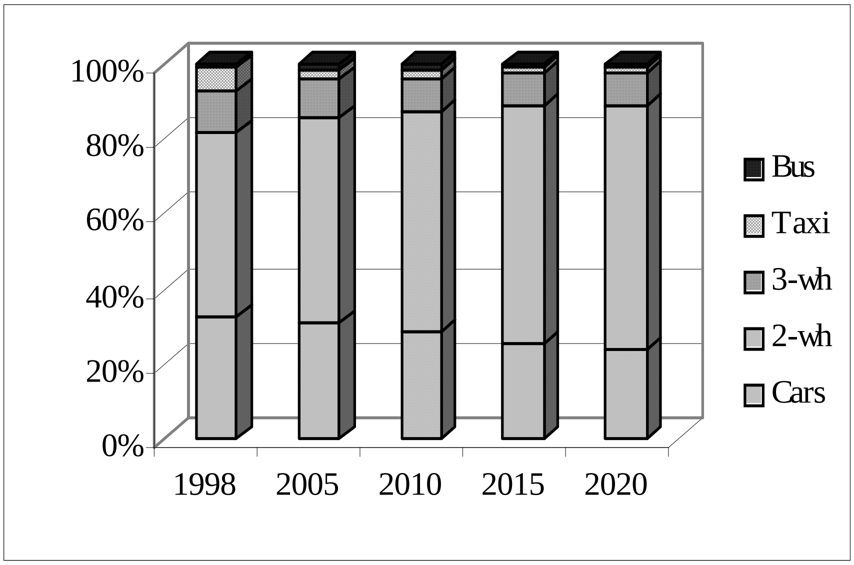


Figure 2.10: Passenger vehicle mix (%) in Alternate Scenario 2 (Mumbai)

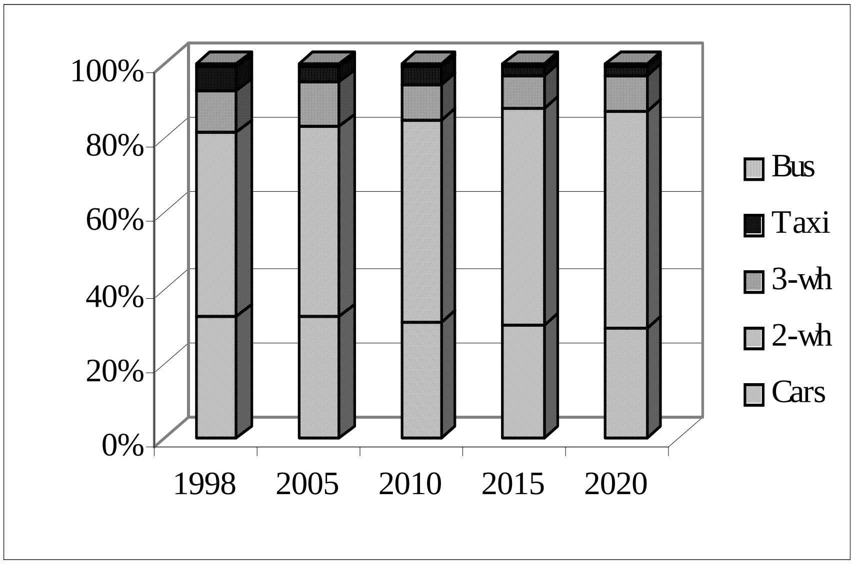


Figure 2.11: Passenger vehicle mix (%) in Alternate Scenario 3 (Mumbai)

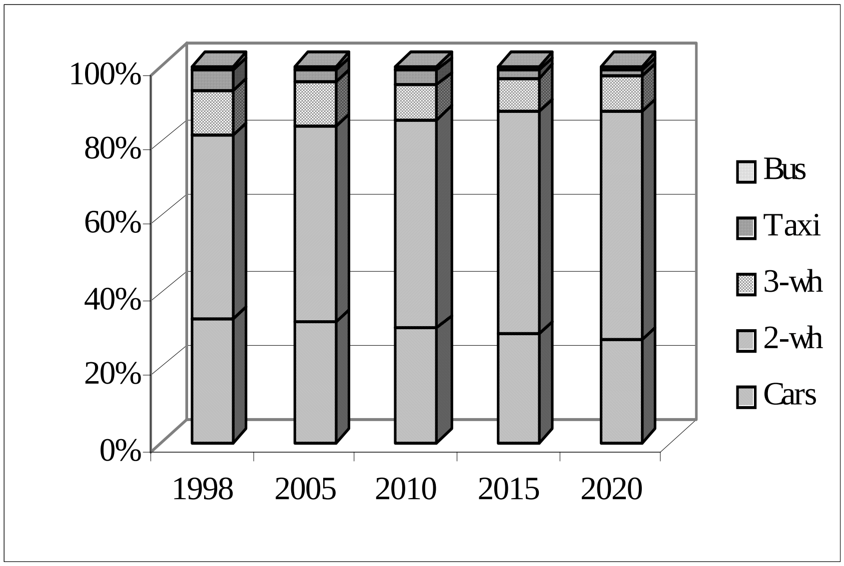


Figure 2.12: Passenger vehicle mix (%) in Alternate Scenario 4 (Mumbai)

Higher Economic growth rates in Alternate Scenario 1 and 2 lead to about 8 and 5 times increase in passenger travel demand between 1998 and 2020 in Delhi (Table 2.28).

Demand for freight also showed a similar growth. Per capita per day travel need increases drastically from 17.5 km in 1998 to about 75 km and 47 km in 2020 in two scenarios respectively (Table 2.29). Low economic growth and implementation of MRTS pull down the demand for motorized transport in Alternate Scenario 3 from 73 billion pkms in 1997 to 47 billion pkms in 2020. It declines further to 22.4 billion pkms in 2015 due to the assumption on doubling the carrying capacity of MRTS in that year. However, it increases to 37 billion pkms afterwards. Per capita per day transportation requirement falls drastically from 17.5 km in 1998 to about 3 km in 2015. Demand for freight falls gradually from 2.6 billion tkms to 2.0 billion tkms in 2015, however, it increases to 2.3 billion tkms afterwards (Table 2.30). In Alternate Scenario 4, although motorized passenger travel demand falls in 2005 and 2015 for the same reason as in the case of Alternate Scenario3. However, on the whole, travel demand in this case increases from 73 billion pkms in 1998 to 112 billion pkms in 2020. Per capita per day travel need declines from 17.5 km to about 14 km in 2020. Table 2.31 compares the assumed GDP growth rates with the estimated growth rates of both types of demand. Excepting, Alternate Scenario 1, in all other scenarios, annual growth in transport demand, both passenger as well as freight, is lower than GDP growth rate.

Table 2.32 and 2.34 present projected passenger travel and freight demand in Mumbai in different scenarios. Growth in economic activities stimulates demand for transportation. Assumption of higher economic growth leads to about 10-fold increase in passenger travel demand in Alternate Scenario 1.A similar trend is observed in Alternate Scenario 2. Low economic growth in Alternate Scenario 3 contributes a very low growth in travel demand for both types. Travel demand of both types just become double over 22 years time period of 1998-2020, in Alternate Scenario 4. In the Alternate Scenario 1 and 2, both types of travel demand showed higher annual rate of growth during 1998-2020 than assumed annual GDP growth rate (Table 2.35). Growth rate is much lower than GDP growth rate in Alternate Scenario 3.

Per capita per day passenger travel demand increases almost 8 times and 5 times respectively between 1998 and 2020 in Alternate Scenario 1 and 2 (Table 2.33). However during the same time period, it declines from 8.16 km to 7.68 km in Alt Scenario 3. In Alternate Scenario 4, it almost doubles.

Table 2.28: Projected motorized passenger travel demand (billion pkms) in Delhi

Year	BAU Scenario	Alt. Scenario 1	Alt. Scenario 2	Alt Scenario 3	Alt Scenario 4
1997	73.1	73.1	73.1	73.1	73.1
2005	99.8	164.2	129.6	47.2	71.8
2010	133.9	267.7	193.4	40.0	82.0
2015	159.3	384.8	253.2	22.4	79.2
2020	223.8	601.9	376.7	37.1	112.0

Table 2.29: Per capita per day motorized travel demand (km) in different scenarios in Delhi

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1997	17.48	17.48	17.48	17.48	17.48
2005	17.06	28.07	22.15	8.06	12.26
2010	20.35	40.70	29.40	6.08	12.47
2015	21.90	52.93	34.83	3.08	10.89
2020	27.86	74.92	46.89	4.62	13.94

Table 2.30: Projected freight demand (billion tkms) in different scenarios (Delhi)

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt. Scenario 4
1997	2.6	2.6	2.6	2.6	2.6
2005	3.6	5.2	4.3	2.2	2.9
2010	4.4	7.7	5.9	2.0	3.1
2015	5.5	11.3	7.9	2.0	3.5
2020	7.2	16.9	11.1	2.3	4.3

Table 2.31: Growth rate (%) of transport demand vis-à-vis GDP (Delhi)

Growth of	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
GDP	5.6	8.4	7	2.8	4.2
Passenger travel demand	4.98	9.60	7.39	-2.90	1.87
Freight demand	4.47	8.42	6.48	-0.65	2.12

Table 2.32: Projected passenger travel demand(billion pkms) in Mumbai

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	32.2	32.2	32.2	32.2	32.2
2005	61.0	90.4	75.0	38.0	49.0
2010	79.3	147.7	110.6	33.8	54.6
2015	99.9	222.6	153.0	34.4	62.5
2020	136.5	356.4	226.7	40.0	79.0

Table 2.33: Per capita per day travel demand (km) in different scenarios (Mumbai)

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	8.16	8.16	8.16	8.16	8.16
2005	14.02	20.77	17.25	8.74	11.26
2010	17.16	31.96	23.94	7.31	11.82
2015	20.37	45.38	31.19	7.01	12.74
2020	26.20	68.41	43.50	7.68	15.15

Table 2.34: Projected freight travel demand (in billion tkms) for Mumbai

Year	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
1998	0.36	0.36	0.36	0.36	0.36
2005	0.49	0.74	0.61	0.29	0.39
2010	0.66	1.25	0.93	0.27	0.45
2015	1.00	2.14	1.50	0.36	0.64
2020	1.37	3.43	2.22	0.42	0.81

Table 2.35: Growth rate(%) of GDP vis-à-vis passenger travel and freight demand during 1998-2020 in different scenarios (Mumbai)

Growth rate of	BAU Scenario	Alt Scenario 1	Alt Scenario 2	Alt Scenario 3	Alt Scenario 4
GDP	6.6	9.9	8.25	3.3	4.95
Passenger travel demand	6.79	11.55	9.28	0.99	4.16
Freight demand	6.27	10.80	8.64	0.72	3.76

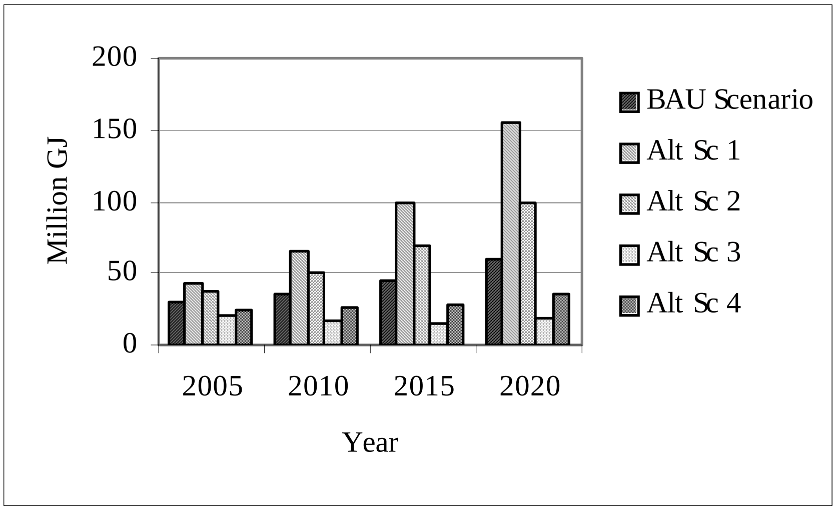


Figure 2.13: Energy demand in different scenarios (Delhi)

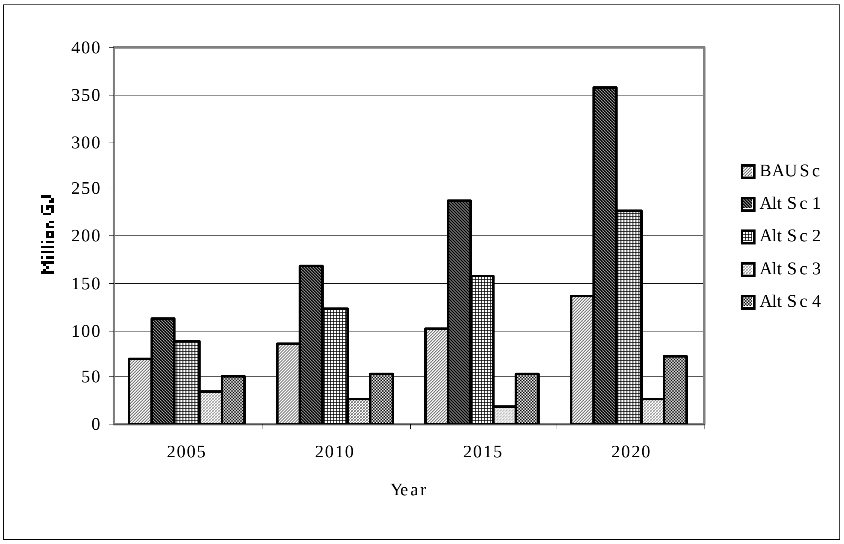


Figure 2.14: Energy demand in different scenarios (Mumbai)

2.2.2 Energy demand

Figures 2.13 and 2.14 illustrate the estimated energy demand by the urban transport system in Delhi and Mumbai in all the scenarios under consideration. In Delhi, in Alternate Scenario 1, which assumes 50% higher annual GDP growth rate, than BAU Scenario, during 1997-2020, transport system demand about 2.6 times more energy in 2020. In

Alternate Scenario 2, this figure is 1.65 times more than BAU Scenario. Estimated annual growth rates in energy demand during 1997-2020, in these two scenarios are respectively, 8.9% and 6.8%. In Alternate Scenario 3, which assumes a pessimistic situation, where GDP growth is 50% lower during the entire time horizon, in 2020, urban transport system in Delhi demand only 20% of energy that its demand in BAU Scenario. This is even 50% lower than the energy consumption 1997. In Alternate Scenario 4, model estimates the energy demand for 2020 as 71 million GJ, as against 50 million GJ in 1997. In all scenarios, except Alternate Scenario 1, energy-GDP elasticity is less than 1.

In Mumbai, in Alternate Scenario 1, energy demand is expected to grow annually at a rate of 9.7% per annum during 1998-2020, for assumed GDP growth rate of 9.9% during the same period. Energy demand in 2020, in absolute terms is about 2.5 times higher than the same in BAU Scenario. In Alternate Scenario 2, annual GDP growth rate of 8.25% during 1998-2020, will lead to 7.4% annual growth rate in energy demand. In Alternate Scenario 3, urban transport system would demand about 18 million GJ which is 87% of energy that is actually consumed in 1998. In Alternate Scenario 4, energy demand shows annual growth rate of 2.5% during 1998-2020, as against assumed GDP growth rate of 4.95%.

Similar to the BAU Scenario, passenger travel dominates the total energy need in both Delhi and Mumbai (Table 2.36 and 2.37). In Delhi it accounts for about 82-83% in first two alternate scenarios. In Alternate Scenario 3, share goes down to about 62.7% in 2015 and then rises to about 70% in 2020. Share remains at about 80% during 2005-2020 in Alternate Scenario 4.

Share of passenger travel in total energy demand is even higher in Mumbai, about 92-94% in all the scenarios. Freight accounts for the remaining 6-8%.

Table 2.38 presents the energy demand by vehicle type for Delhi. In Delhi, in all the scenarios, cars account for highest share in total energy demand, followed by bus. While share of car in total energy demand is about 48-50% in first two alternate scenarios, bus accounts for about 26-28% in the same two scenarios. In Alternate Scenario 3, share of energy demand by car in total energy demand goes down to 37% in 2010 and 2015, however, it grows up again to 49% in 2020. Similar trend for car is observed in Alternate Scenario 4. 2-wheeler is the third largest energy consumer, accounts for about 15% in total energy consumption in all scenarios.

Table 2.36: Energy demand by travel mode and its share (%) in total (Delhi)

Scenario	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
	Passenger travel energy demand (mill GJ)					Share (%) of passenger travel energy demand in total				
BAU Sc	42.5	57.0	70.0	82.7	111.9	84.5	82.8	81.8	81.0	81.5
Alt Sc 1	42.5	92.4	140.5	197.9	297.2	84.5	83.0	83.8	83.2	83.2
Alt Sc 2	42.5	73.3	101.4	130.5	187.3	84.5	83.6	83.0	82.3	82.5
Alt Sc 3	42.5	28.2	20.3	11.8	19.1	84.5	79.1	73.7	62.7	70.4
Alt Sc 4	42.5	41.7	42.6	41.2	56.5	84.5	81.4	79.5	77.1	78.9
	Freight energy demand (mill GJ)					Share (%) of freight energy demand in total				
BAU Sc	8.1	11.9	15.5	19.4	25.5	16.2	17.2	18.1	19.0	18.5
Alt Sc 1	8.1	18.9	27.1	39.9	59.8	16.2	17.0	16.2	16.8	16.8
Alt Sc 2	8.1	14.4	20.7	28.1	39.5	16.2	16.4	16.9	17.7	17.4
Alt Sc 3	8.1	7.5	7.2	7.0	8.0	16.2	21.0	26.1	37.1	29.5
Alt Sc 4	8.1	9.5	11.0	12.3	15.1	16.2	18.6	20.5	23.0	21.1

Source: Estimated by the project team at IGIDR

Table 2.33: Energy demand by travel mode and its share (%) in total (Mumbai)

	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
	Passenger travel energy demand (mill GJ)					Share (%) of passenger travel energy demand in total				
BAU Scenario	19.1	28.2	33.8	41.5	55.5	94.3	94.3	93.5	92.2	92.0
Alt Sc 1	19.1	41.3	61.9	91.4	142.4	94.3	94.2	93.4	92.5	92.2
Alt Sc 2	19.1	34.8	46.9	63.1	91.3	94.3	94.3	93.5	92.4	92.2
Alt Sc 3	19.1	18.9	15.5	14.4	16.4	94.3	95.2	94.3	92.1	91.6
Alt Sc 4	19.1	23.6	24.1	26.0	32.2	94.3	94.6	94.0	92.1	91.9
	Freight energy demand (mill GJ)					Share (%) of freight energy demand in total				
BAU Scenario	1.2	1.7	2.3	3.5	4.8	5.7	5.6	6.4	7.8	8.0
Alt Sc 1	1.2	2.5	4.4	7.5	12.0	5.7	5.7	6.6	7.6	7.8
Alt Sc 2	1.2	2.1	3.2	5.2	7.7	5.7	5.7	6.4	7.6	7.8
Alt Sc 3	1.2	1.0	0.9	1.3	1.5	5.7	4.9	5.5	8.0	8.2
Alt Sc 4	1.2	1.3	1.6	2.2	2.8	5.7	5.3	6.1	7.9	8.0

Source: Estimated by the project team at IGIDR

In Mumbai, there is significant change in demand patterns by different modes (Table 2.39). However, bus dominates the total energy demand in all the scenarios. Its share goes up significantly from 33% in 1998 to about 49% in 2020. Share of intermediate transport (taxi and 3-wheeler), on the other hand, declines considerably over time. Share of car remains almost same at about 25% in the entire time period in all the scenarios.

Table 2.38: Share(%) of different passenger travel mode in total energy consumption (Delhi)

Travel mode	1997	2005	2010	2015	2020
	Alternate Scenario 1				
2-wheeler	14.2	16.2	15.2	15.3	14.8
Car	42.8	47.5	46.5	48.5	50.0
3-wheeler	10.8	8.1	8.2	7.5	5.8
taxi	3.7	1.5	1.8	2.0	1.7
bus	28.4	26.7	28.2	26.8	27.8
Total energy demand (mill GJ)	42.5	92.43	140.6	197.92	297.21
	Alternate Scenario 2				
2-wh	14.2	16.0	15.2	15.2	14.8
Car	42.8	48.3	46.0	48.4	50.2
3-wh	10.8	8.1	8.6	8.0	6.0
taxi	3.7	1.4	1.9	2.0	1.8
bus	28.4	26.3	28.3	26.4	27.1
Total energy demand (mill GJ)	42.5	73.29	101.45	130.46	187.25
	Alternate Scenario 3				
2-wh	14.2	13.9	13.8	11.1	14.1
Car	42.8	53.5	37.9	37.6	48.7
3-wh	10.8	7.8	13.8	22.2	12.0
taxi	3.7	1.8	3.4	5.1	3.7
bus	28.4	23.0	31.0	23.9	21.5
Total energy demand (mill GJ)	42.5	28.22	20.3	11.7	19.1
	Alternate Scenario 4				
2-wh	14.2	15.0	14.8	14.5	14.7
Car	42.8	50.7	43.5	46.3	50.1
3-wh	10.8	8.0	10.3	11.2	7.6
taxi	3.7	1.6	2.4	2.7	2.3
bus	28.4	24.7	29.0	25.2	25.2
Total energy demand (mill GJ)	42.5	41.63	42.55	41.21	56.5

Source: Estimated by the project team at IGIDR

Table 2.39: Share(%) of different passenger travel mode in total energy demand (Mumbai)

	1998	2005	2010	2015	2020
			Alternate Scenario1		
2-wheeler	4.7	6.1	7.2	8.9	9.3
car	27.0	22.6	24.1	25.7	24.4
3-wheeler	18.8	15.6	11.3	10.5	10.7
taxi	16.0	9.3	7.2	6.5	6.4
bus	33.5	46.5	50.3	48.4	49.2
Total energy demand by passenger travel (Mill GJ)	19.09	41.3	61.94	91.4	142.41
			Alternate Scenario 2		
2 wheeler	4.7	5.9	6.9	8.5	8.6
car	27.0	22.8	24.4	26.3	25.1
3-wheeler	18.8	16.0	11.4	10.6	10.9
taxi	16.0	9.7	7.7	6.6	6.5
bus	33.5	45.6	49.6	48.0	49.0
Total energy demand by passenger travel (Mill GJ)	19.09	34.83	46.9	63.09	91.32
			Alternate Scenario 3		
2 wheeler	4.7	5.3	6.1	7.0	6.7
car	27.0	23.6	25.9	28.7	27.5
3-wheeler	18.8	18.5	12.3	11.2	11.3
taxi	16.0	12.3	12.4	6.9	6.8
bus	33.5	40.3	43.4	46.1	47.7
Total energy demand by passenger travel (Mill GJ)	19.09	18.885	15.5	14.368	16.44
			Alternate Scenario 4		
2 wheeler	4.7	5.5	6.3	7.6	7.4
car	27.0	23.3	25.3	27.9	26.6
3-wheeler	18.8	17.4	11.8	11.0	11.2
taxi	16.0	11.2	9.9	6.8	6.7
bus	33.5	42.7	46.6	46.7	48.2
Total energy demand by passenger travel (Mill GJ)	19.09	23.65	24.02	25.91	32.18

Source: Estimated by the project team at IGIDR

2.2.3 Emissions

Tables 2.40 and 2.41 present the projected total pollution (local) load in different scenarios in Delhi and Mumbai. It can be noted that, in Delhi, total pollution load in Alternate

Scenario 1 doubles in 2020 from the present level of 4,12,000 tonnes. Therefore, in terms of pollution, this economic growth scenario is unsustainable unless some stricter abatement rules and measures are adopted. In Alternate Scenario 2, initially pollution load declines to 3,44,000 tonnes in 2010 and then increases again to 5,42,000 tonne in 2020. Alternate Scenario 3, which is a pessimistic one, in terms of economic growth, pollution declines to 66,000 tonne from the existing level of 4,12,000 tonnne in 1997. Pollution load in Alternate Scenario 4, declines to 1,50,000 tonne in 2015 from 4,12,000 tonne in 1997, and then increases to 1,67,000 tonne in 2020.

Table 2.40: Pollutants load (local) in different scenarios in Delhi

Scenario	1997	2005	2010	2015	2020
BAU Scenario	412.1	327.1	242.0	242.7	328.5
Alternate Scenario1	412.1	519.4	460.2	541.0	824.3
Alternate Scenario 2	412.1	417.0	344.6	372.7	542.1
Alternate Scenario 3	412.1	169.4	78.7	43.6	66.0
Alternate Scenario 4	412.1	243.1	152.5	150.5	167.4

Source: Estimated by the project team at IGIDR

In Alternate Scenario 1, pollution level in Mumbai, grows by 66% in 2020, from the present level. It is almost three times the pollution load of about 84,000 tonne in 2020 in BAU Scenario. Pollution load in Alternate Scenario 2 declines initially and reaches 86,000 tonne in 2010, however, it increases after that and reaches the almost existing level again in 2020. In Alternate Scenario 3, it goes down abnormally to 23,000 tonne in 2020, from the present level of 1,36,000 tonne, because of low transportation activities. In Alternate Scenario 4, also, pollution load declines drastically over the time horizon of the analysis.

Table 2.41: Pollutants load (local) in different scenarios in Mumbai

Scenario	1998	2005	2010	2015	2020
BAU Scenario	135.4	100.8	61.5	61.0	83.8
Alternate Scenario1	136.0	145.4	116.0	139.2	226.2
Alternate Scenario 2	136.0	121.5	85.7	95.2	139.3
Alternate Scenario 3	136.0	67.1	27.5	20.2	23.4
Alternate Scenario 4	136.0	83.7	43.4	37.1	47.2

Source: Estimated by the project team at IGIDR

Tables 2.42 and 2.43 present the projected emissions by pollutant types (local as well as global). In Alternate Scenario 1 and 2, CO_2 emissions in Delhi, increase significantly from 3,620 thousand tonne in 1997 to 24,200 thousand tonne and 15,400 thousand tonne in 2020 respectively. In Mumbai, these figures are 9,960 thousand tonne and 6,500 thousand tonne respectively in 2020 as compared to 1,500 thousand tonne in 1998. In Alternate Scenario 3, GDP growth rate of 2.8% per annum will cut down the emissions in 2020 almost by 50% from 1997 level in Delhi. In Mumbai, it is reduced by about 23% from the existing level. CO_2 emissions in 2020 will increase by 36% and 53% respectively from the existing level in Delhi and Mumbai in Alternate Scenario 4. All other pollutants also show the similar trend.

Passenger transport is responsible for the bulk of the CO_2, CO, HC and lead emissions. In fact, the entire lead is emitted by it. Its contribution in NO_x, SO_x and particulate decreases over the years.

Table 2.42: Pollution (1000 tonne) in different scenarios (Delhi)

		1997	2005	2010	2015	2020
CO_2	BAU	3620	4665	5796	7011	9364
	Alternate 1	3620	7500(81.7)	11300(82.6)	16200(81.9)	24200(81.7)
	Alternate 2	3620	5900(82.5)	8300(81.3)	10800(81.2)	15400(81.2)
	Alternate 3	3620	2400(78.7)	1900(71.2)	1300(64.2)	1920(69.3)
	Alternate 4	3620	3500(79.5)	3600(78.7)	3700(75.8)	4900(77.9)
CO	BAU	263	203	127	129	182
	Alternate 1	263	327(92.0)	252(88.1)	301(88.7)	475(89.2)
	Alternate 2	263	259(92.7)	183(88.0)	200(88.0)	302(88.7)
	Alternate 3	263	105(90.5)	38.8(79.9)	19.9(70.0)	33.4(79.6)
	Alternate 4	263	151(91.4)	79(84.7)	65(84.1)	93(86.9)
HC	BAU	88	76	65.5	63	81
	Alternate 1	88	125(97.4)	130(96.9)	148(97.1)	214(97.2)
	Alternate 2	88	99(96.9)	94.6(96.9)	98(96.8)	136(96.7)
	Alternate 3	88	36.5(95.9)	19.4(94.9)	8(90.0)	13.9(93.5)
	Alternate 4	88	55(96.9)	40(96.5)	30(97.7)	41(96.7)
Lead	BAU	0.265	0.16	0.05	0.053	0.07
	Alternate 1	0.265	0.25(100)	0.11(100)	0.12(100)	0.18(100)
	Alternate 2	0.265	0.2(100)	0.08(100)	0.08(100)	0.12(100)
	Alternate 3	0.265	0.08(100)	0.01(100)	0.006(100)	0.01(100)
	Alternate 4	0.265	0.12(100)	0.03(100)	30(100)	0.03(100)
NO_x	BAU	49	39	40	40	52
	Alternate 1	49	61.6(43.0)	72.6(30.4)	85.8(26.6)	127(26.1)
	Alternate 2	49	48(44.0)	54(29.4)	59(25.4)	83(25.1)
	Alternate 3	49	22.5(38.7)	16.5(18.2)	12.3(10.6)	14.7(14.3)
	Alternate 4	49	30(41.3)	27(24.4)	0.025(19.6)	30(20.7)
SO_x	BAU	4.6	3.5	2.8	2.7	3.2
	Alternate 1	4.6	5.5(61.8)	5.5(61.3)	6.09(64.0)	8.11(59.1)
	Alternate 2	4.6	4.3(63.5)	4.02(59.7)	4.1(62.7)	5.2(58.6)
	Alternate 3	4.6	1.95(57.4)	0.99(40.4)	0.58(32.8)	0.75(40.0)
	Alternate 4	4.6	2.7(59.3)	1.8(54.4)	24	1.75
Part	BAU	7.2	5.4	6.6	7.9	10.2
	Alternate 1	7.2	8.5(8.2)	11.7(6.4)	16.4(2.4)	24(0)
	Alternate 2	7.2	6.5(8.6)	8.9(6.1)	11.5(2.4)	15.8(0)
	Alternate 3	7.2	3.32(7.2)	3(3.0)	2.8(0.7)	3.2(0)
	Alternate 4	7.2	4.3(7.9)	4.65(4.5)	1.5(1.7)	1.6(0)

Figures in the brackets are share(%) of passenger transport in total emissions.
Source: Estimated by the project team at IGIDR

Table 2.43: Pollutant load (1000 tonne) in different scenarios in Mumbai

Pollutant	Scenario	1998	2005	2010	2015	2020
CO_2	BAU	1500	2010	2310	2950	3950
	Alternate 1	1500	2950(91.9)	4230(92.5)	6370(91.4)	9960(91.1)
	Alternate 2	1500	2500(93.6)	3200(92.6)	4400(91.2)	6500(92.1)
	Alternate 3	1500	1350(94.5)	1060(93.0)	1030(89.6)	1160(90.9)
	Alternate 4	1500	1710(93.1)	1660(91.9)	1850(89.9)	2300(89.0)
CO	BAU	83.3	55	32	33	46
	Alternate 1	83.5	78.4(95.4)	60.4(92.7)	74.7(91.0)	121.9(91.7)
	Alternate 2	83.5	66(96.1)	45(93.3)	51(91.2)	76(92.1)
	Alternate 3	83.5	37(97.0)	15(92.0)	11(92.7)	13(91.2)
	Alternate 4	83.5	46(95.6)	23(93.0)	20(93.5)	26(91.1)
HC	BAU	29	26	17.3	16	22
	Alternate 1	29	37(98.6)	33(97.9)	39(99.0)	64(97.8)
	Alternate 2	29	31(99.7)	24(99.4)	26(98.5)	38(98.9)
	Alternate 3	29	17.8(98.7)	7.7(98.7)	5(98.2)	5.6(98.2)
	Alternate 4	29	21.7(98.6)	12(99.2)	9.8(97.9)	11.9(97.5)
Lead	BAU	0.08	0.03	0.02	0.01	0.02
	Alternate 1	0.08	0.04(100)	0.03(100)	0.03(100)	0.04(100)
	Alternate 2	0.08	0.04(100)	0.02(100)	0.02(100)	0.03(100)
	Alternate 3	0.08	0.02(100)	0.01(100)	0.01(100)	0.01(100)
	Alternate 4	0.08	0.02(100)	0.01(100)	0.01(100)	0.01(100)
NO_x	BAU	18.5	16.4	10.2	9.9	13.2
	Alternate 1	18.9	24.7(79.3)	19(56.3)	21(46.2)	33.7(43.6)
	Alternate 2	18.9	20(82.0)	14(57.9)	15(44.7)	21(44.8)
	Alternate 3	18.9	10(83.2)	4(65.0)	3.5(43.4)	3.98(41.7)
	Alternate 4	18.9	13(82.3)	7(58.6)	6(45.0)	7.8(42.3)
SO_x	BAU	1.9	1.2	0.7	0.64	0.7
	Alternate 1	1.9	1.9(84.2)	1.2(78.3)	1.4(70.7)	1.9(65.3)
	Alternate 2	1.9	1.61(84.5)	0.9(77.8)	0.97(71.1)	1.2(65.0)
	Alternate 3	1.9	0.89(86.5)	0.3(76.7)	0.22(71.8)	0.21(61.9)
	Alternate 4	1.9	1.1(86.4)	0.5(72.0)	0.4(70.0)	0.4(67.5)
Part	BAU	2.6	2.2	1.3	1.4	1.9
	Alternate 1	2.65	3.4(68.5)	2.4(25.0)	3.1(3.9)	4.7(0)
	Alternate 2	2.65	2.86(68.2)	1.77(26.5)	2.17(4.1)	3.05(0)
	Alternate 3	2.65	1.43(69.2)	0.52(28.8)	0.52(3.8)	0.58(0)
	Alternate 4	2.65	1.86(68.8)	0.86(27.9)	0.9(4.3)	1.12(0)

Figures in the brackets are share(%) of passenger transport in total emissions.
Source: Estimated by the project team at IGIDR

3. SUMMARY AND CONCLUSIONS

Like any other developing country, India has faced rapid urbanization. There is a two-fold increase in urban population during 1971-1991, registering a compounded annual growth rate (CAGR) of 3.8%. There are 23 metropolitan cities, each with over 1 million people, accounting for roughly one-third of urban population. Over 50% of the population living in these metropolitan cities lives in the five giant metros- Kolkata, Mumbai, Delhi, Madras and Bangalore.

Urbanization has caused a number of problems. Urban transport is considered as the most serious among them. Despite years of planning, India has been unable to tackle this problem. In many cities, population is doubling in a decade or little more. In contrast, roads and other transport infrastructure have grown at a much slower pace. Lack of effective policy and investment along with the uncontrolled urbanization growth has resulted in growing gap between supply and demand of transport services. Inadequate public transport system has led to a tremendous growth in personalized vehicles on the one hand, and at the same time, road space has not grown proportionately leading to congestion, longer travel time, increasing travel cost, more energy consumption, and pollution.

Transportation has serious implications for pollution caused by fuel burning. Pollution levels in all Indian metros have reached at alarming situation. Delhi has been declared as the fourth most polluted city in the world, while a number of other cities are following closely behind. Transport system is the dominant polluter. A massive increase in number of vehicles and a large number of old, in-efficient, ill-maintained and obsolete vehicles, results into emission of a stupendous quantity of pollutants about lakhs of tonnes annually in gaseous and particulate forms into the atmosphere. Use of poor quality fuel, bad road conditions, and congestion further contribute into it. Around 67 percent of air pollution in Delhi was caused by motor vehicles in 1996. In 1994, the share of automobiles in total pollutant load was 52% in Mumbai. Most disturbing is, this share is growing.

With this background, present study discusses the urban transportation system and its energy-environment implications for two mega cities in India, viz., Delhi and Mumbai. In addition, this study carries out an analyses on the travel demand, energy demand and emissions from the transport system for this two cities for the period 1997(1998 for Mumbai)-2020. Also, it examines the implications of a range of economic growth scenarios on travel demand, energy demand and emissions. BAU Scenario considers respectively 5.6% and 6.6% annual growth rate of GDP for Delhi and Mumbai, for the entire period of analysis. Four Alternative Scenarios are constructed based on different GDP growth rates. While, Alternate Scenario 1 and 2, consider respectively 50% and 25% higher annual GDP growth rates as compared to BAU Scenario, Alternate Scenario 3 and 4 considers annual GDP growth rates respectively 50% and 25% lower than BAU Scenario. Major findings are discussed in the following sections.

BAU Scenario

Travel demand

Population growth and growing economic activities contribute to many-fold increase in travel demand in both cities and consequently, growth of vehicles stock. Per capita travel demand is expected to grow from 17 km in 1997 to 31 km. in 2020 in Delhi and from 8.2 km in 1998 to 26 km in Mumbai. Despite assumptions on implementation of MRTS with carrying capacity of 6.4 million passengers by 2015, about 8.85 million of vehicles are expected to roll down on Delhi roads in 2020. The figure is 2.5 million for Mumbai which is about 5 times higher than the existing figure. Significant growth in personalized transport (car and 2-wheeler) is expected. Due to growing income, ownership of these two vehicles may double by 2020 in both cities. Share of motorized travel demand met by personalized mode of transport is expected to increase in Delhi from about 40% in 1997 to 45% in 2020. Share of bus in total travel demand, on the other hand, will decline from 53% to 48%. In Mumbai, however, bus continues to be the dominant mode of passenger transport.

Energy demand

There would be a significant growth in transport energy demand. However, in Delhi, assumptions on MRTS, curbs the energy demand for motorized transport at some extent. It grows by 2.3 times during 1997-2020, from 50.6 million GJ to 137 million GJ. In Mumbai, during the same period, a 3 fold increase is expected, from 20 million GJ to 60 million GJ. Annual growth rates are worked out to be 4.4% and 5.1% respectively for Delhi and Mumbai, as against assumed economic growth rates of 5.6% and 6.6% respectively.

In both cities, energy intensity for passenger transport falls over the years due to penetration of more energy efficient CNG and battery operated vehicles. However, energy intensity for freight transport, increases during the same period, due to increase in share of LCV in total freight transport which is relatively energy inefficient. Passenger transport dominates the energy demand. However, its share falls from 84% in 1997 to 81% in 2020 in Delhi and from 94% in 1998 to 92% in 2020 in Mumbai.

As far as individual fuel is concerned, natural gas demand of about 1 billion cubic meters in both the cities suggests the need for an elaborate CNG supply network. Replacement of diesel driven passenger vehicles like buses, taxis etc. by CNG driven vehicles, wills lead to a fall in demand for diesel. In the latter period only good vehicles will increase demand for diesel. Because of higher share of personalized model of transport, growth in gasoline demand is 2.35 times the present consumption in Delhi .

Emissions

Despite a moderate economic and population growth, fuel substitution, supply of clean fuel, implementation of strict emissions norms, and MRTS, would help Delhi to reduce the pollution load (local) from 412,000 thousand tonnes to 328,000 tonnes in 2020, about 20% decrease. Use of low lead gasoline reduces the lead emissions drastically. Similarly, use of low sulfur diesel, stricter emission norms and substitution of diesel in passenger transport, reduces the sulfur emissions from 4,600 tonnes to 2,700 tonnes in 2015, however, it increases marginally in 2020, due to growth in freight travel demand. Stricter emission norms and introduction of CNG driven bus, reduce NO_x emissions as well. Cars and 2-wheelers together contribute about 80% of HC emissions in Delhi. 2-wheelers alone contribute about 70% of total CO emissions. Therefore, in Delhi, there is further scope of reduction in CO and HC by reducing use of personalized transport. Phasing out of diesel driven bus system would limit the growth in particulate emissions.

Situation is relatively better in Mumbai. Implementation of strict emissions norms and introduction of clean fuel and fuel substitution along with heavy dependence on public transport, would help Mumbai to remain relatively clean. Pollution load declines by about 40%, from 135,000 tonnes in 1998 to 84,000 tonne in 2020. CO and HC continue to be the main pollutants, emitted by mainly the gasoline driven vehicles. Particulates, SO_x and NO_x emissions go down considerably during 1998-2020 because of lesser use of diesel driven vehicles, low sulphur diesel and stricter emissions norm.

Alternate Scenarios

Travel demand

In Alternate Scenario 1, as expected, an explosion in vehicle stock is going to take place in both the cities due to high economic growth. While in Delhi, there is 10-fold increase in vehicle stocks during 1997-2020, in Mumbai, it goes up by 14 times from the present level. In Delhi, while annual growth rate in vehicle stock was 5.8% in BAU Scenario, in this scenario, it would be about 10.4% per annum. This figure is even higher in Mumbai at 12.8%, as against 7.7% in BAU Scenario.

In Alternate Scenario 2, total number of vehicles in 2020 is projected as 14.7 million in Delhi, as compared to 8.85 million in BAU Scenario. Vehicles stocks in Mumbai in 2020 increases by about 8.7 times from 1998 level, as against 5 times increase in BAU scenario.

Alternate Scenario 3, which assumes a pessimistic economic growth rate, total vehicle stocks in Delhi, declines from 2.38 million in 1997, to 1.54 million in 2020. Overall, number of vehicles fall by about 0.8 million during 1997-2020. In Alternate Scenario 4, vehicle stocks grow gradually from 2.38 million to 4.5 million in 2020. In Alternate Scenario 3 and 4, only 1.4 and 2.8 fold increase in vehicle stock is expected in Mumbai, during the same period.

In both the cities, similar vehicular mix as in BAU Scenario is observed in all alternate scenarios. Personalized mode of transport dominates heavily the total vehicle stock. As expected, due to higher economic growth, there is many fold increase in ownership of vehicles in both the cities, in first two alternative scenarios. In Alternate Scenario 3 and 4, lower economic growth limits the ownership in personalized vehicles. Number of 2-wheelers per 1000 persons declines from existing 134 to 21 in 2015, however, it grows to 43 in 2020. Due to same reason, number of cars per 1000 persons drops from 58 to 9 in 2015 and then increases to 18 in 2020. In Mumbai, in Alt Scenario 3, while car per 1000 persons remains same of 14 as in 1998, number of 2-wheelers per 1000 persons would grow marginally from 22 in 1998 to 27 in 2020. In Alternate Scenario 4, 2-wheeler and car per 1000 persons increases from 14 and 22 to 26 and 58 respectively in 1998-2020.

Higher Economic growth rates in Alternate Scenario 1 and 2 lead to about 8 and 5 times increase in passenger travel demand between 1998 and 2020 in Delhi. Demand for freight also showed the similar growth. Per capita per day travel need increases heavily from 17.5 km in 1998 to about 75 km and 47 km in 2020 in respective two scenarios. Low economic growth and implementation of MRTS, pull down the demand for motorized transport in Alternate Scenario 3 from 73 billion pkms in 1997 to 37 billion pkms in 2020 in Delhi. Per capita per day transportation requirement falls drastically from 17.5 km in 1998 to about 3 km in 2015. Demand for freight falls gradually from 2.6 billion tkms to 2.0 billion tkms in 2015, however, it increases to 2.3 billion tkms afterwards. In Alternate Scenario 4, on the whole, passenger travel demand increases from 73 billion pkms in 1998 to 112 billion pkms in 2020. Per capita per day travel need declines from 17.5 km to about 14 km in 2020.

In Mumbai, about 10-fold increase in passenger travel demand is expected in Alternate Scenario 1. Similar trend is observed in Alternate Scenario 2. Low economic growth in Alternate Scenario 3, contribute a very low growth in travel demand for both types. Travel demand of both types just become double over 22 years time period of 1998-2020, in Alternate Scenario 4. In the Alternate Scenario 1 and 2, both types of travel demand showed higher annual rate of growth during 1998-2020 than assumed annual GDP growth rate. Per capita per day passenger travel demand increases by almost 8 times and 5 times respectively between 1998 and 2020 in Alternate Scenario 1 and 2. However during the same time period, it declines from 8.16 km to 7.68 km in Alt Scenario 3. In Alternate Scenario 4, it almost doubles.

Energy demand

In Delhi, in Alternate Scenario 1, which assumes 50% higher annual GDP growth rate, than BAU Scenario, during 1997-2020, transport system demand about 2.6 times more energy in 2020 than the same in BAU Scenario. In Alternate Scenario 2, this figure is 1.65 times more than BAU Scenario. Estimated annual growth rates in energy demand during 1997-2020, in these two scenarios are respectively, 8.9% and 6.8%. In Alternate Scenario 3, which assumes a pessimistic situation, where annual GDP growth is only 50% of that in

BAU Scenario, during the entire time horizon, in 2020, urban transport system in Delhi demand only 20% of energy that its demand in BAU Scenario. This is about 50% of the energy consumption in 1997. In Alternate Scenario 4, model estimates the energy demand for 2020 as 71 million GJ, as against 50 million GJ in 1997.

In Mumbai, in Alternate Scenario 1, energy demand is expected to grow annually at a rate of 9.7% per annum during 1998-2020, for assumed GDP growth rate of 9.9% during the same period. Energy demand in 2020, in absolute terms, is about 2.5 times higher than the same in BAU Scenario. In Alternate Scenario 2, annual GDP growth rate of 8.25% during 1998-2020, will lead to 7.4% annual growth rate in energy demand. In Alternate Scenario 3, urban transport system would demand about 18 million GJ which is 87% of energy that is actually consumed in 1998. In Alternate Scenario 4, energy demand shows annual growth rate of 2.5% during 1998-2020, as against assumed GDP growth rate of 4.95%.

Similar to the BAU Scenario, passenger travel dominates the total energy need in both Delhi and Mumbai. Also, demand pattern by vehicle mode is same as in BAU Scenario.

Emissions

In Delhi, total pollution load in Alternate Scenario 1 doubles in 2020 from the present level of 412,000 tonne. Therefore, in terms of pollution, this economic growth scenario is unsustainable unless some even stricter abatement rules and measures are adopted. In Alternate Scenario 2, initially pollution load declines to 344,000 tonne in 2010 and then increases again to 542,000 tonne in 2020. Alternate Scenario 3, which is a pessimistic one, in terms of economic growth, pollution declines to 66,000 tonne from the existing level of 412,000 tonnne in 1997. Pollution load in Alternate Scenario 4, declines to 150,000 tonne in 2015 from 412,000 tonne in 1997, and then increases to 167,000 tonne in 2020.

In Alternate Scenario 1, pollution level in Mumbai, grows by 66% in 2020, from the present level. It is almost three times than the pollution load of about 84,000 tonne in 2020 in BAU Scenario. Pollution load in Alternate Scenario 2 declines initially and reaches to 86,000 tonne in 2010, however, it increases after that and reaches the almost existing level again in 2020. In Alternate Scenario 3, it goes down abnormally to 23,000 tonne in 2020, from the present level of 136,000 tonne, because of low transportation activities. In Alternate Scenario 4, also, pollution load declines drastically over the time horizon of the analysis.

As far as individual pollutants are concerned, in Alternate Scenario 1 and 2, CO_2 emissions in Delhi, increase significantly from 3620 thousand tonne in 1997 to 24,200 thousand tonne and 15,400 thousand tonne in 2020 respectively. In Mumbai, these figures are 9,960 thousand tonne and 6,500 thousand tonne respectively in 2020 as compared to 1,500 thousand tonne in 1998. In Alternate Scenario 3, GDP growth rate of 2.8% per annum will cut down the emissions in 2020 almost by 50% from 1997 level in Delhi. In

Mumbai, it is reduced by about 23% from the existing level. CO_2 emissions in 2020 will increase by 36% and 53% respectively from the existing level in Delhi and Mumbai in Alternate Scenario 4. All other pollutants also show the similar trend.

Passenger transport is responsible for the bulk of the CO_2, CO, HC and lead emissions. In fact, entire lead is emitted by it. Its contribution of NO_x, SO_x and particulate decreases over the years.

Conclusions

In the above analysis we have made a number of assumptions. The analysis assumes a declining emissions factor due to stricter emissions norms and supply of cleaner fuel. Also it assumes MRTS of capacity 3.4 million passengers by 2005 in Delhi and doubling its capacity by 2015. Also it assumes the policy of replacement of diesel bus system by CNG and introduction of electricity driven intermediate mode of transport. Therefore, unless the following measures are implemented, emission levels will go up many fold over the estimated one.

- Implementation of strict emission norms is extremely necessary.
- Supply of clean fuel (low lead gasoline, low sulphur) should be made mandatory.
- Implementation of MRTS in Delhi
- Supply of CNG should be ensured.
- Large scale CNG driven and battery operated vehicle manufacturing capacity.

From the scenario analysis, the study concludes that in terms of pollution, high economic growth scenarios are unsustainable unless some even stricter abatement rules and measures than that assumed in BAU Scenario are adopted.

Section II

Energy Efficiency Improvement of Urban Transport System and Mitigation of GHGs and other harmful emissions

1. OBJECTIVE

Energy efficiency improvement of urban transport system and mitigation of GHG and other harmful emissions

Objective of this study is to analyse the most suitable technological and management options available for transportation system in Delhi and Mumbai. These options have been anaylsed for their potential to reduce pollution generation from urban transportation as well as their economic feasibility by finding out unit pollution abatement cost for each of those options.

2. OPTIONS FOR MITIGATION OF EMISSIONS

2.1 Introduction

In this chapter are analysed various technological and management options available for the improvement of urban transport sector in Delhi and Mumbai. There are a number of options to migigate environmental emissions as also less energy intensive options. However, the options are case and locational specific. Their performance and effectiveness depends on various conditions. Hence, in the process of identifying potential options to improve transport systems in Delhi and Mumbai, various methods proven elsewhere have been analysed. Based on the analysis, a few potential options are selected for further analysis and assessment.

2.2 Review of the Available Options

Following are the different alternative options available to improve the urban transport system. These options have a proven history of performance in different countries and cities. In the present study they are considered for the cases of Delhi and Mumbai and their potential both technologically and economically are tested. Further, their adaptability is also examined.

In broad sense the alternative transportation options can be classified into two categories. One is alternative fuels and the other is alternative and advanced technologies and management practices. Following are the different individual candidates in each of those categories.

⇒ Alternative Fuels

- Compressed Natural Gas (CNG) for cars/buses/3-wheelers/2-wheelers
- Electric and battery for three wheelers/mini buses/cars
- Electricity for MRTS/trolley buses etc.

- Duel Fueled (hybrid)
- Fuel cells for cars
- Ethanol/Methanol for cars
- Bio-fuel (bio-diesel)
- LPG for cars/buses
- Fuel quality improvements (unleaded/low sulfur)

⇒ Technology and other options

- Four stroke-two wheelers in place of two-stroke two wheelers
- Control devices like Magnetizers, Catalytic Converters etc.
- Inspection and Maintenance
- Increased share of public transport
- Efficient vehicles (as in developed countries)
- CVID (computer variable ignition device for cars)

All these options cover only the supply side management; whereas the urban transportation improvement programmes should be integration of both demand and supply side management. In this work we consider only the supply side management which ultimately can be integrated with demand side management to achieve sustainable urban transportation system.

Adoption of cleaner fuels is an increasing pursuit of urban transport all around the globe. Compressed natural gas leads the list of cleaner fuels. This has been used as fuel in almost all modes of transport. CNG vehicles have been manufactured, though retrofitting is the most commonly adopted practice. LPG is another alternative fuel used and it has some limitations on its use due to space required as also security considerations. Hybrid fuelled engines are a common sight with different mixtures of gasoline and ethanol. Gasoline (95%) and Ethanol (5%) mix can be applied to the existing gasoline driven vehicles without any further modifications. Use of methanol as a fuel in transportation has its limitations due to its adverse effect on environment. Methanol results in increased methane emission to the atmosphere, which adds to the green house gas problem.

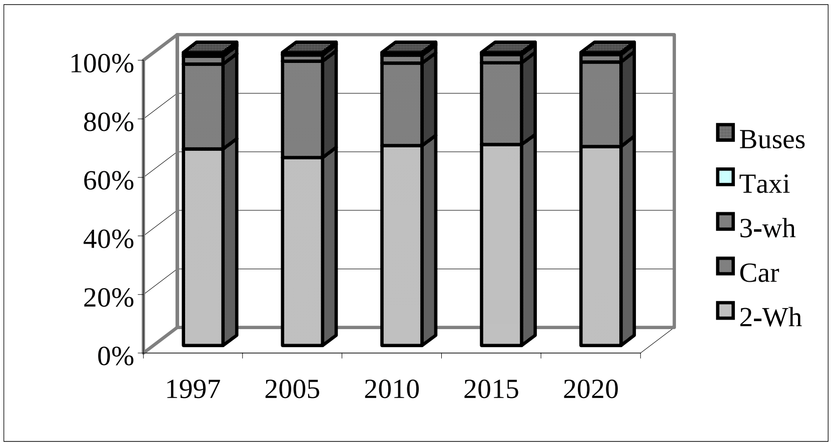
Fuel quality improvement is another potential and possible option to mitigate pollution. Unleaded gasoline and low sulfur gasoline are the potential options for controlling lead emissions and SO_2 emissions from transport sector. In India unleaded petrol programme was started in June 1994 and by April 2000 the entire country went in for unleaded petrol. Similarly reducing sulfur content in diesel was also started in April 1996. By April 1999 the sulfur content in diesel in entire country was brought down from 0.5% to 0.25% (CPCB, 1999).

Electric vehicles are a new rising mode in transportation. Toyota and Honda of Japan have produced electric vehicles. But it takes a while to get this advancement to developing countries like India. Fuel cell technology is still under research and development stage and its adaptability in less developed countries needs to be tested thoroughly.

Among the technological and management alternatives for urban transport, converting 2-stroke two wheelers to 4-stroke two wheelers is an important and potential option. It has a proven record and also under implementation in Indian cities like Delhi and Mumbai but with lower intensity. Pollution control devices like catalytic converters and magnetizers are proved effective but can not offer a solution alone. But it is very effective option in case of old vehicles with very poor fuel conversion efficiency still running on roads. Improved and regular operation and maintenance also can improve the energy efficiency and pollution generation. Increased share of public transport also can provide an effective check on pollution from urban transpiration.

2.3 Selection of Options

Delhi and Mumbai present two very different transport systems. In Delhi transportation network is predominantly road based. The city has a ring railway. But its role is minimal in meeting travel demand. Delhi has a ring road, which is a major facilitator for the traffic to move in different directions. However, with the rapid increase in the vehicles and traffic levels, all the major traffic junctions along the ring road are congested that pose traffic problems. Personal vehicle stock has been dominating due to the fact that Delhi has a better road network and per capita road area and also due to the absence of MRTS. Figure 2.1 shows the share of different modes in Delhi. As is evident from in figure, 2-wheelers dominate the road followed by cars. And the same trend is expected to continue for next 20 years.



Source: Work done by IGIDR

Figure 2.1: Share of various transport modes in Delhi

Measures have been taken to control the rapid growth in personalized vehicles so as to improve the traffic conditions. Since 1970, an integrated Mass Rapid Transport System (MRTS) with a proposed length of 144 km surface rail corridor, which would utilize the existing railway corridors in Delhi, and an under ground /elevated metro rail system of 41 km consist of two corridors the East-West (24 km) and the North-South (17 km) is under consideration. Recently, Phase I of the project consisting of 2 surface corridors for a total length of 44.3 km and one under ground corridor for a length of 11 km has been cleared for implementation. The first section of the project which covers a distance of 8 km is expected to be commissioned by 2002 and the whole project by March 2005. This has been considered in the energy demand and emission estimates, which carried out in the issue #1.

As the Delhi traffic is dominated by cars and buses, it would be logical to consider buses and cars running on cleaner fuels and also shifting 2-stroke two wheelers to 4-stroke two wheelers. Introducing MRTS need not be considered to be a candidate as this has already been incorporated in the base scenario. Hence the following options have been considered for the case of Delhi to improve the transportation and to control pollution.

Alternative option 1: Buses run on Compressed Natural Gas (CNG)

Alternative option 2: Cars run on Compressed Natural Gas (CNG)

Alternative option 3: Replacement of 2-stroke 2 – Wheelers by 4-stroke 2 – Wheelers

Alternative option 4: BOV – Cars

Unlike Delhi, Mumbai presents a different case of transport system dominated by public and mass transport systems. In Mumbai local rail network and buses cater for the major share of travel demand. In transport terms, Mumbai has become a victim of its own success. Fourfold growth of population since 1951 has been largely accommodated in the suburbs, while the highest concentration of jobs has remained on the Island City. Moreover, the physical characteristics of the city are such that the suburbs have been constrained to spread northwards only, and all transport facilities are concentrated within three narrow corridors. This has put tremendous stress on all modes operating in these corridors.

The urban transport in Mumbai is based on suburban railway services provided by the Western and Central Railways, Buses, taxis, three-wheelers, and personalized vehicles. Public transport accounts for more than 80% of the journeys or trips with the rail system and buses having almost equal share between them selves. However, in terms of passenger kms, railways carries nearly four times traffic carried by the buses because of longer average lead.

Suburban rail network, which has served the needs of the metro well and is also ably, supported by an efficient bus service under BEST Undertaking. Suburban rail services operating along a network of some 300 km of electrified broad gauge provided by two zones of the Indian Railways transporting about 5.2 million suburban passengers per day through some 2000 daily electric motive unit (EMU) services. In spite of these successful and efficient services, the problem of transport is one of ever increasing complexities in Mumbai due to the rapid population growth and also migration. Hence, the problems are expected to be even more acute in the commercial capital of India with the city's population estimated at around 22 million by the end of the decade and other mega trends in the growth of passenger and traffic within and outside its horizons.

Mumbai roads are dominated by cars and 2-wheelers followed by 3-wheelers. Figure 2.2 shows the distribution of various travel modes and their share on Mumbai roads. In the time horizon under consideration, 2-wheeler are expected to become more dominating. Three wheelers continue to contribute a major share.

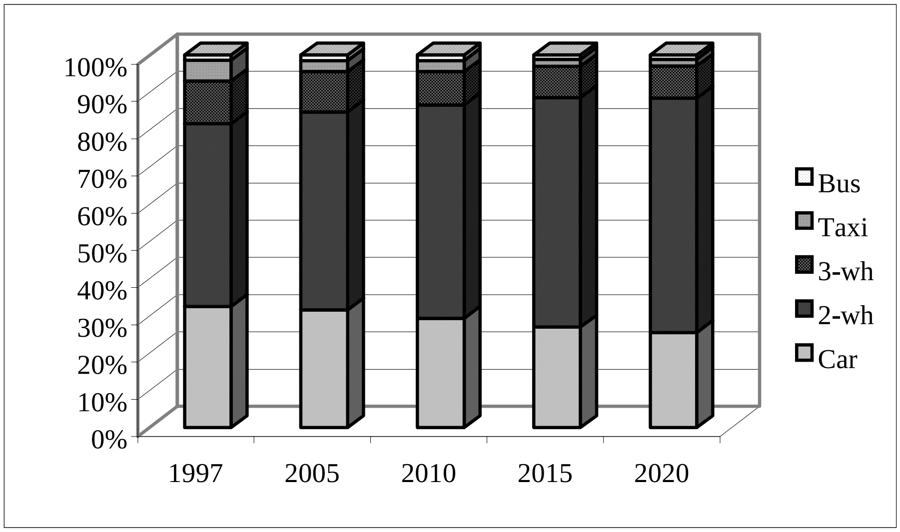


Figure 2.2: Share of various transport modes in Mumbai
Source: Work done by IGIDR

As the MRTS and public transport is dominant in Mumbai, use of cleaner fuels in buses would provide a good alternative for pollution reduction. Conversion of 2-stroke 2-wheelers to 4-stroke 2-wheelers would also be a good choice to be considered. As the cars do have a major share, use of cleaner fuels would solve the pollution problem to a greater extent. Unlike in Delhi, Mumbai has dominating role of 3-wheelers on roads. Three wheelers are proved to be more pollution. They contribute 15% of $C0_2$, 37% of CO, 56% HC, 24% of TSP and 41% of Pb pollution in Mumbai. Therefore they play a major role in Mumbai air pollution. Using cleaner fuels like CNG and electricity (BOV) would result in considerable reduction in pollution. Thus the following alternatives are selected for analysis in the case of Mumbai:

Alternative option 1: Buses run on Compressed Natural Gas (CNG)

Alternative option 2: Cars run on Compressed Natural Gas (CNG)

Alternative option 3: Replacement of 2-stroke 2 – Wheelers by 4-stroke 2 – Wheelers

Alternative option 4: 3 – Wheelers running on Compressed Natural Gas (CNG)

Alternative option 5: BOV – 3 - Wheelers

2.4 Conclusions

Considering the existing traffic conditions and also the characteristics of the travel modes and the pollution generation both for the cases of Delhi and Mumbai different alternative options were selected for analysis. For Delhi where 2-wheelers, cars and buses dominate the traffic 4 options namely use of CNG for buses, use of CNG for cars, conversion of 2-stroke 2-wheelers to 4-stroke 2-wheelers and BOV buses.

In the case of Mumbai where, there is more fleet of buses and 3-wheelers and also dominant share of cars, 5 alternative options namely: use of CNG for buses, use of CNG for cars, converting 2-stroke 2-wheelers to 4-stroke 2-wheelers, use of CNG in 3-wheelers and BOV three wheelers.

3. DATA AND ASSUMPTIONS

3.1 Data Input

This study involves very wide data survey and references to published and research work. This chapter explains different data inputs at different stages of this work.

In the first phase of the work, emissions of various existing and alternative technologies were determined and the following data inputs were required.

- Energy efficiency by different vehicle type/technology
- Emission factors of various pollutants for different vehicle types/technologies
- Utilization of the vehicles

Table 3.1: Energy efficiency by vehicle type/technology

Technology		Fuel	MJ/pkm or tkm
2-wheeler	2 stroke	gasoline	0.54052
2-wheeler	4 stroke	gasoline	0.369549
2-wheeler	4 stroke/CC	gasoline	0.369549
3-wheeler	2 stroke	Gasoline	1.003855
Car(pre 84 model)		Gasoline	1.425809
Car (post 84 model)		Gasoline	0.948245
Car	CC	Gasoline	0.908311
Car		Diesel	1.605569
Taxi		Gasoline	2.433866
Taxi		Diesel	2.740717
Bus		Diesel	0.312199
3-wheeler	CC	CNG	0.682091
Car		CNG	0.644446
Taxi		CNG	1.654397
Bus		CNG	0.301978
3-wheeler		Electricity	0.203978
Car		Electricity	0.214556
Bus		Electricity	0.075452
LCV		Diesel	9.681948
HCV		Diesel	2.0354

CC: Catalytic Converter, Source: (Bose, 1998)

- Load factors for different vehicles in both Delhi and Mumbai
- Travel demand in PKM both for Delhi and Mumbai

- Capital costs of various vehicles both of existing and alternative technologies
- Fuel costs of various vehicles both of existing and alternative technologies
- Operation and Maintenance costs of different vehicles of different technologies
- Various other costs involved in vehicle operation
- Discount rate
- Life of vehicles of different technologies

And so on.

3.1 Assumptions

As the present study requires a lot of data on different technologies, that are hard to obtain, assumptions were made whenever required. All the cost parameters were considered at the base year 1997. When data were not available for the base year it was adjusted to the base year using standard indicators.

Other assumptions are made specific to a situation and are given at the respective places when and where they are made..

4. ASSESSMENT OF EMISSIONS MITIGATION POTENTIAL

4.1 Introduction

In this section has been assessed the potential of the above listed options to mitigate environmental emissions viz. CO2, CO, SOx, NOx, HC, TSP, Pb from transport sector. Methodology adopted has been developed by AIT in consultation with other national institutes from participating countries. For any alternative option to be successful in replacing the existing one it needs to demonstrate the potential to mitigate some of the above pollutants if not all.

From the estimated travel demands in the issue #1, emission of different pollutants in the existing technology and also the alternative technologies have been calculated using various emission factor which are shown in Table 4.1. And also this section provides the Emission Reduction Potential (ERP) for all the options under consideration for both cities of Delhi and Mumbai.

4.2 Emission factors of the selected alternative options

Apart from the existing technologies, cleaner fuels such as CNG and BOV were considered as well as efficient technologies like conversion of 2-stroke 2-wheelers to 4-stroke 2-wheelers were used in the present study. Emission factors employed in the calculation of the total emission of different pollutant from different alternative technologies are given in Table 4.1. All emission factors were taken as gram of pollutant per liter of fuel used. Battery operated vehicles are reported to be pollution free and so all emission factors have been taken as zero for BOV vehicles.

4.3 Methodology

Emission of pollutants (CO, NO_x, SO_x, TSP, HC and CO_2) from each of the above options has been estimated using the following equation for both Delhi and Mumbai. This methodology has been developed by AIT in consultation with the other national institutes from the participating countries. With the emission of pollutants from the exiting technology being estimated already (in issues # 2) , the emission mitigation potential of the alternative technologies has been calculated as follows.

$$P_{jt} = F_{kt} \times EF_{kjt}$$

Where

P_{kit} = Emissions (tonnes) of type ‘i’ from vehicle type ‘k’ in the year ‘t’

F_{kt} = Fuel demand by vehicle type ‘k’ in the year ‘t’

EF_{kit} = Emission factor (gm/l) of pollutant type ‘i’ from vehicle type ‘k’ in the year ‘t’

Table 4.1: Emission factor for different technologies

Alternative option	Fuel	Emission factors (gm/l) based on IIP survey data						
		CO_2	CO	SO_x	NO_x	HC	TSP	Pb
2 – Wheelers								
-- 2-stroke	Gasoline	3070	368.8	2.102	4.44	230.2	22.22	0.15
-- 4-stroke	Gasoline	3070	539.5	2.102	25.35	46.80	5.20	0.15
3 – Wheelers	Gasoline	3070	250.0	2.102	2.04	156.1	10.21	0.15
	Diesel	--	--	8.263	--	2.48	5.32	0
	CNG	4.1	2.24^{-4}	0	2.46^{-3}	0	0	0
	BOV	0	0	0	0	0	0	0
Cars	Gasoline	2480	272.5	2.102	25.46	58.47	3.11	0.15
	Diesel	3140	9.75	8.263	12.40	2.48	5.32	0
	CNG	4.1	2.24^{-4}	0	3.52^{-3}	0	0	0
	BOV	0	0	0	0	0	0	0
Taxi	Gasoline	2310	272.5	2.102	25.46	58.47	3.11	0.15
	Diesel	3140	9.75	8.263	12.40	2.48	5.32	0
	CNG	4.1	2.24^{-4}	0	3.52^{-3}	0	0	0
	BOV	0	0	0	0	0	0	0
Buses	Diesel	3140	41.91	8.263	69.30	6.93	6.60	0
	CNG	4.1	2.24^{-4}	0	3.52^{-3}	0	0	0
	BOV	0	0	0	0	0	0	0
LCV	Diesel	3010	53.9	8.263	93.40	6.60	9.00	0
	CNG	4.1	2.24^{-4}	0	3.52^{-3}	0	0	0
HCV	Diesel	3010	70.49	8.263	116.5	11.66	11.10	0
	CNG	4.1	2.24^{-4}	0	3.52^{-3}	0	0	0

The emissions of different pollutants are estimated in terms of emission per unit of output (tonnes / pkm or tkm) for both the existing and alternative technologies. This potential has been estimated for the base year although the emissions of all alternative option were calculated for all the years. This is so due the fact that few alternative option are expected to come in to effect after some time even in business as usual (BAU) case. Hence it will be appropriate to compare the base case and the alternative option at a different time period. Pollution mitigation potential of different alternatives was calculated for all the listed pollutants.

To assess the potential of the alternative in reducing pollution, pollution mitigation was indexed by quantifying the pollutant emission from new technology over the old one. It is shown in the expression below.

Emission Reduction Potential (ERP) = $$1-\left(\frac{Emission.per.unit.output.from.the.alternative.option}{Emission.per.unit.output.from.the.existing.option}\right)$$

As the value of ERP approaches unity better is the potential. It is possible to get values more that unity in the case when the new technology results in an increase in pollution (it may be an economically viable option). This further can be made a compound index for all pollutants or it can even be developed for compound pollutant loads also. In the present study as different option have different influence over different pollutants, this EMP has been considered in its desecrate nature only. This kind of quantitative approach would facilitate comparison among different potential options. Unit emission of all local pollutants, both for existing and alternative technologies were considered in making a judgement over the alternative options and their selection.

4.4 Data Input and Assumptions

The data requirement includes the travel demand met by different models of transport, energy demands of various transport modes, and pollutant emissions. The emission factors for both existing and the alternative technologies has been collected from Indian Institute of Petroleum (IIP) and was reported in the previous section. Travel demand met by different modes of transport viz. 2-wheelers, 3-wheelers, cars and taxis, buses and LCV & HCV was calculated from the issues # 2 of the same study. The energy demands for the alternative technologies were taken from Bose (1998) which is presented in the earlier section.

While calculating the pollution per the unit output, only the mode of transport involved was considered. For instance, in option “use of CNG for buses” pollution generation per the unit output by buses was found out of different pollutants for both the existing technology and the alternative one. This gives the clear idea of the potential of the option. Incase of considering all the modes the effect may get diluted due to the effect of normalization.

Total Emission of local pollutants per unit out put was considered in selection of options as they provide a clear and significant distinction between the options.

In case of CNG cars, both cars and taxis have been considered together with the utilization factors and the occupancy values being considered after taking the average of both. The difference in emission due to different emission factor was not considered as this would not be very significant with a fact that cars dominate in the number and the utilization, which has less emission factor over taxis. However, the emissions from both cars and taxis have been calculated separately and added together. Hence, it should not make any difference even after considering them together.

4.5 Emission of Pollutants under Different Options

In this section emission of pollutants under different alternative options was calculated and based on the Emission Reduction Potential (ERP) of each option. Both cases of Delhi and Mumbai are considered separately and ERP has been calculated for each option for both the cities.

Delhi

As presented in the earlier section, the following options were considered to reduce environmental emissions in Delhi.

Alternative option 1 (**D1**): Buses run on Compressed Natural Gas (CNG)

Alternative option 2 (**D2**): Cars run on Compressed Natural Gas (CNG)

Alternative option 3 (**D3**): Replacement of 2-stroke 2 – Wheelers by 4-stroke 2 – Wheelers

Alternative option 4 (**D4**): BOV – Cars

Alternative option 5 (**D5**): Increased share of public transport

Alternative option 1: Replacing all gasoline buses by CNG buses

Let the diesel is replaced by CNG for Buses. Table 4.2 - 4.4 gives the emissions of different pollutants with this option both at the base year and also in the entire time horizon under consideration. Table 4.3 presents the percentage change in emission of different pollutants in alternative option 1.

Table 4.2: Emission of various pollutants in alternative option 1

Pollutant	Base scenario ('000 t)					Alternative option 1 ('000 t)				
	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
CO2	3490	5100	6480	7750	10880	3950	5100	6480	7750	10880
CO	173.12	248.63	300.97	381.74	522.81	161.27	248.63	300.97	381.74	522.81
SOx	6.77	4.577	4.789	5.912	7.889	4.42	4.577	4.789	5.912	7.889
NOx	50.02	47.94	61.01	77.33	103.6	31.69	47.94	61.01	77.33	103.6
HC	59.02	49.83	43.89	34.17	46.61	57.05	49.83	43.89	34.17	46.61
TSP	10.04	8.25	8.47	8.62	11.57	8.16	8.25	8.47	8.62	11.57
Pb	0.0773	0.114	0.131	0.16	0.219	0.0773	0.114	131.75	0.16	0.219

Table 4.3: Percentage change in emission of different pollutants in alternative option 1

Pollutant	Percentage reduction in Alternative option 1				
	1997	2005	2010	2015	2020
CO2	-13.181	0	0	0	0
CO	6.84496	0	0	0	
Sox	34.712	0	0	0	0
NOx	36.6453	0	0	0	0
HC	3.33785	0	0	0	0
TSP	18.7251	0	0	0	0
Pb	0	0	0	0	0

By replacing diesel with CNG for buses there is a considerable reduction in local pollution. 35% of the SOx emissions could be reduced with this alternative. The SOx emission has come down from 6.77 ‘000 t to 4.22 ‘000 t. NOx emission was also found to reduce by 37%. And also a considerable reduction in TSP was noticed. Suspended particulate matter emission has come down to 10.04 ‘000 t to 8.18 ‘000 t. There is a slight reduction in CO and HC as well though not very significant due to the fact that gasoline buses are not prominent in the emission of those. Figure 4.1 presents the reduction on graphical mode. Unlike the local pollutants CO_2 showed some increase in emission. This may be due to the fact that CNG is not very energy efficient and so consume more fuel resulting in increased CO_2 emission.

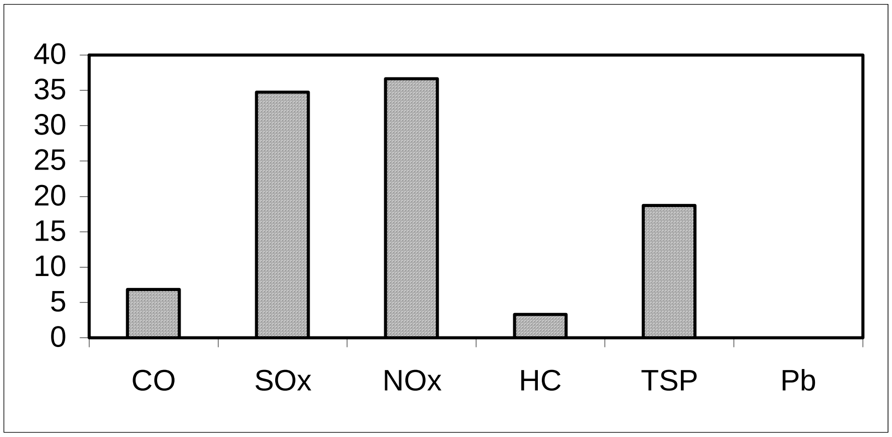


Figure 4.1: Percentage reduction in various pollutant emissions for alternative option 1

Table 4.4 presents the emission reduction per unit output (pkm) of the selected mode of option. As it can be seen from the table, there is a considerable change in emission per every pkm covered. Figure 4.2 presents the reduction in emission per every pkm in the alternative option 1.

Table 4.4: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode in alternative option 1

Pollutant	PKM (1997)	Pollutant/PKM	
		Base case	Alternative option 1
CO2	39.02	23.0464	34.9206
CO	39.02	0.30548	0.00192
SOx	39.02	6E-05	0
NOx	39.02	0.50538	0.03075
HC	39.02	5E-05	0
TSP	39.02	4.8E-05	0
Pb	39.02	0	0

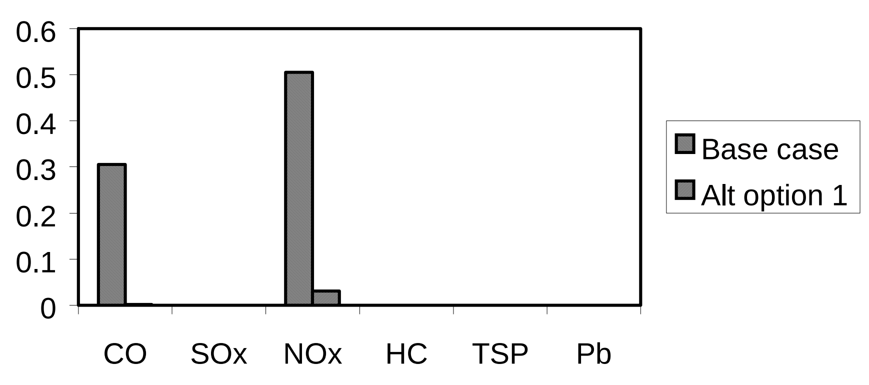


Figure 4.2: Emission of various pollutants per unit output (pkm) for alternative option 1

Replacing diesel buses by CNG buses, the load of NOx, SOx and CO on Delhi atmosphere can be reduced considerably. With the new alternative option the pollution from the mode of transport "Buses" has almost become negligible. This shows the potential of this option in reducing the emission of various local pollutants. The emission reduction potential for different pollutants has been calculated and is presented in Figure 4.3. Converting diesel buses into CNG buses showed complete potential to reduce SOx, TSP, HC, and Pb emission. And also it reached ERP of 0.994 and 0.939 in the case of CO and NOx, respectively. CO_2 showed a negative value, which indicates that there is a rise in emission.

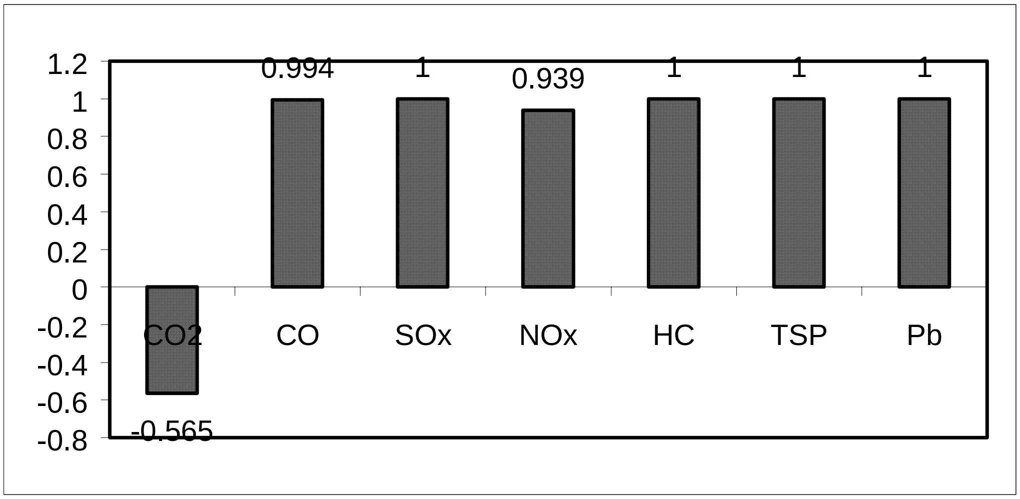


Figure 4.3: Emission Reduction Potential of Alternative Option 1 for different pollutants

Alternative option 2: Replacing all gasoline cars by CNG cars

In this option gasoline and diesel driven cars are replaced by CNG fueled cars. The necessary assumptions considered have been explained in Chapter 3. Table 6 explains the changes achieved in pollution level by replacing gasoline and diesel cars by CNG cars. All other modes remain similar to the base case. As the base case does not have a complete penetration of CNG fueled cars in the time horizon, this alternative shows a significant difference in pollution levels in all years under consideration unlike the alternative option 1 which showed a variation in only the base case.

Table 4.5: Emission of various pollutants in alternative option 2

Pollutant	Base scenario ('000 t)					Alternative option 2 ('000 t)				
	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
CO2	3480	5100	6480	7750	10880	3570	5600	7200	8630	12080
CO	173.12	248.63	300.97	381.74	522.81	101.25	104.65	127.17	167.15	230.25
SOx	6.77	4.577	4.789	5.912	7.889	4.398	2.724	3.41	4.211	5.574
NOx	50.02	47.94	61.01	77.33	103.6	41.44	34.22	45.39	58.07	77.37
HC	59.02	49.83	43.89	34.17	46.61	52.06	37.71	29.16	16.04	22
TSP	10.04	8.25	8.47	8.62	11.57	7.922	5.876	6.147	5.759	7.668
Pb	0.077	0.114	0.131	0.16	0.219	0.0395	0.0339	0.033	0.0388	0.0539

This alternative option provided a significant difference in pollution levels of all kind and in all years of the time horizon. In the base year there is a reduction of CO to the extent of 41%. SOx emission was reduced by 35% compared to the base case. Total suspended particulate matter could be brought down successful by 21%. And another pollutant prominently emitted from gasoline cars, Pb could be reduced by almost 50%. In addition to this, NOx and HC also were brought down by 17% and 11%, respectively. In the year 2010 CO reduction could reach as high as 58% and by 2020 Pb reduction could be 75% and TSP would get reduced by 34%. By the year 2015 HC emission would come down by 53%.

Table 4.6: Percentage change in emission of different pollutants in alternative option 2

Pollutant	Percentage reduction in alternative option 2				
	1997	2005	2010	2015	2020
CO2	-2.2923	-9.8039	-11.111	-11.355	-11.029
CO	41.5146	57.9093	57.7466	56.2137	55.9591
Sox	35.0369	40.485	28.7952	28.772	29.3447
NOx	17.1531	28.6191	25.6024	24.9062	25.3185
HC	11.7926	24.3227	33.5612	53.0582	52.7998
TSP	21.0956	28.7758	27.4262	33.1903	33.7252
Pb	48.5844	70.2632	74.8092	75.75	75.3881

Unlike alternative option 1, this option results in a very marginal rise in CO_2 emission. Figure 4.4 provides the diagrammatic representation of the performance of this alternative option.

This option proved to be very effective in reducing pollution in Delhi might be due the fact that Delhi roads are dominated by personal cars. So using cleaner fuels in Cars would certainly provide a feasible solution to the reduction of air pollution in Delhi. Table 4.7 provided the change in emission of various pollutants per unit out put (pkm) under alternative option 2.

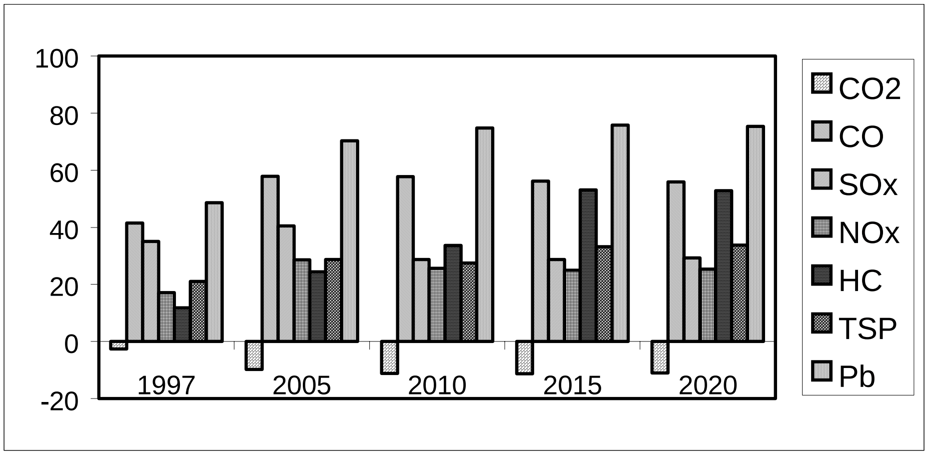


Figure 4.4: Percentage change in emission of different pollutants in alternative option 2

Table 4.7: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode in alternative option 2

Pollution/PKM or TKM	Base case	Alternative option 2
CO2	73.1943	78.0061
CO	3.95927	0.00419
SOx	0.13056	0
NOx	0.54951	0.06697
HC	0.38327	0
TSP	0.11644	0
Pb	0.00224	0

This option provides a promising result in controlling most of the local pollutants. As it can be observed from Table 4.7 and Figure 4.5 using cleaner fuel in cars (CNG) CO emission per PKM has reduced from 3.95 gm to as low as 0.00419 gm. Similar trend was observed with other pollutants and along the time period. Emission reduction potential (ERP) was calculated and presented in Figure 4.6. Use of CNG fuel for cars proved much a superior option to the use of CNG for Buses (alternative option 1) except in the case of reducing NOx. Alternative option 1 showed ERP of 0.939 for NOx where as alternative option 2 showed an ERP of 0.878. Alternative option 2 showed a better performance with respect to CO_2 also.

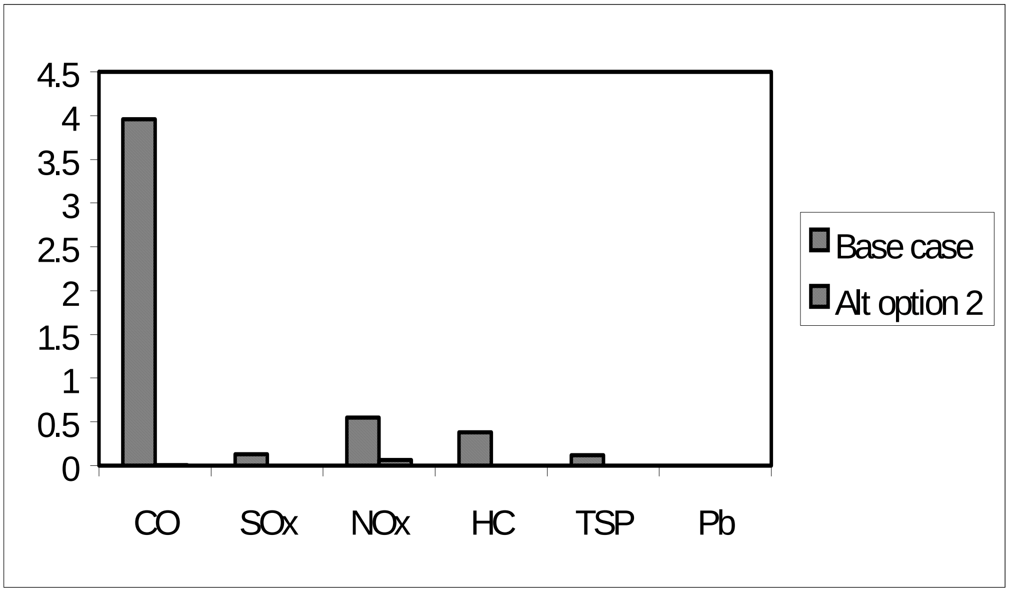


Figure 4.5: Emission of various pollutants per unit out put (pkm) of selected mode of option under alternative option 2

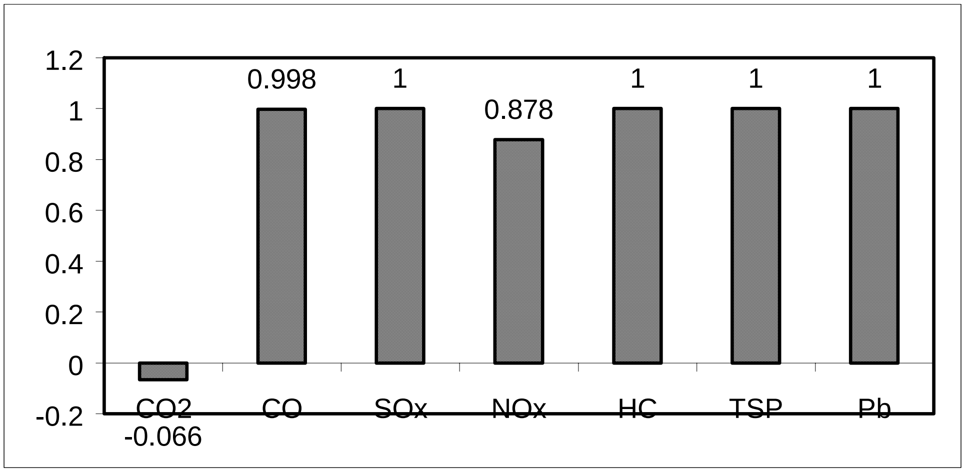


Figure 4.6: Emission Reduction Potential for various pollutants for alternative option 2

Alternative option 3: Replacing all 2 stroke 2-wheelers to 4 stroke 2-wheelers

Alternative option 3 propose to replace all 2-stroke 2-wheelers by 4-stroke 2-wheelers. This option of urban transport was found giving excellent result in reducing emissions and also being adopted in many part of the world. This option is an important option for Delhi with a fact that Delhi vehicular stock was dominated by 2-wheelers and continues to be so for the next 20 years. Table 4.8 presents the difference in emission of various pollutants in alternative option 3.

Table 4.8: Emission of various pollutants in alternative option 3

Pollutant	Base scenario (‘000 t)					Alternative option 3 (‘000 t)				
	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
CO2	3480	5100	6480	7750	10880	3350	5010	6400	7750	10880
CO	173.12	248.63	300.97	381.74	522.81	173.16	248.66	301	381.74	522.81
SOx	6.77	4.577	4.789	5.912	7.889	6.678	4.513	4.733	5.912	7.889
NOx	50.02	47.94	61.01	77.33	103.6	52	49.2	62.12	77.33	103.6
HC	59.02	49.83	43.89	34.17	46.61	31.5	30.51	27.00	34.17	46.61
TSP	10.04	8.25	8.47	8.62	11.57	7.45	6.43	6.88	8.62	11.57
Pb	0.077	0.114	0.131	0.16	0.219	0.0707	0.109	0.128	0.16	0.219

In the base case it was assumed that the technology penetration would be complete by 2015. It implies that even in the business as usual case all the 2-stroke 2-wheelers are expected to be replaced by 4-stroke 2-wheelers. Hence, the change in emission level was zero for the years 2015 and 2020 in this alternative option. In the base year it was observed that this option resulted in reducing emission levels of all pollutants except CO and NOx. Table 4.9 shows the percentage changes of pollution levels by shifting from 2-stroke bikes to 4-stroke bikes. There was a significant fall in emissions of hydrocarbons (HC) and total suspended particulate matter (TSP). This option could result in 47% reduction in HC emissions which quite significant. This option further reduced TSP emission by 26%. And also slight fall in Pb (8%) and SOx (1.35%) emissions was noticed. There was insignificant rise in CO emissions and it accounted for 0.023%. This is due the fact that the CO emission factor for 4-stroke bikes was almost 40% more than that of 2-stroke bike. It may be due to more fuel efficiency. This huge difference in emission factor got nullified to 00.023% rise in emission levels. And further it was noticed that there was a 4% rise in NOx emissions; also due to higher emission factor. The results are shown in Figure 4.7.

Table 4.9: Percentage change in emission of different pollutants in alternative option 3

Pollutant	Percentage reduction in Alternative option 3				
	1997	2005	2010	2015	2020
CO2	4.011	1.76471	1.23457	0	0
CO	-0.0231	-0.0121	-0.010	0	0
Sox	1.35894	1.3983	1.1693	0	0
NOx	-3.9584	-2.6283	-1.8194	0	0
HC	46.6283	38.7718	37.0016	0	0
TSP	25.7968	22.0606	18.0638	0	0
Pb	8.18182	4.38596	2.29008	0	0

Unlike the earlier two options, replacing 2-stroke bikes by 4-stroke bikes resulted in reduced CO_2 emissions also. CO_2 emission was brought down by 4% by using 4-stroke bikes in comparison to 2-stroke bikes. This improved performance also can be attributed to the improved efficiency of 4-stroke engines as the emission factors are quite close to each other.

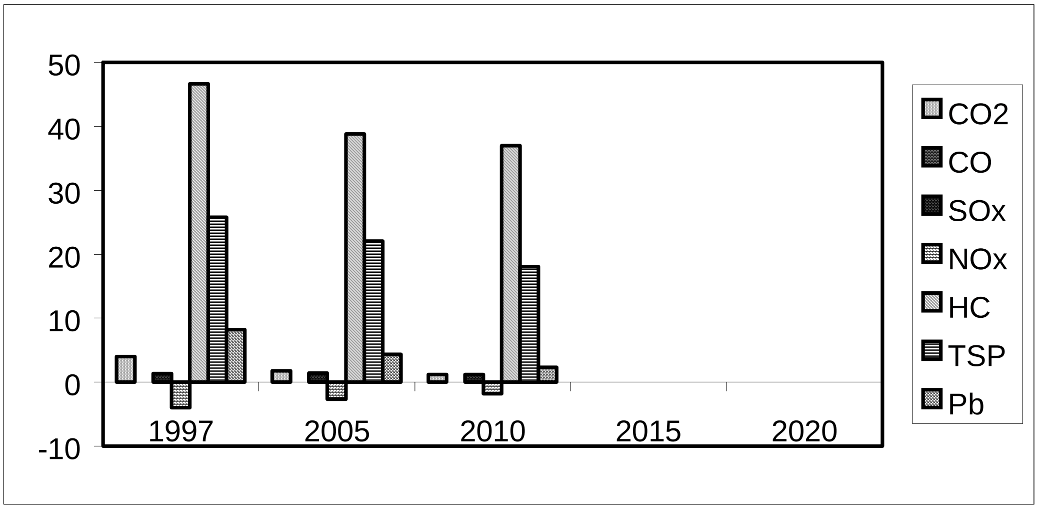


Figure 4.7: Percentage change in emission of different pollutants for alternative option 3

Table 4.10 presents the emissions of various pollutants per unit output of the transportation. It can be observed that unlike the earlier two options, the change of magnitude is apparent in all pollutants. Except for the case of CO and NOx all other pollutants were showing a downward trend with this improved option of transportation making it a potential alternative for transportation in Delhi. As it can be seen from Figure 4.8, there is a significant performance of this option in reducing most of the pollutant emissions.

Table 4.10: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode for alternative option 3

Pollution/PKM or TKM	Base case	Alternative option 3
CO2	37.7032	25.8339
CO	4.5318	4.53534
SOx	0.02579	0.01767
NOx	0.05451	0.21281
HC	2.82509	0.39399
TSP	0.27261	0.04373
Pb	0.00184	0.00126

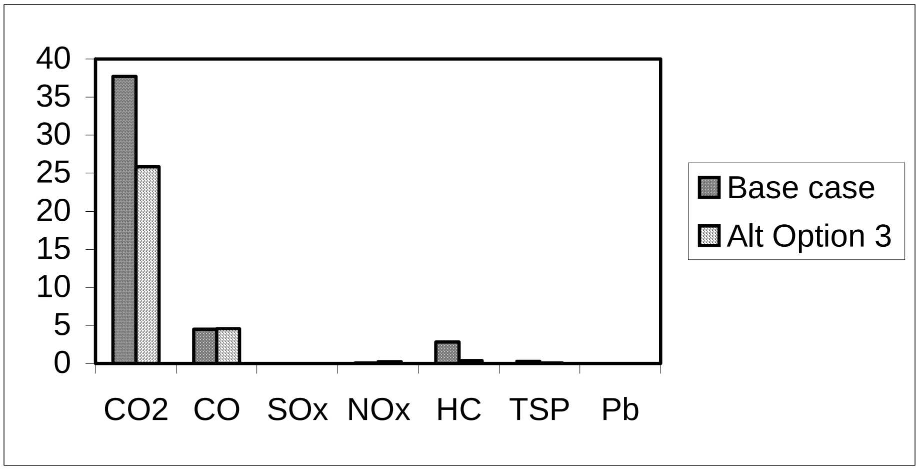


Figure 4.8: Emissions per unit out put (pkm) in alternative option 3

Figure 4.9 presents the emission reduction potential of alternative option 3 for various pollutants. As it can be seen from the diagram, it is a mixer of performances varying from 0.313 on improvement side to 2.904 on worsening side. From the figure below it is very clear that replacing 2-stroke bikes by 4-stroke bike results in reduced local pollutants. It further reduces the CO_2 emission but contribute to NOx emission.

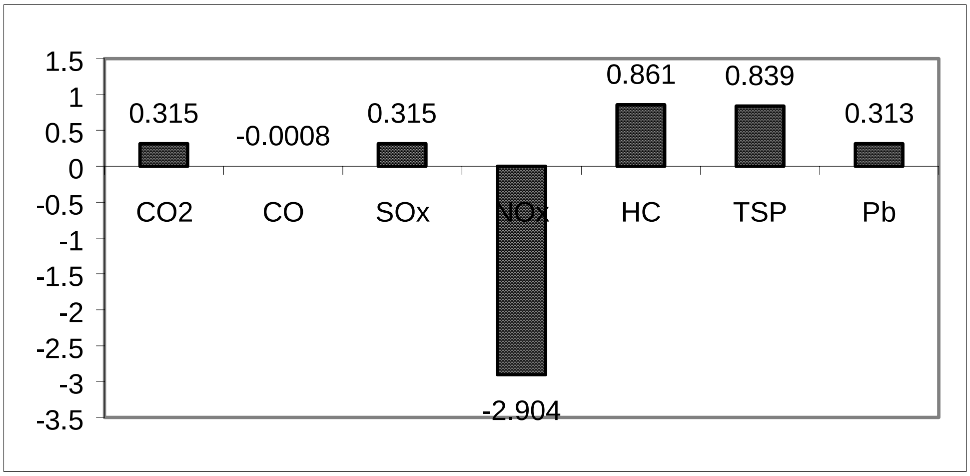


Figure 4.9: Emission reduction potential of alternative option 3 for different pollutants

Alternative option 4: Replacing all diesel buses by BOV buses

This is an environmental rich option with almost zero pollution expected out of it. Though it has limitations of battery size and the distance to be covered and has severe limitations for long distance travel, this can be a feasible option for city and suburban bus services. With this point of view in mind this option has been tested for its feasibility to achieve sustainable transport. In this option it was assumed that all buses running on diesel would be replaced by battery operated buses (BOV). Table 4.11 demonstrates the potential of this option in cutting the overall emissions of different pollutants in Delhi. As in the alternative option 2 (CNG cars) this option also shows a variation in emission reduction throughout the time period. This is due to the fact that in the base case technology penetration BOV bus does not have a share. This option of converting diesel buses to battery operated buses resulted in significant emission reduction.

As it can be seen from the Table 4.11 and 4.12, there is a considerable reduction in overall emission if CO_2, SOx and NOx. Carbon dioxide emission could be brought down by 25% in the base year and up to 37% in 2010. It shows the potential for mitigating GHG emissions from the transport sector. Unlike the earlier three alternatives options this option exhibits a perfect potential for global pollutants control. BOV buses in place of diesel buses could curb the SOx pollution in Delhi by 35%. This trend could not be observed in the other time periods because in the base scenario it was assumed that CNG buses would replace the diesel buses by the year 2005. Hence the emission reduction was not very significant as CNG buses are also less polluting.

Table 4.11: Emission of various pollutants in alternative option 4

Pollutant	Base scenario ('000 t)					Alternative option 4 ('000 t)				
	1997	2005	2010	2015	2020	1997	2005	2010	2015	2020
CO2	3480	5100	6480	7750	10880	2587	3347	4097	5253	7337
CO	173.12	248.63	300.97	381.74	522.81	161.2	248.5	300.84	381.6	522.6
SOx	6.77	4.577	4.789	5.912	7.889	4.42	4.58	4.789	5.912	7.889
NOx	50.02	47.94	61.01	77.33	103.6	30.49	46.44	58.96	75.19	100.56
HC	59.02	49.83	43.89	34.17	46.61	57.05	49.83	43.89	34.17	46.61
TSP	10.04	8.25	8.47	8.62	11.57	8.16	8.25	8.47	8.62	11.57
Pb	0.077	0.114	0.131	0.16	0.219	0.077	0.114	0.131	0.16	0.219

Replacing existing buses by BOV could result in 7% reduction in overall CO emissions in Delhi. Due to the possible technology penetration in the base case itself the emission reduction for the years other than the base year was not very significant. However, to assess the potential of the alternative option to control the pollution the emission reduction during the base year itself can be used effectively.

Table 4.12: Percentage change in emission of different pollutants in alternative option 4

Pollutant	Percentage reduction in Alternative option 4				
	1997	2005	2010	2015	2020
CO2	25.8739	34.3725	36.7747	32.2194	32.5643
CO	6.8854	0.05229	0.04319	0.03667	0.04017
Sox	34.712	-0.0655	0	0	0
NOx	39.0444	3.12891	3.3601	2.76736	2.93436
HC	3.33785	0	0	0	0
TSP	18.7251	0	0	0	0
Pb	0	0	0	0	0

The potential of this alternative option is further proved by the reduction of NOx. From the overall emissions of NOx could be cut down by 40% in the base year. And also it showed the potential to control the NOx pollution for the other time periods also. It further showed much potential in controlling TSP emission by 19% of the overall emission. As the buses do not contribute much to the HC emission the potential of this option for HC control was not very significant. Figure 4.10 shows the percentage changes in different pollutants for the alternative option 4 in Delhi.

Table 4.13: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode for alternative option 4

Pollution/PKM or TKM	Base case	Alternative option 4
CO2	23.0464	0
CO	0.30753	0
Sox	6E-05	0
NOx	0.50871	0
HC	5.1E-05	0
TSP	4.8E-05	0
Pb	0	0

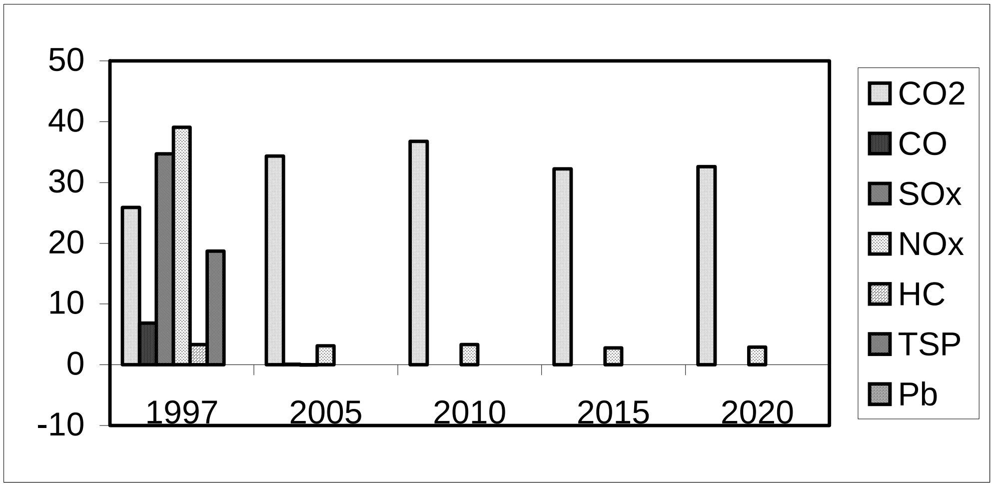


Figure 4.10: Percentage reduction in overall emission of different pollutants for alternative scenarios 4

The potential of this alternative option for Delhi transportation in cutting global emissions is apparent from the above figure. In this option all emissions per capita out put are tend to zero as this option is known as zero pollution option. The emission reduction potential for different pollutants was found to be unity, which presents its potential to curb the pollution whether it is local or global.

Figure 4.11 presents the percentage reduction of different pollutants in the base year for all the alternative options adopted for the case of Delhi. Alternative option 4 presents the perfect pollution mitigation scenario with better percentage of pollution reduction in all cases. Alternative option 3, though showed much promise in controlling HC and TSP it failed, in comparison to others, in checking the other pollutants. It also resulted in increase of NOx emissions. Alternative option 2 showed a promising performance in curbing local pollutants except a slight rise in CO_2 emissions. It showed a better performance in controlling all pollutants with a major reduction in CO, SOx and Pb. Alternative option 1 showed promise in controlling SOx, NOx and TSP. But its overall performance was not comparable to alternative option 2. It also contributed to increased CO_2 emission.

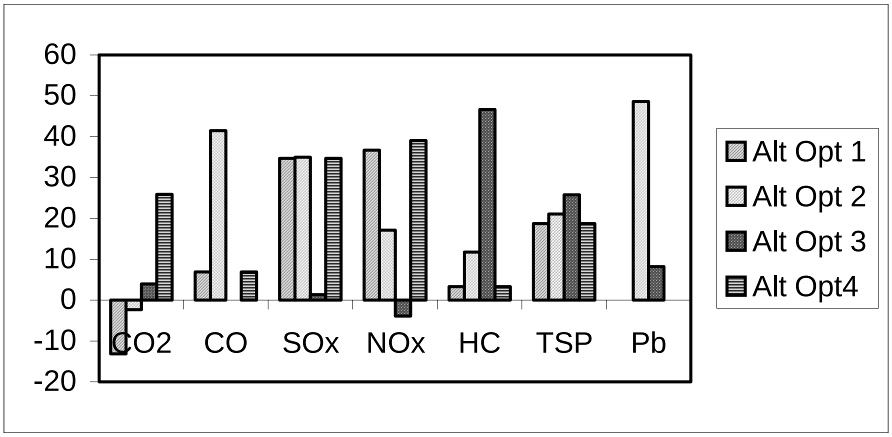


Figure 4.11: Percentage reduction of emissions of different pollutants for different alternative options in Delhi

Emission reduction potential was considered as a measure of potential for the alternative option in controlling pollution. An integrated index would have been a good measure, which can take care of all the pollutant with weighted average of values. However, in the present study the ERP values are treated in isolation to identify the better and potential options to control or reduce the emission from transport sector in Delhi. Table 4.14 provides the summery of ERP of different pollutants for all four alternative options under consideration. Figure 4.12 presents the graphical view of the ERP values.

Table 4.14: Emission Reduction Potential for different alternatives in Delhi

Option	Emission reduction potential (base year)						
	CO_2	CO	SO_x	NOx	HC	TSP	Pb
Alternative option 1	-0.565	0.994	1.000	0.939	1.000	1.000	0.000
Alternative option 2	-0.066	0.998	1.000	0.878	1.000	1.000	1.000
Alternative option 3	0.3148	-0.0008	0.315	-2.904	0.861	0.839	0.313
Alternative option 4	1.000	1.000	1.000	1.000	1.000	1.000	0

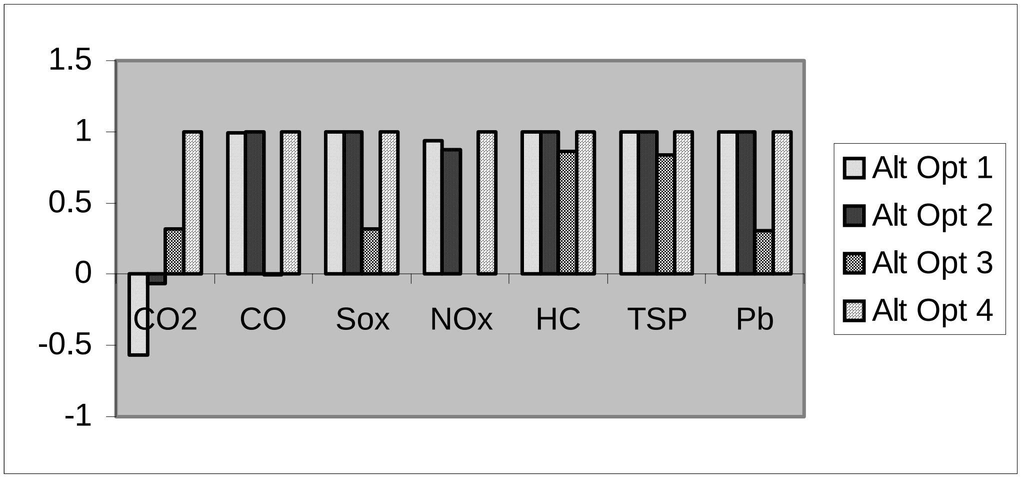


Figure 4.12: Emission reduction potential of different option for four alternative options for Delhi transport

From the above figure it is apparent alternative option 3 is not faring well in ERP values as compared to other options. Though alternative option 1 and 2 showed a similar trend of ERP values, alternative option 1 contributed much stronger to GHG emissions. Alternative option lead the sheet with potential to control all pollutants.

Mumbai

For the case of Mumbai five alternative options have been selected from a list of alternative described in chapter 2. Following are the options that are tried:

Alternative option 1: Buses run on Compressed Natural Gas (CNG)

Alternative option 2: Cars run on Compressed Natural Gas (CNG)

Alternative option 3: Replacement of 2-stroke 2 – Wheelers by 4-stroke 2 – Wheelers

Alternative option 4: 3 – Wheelers running on Compressed Natural Gas (CNG)

Alternative option 5: BOV – 3 - Wheelers

Alternative option 1: Replacing all diesel buses by CNG buses

Table 4.15 gives the emissions of different pollutants with this option both at the base year and also in the entire time horizon under consideration. Replacing diesel buses by CNG buses resulted in improvement of local pollution. However, it contributed to the global pollution.

Table 4.15: Emission of various pollutants for alternative option 1

Pollutant	Base scenario ('000 t)					Alternative option 1 ('000 t)				
	1998	2005	2010	2015	2020	1998	2005	2010	2015	2020
CO2	1350.7	2692.9	3387.3	4239.2	5785.2	1628.3	2692.9	3387.3	4239.2	5785.2
CO	54.97	70.93	73.63	103.74	135.07	48.46	70.93	73.63	103.74	135.07
SOx	2.674	1.053	1.006	1.38	1.828	1.382	1.053	1.006	1.38	1.828
NOx	17.62	10.79	14.45	20.03	26.69	7.44	10.79	14.45	20.03	26.69
HC	22.63	21.18	12.49	11.33	14.86	21.55	21.18	12.49	11.33	14.86
TSP	3.414	2.289	1.851	2.099	2.775	2.382	2	1.851	2.099	2.775
Pb	0.029	0.0397	0.0397	0.0503	0.0644	0.0299	0.0397	0.0397	0.0503	0.0644

By changing the fuel for the buses to cleaner mode, the CNG, significant reduction in SOx, NOx and TSP emissions was noticed. 48% SOx from the overall emission could be achieved by adopting cleaner fuel for buses. It was 58% for NOx and 30% for TSP. In addition to this there was fall in CO emissions by 12%. These follow the similar trend as the case in Delhi but the magnitude of effect is more because of the fact that Mumbai is mass transport based system and bus plays as important role as that of metro rail system. There was a rise in CO_2 emissions but the significant reduction in NOx would compensate the contribution to the GHG emissions.

Table 4.16: Percentage change in emission of different pollutants in alternative option 1

Pollutant	Percentage reduction in Alternative option 1				
	1998	2005	2010	2015	2020
CO2	-20.554	0	0	0	0
CO	11.8428	0	0	0	0
Sox	48.3171	0	0	0	0
NOx	57.7753	0	0	0	0
HC	4.77243	0	0	0	0
TSP	30.2285	0	0	0	0
Pb	-3.1034	0	0	0	0.04658

Figure 4.13 presents the trends of pollution reduction for alternative option 1 in Mumbai. There is a rise in CO_2 emission in alternative option 1 in Mumbai also and the reason for this rise could be explained in the similar way as in the case of Delhi. Table 4.17 presents the emission of various pollutants per unit output (pkm) in both base case as well as alternative option. There is a significant change in emission of all local pollutant per every pkm in the alternative option signifying its potential in curbing the pollution.

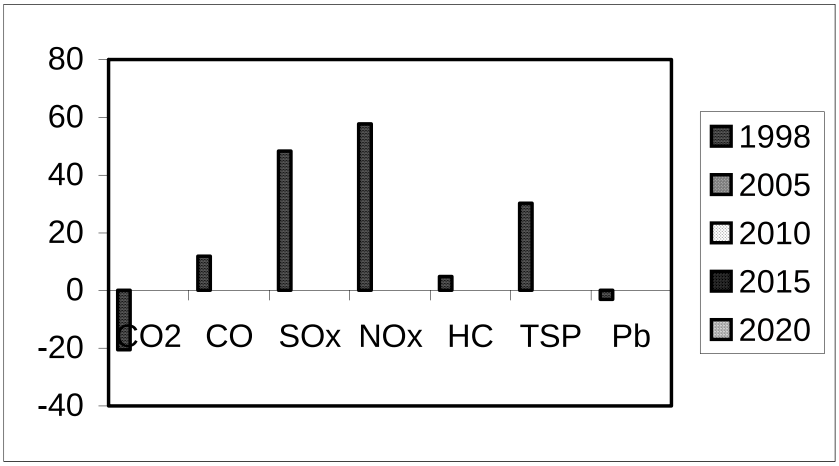


Figure 4.13: Percentage reduction in overall emission of different pollutants for alternative scenarios 1

In the new alternative option the emission of various pollutants for every pkm by buses has become almost negligible as it can be observed from the figure 4.14.

Table 4.17: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode in alternative option 1

Pollution/PKM or TKM	Base case	Alternative option 1
CO2	22.9021	35.8507
CO	0.3056	0.00192
SOx	0.06026	0
NOx	0.5056	0.03074
HC	0.05056	0
TSP	0.06157	0
Pb	0	0

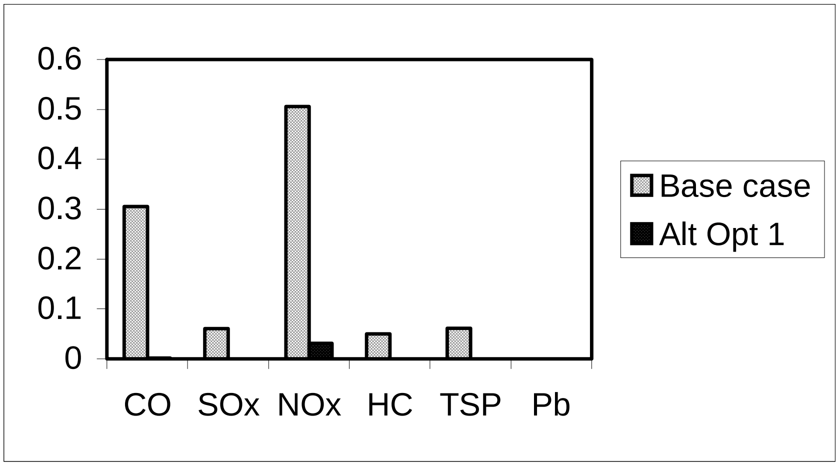


Figure 4.14: Emission of various pollutants per unit out put (PKM/TKM) for alternative option 1

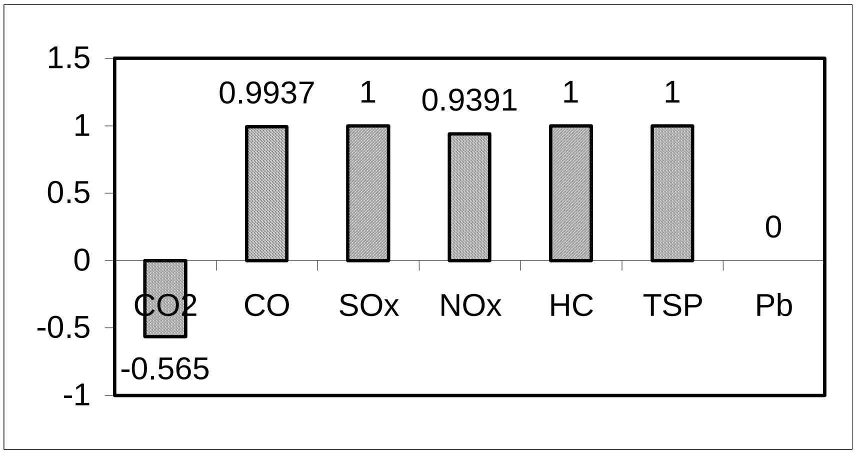


Figure 4.15: Emission reduction potential of alternative option 1 for different pollutants

The emission reduction potential of the alternative option for various local as well as global pollutants has been calculated and presented in Figure 4.15. Use of clean fuel for buses showed much better potential to reduce SOx, HC and TSP emissions. It also reached a higher value of 0.994 and 0.939 for CO and NOx, respectively. CO2 showed a marginal negative value, which indicates a rise in concentration with this new alternative option.

Alternative option 2: Replacing all gasoline and diesel cars by CNG cars

In this alternative option for Mumbai transport system, all cars running on gasoline and diesel are replaced by CNG driven cars. There are a few assumptions made for this option given in Chapter 3. Table 4.18 presents the difference in the emission of various pollutants due to alternative option 1. Unlike the previous option this option shows a significant difference in emissions throughout the time period. And the reason for that could be the fact that the penetration of CNG technology in the cars was not great in the time period considered for the base case. Hence this option shows a difference in emission levels for all pollutants in and for all years.

The percentage change in emission of different pollutants is presented in Table 4.19 and represented graphically in Figure 4.16. This alternative option showed a great promise in bringing down all the pollutants with a major potential in CO and SOx. In the base year there was reduction of 33% in CO and 35% in SOx emissions. This level of reduction in CO and SOx was even higher and goes as high as 65% and 49% for CO and SOx in year 2010 and 2005, respectively.

Table 4.18: Emission of various pollutants for alternative option 2

Pollutant	Base scenario ('000 t)					Alternative option 2 ('000 t)				
	1998	2005	2010	2015	2020	1998	2005	2010	2015	2020
CO2	1350.7	2692.9	3387.3	4239.2	5785.2	1401.3	2843.7	3619.3	4527.1	6143.2
CO	54.97	70.93	73.63	103.74	135.07	36.58	34.79	25.98	41.76	58.69
SOx	2.674	1.053	1.006	1.38	1.828	1.733	0.537	0.55	0.817	1.128
NOx	17.62	10.79	14.45	20.03	26.69	14.45	6.76	9.34	13.71	18.83
HC	22.63	21.18	12.49	11.33	14.86	18.98	16.4	6.04	3.9	5.47
TSP	3.414	2.289	1.851	2.099	2.775	2.613	1.616	1.101	1.168	1.618
Pb	0.029	0.0397	0.0397	0.0503	0.0644	0.0155	0.0154	0.0071	0.0102	0.0143

Another significant reduction was notice in the case of Lead (Pb). As gasoline driven cars are the major source of lead emissions, this option of using clean fuels resulted in Pd reduction as high as 47% in base year and it went up to 82% in 2010. This shows the potential of this option in curbing the local pollutants from transportation sector.

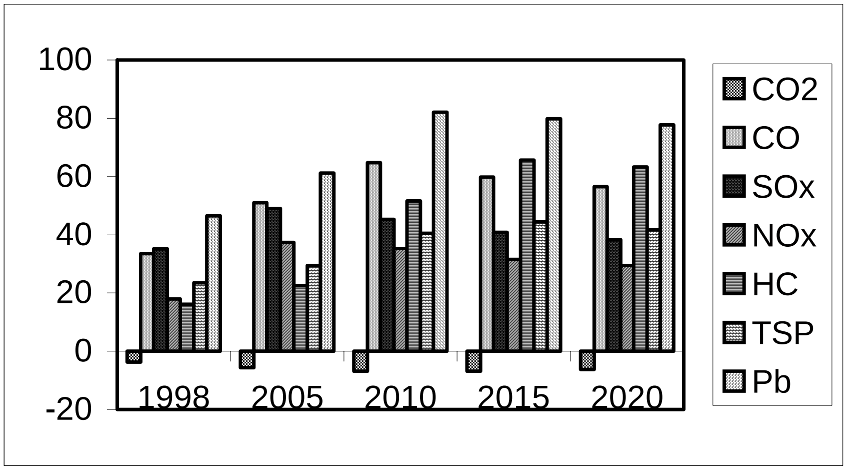


Figure 4.16: Percentage reduction in overall emission of different pollutants for alternative scenarios 2

Further, this option could reduce the NOx and HC emissions by 18% and 16% respectively in the base year. Like the other pollutants this reduction potential went up to 37% and 66% for NOx and HC respectively in the years 2005 and 2015.

Table 4.19: Percentage change in emission of different pollutants in alternative option 2

Pollutant	Percentage reduction in Alternative option 2				
	1998	2005	2010	2015	2020
CO2	-3.7425	-5.5991	-6.8515	-6.7899	-6.1887
CO	33.4546	50.9516	64.7155	59.7455	56.5485
Sox	35.1907	49.0028	45.328	40.7971	38.2932
NOx	17.9909	37.3494	35.3633	31.5527	29.4492
HC	16.129	22.5685	51.6413	65.5781	63.1898
TSP	23.4622	29.4015	40.5186	44.3545	41.6937
Pb	46.5517	61.0929	82.1159	79.8012	77.764

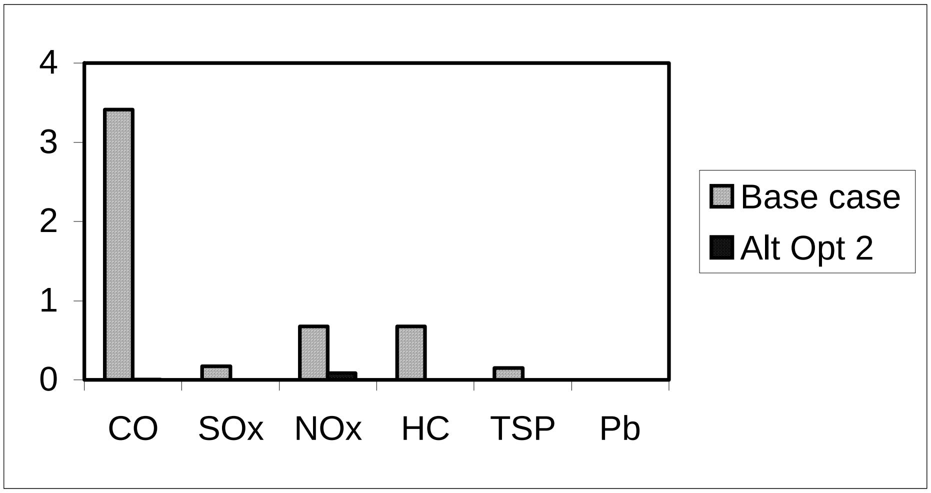


Figure 4.17: Emission of various pollutants per unit out put (PKM/TKM) for alternative option 2

Figure 4.18 presents the emission of various pollutants per unit out put by the mode of transport under consideration. It can be observed that emission per output has been brought down significantly for all pollutants but it is much further significant in the case of CO. There was a slight rise in the CO_2. However, the reduction in NOx would compensate the rise in CO2 in neutralizing GHG potential of this option.

Table 4.20: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode for alternative option 2

Pollution/PKM or TKM	Base case	Alternative option 2
CO2	94.0426	103.404
CO	3.41148	0.00555
Sox	0.17417	0
NOx	0.67444	0.08878
HC	0.67574	0
TSP	0.14835	0
Pb	0.00267	0

Emission reduction potential of this alternative option for various pollutants were calculated and are presented in Figure 4.18.

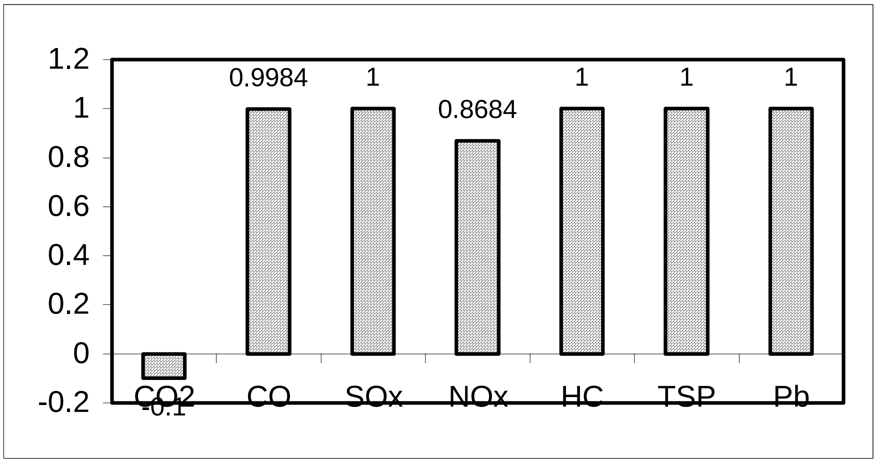


Figure 4.18: Emission reduction potential of alternative option 2 for different pollutants

As it can be observed from the figure, this option has shown a great potential in reducing emissions of SOx, HC, TSP and Pb. ERP values of these pollutants was found to be 1.000, which indicates that this option has highest potential to curb these emissions. It further showed ERP values of 0.998 and 0.868 for CO and NOx. It showed ERP value of –0.1 for CO_2, which is much less than the previous option (use of clean fuels in buses). Thus, it shows the potential to handle the GHG emissions also.

Alternative option 3: Replacing all 2 stroke 2-wheelers to 4 stroke 2-wheelers

In alternative option 3 it was proposed that all 2-stroke 2-wheelers be replaced by 4-stroke 2-wheelers. This is a well proved and potential option to reduce emissions from 2-wheelers. Use of catalytic converter was useful but not as efficient as 4-stroke 2 wheelers. Hence, instead of trying catalytic converter 4-stroke bike have been selected as an option. The reduction in emission of various pollutants is given in Table 4.21. Unlike the earlier two options, alternative option 1 and alternative option 2, this option could reduce the CO_2 emission also.

Table 4.21: Emission of various pollutants in alternative option 3

Pollutant	Base scenario (‘000 t)					Alternative option 3 (‘000 t)				
	1998	2005	2010	2015	2020	1998	2005	2010	2015	2020
CO2	1350.7	2692.9	3387.3	4239.2	5785.2	1330.2	2673.1	3369.7	4239.2	5785.2
CO	54.97	70.93	73.63	103.74	135.07	54.98	70.94	73.94	103.74	135.07
SOx	2.674	1.053	1.006	1.38	1.828	2.66	1.039	0.994	1.38	1.828
NOx	17.62	10.79	14.45	20.03	26.69	17.89	11.06	14.68	20.03	26.69
HC	22.63	21.18	12.49	11.33	14.86	18.44	17.12	8.88	11.33	14.86
TSP	3.414	2.289	1.851	2.099	2.775	3.019	1.907	1.511	2.099	2.775
Pb	0.029	0.0397	0.0397	0.0503	0.0644	0.0289	0.0387	0.0388	0.0503	0.0644

As in the case of Delhi, it was assumed that 4-stroke bikes would replace 2-stroke bikes by the year 2015 in the base scenario. Hence the alternative option 3 would not show any improvement in years 2015 and 2020. In the base year it was observed that there is a significant reduction in HC and TSP emissions. HC was reduced by 18% and TSP emission was cut down by 12%. Though there is a reduction in SOx and Pb, it was not very significant. There was a small rise in NOx and CO emissions. It was also observed that CO_2 emission could be reduced by 1.5%. Similar trends were observed for year 2005 and 2010 with HC and TSP emission reductions as high as 29% and 18%, respectively.

Table 4.22: Percentage change in emission of different pollutants in alternative option 3

Pollutant	Percentage reduction in Alternative option 3				
	1998	2005	2010	2015	2020
CO2	1.51698	0.73526	0.51989	0	0
CO	-0.0182	-0.0141	-0.421	0	0
Sox	0.52356	1.32953	1.19284	0	0
NOx	-1.5323	-2.5023	-1.5917	0	0
HC	18.5152	19.169	28.9031	0	0
TSP	11.57	16.6885	18.3684	0	0
Pb	0.34483	2.41753	2.16625	-0.0795	0.04658

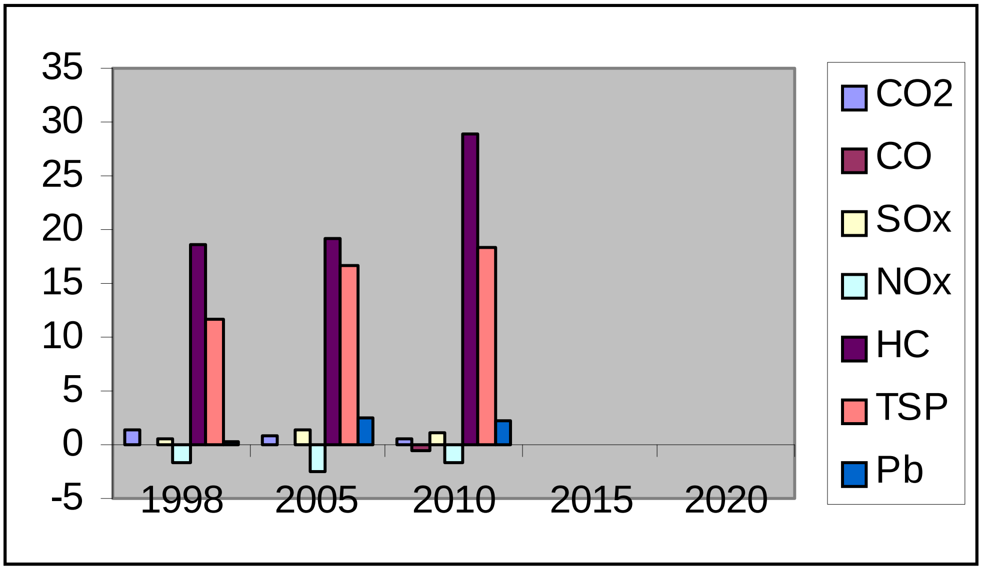


Figure 4.19: Percentage reduction in overall emission of different pollutants for alternative scenarios 3

Emission of various pollutants per unit output by the mode under consideration was calculated and is given in Table 4.23. CO_2 emission per unit output could be reduced from 37.83 kg to 25.91. As is the case with Delhi, in Mumbai also this alternative option resulted in increased NOx emissions. But it is not a significant rise in emission.

Table 4.23: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode for alternative option 3

Pollution/PKM or TKM	Base case	Alternative option 3
CO2	37.8314	25.9186
CO	4.54651	4.55233
Sox	0.02587	0.01773
NOx	0.05471	0.2136
HC	2.83372	0.39512
TSP	0.27355	0.0439
Pb	0.00185	0.00127

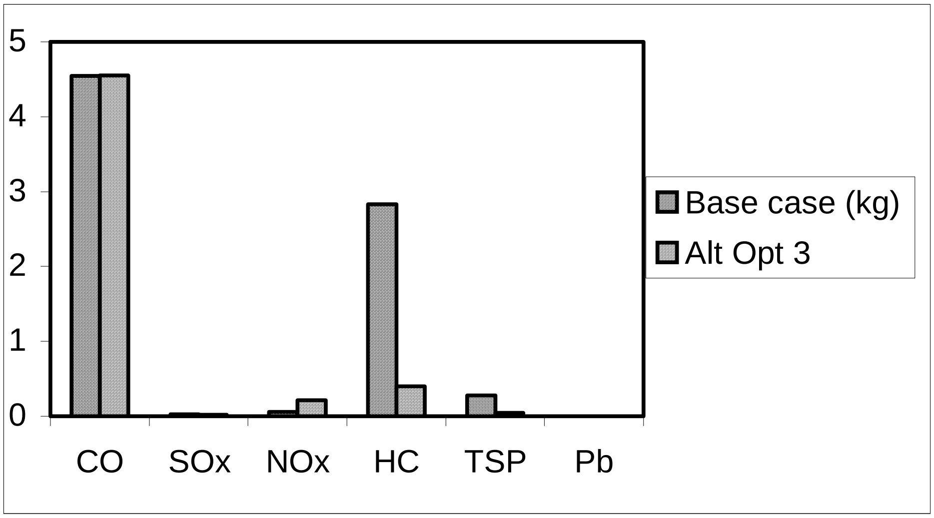


Figure 4.20: Emission of various pollutants per unit out put (PKM/TKM) for alternative option 3

As it is seen from the figure above, emission levels of HC and TSP per unit out put could be reduced by replacing 2-stroke bikes by 4-stroke bikes. Emission factor for 4-stroke bikes is higher than that for 2-stroke bike and that resulted in increased emissions of NOx.

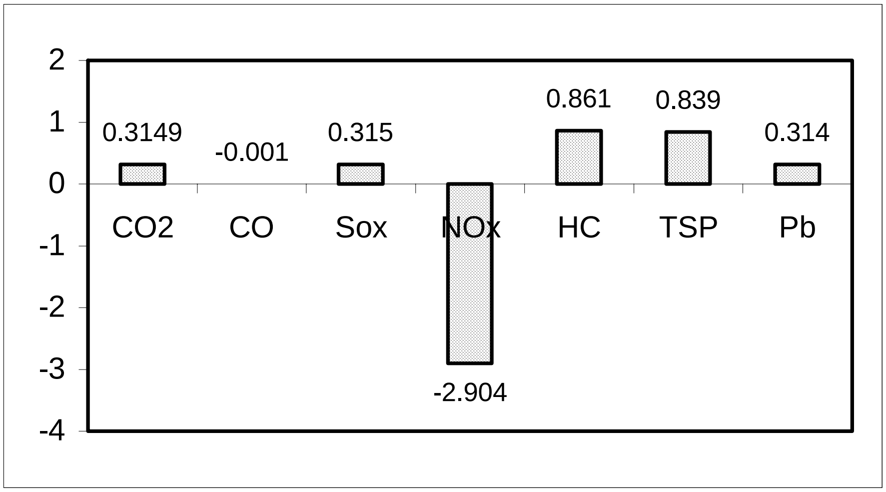


Figure 4.21: Emission reduction potential of alternative option 3 for different pollutants

Emission reduction potential of this alternative option calculated for all the pollutants reveals an interesting story. Except for NOx emissions, this alternative showed some potential to curb the pollution levels. However, the level of reduction was not so significant with highest ERP values standing at 0.861 and 0.839 for HC and TSP, respectively. CO2, SOx and Pb are at the same level with 0.315. Hence, this option provides a mixture of potentials may not be very significant but has influence over all pollutants. This may be due to the fact that 2-wheelers are not the dominating mode of transport on Mumbai roads and in pollution.

Alternative option 4: Replacing all gasoline and diesel 3-wheelers by CNG 3-wheelers

Being a city with a perfect and efficient public transport system, Mumbai has a significant place for 3-wheelers in its transportation system. Three wheelers cater for a major share of traffic demand and being less fuel efficient they contribute to pollution as well. In this alternative option use of efficient fuel was considered for 3-wheelers popularly known as "auto-rickshaws" in India cities. Use of CNG in place of gasoline and diesel was considered and the resulting reduction in pollution was calculated. Table 4.24 gives the pattern of pollution reduction with the use of CNG.

Table 4.24: Emission of various pollutants for alternative option 4

Pollutant	Base scenario ('000 t)					Alternative option 4 ('000 t)				
	1998	2005	2010	2015	2020	1998	2005	2010	2015	2020
CO2	1350.7	2692.9	3387.3	4239.3	5785.2	1430.7	2878.2	3656.2	4622.3	6328.9
CO	54.97	70.93	73.63	103.74	135.07	34.52	53.84	73.65	103.76	135.09
SOx	2.674	1.053	1.006	1.38	1.828	2.502	0.909	1.006	1.38	1.828
NOx	17.62	10.79	14.45	20.03	26.69	17.69	10.96	14.68	20.36	27.16
HC	22.63	21.18	12.49	11.33	14.86	9.86	10.5	12.49	11.33	14.86
TSP	3.414	2.289	1.851	2.099	2.775	2.579	1.591	1.851	2.099	2.775
Pb	0.029	0.0397	0.0397	0.0503	0.0644	0.0176	0.0294	0.0397	0.0503	0.0644

Unlike CNG buses and 4-stroke 2-wheelers, use of clean fuels does not receive any penetration in the base case and hence the influence of this alternative option is apparent in all the year under consideration.

Table 4.25: Percentage change in emission of different pollutants for alternative option 4

Pollutant	Percentage reduction in Alternative option 4				
	1998	2005	2010	2015	2020
CO2	-5.9228	-6.8787	-7.9397	-9.037	-9.3988
CO	37.2021	24.0942	-0.0272	-0.0193	-0.0148
Sox	6.43231	13.6752	0	0	0
NOx	-0.3973	-1.5755	-1.5917	-1.6475	-1.761
HC	56.4295	50.4249	0	0	0
TSP	24.4581	30.4937	0	0	0
Pb	39.2414	25.8373	0	-0.0795	0.04658

Table 4.25 presents the percentage changes in emission level in overall environmental emissions with the possible change in fuel for 3-wheelers. This option apparently influenced the emissions of CO, HC, TSP and Pb to a great extant. It has resulted in 37% reduction of CO during the base year. Interestingly the percentage reduction has come down with time. This could be because of the fact that there is some level of CNG penetration in this mode and also technology penetration in other modes of transportation. As one of the major influence, CNG 3-wheelers reduced HC emissions by 56%. HC being the major pollutant from 3-wheelers will have the major impact from this alternative option. The results are shown in Figure 4.22.

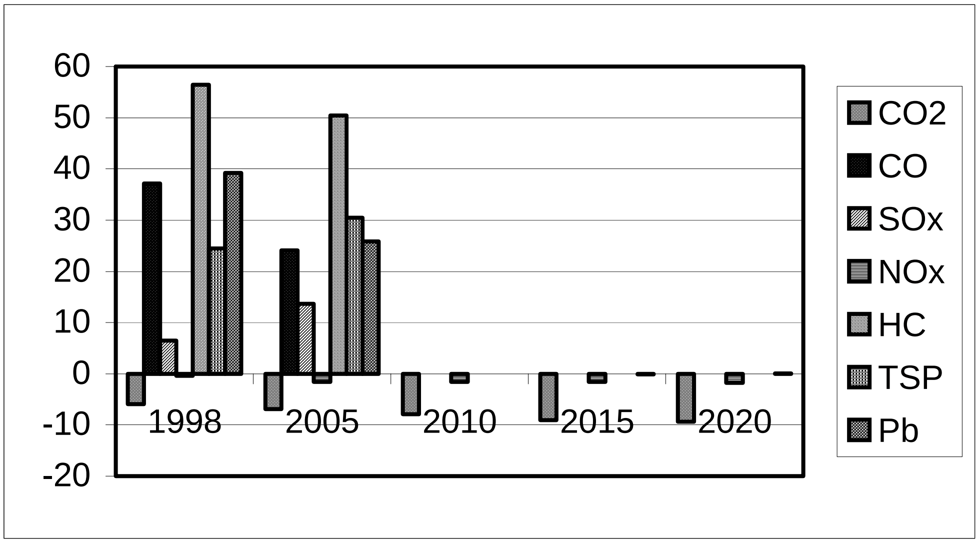


Figure 4.22: Percentage reduction in overall emission of different pollutants for alternative scenarios 4

Total suspended particulate matter also could be reduced by 40%. In addition to this there was a reduction of SOx by 6.4%. This alternative option may not provide a feasible solution with CO_2 and NOx emissions increasing in the base year. There was 6% rise CO2 emission and a marginal (0.4%) rise in NOx emission.

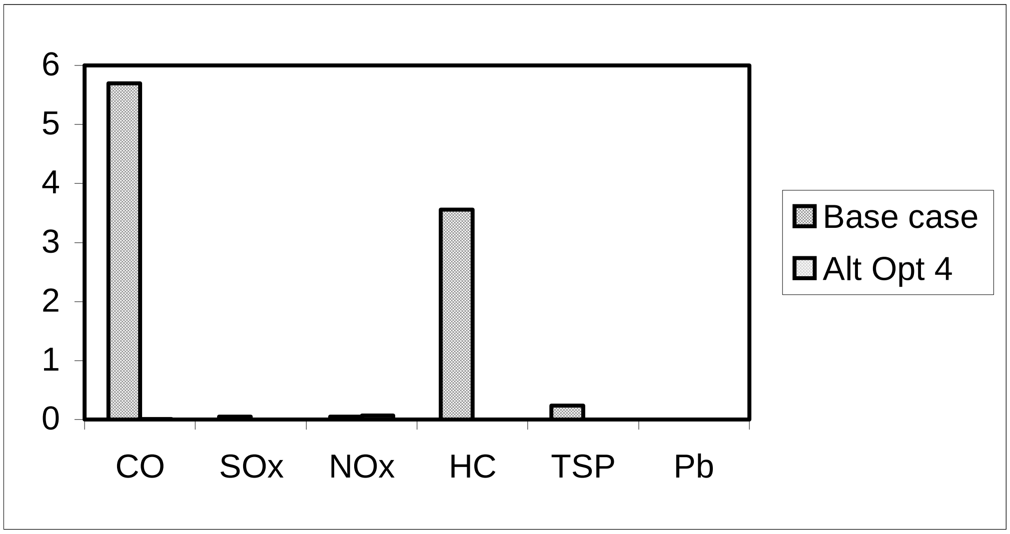


Figure 4.23: Emission of various pollutants per unit out put (PKM/TKM) for alternative option 4

Table 4.26 presents the emission of various pollutants per unit out of the mode of transport under consideration for alternative option 4. There is a significant change in CO emission per unit output. Other pollutants also showed a significant difference with SOx, HC, TSP and Pb tend to reach zero emission per unit output. Hence this option provides a good choice for the control of local pollutants, which is apparent from Figure 4.23.

Table 4.26: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode in alternative option 4

Pollution/PKM or TKM	Base case	Alternative option 4
CO2	56.5543	78.8384
CO	5.70195	0.00423
SOx	0.04788	0
NOx	0.04652	0.06769
HC	3.5571	0
TSP	0.23259	0
Pb	0.00342	0

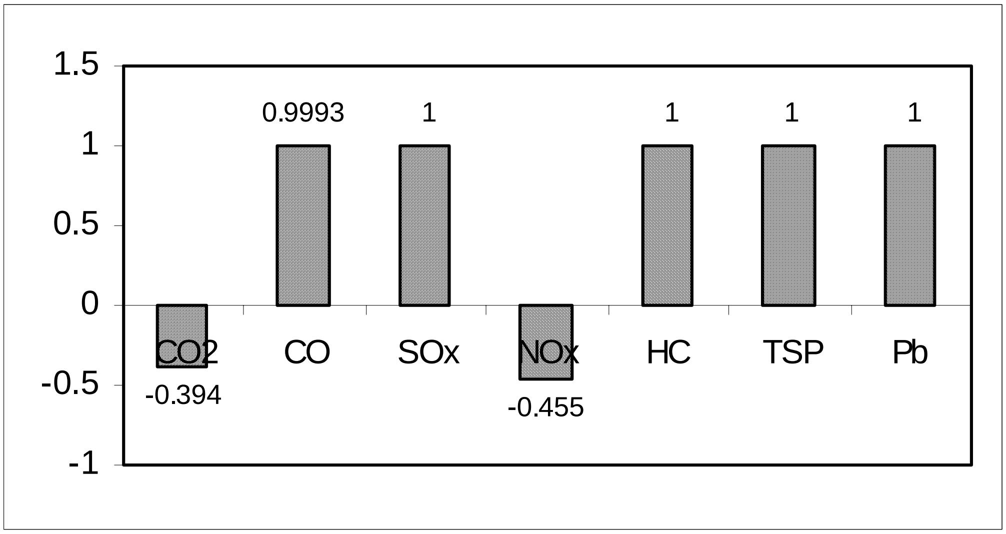


Figure 4.24: Emission reduction potential of alternative option 4 for different pollutants

This observation was further strengthened by the Figure 4.24. Emission reduction potential of each pollutant for the alternative option 4 is presented in Figure 24. CNG 3-wheelers have shown better ERP values for SOx, HC, TSP and Pb with values at unity. And other local pollutant of the list got an ERP value of 0.999. This makes it very apparent that this option is very potential in curbing local air pollution. However, as it can be observed from the above figure, ERP values for CO_2 and NOx are –0.390 and -0.450, respectively. This implies that this option is not very friendly for global pollutant mitigation programme.

<u>Alternative option 5: Replacing all gasoline and diesel 3-wheelers by BOV 3-wheelers</u>

In continuation with alternative option 4, in this section, use of electricity for 3-wheelers was considered. BOV 3-wheelers can overcome many of the limitations that BOV vehicles have in their adaptability. Table 4.27 presents the change in overall emission levels of various pollutants for the option of BOV 3-wheelers. This option shows very significant effect on all pollutants except NOx.

Table 4.27: Emission of various pollutants for alternative option 5

Pollutant	Base scenario ('000 t)					Alternative option 5 ('000 t)				
	1998	2005	2010	2015	2020	1998	2005	2010	2015	2020
CO2	1350.7	2692.9	3387.3	4239.2	5785.2	1147.7	2404.8	3118.3	3856.1	5241.5
CO	54.97	70.93	73.63	103.74	135.07	34.5	53.81	73.62	103.72	135.04
SOx	2.674	1.053	1.006	1.38	1.828	2.502	0.9097	1.0067	1.38	1.828
NOx	17.62	10.79	14.45	20.03	26.69	17.45	10.55	14.22	19.7	26.23
HC	22.63	21.18	12.49	11.33	14.86	9.86	10.5	12.49	11.33	14.86
TSP	3.414	2.289	1.851	2.099	2.775	2.5797	1.5909	1.851	2.099	2.775
Pb	0.029	0.0397	0.0397	0.0503	0.0644	0.0176	0.0294	0.0397	0.0503	0.0644

There is a considerable reduction in CO_2 emissions with 15% fall in overall emission level. This option has its significance in reducing CO, HC, TSP and Pb emissions levels. CO emissions could be reduced by 37% in base year, which is very close to the previous option (CNG 3-wheelers). HC emissions were cut down by 56% and TSP and Pb emissions were brought down by 24% and 39%, respectively. These values are very close to the option of CNG 3-wheelers. However, this option resulted in reduction of CO_2 emission by 15% making this option more sustainable with its potential to control both local as well as local pollutants. There was a slight reduction in overall emission level of NOx also. These trends of reduction in pollution are shown in Figure 4.25.

Table 4.28: Percentage change in emission of different pollutants for alternative option 5

Pollutant	Percentage reduction in Alternative option 5				
	1998	2005	2010	2015	2020
CO2	15.0314	10.6987	7.93973	9.03676	9.39881
CO	37.2385	24.1365	0.01358	0.01928	0.02221
Sox	6.43231	13.6087	-0.0696	0	0
NOx	0.96481	2.22428	1.5917	1.64753	1.72349
HC	56.4295	50.4249	0	0	0
TSP	24.4376	30.498	0	0	0
Pb	39.3103	25.8373	0	-0.0795	0.04658

From the figure it is very clear that this option has potential for most of the pollutants with prominence for HC, CO, TSP and Pb. Emission per unit output of the mode of transport (3-wheelers in this case) were calculated and presented in Table 4.29. As the BOV is considered as zero pollution option there is a significant difference in emission per unit output with the new option giving zero emission for every PKM.

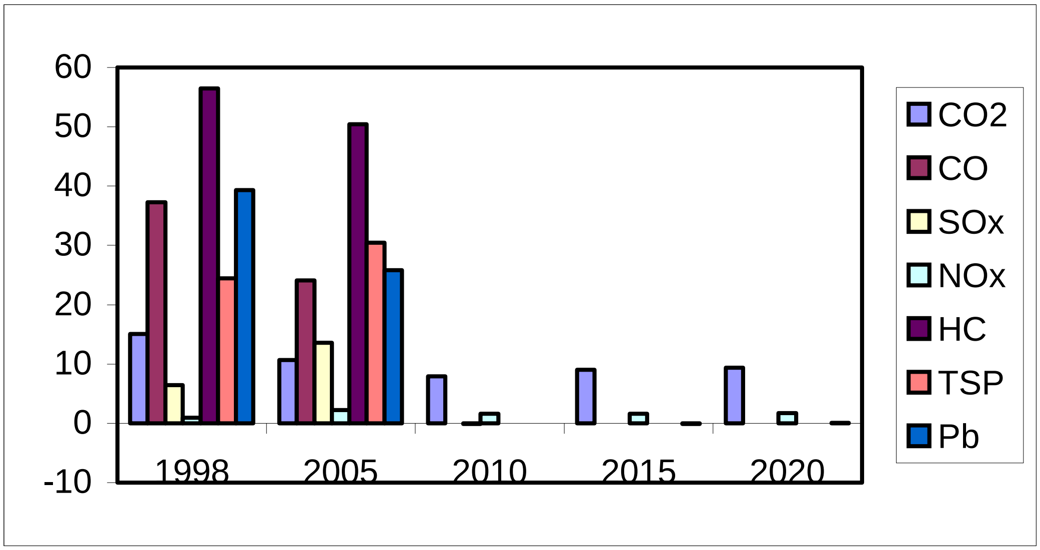


Figure 4.25: Percentage reduction in overall emission of different pollutants for alternative scenarios 5

Table 4.29: Emission of various pollutants per unit out put (PKM/TKM) of the transportation mode in alternative option 5

Pollution/PKM or TKM	Base case	Alternative option 5
CO2	56.5543	0
CO	5.70195	0
Sox	0.04788	0
NOx	0.04652	0
HC	3.5571	0
TSP	0.23259	0
Pb	0.00342	0

Emission reduction potential was calculated for all the pollutants for this alternative option. Because of the fact that this option is giving a zero emission per unit output, all ERP values tend to unity, which indicates that this option has the highest potential for emission reduction.

Figure 4.26 presents the percentage reduction of different pollutants in the base year for all the alternative options adopted for the case of Mumbai. Alternative options 1, 2 and 4 showed slight increase in CO_2 emissions where are options 3 and 5 which are "replacing 2-stroke bikes by 4-stroke bike" and BOV 3-wheelers, respectively showed potential in cutting CO_2 emissions. Similar trend was observed for NOx emissions also with option 3, 4 that's are adding to NOx emissions though it is a very insignificant change. Except alternative option 3 all other options could reduce CO emissions. And among all alternatives option 4 and 5 showed better potential for reducing CO emission. All options could cut SOx emissions with alternative option 1 doing best and option three the least. It was the opposite when considered HC. Option 4 and 5 could reduce the HC emission to the maximum extent and option 1 was on lower side. Except alternative option 3, all other options showed a similar potential for reduction of TSP. Alternative options 2 lead the sheet for reduction of Pb with options 1 and 3 contributing the least.

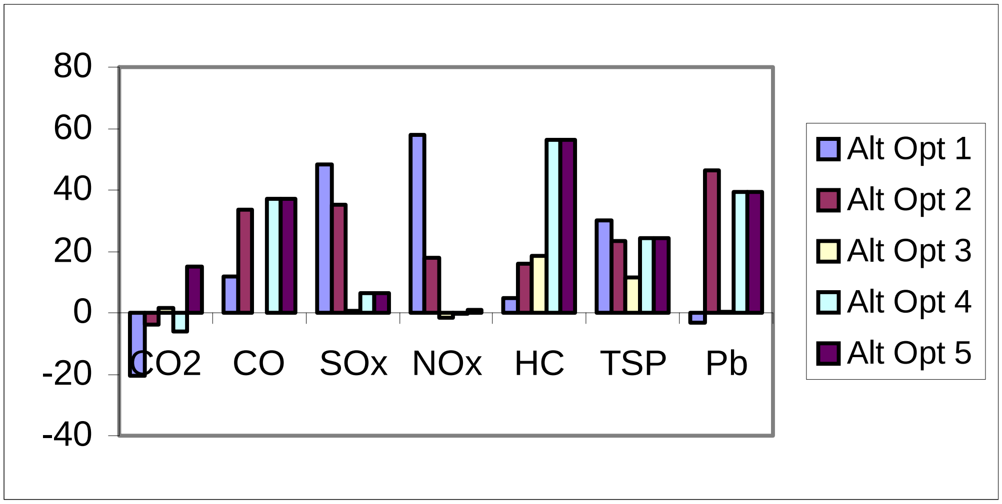


Figure 4.26: Percentage reduction of emissions of different pollutants for different alternative options in Mumbai

It is a difficult task to select some options out of these five options as each one is doing better in some respects and worse in others. Hence Emission reduction potential was calculated for all alternatives and pollutants which are presented in Table 4.30. As it can be observed from Table 4.30, Alternative option 3 showed less promise even though it showed a best performance in reducing CO_2 emission among the other options. Its poor performance is very clearly seen in the Figure 4.27. This may be due to the fact that 2-wheelers are not the leading mode of transport in Mumbai. Option 1, 2, 4 are very close in performance except for few pollutants. Alternative 1 and 2 are very close to each other.

However, option 2 could be rated better as its CO_2 reduction potential is much better than option 1. Option 4 has more negative value for CO_2 and also NOx in comparison to option 1 and 2.

Table 4.30: Emission Reduction Potential for different alternatives in Mumbai

Option	Emission reduction potential						
	CO_2	CO	SO_x	NOx	HC	TSP	Pb
Alternative option 1	-0.565	0.9937	1.000	0.9391	1.000	1.000	0
Alternative option 2	-0.100	0.9984	1.000	0.8684	1.000	1.000	1.000
Alternative option 3	0.3149	-0.001	0.315	-2.904	0.8606	0.8395	0.3145
Alternative option 4	-0.394	0.9993	1.000	-0.455	1.000	1.000	1.000
Alternative option 5	1.000	1.000	1.000	1.000	1.000	1.000	1.000

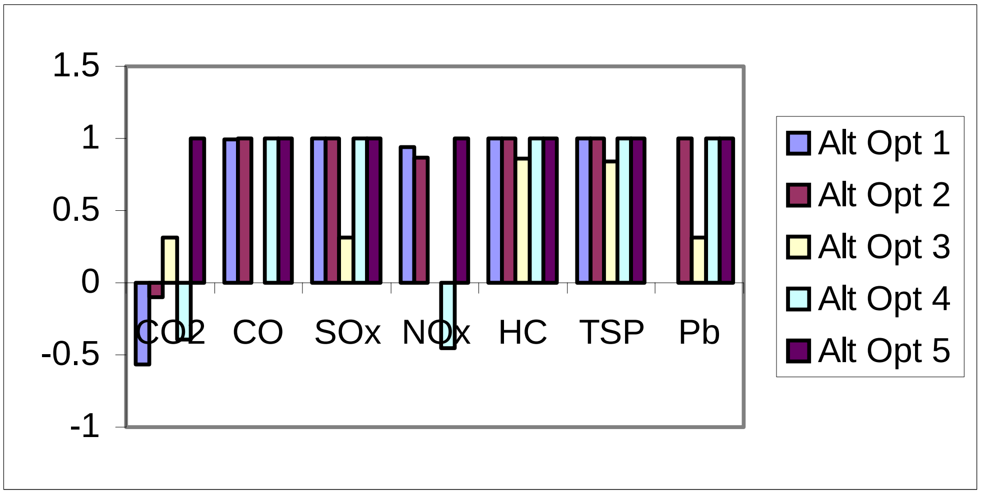


Figure 4.27: Emission reduction potential of different option for four alternative options for Delhi transport

4.6 Environment Friendly Options

In the previous section all the selected options for Delhi and Mumbai were analyzed for their emission reduction potential. Based on the results and discussion the following options are selected for further economic analysis.

Delhi

Alternative option 1 (D1): Use of CNG for buses replacing diesel
Alternative option 2 (D2): Use of CNG for cars replacing gasoline and diesel
Alternative option 3 (D4): Replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers

Mumbai

Alternative option 1 (B1): Use of CNG for buses replacing diesel
Alternative option 2 (B2): Use of CNG for cars replacing gasoline and diesel
Alternative option 4 (B4): Use of CNG for 3-wheelers
Alternative option 5 (B5): BOV 3-wheelers

4.7 Conclusions and Recommendations

Among various options that are considered to mitigate emission of various pollutants both for the cases of Delhi and Mumbai, six options have been selected for further analysis of economic feasibility. Selection process included determination of emission reduction potential of each alternative option for each of the pollutant. For Delhi it was considered that, conversion of 2-stroke bike to 4-stroke bike be included in the options in spite of its poor ERP. It was decided so because of the fact that Delhi traffic is fully dominated by 2-wheelers. The other options selected for Delhi were CNG cars and CNG driven buses. These two have shown a higher potential. BOV buses were not considered for further analysis due to the fact that, the information on cost as well as performance was not available for BOV buses in India and also it needs some time before this emission free technology can be used on Indian roads especially for buses.

In the case Mumbai, CNG buses, CNG cars and CNG 3-wheelers were selected for further economic analysis. Conversion of 2-stroke 2-wheelers did not show much promise in curbing pollution in Mumbai and also due the fact that as 2-wheelers are not the dominating mode in Mumbai they were not selected.

5. COST EFFECTIVENESS OF SELECTED OPTIONS

5.1 Introduction

Economic viability is an important requirement for any development activity to be successful. Literature demonstrates the fact that any development option, irrespective of its technical potential tends to fail if it is not a cost-effective option. Hence, for the present problem of selecting various potential pollution mitigation options from transport sectors both in Delhi and Mumbai, economic analysis was carried out for all the options that are selected based on their potential for emission reduction.

The costs were considered through out the life time of each option to determine the present value and also the net present value. Levelised cost was determined for each option by considering the present value and certain discount rate (excluding) and life span of the vehicle. Taking annual passenger kilometer covered by the respective mode in to account, life cycle operating cost was determined for each option. Subsequently, per unit of pollution abatement cost (PAC) was determined for each option.

5.2 Levelised Costs (LC) of the Selected Options

Levelised cost is the concept used in economics to determine the cost of the system distributed thorough out its life span. In this section, levelised cost was determined for all the options. The net present value was determined by taking all the cost viz. capital, operation and maintenance, fuel costs and taxes etc. Subsidy on fuel has been factored out. This present value was used to determine the levelised cost of each option under consideration. Following is the brief methodological note on determination of LC.

Levelised cost of each option was determined using the following equation.

$$\text{Levelised cost (LC)} = PV * \left[\frac{i}{1-(1+i)^{-n}} \right] \qquad 5.1$$

where

PV present value
i discount rate
n life span

Delhi

As it was mentioned in the previous chapter three options, which showed great potential to reduce emission of various pollutants from transport system, viz. use of CNG for buses, use of CNG for cars and taxis and conversion of 2-stroke bike to 4-stroke bike, were considered for economic feasibility analysis. Table 5.1 presents various costs involved in the option 1 (D1). For all the options 10% discount rate was chosen. Life span of bus is taken as 20 years. Option I showed a LC of 169,768 over the LC of the existing buses, Rs. 159,937. The initial cost was so high in the case of CNG buses and it added up to the LC of this option in spite of a large difference in fuel costs.

Option II (use of CNG in cars) the levelised cost for the CNG car was found to be Rs. 36387.5 over the levelised cost of the existing cars and taxis, Rs. 46397. Unlike the earlier option this option showed a better LC for the alternative option. This may be due to the fact that the retrofitting charges for the CNG kit was not very high and also there is a major saving in the fuel cost. Where as in the earlier option the conversion charges are very high (as high as 40% of the capital. This must be the reason for the high LC of the alternative option over the existing one.

Option III (conversion of 2-stroke 2-wheelers to 4-stroke 2-wheelers) also showed a better LC over the existing mode of option. Levelised cost of the alternative was found to be Rs. 8332 where as the LC for the base case was found to be Rs. 8893. There was an effective fall in the LC with a magnitude of 8%. The analysis and results were presented in Table 5.1, 5.2 and 5.3, respectively for Option I, II and III.

Mumbai

Four options were tried for this one of the largest metropolitan city if India. Use of CNG for buses, cars and 3-wheelers and BOV 3-wheelers were analyzed for their economic feasibility.

Present values were found out using a discount rate of 10% and life span of the respective mode. The results are shown in Table 5.4 to Table 5.7.

Option I (use of CNG for buses) showed a higher LC for the alternative cost in comparison to the existing case. LC for CNG bus was found to be Rs. 169,768 where as LC for Diesel bus was Rs. 159,937. The rise in levelised cost could be due to the heavy initial investment for the new technology. Option II (use of CNG for cars) showed the reverse trend with a decreasing LC for the advanced technology. LC of the existing system was found to be Rs. 46, 397 where as the CNG cars showed a LC of Rs. 36,387. Option III (use of CNG for 3-wheelers) showed a promising performance with the difference in LC s as high as 45%. Existing 3-wheelers showed LC of Rs. 70,040 with the alternative option showing LC as low as Rs. 38,714. This efficiency has furthered with BOV 3-wheelers. In the case of alternative option IV (BOV 3-wheelers), the difference in LCs was found to be 47% with LC of the existing system at Rs. 70,040 and the alternative option at Rs. 37,152. Calculations and results are tabulated in Table 5.4 – 5.7.

Table 5.1: Calculation of LC and LCC for the alternative option of using CNG for Buses (D1) in Delhi transportation

Option 1: CNG Bus

Existing buses	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	20	758718	0	0	0	0	0	0	0
O&M			3000	3000	3000	3000	3000	3000	3000	3000
OC/yr			61380	61380	61380	61380	61380	61380	61380	61380
Total			823098	64380	64380	64380	64380	64380	64380	64380
PV		**1361632**	823098	58527.3	53206.6	48369.6	43972.4	39974.9	36340.8	33037.1
LC		**159937**								
LCC		0.070424	rs/pkm							

CNG buses	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	20	1058718	0	0	0	0	0	0	0
O&M			2000	2000	2000	2000	2000	2000	2000	2000
OC/yr			39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2
Total			1100001	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2
PV		**1445332**	1100001	37530.2	34118.3	31016.7	28197	25633.6	23303.3	21184.8
LC		**169768**								
LCC		61380		37	2271060					
		0.074753	rs/pkm							
PAC		**0. 00045**								

contd…

Table 5.1: Calculation of LC and LCC for the alternative option of using CNG for Buses (D1) in Delhi transportation

8	9	10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0	0	0
3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
61380	61380	61380	61380	61380	61380	61380	61380	61380	61380	61380	61380
64380	64380	64380	64380	64380	64380	64380	64380	64380	64380	64380	64380
30033.7	27303.4	24821.3	22564.8	20513.5	18648.6	16953.3	15412.1	14011	12737.2	11579.3	10526.6

8	9	10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0	0	0
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2
41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2
19258.9	17508.1	15916.5	14469.5	13154.1	11958.3	10871.2	9882.87	8984.43	8167.66	7425.15	6750.13

Table 5.2: Calculation of LC and LCC for the alternative option of using CNG for cars (D2) in Delhi transportation

Option 2: CNG car

Existing cars	Discount	Life	0	1	2	3	4	5	6	7
Capital cost	0.1	18	178095	0	0	0	0	0	0	0
O&M			1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3
OC/yr			20625	20625	20625	20625	20625	20625	20625	20625
Total			200533	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3
PV		**380523**	200533	20398.5	18544	16858.2	15325.7	13932.4	12665.8	11514.4
LC		**46397.3**								
LCC		2.450505	Rs/pkm							

CNG cars	Discount	Life	0	1	2	3	4	5	6	7
Capital cost	0.1	18	213095	0	0	0	0	0	0	0
O&M			1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86
OC/yr			8250	8250	8250	8250	8250	8250	8250	8250
Total			222554	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86
PV		**298429**	222554	8598.96	7817.24	7106.58	6460.53	5873.21	5339.28	4853.89
LC		**36387.5**								
LCC		1.921832	Rs/pkm							

PAC **-0.1044**

Contd…

Table 5.2: Calculation of LC and LCC for the alternative option of using CNG for cars (D2) in Delhi transportation

8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0
1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3
20625	20625	20625	20625	20625	20625	20625	20625	20625	20625
22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3
10467.6	9516.03	8650.94	7864.49	7149.53	6499.58	5908.71	5371.55	4883.23	4439.3

8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0
1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86
8250	8250	8250	8250	8250	8250	8250	8250	8250	8250
9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86
4412.63	4011.48	3646.8	3315.27	3013.88	2739.89	2490.81	2264.38	2058.52	1871.39

Table 5.3: Calculation of LC and LCC for the alternative option of replacing 2-stroke bikes by 4-stroke bikes (D3) in Delhi transportation

Option 3: Replacing 2-stroke 2-wheelers by 4-stroke 2-W

2-stroke 2-W	Discount	Life	0	1	2	3	4	5	6	7
Capital cost	0.1	15	28337.6	0	0	0	0	0	0	0
O&M			1000	1000	1000	1000	1000	1000	1000	1000
OC/yr			3697.65	3697.65	3697.65	3697.65	3697.65	3697.65	3697.65	3697.65
Total			33035.2	4697.65	4697.65	4697.65	4697.65	4697.65	4697.65	4697.65
PV		**67641.3**	33035.2	4270.59	3882.36	3529.41	3208.56	2916.87	2651.7	2410.64
LC		**8893.06**								
LCC		1.330798								

4-stroke 2-W	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	15	38462.6	0	0	0	0	0	0	0
O&M			750	750	750	750	750	750	750	750
OC/yr			2227.5	2227.5	2227.5	2227.5	2227.5	2227.5	2227.5	2227.5
Total			41440.1	2977.5	2977.5	2977.5	2977.5	2977.5	2977.5	2977.5
PV		**63374.4**	41440.1	2706.82	2460.74	2237.04	2033.67	1848.79	1680.72	1527.93
LC		**8332.07**								
LCC		1.24685								
PAC		**-0.0335**								

Contd….

Table 5.3: Calculation of LC and LCC for the alternative option of replacing 2-stroke bikes by 4-stroke bikes (D3) in Delhi transportation

8	9	10	11	12	13	14
0	0	0	0	0	0	0
1000	1000	1000	1000	1000	1000	1000
3697.65	3697.65	3697.65	3697.65	3697.65	3697.65	3697.65
4697.65	4697.65	4697.65	4697.65	4697.65	4697.65	4697.65
2191.49	1992.26	1811.15	1646.5	1496.82	1360.74	1237.04

8	9	10	11	12	13	14
0	0	0	0	0	0	0
750	750	750	750	750	750	750
2227.5	2227.5	2227.5	2227.5	2227.5	2227.5	2227.5
2977.5	2977.5	2977.5	2977.5	2977.5	2977.5	2977.5
1389.03	1262.75	1147.96	1043.6	948.723	862.476	784.069

MUMBAI

Table 5.4: Calculation of LC and LCC for the alternative option of using CNG for buses (B1) in Mumbai transportation

Option 1: CNG Bus

Existing buses	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	20	758718	0	0	0	0	0	0	0
O&M			3000	3000	3000	3000	3000	3000	3000	3000
OC/yr			61380	61380	61380	61380	61380	61380	61380	61380
Total			823098	64380	64380	64380	64380	64380	64380	64380
PV		**1E+06**	823098	58527.3	53206.6	48369.6	43972.4	39974.9	36340.8	33037.1
LC		**159937**								
LCC		0.05206	Rs/pkm							

CNG buses	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	20	1058718	0	0	0	0	0	0	0
O&M			2000	2000	2000	2000	2000	2000	2000	2000
OC/yr			39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2
Total			1100001	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2
PV		**1E+06**	1100001	37530.2	34118.3	31016.7	28197	25633.6	23303.3	21184.8
LC		**169768**								
LCC		0.05526	Rs/pkm							

PAC **0.00034**

Contd….

Table 5.4: Calculation of LC and LCC for the alternative option of using CNG for buses (B1) in Mumbai transportation

8	9	10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0	0	0
3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
61380	61380	61380	61380	61380	61380	61380	61380	61380	61380	61380	61380
64380	64380	64380	64380	64380	64380	64380	64380	64380	64380	64380	64380
30033.7	27303.4	24821.3	22564.8	20513.5	18648.6	16953.3	15412.1	14011	12737.2	11579.3	10526.6

8	9	10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0	0	0
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2	39283.2
41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2	41283.2
19258.9	17508.1	15916.5	14469.5	13154.1	11958.3	10871.2	9882.87	8984.43	8167.66	7425.15	6750.13

Table 5.5: Calculation of LC and LCC for the alternative option of using CNG for cars (B2) in Mumbai transportation

Option 2 CNG car

Existing cars	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	18	178095	0	0	0	0	0	0	0
O&M			1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3
OC/yr			20625	20625	20625	20625	20625	20625	20625	20625
Total			200533	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3
PV		**380523**	200533	20398.5	18544	16858.2	15325.7	13932.4	12665.8	11514.4
LC		**46397**								
LCC		1.94303	Rs/pkm							

CNG cars	Discount	life	0	1	2	3	4	5	6	7
Capital cost	0.1	18	213095	0	0	0	0	0	0	0
O&M			1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86
OC/yr			8250	8250	8250	8250	8250	8250	8250	8250
Total			222554	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86
PV		**298429**	222554	8598.96	7817.24	7106.58	6460.53	5873.21	5339.28	4853.89
LC		**36387**								
LCC		1.52384	Rs/pkm							
PAC		**-0.0839**								

Contd…..

Table 5.5: Calculation of LC and LCC for the alternative option of using CNG for cars (B2) in Mumbai transportation

8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0
1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3	1813.3
20625	20625	20625	20625	20625	20625	20625	20625	20625	20625
22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3	22438.3
10467.6	9516.03	8650.94	7864.49	7149.53	6499.58	5908.71	5371.55	4883.23	4439.3

8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0
1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86	1208.86
8250	8250	8250	8250	8250	8250	8250	8250	8250	8250
9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86	9458.86
4412.63	4011.48	3646.8	3315.27	3013.88	2739.89	2490.81	2264.38	2058.52	1871.39

Table 5.6: Calculation of LC and LCC for the alternative option of using CNG for 3-wheelers (B4) in Mumbai transportation

Option 4 CNG 3-W

Existing 3-W	Discount	life	0	1	2	3	4	5	6	7	8
Capital cost	0.1	9	50000	0	0	0	0	0	0	0	0
O&M			1000	1000	1000	1000	1000	1000	1000	1000	1000
OC/yr			54780	54780	54780	54780	54780	54780	54780	54780	54780
Total			105780	55780	55780	55780	55780	55780	55780	55780	55780
PV		**403362**	105780	50709.1	46099.2	41908.3	38098.5	34635	31486.4	28624	26021.8
LC		**70040**									
LCC		1.17913									

CNG 3-W	Discount	life	0	1	2	3	4	5	6	7	8
Capital cost	0.1	9	70000	0	0	0	0	0	0	0	0
O&M			714.3	714.3	714.3	714.3	714.3	714.3	714.3	714.3	714.3
OC/yr			23430	23430	23430	23430	23430	23430	23430	23430	23430
Total			94144.3	24144.3	24144.3	24144.3	24144.3	24144.3	24144.3	24144.3	24144.3
PV		**222952**	94144.3	21949.4	19954	18140	16490.9	14991.7	13628.8	12389.8	11263.5
LC		**38714**									
LCC		0.65174									

PAC **-0.0554**

Table 5.7: Calculation of LC and LCC for the alternative option of BOV 3-wheelers (B5) in Mumbai transportation

Option 5 - BOV 3-W

Existing 3-W	Discount	life	0	1	2	3	4	5	6	7	8
Capital cost	0.1	9	50000	0	0	0	0	0	0	0	0
O&M			1000	1000	1000	1000	1000	1000	1000	1000	1000
OC/yr			54780	54780	54780	54780	54780	54780	54780	54780	54780
Total			105780	55780	55780	55780	55780	55780	55780	55780	55780
PV		**403362**	105780	50709.1	46099.2	41908.3	38098.5	34635	31486.4	28624	26021.8
LC		**70040**									
LCC		1.17913									

BOV 3-W	Discount	life	0	1	2	3	4	5	6	7	8
Capital cost	0.1	9	105000	0	0	0	0	0	0	0	0
Battery			45000			45000			45000		
O&M			750	750	750	750	750	750	750	750	750
OC/yr*			0	0	0	0	0	0	0	0	0
Total			150750	750	750	45750	750	750	45750	750	750
PV		**213962**	150750	681.818	619.835	34372.7	512.26	465.691	25824.7	384.869	349.881
LC		**37152**									
LCC		0.62546									

PAC **-0.05774**

* Charging batteries has been included in the capital cost as ‘battery cost’

5.3 Life Cycle Costs (LCC) of the selected options

Life cycle cost is the operating cost involving per unit output of the alternative option expressed in terms of Rs./unit output (km or pkm). This has been calculated for all the options under consideration both for Delhi and Mumbai. The following equation was used to calculate the life cycle operating cost:

$$\text{Life cycle operating cost} \qquad LCC = \frac{LC}{pkm} \qquad 5.2$$

where

LC levelised cost of the option

Pkm annual passenger-km traveled = annual utilization x load factor of the mode

The results are shown in Table 5.1 to Table 5.7. In case of Delhi it is quite interesting to notice that CNG bus showed a more LCC than that of the existing gasoline bus. LCC of the CNG bus was found to be 0.074 Rs/pkm where as the existing bus it was 0.704. The difference was very insignificant. Hence it would be difficult to assess it potential unless it is compared with the emission reduction. Alternative option II showed a reverse trend as far as LCC is concerned. LCC of the existing car system was found to be 2.4505 where as LCC of the CNG car was found to be 1.9212. This may be due to the fact that retrofitting cost of CNG kits was not very high and the fuel savings were considerable unlike in the case of buses. However, it is interesting to notice that overall life cycle operating cost is much higher for cars in comparison to buses.

Replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers showed a promising trend in LCC with a value of 1.247 over 1.331 for 2-stroke bikes. LCC of all three alternative options are shown in Figure 5.1.

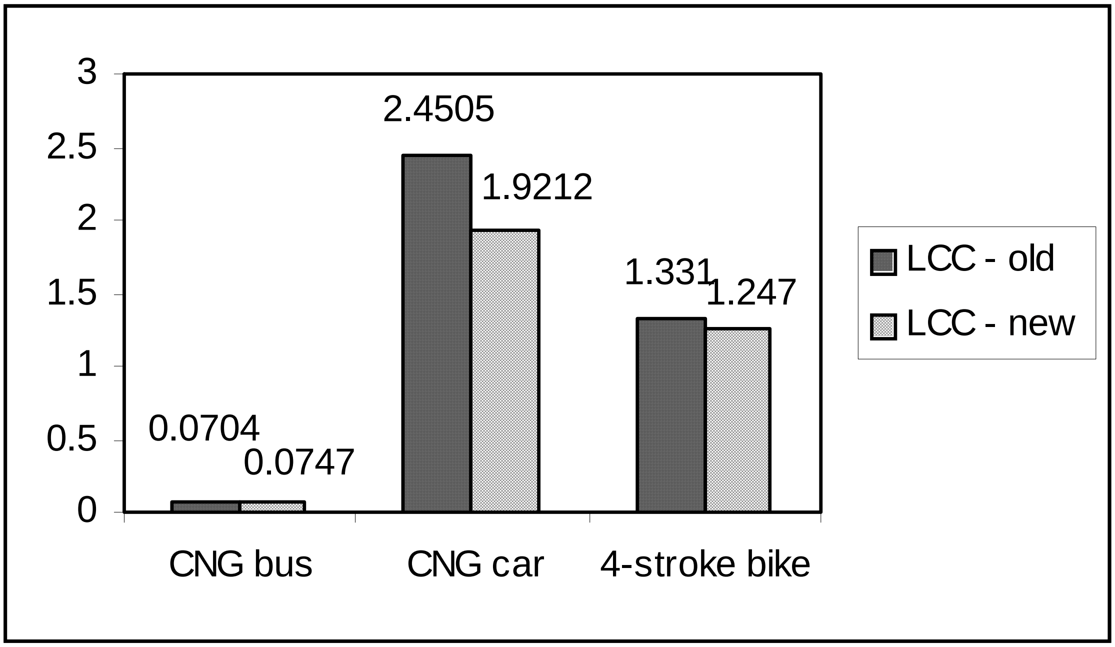


Figure 5.1: Life cycle operating cost of various alternative options for the case of Delhi

As it can be observed from the above figure, LCC of car, which is a personalized mode of transport, is much higher than the other two public modes of transportation. The variation of LCC was found very insignificant for the case of buses, which is a cheaper mode of transport in comparison to 2-wheelers and cars.

Mumbai also poses the similar scenario in the case of LCC. LCC of option I (use of CNG in buses) was found to be slightly higher than the existing system with LCC at 0.05526. LCC of the existing bus system was found to be 0.0521. In the case of CNG cars the LCC was much lesser than that of the existing cars. There was a difference of 22%. Option III and option IV are similar in their trends with option IV showing a better performance. The difference in LCC of the alternative technology over the base case was found to be as high as 44.7 and 47, respectively for alternative option III and IV. LCC of different alternative options are shown in Figure 5.2.

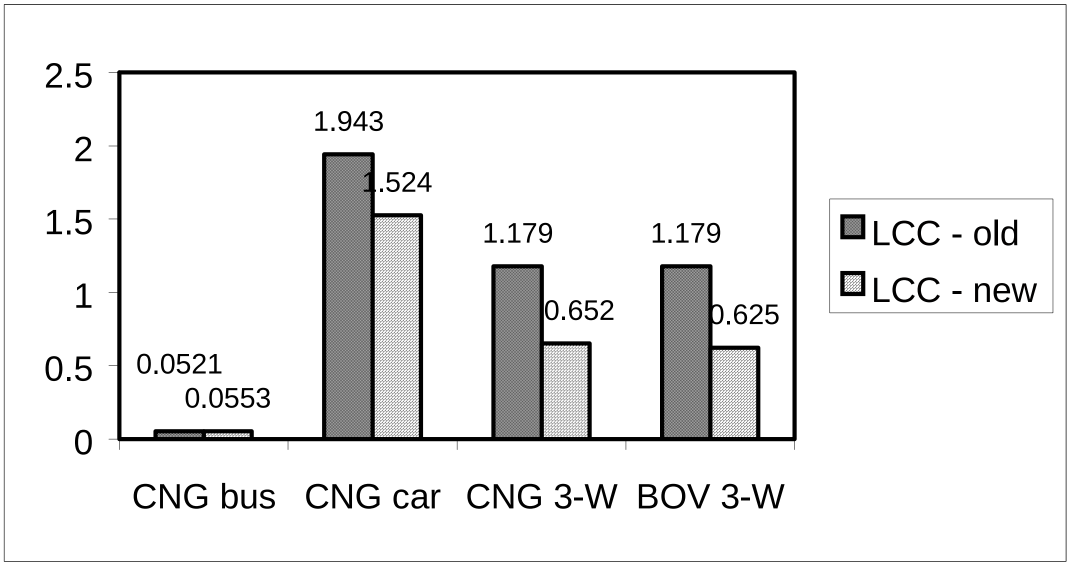


Figure 5.2: Life cycle operating cost of various alternative options for the case of Mumbai

Public transport, a cheaper mode of transport, shows less sensitiveness to the alternative option, as it is apparent from the figure. There was a very insignificant change in LCC of the existing bus and CNG buses. Where as the costly mode of transport showed a much significant change in LCC values.

5.4 Pollution Abatement Cost

For all the options in both Delhi and Mumbai, the emission reduction potential in terms of ERP values and the economic feasibility in terms of LCC were determined. As the two different tools used to alleviate the overall potentiality of the option revealed different stories, to arrive at a overall consensus about these alternative option for urban transport it is required to assess their benefits over costs. Per unit of pollution abatement cost (PAC) is represented by the additional cost, which would be incurred in introducing an environment friendly technology i.e., which would result in reduction of emission from the transport sector. This is derived in terms of Rs./ton and is given by the following equation:

$$\text{PAC} = \frac{\text{LCC}_1 - \text{LCC}_0}{\text{E}_0 - \text{E}_1} \qquad 5.3$$

where

PAC	Per unit of pollution abatement cost
LCC_0	Life cycle cost of the existing technology
LCC_1	Life cycle cost of the alternative technology
E_0	Emission per unit output of the existing technology
E_1	Emission per unit output of the alternative technology

PAC tends to get negative values if the alternative technology is cheaper than the existing one and also less polluting. This attains a positive value if the alternative technology is costlier than the existing one and also less polluting. However, it is possible to get PAC negative if the alternative technology is costly as well as more polluting. This is possible with some alternatives that result in certain non-target increasing pollutants. In such a case the PAC attains a positive value when the technology is cheaper but is more polluting. Table 5.8 demonstrates various possible PAC characters.

Table 5.8: Characteristics of PAC values

PAC	Conditions
Positive (+ve)	Technology is costly and less polluting
Negative (-ve)	Technology is cheaper and less polluting
Positive (+ve)	Technology is costly and more polluting
Negative (-ve)	Technology is cheaper but more polluting

PAC for each alternative option has been calculated both for Delhi and Mumbai are presented in Table 5.1 – 5.7. However, for convenience sake they have been presented in the following table once again:

PAC for various alternative options (including all pollutants)

Alternative option	PAC (Rs/gm)
Use of CNG for buses – DELHI	0.00045
Use of CNG for Cars – DELHI	- 0.1044
Replacing 2-S bikes by 4-S – DELHI	- 0.0335
Use of CNG for buses – MUMBAI	0.00034
Use of CNG for cars – MUMBAI	- 0.0839
Use of CNG for 3-W – MUMBAI	- 0.0554
BOV 3-W – MUMBAI	- 0.0577

From the above table it is apparent that BOV 3-wheelers and CNG 3-wheelers are faring well in controlling pollution at least cost. In Delhi it was CNG cars that were doing well followed by 4-stroke bikes replacing 2-stroke bikes.

5.5 Conclusions

Levelised cost, life cycle operating cost and cost per unit abatement of pollution was determined for each of the alternatives under consideration for Delhi as well as Mumbai. It was observed that car is the most expensive mode of transport in Delhi, followed by 2-wheelers and buses. It was also observed that the difference in LCC for the existing technology and alternative technology was very narrow in the case of buses, which may be due to its low cost. PAC analysis proved that it is expensive to reduce pollution using the CNG bus. CNG car is a much cheaper mode to reduce pollution than that of a shift to 4-stroke bikes.

In the case of Mumbai it was observed that CNG car is the best mode of reducing pollution. As in Delhi, car was found the most expensive mode of transport and bus the most economical. BOV 3-wheelers have proved to be better than CNG 3-wheelers as far as LCC is concerned. PAC was found better in the case of cars followed by BOV 3-wheelers and CNG 3-wheelers. As in the case of Delhi, CNG bus was found to be an expensive mode to reduce pollution.

6. CONSTRUCTION OF MITIGATION SCENARIOS INTEGRATING MULTIPLE MITIGATION OPTIONS

6.1 Introduction

In the previous section, levelised cost, life cycle operating cost and per unit abatement costs were determined for each potential alternative option. They showed varying potential in handling the pollution levels at lower cost. In Delhi it was CNG cars doing well followed by replacement of 2-stroke bikes by 4-stroke bikes and converting the existing buses to CNG buses. In the case of Mumbai, BOV 3-wheelers and CNG 3-wheelers were found doing well in controlling pollution at least cost which were followed by CNG cars and buses.

Though there exist a number of alternative options in discrete attempts, a least cost scenario needs to be developed to achieve the control in pollution over a period of time and at least cost. For this the above list of alternative options needs to be optimized to achieve a globally feasible solution.

6.2 Methodology

The total cost includes capital cost and operational and maintenance cost of the vehicles that should be added during the planning horizon and the operational and maintenance cost of the existing vehicles for the passenger transportation. All costs are expressed as a total net present value to the base year.

- **Variable**

X_{idv}—number of vehicle, mode *i* device *d* to be commissioned in year *v*
V_{idvt} —km traveled by vehicle mode *i*, device *d*, vintage *v*, year *t*

- **Parameters**

C_{idv} --Discounted capital cost of a vehicle mode *i*, device *d*, vintage *v*
S_{idv} --Discounted salvage value of a vehicle mode *i*, device *d*, vintage *v*
O_{idvt} --Operating cost of vehicle mode *i*, device *d*, vintage *v*, year *t*,
OC_{idt} --Occupancy rate of a vehicle, mode *i*, device *d, year t*
L_{idv} --Life period of a vehicle, mode *i* device *d*, vintage *v*
LF_{idt}—Load factor of a vehicle, mode *i*, device *d*, in year *t*
FA_{jt} --Fuel availability of fuel type *j* in year *t*
SFC_{idvt} --Specific fuel consumption of a vehicle, mode i and device d, vintage *v*, year *t*

TD_t --Total travel demand in p-km in year *t*

TD_{it}^{max} --Maximum level of total travel services by transport mode *i* in year *t*

TD_{it}^{min} -- Minimum levels of total travel services by transport mode *i* in year *t*

V_{idt}^{max} --Maximum km traveled by a vehicle, mode *i*, device *d*, year *t*

X_{idt}^{max} --Maximum number of candidate vehicle, mode *i*, device *d*, year *t*

EF_{idvt} --Emission-factor of vehicle, mode *i* device *d*, vintage *v*, year *t*

E_t^{max} --Target level of CO_2 emission in year *t* from all vehicles

E^{max} --Target level of overall CO_2 emission during the planning horizon

GWP_t^{max} —Target level of global warming potential in year *t*

GWP^{max} —Target level of global warming potential during the planning horizon

Objective function:

To minimize total costs (capital, operational and maintenance cost) of new vehicles and operating and maintenance costs of existing as well as new vehicles.

$$\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=1}^{V} X_{idv}(C_{idv} - S_{idv}) + \sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t}\sum_{t=1}^{T} V_{idvt} * O_{idvt} \qquad 6.1$$

Constraints

1) Travel demand constraints

Passenger travel demand

i) Transport services supply in *p-km* in year *t* must be greater than the forecasted demand in the year *t*. *p-km* is calculated by multiplying the *v-km* by occupancy rate.

$$(\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt}) * OC_{idt} \geq TD_t \quad \forall_t$$

ii) Total travel services in *p-km* by each modes (bus, car, 2-wheeler, and 3-wheeler) of transport services in year *t* must be greater than that of the minimum level in year *t*. When the share of HOV increased, the minimum demand for the low occupancy vehicles (car, 3-wheeler and 2-wheeler) will be reduced from the forecasted demand but the minimum demand for the HOV will not be reduced.

$$\left(\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt}\right) * OC_{idt} \geq TD_{it}^{min} \qquad \forall_{i,t}$$

Freight travel demand

iii) Transport services supply in *ton-km* in year *t* must be greater than the forecasted demand in the year *t*. *ton-km* is calculated by multiplying the *v-km* by load factor, (only for goods vehicles).

$$\left(\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt}\right) * LF_{idt} \geq FD_{t} \qquad \forall_{t}$$

iv) Total travel services in *ton-km* by each mode of transport services in year *t* must be greater than that of the minimum level in year *t*.

$$\left(\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt}\right) * LF_{idt} \geq FD_{it}^{min} \qquad \forall_{i,t}$$

2) Availability: Here, the numbers of vehicles is related with vehicle utilization.
Total km traveled by each types of vehicle cannot exceed its availability, which depends on the vehicle utilization rate. The maximum vehicle-km that can be traveled by a vehicle could be the average vehicle utilization rate.

$$\left(\sum_{v=-v}^{t} V_{idvt}\right) \leq \left(\sum_{v=-v}^{t} X_{idv} - \sum_{t=1}^{T} RV_{idt}\right) * V_{idt}^{max} \qquad 6.2$$

Total retired number of vehicles can be represented by the following equation

$$\sum_{t=1}^{T} RV_{idt} = \sum_{v=-v}^{t-L_{idv}} X_{idv}$$

Then the equation (2) can be written as

$$\left(\sum_{v=-v}^{t} V_{idvt}\right) \leq \left(\sum_{v=-v}^{t} X_{idv} - \sum_{v=-v}^{t-L_{idv}} X_{idv}\right) * V_{idt}^{max} \qquad \forall_{i,d}$$

3) Vehicle stock

i) Maximum vehicle stock: for the new technology, total number of new vehicles cannot exceed the total number of vehicles that can be added during the planning horizon (depends on penetration rate).

$$X_{idvt} \le X_{idt}^{max} \qquad \forall_{i,d,t} \quad \text{(For some selected new technology)}$$

4) Resource constraints

For some selected fuel the resource constraint can be applied. Total travel services in v-km depends on the fuel availability for some selected fuels.

$$\sum_{v=-v}^{t} V_{idvt} * SFC_{idvt} \le FA_{jt} \qquad \forall_{j,t}$$

5) Emission constraints

a) This constraint is used when the target is CO_2 emissions reductions.
Emission constraints: The CO_2 emissions are calculated by multiplying the vehicle-km by the CO_2 emission factor.

i) Annual emission constraints: total carbon dioxide emissions by all types of vehicles in a year should not exceed the target level of emission of that year

$$\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt} * EF_{idt} \le E_{t}^{max} \qquad \forall_{t}$$

ii) Overall emission constraints: total carbon dioxide emissions by all types of vehicles during the planning horizon should not exceed the target level, depends on overall emission reduction.

$$\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t}\sum_{t=1}^{T} V_{idvt} * EF_{idt} \le E^{max}$$

b) This constraint is used when the target is Global Warming Potential (GWP). The most recent GWPs (assigned in IPCC, 1996) for the most greenhouse gases are used for the estimation of GWP. GWPS are not provided for the criteria pollutants

CO, NO_x, NMVOCs and SO_2 because there is no agreed upon method to estimate the contribution of gases that have only indirect effects on radiative forcing (IPCC1996).

GWP: The GWP is estimated by multiplying the vehicle-km by the emission factor and with respective GWP assigned in 1996.

iii) Annual GWP constraints: total GWP by all types of vehicles in a year should not exceed the target level of GWP of that year

$$\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t} V_{idvt}\{1*(EF_{idt})_{CO_2} + 21*(EF_{idt})_{methane} + 310*(EF_{idt})_{N_2O}\} \le GWP_t^{max}$$

$$\forall_t$$

iv) Overall GWP constraints: total GWP by all types of vehicles during the planning horizon should not exceed the target level, depends on overall GWP reduction.

$$\sum_{i=1}^{I}\sum_{d=1}^{D}\sum_{v=-v}^{t}\sum_{t=1}^{T} V_{idvt}\{1*(EF_{idt})_{CO_a} + 21*(EF_{idt})_{methane} + 310*(EF_{idt})_{n_2o}\} \le GWP^{max}$$

Delhi and Mumbai present two different cases of transportation with different candidate technologies dominating in each. Therefore, a few amendments have been made to the above mentioned formulation in the respective cases and when and where the situation demanded. An instance for such a change is that freight travel demand constraint was not considered, as there was no room for the freight transport in the list of potential candidates for reducing pollution in both cities under consideration.

The above analysis was aimed at determining the optimal mix of vehicle in any particular year over a time period to achieve the least cost of overall transportation with a set of constraints. Marginal abatement cost of each pollutant under different GHG mitigation scenarios was determined.

6.3 Different Mitigation Scenarios

Based on the technical and economical feasibility study of various alternative options undertaken in the previous section the following options were selected for the determination of optimal mix of vehicle stock for both cases of Delhi and Mumbai.

Delhi:

- 4-stroke 2-wheelers in the place of 2-stroke 2-wheelers
- CNG cars in place of conventional fuel cars (this includes personalized cars and taxis)
- CNG buses in place of conventional fuel buses

Mumbai:

- CNG 3-wheelers in place of conventional 3-wheelers
- Battery operated 3-wheelers in place of conventional 3-wheelers
- CNG cars in place of conventional fuel cars (this includes personalized cars and taxis)
- CNG buses in place of conventional fuel buses

Least cost approach was adapted to determine optimal mix of vehicles for different scenarios. Based on GHG mitigation strategies, the following scenarios are developed and applied in the present study.

Mitigation Scenario I (Base): Base case with out emission regulation (Business-as-usual)

Mitigation Scenario II (MS-I): 5% reduction in the total CO_2 emissions over the time period under consideration

Mitigation Scenario III (MS-II): 10% reduction in the total CO_2 emissions over the time period under consideration

Mitigation Scenario IV (MS-III): 15% reduction in the total CO_2 emissions over the time period under consideration

Mitigation Scenario V (MS-IV): 20% reduction in the total CO_2 emissions over the time period under consideration

Mitigation Scenario VI (MS-V): 25% reduction in the total CO_2 emissions over the time period under consideration

Optimization model was run to determine the total cost of transportation both for Delhi and Mumbai transport systems. Emission of CO_2 constitutes a set of constraints in this optimization model. Various scenarios are constructed based on the emission mitigation levels. BAU scenario considers no emission constraint. Emission mitigation levels of 5%, 10%, 15%, 20% and 25% of total CO_2 emission over the time horizon were considered in the present study.

6.4 Selection of options under different scenarios

DELHI:

Target levels of emission reduction were considered by taking into account CO_2 emissions of BAU scenario over the time horizon. There is a change in vehicular mix for different scenarios in Delhi. In the first scenario (BAU) though pollution abatement is not targeted, minimum level of vehicular penetration was assumed for different categories of vehicles. Given these conditions the change in vehicular mix is not very significant except under considerable pollution mitigation targets. Table 6.1 presents vehicular mix under different scenarios. Technology penetration levels determined in Issue I resulted in considerable addition of CNG vehicles in BAU scenario. It is interesting to note that even without any emission restriction there exist good share of 4-stroke 2-wheelers and CNG cars and buses over the time period. Any restriction in emission resulted in increased share of petrol vehicles in place of diesel vehicles. This trend is clearly visible in case of cars. With increasing emission restriction more petrol cars are chosen over diesel cars. It is interesting to note that share of CNG cars has not shown any change with increased emission restriction. Emission mitigation did not show any change in the trends of vehicle stock in case of buses. More diesel cars are replaced by petrol cars but CNG buses are not chosen over diesel buses. Cars proved to be more effective in controlling CO_2 economically. At a much stricter mitigation strategy CNG cars are also chosen reducing even the number of petrol cars.

At a higher level of emission reduction 2-stroke 2-wheeler were reduced and 4-stroke 2-wheelers dominated. In spite of pollution intensive character, few conventional vehicles viz. 2-stroke 2 wheelers and diesel cars does appear in the table, which indicates the minimum requirement of such mode. Resource constraint was not taken in to account, which might be the reason for considerable share of CNG vehicles over others.

Table 6.1: Vehicular mix under different emission reduction scenarios for Delhi

		2-W		Car			Bus	
		2-S	4-S	P	D	CNG	Diesel	CNG
BAU								
Base		1530944	163032.8	541893	380381.7	0	19211.29	0
	2005	1301910	1074446	661112.6	764854.2	55636	12425	19455
	2010	1271370	2191406	638936.4	962961	130730	9940	26411
	2015	783843	3828203	971670.7	1051742	256939	8709.15	27754
	2020	627074	5768736	1635451	1184333	495357	11441.41	39275
MS I -		5%						
Base		1530944	163032.8	541893	380381.7	0	19211.29	0
	2005	1301910	1074446	661112.6	764854.2	55636	12425	19455
	2010	1271370	2191406	638936.4	962961	130730	9940	26411
	2015	783843	3828203	971670.7	1051742	256939	8709.15	27754
	2020	627074	5768736	*2655083*	*258340.5*	495357	11441.41	39275
MS – II		10%						
Base		1530944	163032.8	541893	380381.7	0	19211.29	0
	2005	1301910	1074446	661112.6	764854.2	55636	12425	19455
	2010	1271370	2191406	638936.4	962961	130730	9940	26411
	2015	783843	3828203	*1896636*	*211722.5*	256939	8709.15	27754
	2020	627074	5768736	*2878447*	*55489*	495357	11441.41	39275
MS – III		15%						
Base		1530944	163032.8	541893	380381.7	0	19211.29	0
	2005	1301910	1074446	687817.5	740601.8	55636	12425	19455
	2010	1271370	2191406	*1603805*	*86703*	130730	9940	26411
	2015	783843	3828203	*2053392*	*69362*	256939	8709.15	27754
	2020	627074	5768736	*2878447*	*55489*	495357	11441.41	39275
MS – IV		20%						
Base		1530944	163032.8	*811567.7*	*135473*	0	19211.29	0
	2005	1301910	1074446	*1383974*	*108378*	55636	12425	19455
	2010	1271370	2191406	*1603805*	*86703*	130730	9940	26411
	2015	783843	*4170067*	*2125908*	*69362*	256939	8709.15	27754
	2020	627074	5782376	*2939547*	*55489*	495357	11441.41	39275
MS – V		25%						
Base		1530944	1693977	*960740.3*	*135473*	0	19211.29	0
	2005	1301910	1074446	*844619.8*	*108378*	55636	12425	19455
	2010	1271370	2191406	*1699275*	*86703*	130730	9940	26411
	2015	783843	*4170067*	*2129768*	*69362*	256939	8709.15	27754
	2020	627074	5782376	*2939547*	*55489*	495357	11441.41	39275

Table 6.2 presents the travel demand and supply of 2 wheelers, cars and buses. Travel demand is, in all cases is less than or equal to the supply by the mix of vehicles.

Table 6.2: Travel demand and supply for different modes of transport in Delhi

	Travel demand (Million PKM)			Supply (Million PKM)		
	2-W	Cars	Buses	2-W	Cars	Buses
1997	11320	18170	39020	11320	18170	43630
2005	15880	29590	48870	15880	29590	54330
2010	23140	34860	66340	23140	34860	75880
2015	30820	45630	69720	30820	45630	82810
2020	42740	65910	98660	42740	65910	115180

In the optimization process maximum utilization of the vehicles (on average) was considered. This resulted in meeting the estimated travel demand. PKM catered by different technologies for the base as well as mitigation cases is given in appendix (Table A1). In the mitigation scenario MS-I (5% reduction), there is a sharp fall in the PKM catered by D-cars adding to the PKM of P-cars. The shift has started to occur in later years of the time domain for lesser mitigation scenario and it spread ahead with time under stringent emission regulation.

MUMBAI:

In the case of Mumbai, four alternative options namely CNG 3-wheelers, BOV 3-wheelers, CNG cars and CNG buses have been tried and minimum cost of alternative options was determined satisfying various set of constraints. Unlike the trend followed in the case of Delhi, CNG vehicles dominated the vehicle stock and also the travel supply. It is noticed that the BOV vehicle and CNG vehicles are chose at milder mitigation scenarios and shifting from diesel to petrol vehicles is observed at higher mitigation scenarios. There is a sharp rise in the number of BOV vehicles over time. It is interesting to see that more CNG buses are chosen over time than cars. This clearly demonstrates the dominance of buses in Mumbai road transport system. BOV 3-wheelers are found to be more chosen more among all 3-W models.

As maximum utilization of the candidate vehicles is considered, the number of vehicles required was found to be less than the projected number in many cases. However the supply of service was always found to be more than the respective demand of that year. CNG bus option was found to be more effective than CNG car option. The vehicular mix for different scenarios is given in Table 6.3.

From Table 6.4 it can be observed that the demand and supply are in a balance. It is interesting to observe that there is a slight difference in the number of vehicles when compared with the demand that has been projected in the earlier section of this work.

Table 6.3: Vehicular mix under different emission reduction scenarios for Mumbai

	3-W			Car			Bus	
	Diesel	CNG	BOV	P	D	CNG	Diesel	CNG
BAU								
Base	54757	60606.06	0	145461	36365	101698.1	6965.017	0.45
2005	78108.1	22902	0	254895	166243	14649	14126.22	0
2010	35045	52051	27382.11	505989.2	23274	37785	14561.92	3893.31
2015	89175.65	74123	1.02	655612.8	18619	76582	22133.26	0
2020	179721.2	52602	0	695314.4	152963	133556	30335.58	0
MS I -								
Base	54757	60606.06	0	*160103.3*	36365	*87055.81*	*6309*	*656.47*
2005	78108.1	22902	0	*392046*	*29092*	14649	14126.22	0
2010	35045	52051	27382.11	505989.2	23274	37785	*11778.71*	*6676.52*
2015	*60140.31*	74123	*29036.35*	655612.8	18619	76582	22133.26	0
2020	179721.2	52602	0	*819329.3*	*28948.11*	133556	30335.58	0
MS – II								
Base	54757	60606.06	0	*197168.7*	36365	*49990.4*	*6309*	*656.47*
2005	*73528.17*	22902	*4579.93*	*392046*	*29092*	14649	14126.22	0
2010	35045	52051	27382.11	505989.2	23274	37785	*8995.50*	*9459.73*
2015	*28036*	74123	*61140.66*	655612.8	18619	76582	22133.26	0
2020	*127119.2*	52602	*52602*	*833382.5*	*14895*	133556	*28801.99*	*1533.59*
MS – III								
Base	54757	60606.06	0	*234234.1*	36365	*12924.99*	*6309*	*656.47*
2005	*55206.1*	22902	*22902*	*392046*	*29092*	14649	*13857.01*	*269.22*
2010	35045	52051	27382.11	505989.2	23274	37785	*6212.29*	*12242.93*
2015	*28036*	74123	*61140.66*	655612.8	18619	76582	*18493.72*	*3639.54*
2020	127119.2	52602	*52602*	*833382.5*	*14895*	133556	*20714.92*	*9620.66*
MS – IV								
Base	54757	60606.06	0	*247159.1*	36365	*0*	*6309*	*1362.72*
2005	*55206.1*	22902	*22902*	*392046*	*29092*	14649	*11019.7*	*3106.52*
2010	35045	52051	*31726.42*	505989.2	23274	37785	*4038*	*14417.23*
2015	*28036*	74123	*61140.66*	655612.8	18619	76582	*14424.03*	*7709.228*
2020	*127119.2*	52602	*52602*	*833382.5*	*14895*	133556	*14038.92*	*16296.66*
MS – V								
Base	54757	60606.06	0	*247159.1*	36365	*0*	*6309*	*2447.12*
2005	*55206.1*	22902	*22902*	*392046*	*29092*	14649	*8182.39*	*5943.82*
2010	35045	52051	51583.3	*505989.2*	23274	37785	*4038*	*14417.23*
2015	*28036*	74123	*61140.66*	655612.8	18619	76582	*10354.33*	*11778.92*
2020	*127119.2*	52602	*52602*	*833382.5*	*14895*	133556	*7888.106*	*22447.47*

Table 6.4: Travel demand and supply for different modes of transport in Mumbai

	Travel demand (Million PKM)			Supply (Million PKM)		
	3-W	Cars	Buses	2-W	Cars	Buses
1998	3600	3400	21400	3600	5400	21400
2005	6000	8300	43300	6000	8299.9	43400
2010	6800	10800	56700	6800	10800	56700
2015	9700	14300	67900	9700	14300	68000
2020	13800	18700	92700	13800	18700	93200

6.5 Mitigation of Pollution under Different Scenarios

DELHI:

Emissions were calculated from the total supply from each mode to the respective years. Table 6.5 presents the difference in total CO_2 emissions under different scenarios of emission reduction.

The mitigation scenarios for CO_2 control resulted in controlling few of the local pollutants like TSP (2.8% under MS-I to 24.8% under MS-V), SOx (6.9% under MS-I and 46.3% under MS-II). However, the other pollutants like CO, NOx, HC and Pb found to be increasing in the atmosphere with the alternative options. Emissions and percentage changes in the emissions of local pollutants are given in the appendix A (Table A2-A8)

Table 6.5: CO_2 reduction potential under different scenarios for Delhi

	CO_2 emission ('000 t)					
	Base	MS I	MS II	MS III	MS IV	MS V
Base year	3449.33	3449.33	3449.33	3449.33	3091.72	2614.74
2005	4665	4665	4665	4629.58	3706.41	2792.31
2010	5796	5796	5796	4516.48	4516.49	4389.88
2015	7011	7011	5786.40	5576.529	5418.03	5412.91
2020	9364	8011.86	7715.66	7715.66	7632.15	7632.15

There is a significant difference in the performance of the model as far as the emission regulations are concerned. The cost was found much lesser in the case of CO_2 mitigation and it was much higher in the case of GWP.

Reduction levels of CO_2 are considerable due to the fact that a potential shift of mode is expected in this time period resulting a change in CO_2 emission. As the developing countries do not have a target level for CO_2 emissions, projected emissions in base case for each year are set as base emission levels and CO2 reduction levels were calculated for each scenarios. Change is CO_2 emission was noticed at higher end of time horizon, which subsequently moved down with stringent emission norms.

When the reduction in total CO_2 emissions over the time period under consideration was studied it is interesting to observe that the measure to reach the target emissions is considered in the later years of the planning horizon. This could be due to the fact that environmental friendly options are more potential in the years to come in comparison to the early stage. And also the penetration would be much stronger than the present time. This would result in achieving the emission reduction much easier than in the present time.

MUMBAI:

Emissions levels were calculated for all scenarios and the corresponding CO_2 emissions are presented in Table 6.6. The CO_2 emissions were calculated externally using the out put data of from the optimization model and the emission factors in the respective cities (Mumbai in this case and Delhi in the earlier case).

As it was mentioned in the previous section, target emissions were taken from the BAU scenario for the respective years. Unlike in the case of Delhi, it is interesting to note that the CO2 mitigation has started uniformly over the time horizon though it is more prominent at higher end of it. This could be due to the reason that more environmentally friendly options like BOV vehicles are considered in the case of Mumbai transport system. Presence of BOV in the options resulted in early result of CO2 reduction even at the mild mitigation target.

Table 6.6: CO_2 reduction potential under different scenarios for Mumbai

	CO_2 emission (‘000 t)					
	Base	MS I	MS II	MS III	MS IV	MS V
Base year	998.408	980.72	995.97	1011.20	990.99	951.80
2005	2051.17	1869.29	1846.09	1743.56	1641.02	1538.48
2010	2012.56	1911.97	1811.39	1710.80	1610.22	1509.63
2015	2942.79	2795.72	2633.09	2501.56	2354.48	2207.40
2020	4233.06	4068.61	3728.09	3435.83	3194.96	2972.26

The mitigation scenarios for CO_2 control resulted in controlling few of the local pollutants like TSP (5.8% under MS-I to 36% under MS-V), SOx (8.4% under MS-I and

43% under MS-V). However, the other pollutants like CO, NOx, HC and Pb found to be increasing in the atmosphere with the alternative options. Emissions and percentage changes in the emissions of local pollutants are given in the appendix A (Table A10-A17). Influence of these mitigation scenarios on TSP, CO, NOx, HC and Pb is much less in Mumbai compared to Delhi. It means that the overall rise in these pollutants is much less than that in Delhi. This could be due to the selection of more BOV and CNG vehicles for Mumbai transport system.

6.6 Marginal Abatement Cost for each pollutant under different scenarios

DELHI:

In this section, marginal abatement cost was determined for each scenario. The vehicle mix was optimized for the minimum cost and the marginal abatement cost was determined using the following equation.

The marginal abatement cost *MC* is given by the following equation.

$$MC_1 = \frac{\sum\left(\frac{(C_1 - C_0)_t}{(1+r)^t}\right)}{\sum\left(\frac{(E_0 - E_1)_t}{(1+r)^t}\right)} \qquad 6.3$$

where
E_0 base level of emissions
C_0 least cost at E_0
E_1 reduced emission level
C_1 least cost at E_1

Total least cost for each scenario was determined using the optimization model and presented in Table 6.7. The cost for base case scenario (BAU) was found to be 16,021,277 USD. The increase in total cost of Delhi transportation for mitigation of 5% CO_2 and 25% CO_2 emission was found to be 0.53% and 5.44%, respectively. Marginal abatement cost for CO_2 mitigation was calculated and presented in Table 6.8. Marginal CO_2 abatement cost varies from 35.68 USD to 115.87 USD. It is considered to be on higher side.

Table 6.7: Cost for CO_2 reduction under different scenarios for Delhi

Emission reduction level (%)	Total cost (USD)
5	16,106,383
10	16,234,043
15	16,340,426
20	16,553,192
25	16,893,617

Table 6.8: Marginal Abatement Cost (MAC) under different scenarios for Delhi

Emission reduction level (%)	MAC (USD)
5	35.68
10	44.59
15	49.08
20	66.08
25	115.87

Figure 6.1 presents the variation of abatement costs with changing levels of emissions reduction. As it can be observed from figure 6.1, CO_2 reduction cost went up drastically as the reduction level goes up.

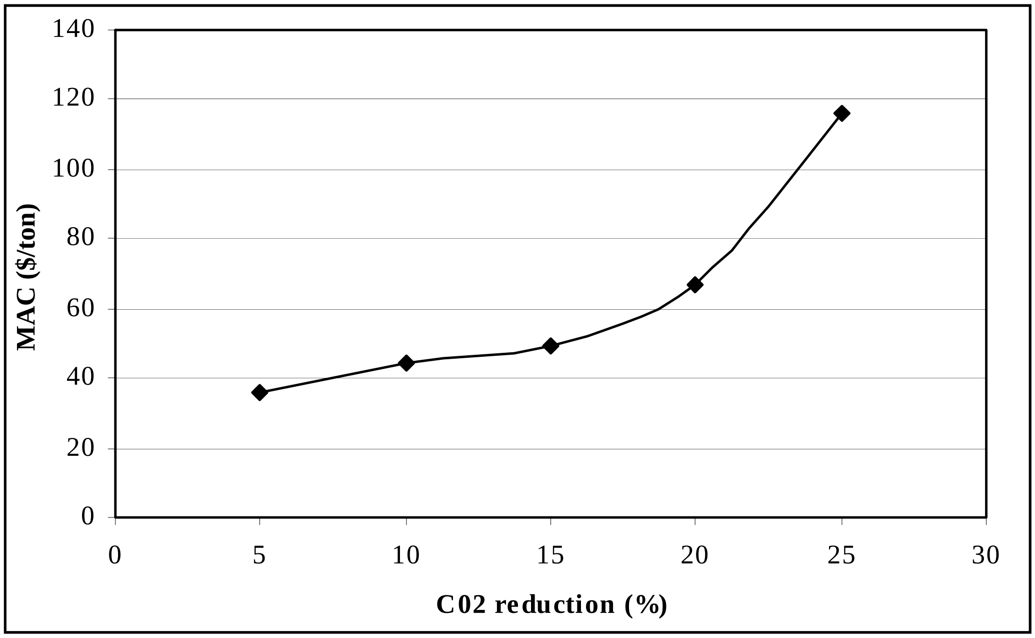


Figure 6.1: Variation in the least cost against the level of CO_2 reduction in Delhi

It was observed that least cost for the abatement is higher in the case of GWP. The difference was found to be around 22%. MAC was found to be less when multiple pollutants are considered in comparison to the CO_2 reduction alone.

MUMBAI:

Total least cost for Mumbai transport under BAU scenario was found to be 4,276,596 USD. This is just 73.3% of the total cost of Delhi transport system. The increase in total cost of Mumbai transportation for mitigation of 5% CO_2 and 25% CO_2 emission was found to be 0.497% and 1.99%, respectively. Rise in MAC is very less compared to that of Delhi

(5.44%). Total cost of Mumbai transport system is presented in Table 6.9. Marginal CO_2 abatement cost under different mitigation scenarios is presented in Table 6.10.

Table 6.9: Cost for CO_2 reduction under different scenarios for Mumbai

Emission reduction level (%)	Total cost (USD)
5	4,297,872
15	4,302,128
20	4,319,149
25	4,340,426
30	4,361,702

Table 6.10: Marginal Abatement Cost (MAC) under different scenarios for Mumbai

Emission reduction level (%)	MAC (USD)
5	17.48
15	19.51
20	21.44
25	24.02
30	47.51

MAC for Mumbai is almost half that of Delhi. This presents an interesting case of CO_2 mitigation. *In a city like Delhi where pollution levels have gone up considerably over time resulting in increased efforts and policy decisions, it would always be expensive to incorporate any further efforts in reaching emission targets. Where as, in cities like Mumbai where the pollution is on rise but still to reach the threshold levels the mitigation of CO_2 would be much cheaper*. This shows that difference in state of environment in both mega metro cities of India. Combating green house gas emissions over a period of 20 years is found to be less expensive in Mumbai than in Delhi.

The trend is shown in Figure 6.2.

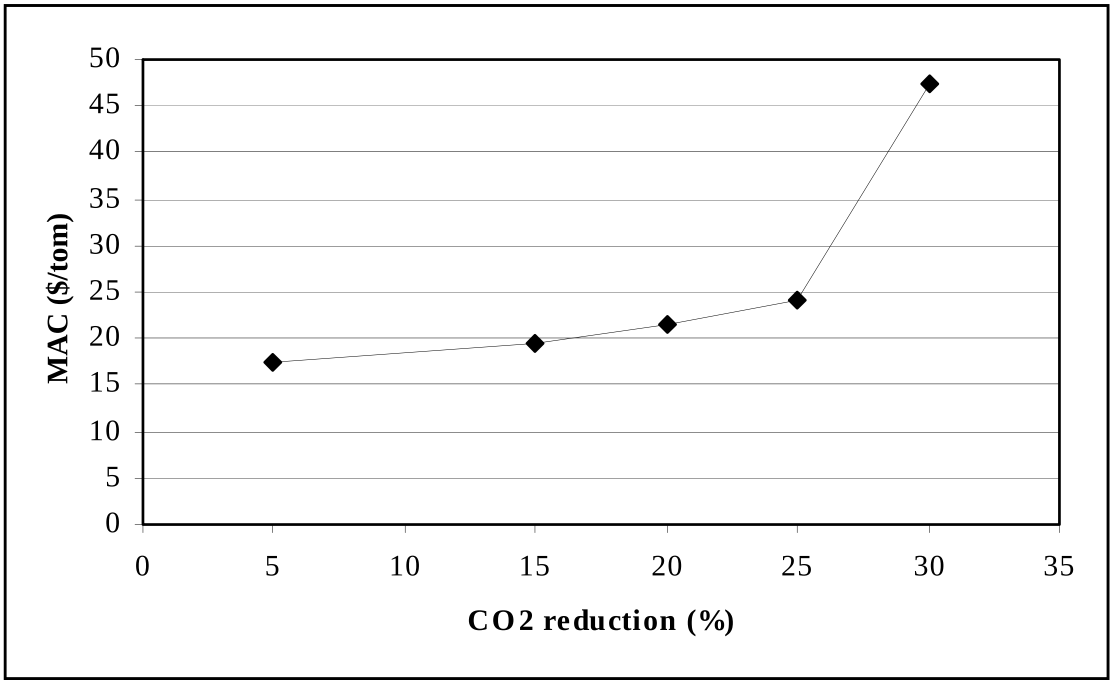


Figure 6.3: Variation in the least cost against the level of GWP reduction for Mumbai

6.7 Conclusions

In this chapter minimization of costs in mitigating global environmental emissions was carried out with a given set of constraints. In the case of Delhi, it was observed that alternative options viz. 4-stroke 2-wheelers, CNG cars and CNG buses are more prominent and in case of Mumbai CNG 3-wheelers, BOV 3-wheelers, CNG cars and CNG buses are more prominent.

In Delhi transport efforts towards the mitigation of CO_2 resulted in reduced use of diesel cars. More travel demand was catered by petrol cars with the share of CNG car remaining more or less uniform. However, diesel cars also had a major share in catering for the travel demand in the initial period but diminishing with time. Cars are found to be targeted more than buses for emission mitigation. The change in vehicular mix was observed in later phase of the time horizon. In Mumbai, unlike Delhi, the change in vehicular mix due to emission mitigation strategy was found to be happening from the initial phase of the time horizon. BOV 3-wheelers are chosen against the conventional 3-wheelers and this option has made the choice very easy. This could be felt with increased share of BOV 3-Ws in Mumbai transport over the time horizon. A shift from D-buses to CNG buses was observed in Mumbai. Unlike Delhi, this change is significant compared to CNG cars which demonstrated the dominance of efficient bus network in Mumbai.

Marginal CO_2 abatement cost in Delhi was found to be double the cost in Mumbai. In Delhi where significant efforts are already made to combat the ever increasing emissions getting closer to the threshold efforts to mitigate CO_2 were found expensive. Where as, in cities like Mumbai where the pollution is on rise but yet to reach the threshold levels, mitigation of CO_2 would be much cheaper. Combating green house gas emissions over a period of 20 years is found to be less expensive in Mumbai than in Delhi.

Barrier analysis is warranted for the above mentioned alternative options as they provide a lot of resistance to their adoption. Options like the CNG vehicles and BOV vehicles would have a number of issues in influencing their promotion. For better implementation they need to be analysed thoroughly and suitable policy recommendations accordingly.

7. CONCLUSIONS AND RECOMMENDATIONS

In this part of the study, which is one component of a bigger study, the technological and economical feasibility of few alternative technologies was carried out for two cities namely Delhi and Mumbai. In the previous exercise, the travel demands, energy demands and possible emissions were calculated for Delhi and Mumbai. The present study was carried out in continuation of that study and getting inputs from part one of this research work.

There exists a list of alternatives to reduce the environmental emissions from transport sector and they can be placed in two broad categories of alternative fuels and alternative technologies. As a generalized opinion, it is easy to obtain results with alternative fuels than with the alternative technology as the penetration of technology shows more friction. Based on various criteria and also the existing trend of the vehicle stock few options were selected for Delhi and Mumbai. In the case of Delhi four options were selected viz. use of CNG for buses, use of CNG for cars, shift of 2-stroke 2-wheelers to 4-stroke 2-wheelers, and BOV buses. For Mumbai five alternative options were selected namely use of CNG for buses, use of CNG for cars, shift of 4-stroke 2-wheelers to 4-stroke 2-wheelers, use of CNG for 3-wheelers and BOV 3-wheelers.

Potential of all the selected options to reduce emission of various pollutants was found out as ERP (emission reduction potential). ERP tends to unity to show the better performance and a negative value shows a rise in pollution. In the case of Delhi it was found that all options were showing better potential. However, BOV buses are a difficult proposition for technology penetration and also its present status being very insignificant, that option was not considered further. Two wheelers showed a moderate performance in comparison to others. However due to the fact that, Delhi traffic is dominated by 2-wheelers, it was selected for further scrutiny. Option one 1 & 2, use of CNG for bus and car respectively, showed a slight rise in CO_2 emissions.

In the case of Mumbai, it was found that except the option of shift from 2-stroke 2-wheelers to 4-stroke 2-wheelers all other options fared relatively well. It may be due to the reason that the 2-wheelers are not dominating mode of transport and so could not show much a potential. Alternative 1 & 4, use of CNG for bus and 3-wheeler respectively have contributed to CO_2 emissions. BOV 3-wheelers are found to be highly potential and also feasible in practice. Therefore, they are selected for further analysis for their economic feasibility. In the case of Mumbai four options were selected for further economic analysis and they are: use of CNG for bus, use of CNG for car, use of CNG for 3-wheelers and BOV 3-wheelers.

Economic feasibility was tested for all the selected and potential emission control options both for Delhi and Mumbai. For both cases of Delhi and Mumbai it was found that life cycle operating cost of bus was very less. And may be because of that the variation in LCC of the existing and alternative technologies was not very significant. And also it is quite interesting to note that CNG bus proves uneconomical as far as the unit pollution abatement cost is concerned. In the case of Delhi, CNG car proved much better with a better PAC (104.4 Rs./kg of pollutant). There is a considerable difference between the performance of CNG cars and 4-stroke 2-wheelers. In the case of Mumbai CNG bus seems to be an expensive option to mitigate a unit of pollution in comparison to other options. Among the other three options, CNG cars proved economical for pollution reduction. Battery operated 3-wheelers are not only efficient in reducing pollution but are cost effective in reducing pollution. In spite of their high initial investment BOV 3-Wheelers proved economical possibly because of their advantage with fuel and other costs.

Section III

Ranking of Barriers for Alternative Options in Urban Transport System

1. OBJECTIVE

Barriers to energy efficiency improvement of urban transport system

For any alternative technology or management option to succeed their adaptability plays an important role. For every option in the urban transport sector to improve efficiency, there exist a variety of barriers from different domains. It is essential to identify all such important barriers and rank them according to their importance. This would help in tailoring efforts to overcome those barriers to achieve better adaptability of the alternative options under consideration. This process of identifying barriers and ranking them needs to be done with due consideration to the opinions of all actors involved in transport system. This report presents such exercise carried out for Delhi and Mumbai transport systems.

Alternatives options short listed in section II are considered as candidates and set of barriers are identified for each one of them.

2. METHODOLOGY

All alternative options have to fit into the existing transportation system. Moreover, any alternative option will have a wide range of barriers of its own penetration. The range of barriers would include various technological, infrastructural, informational, cultural, institutional and administrative, political, economical, financial, individual barriers that affect the implementation. Identification of barriers to an alternative technological option requires detailed understanding of the option and the mechanism of its implementation. Knowledge of the other sectors and activities inter-linked with the option is also essential to identify a correct set of barriers.

While identifying barriers to any particular alternative option it is essential to consider the conditions and geographical location where the option is going to be implemented. These factors would, to a great extent, pose certain barriers.

In the case of Delhi, three options were considered namely, CNG buses, CNG cars and 4-stroke 2-wheelers. In the case of CNG buses there exists a number of barriers to their implementation. The list of barriers could include, non-availability of indigenous technology of CNG conversion kits, high cost of conversion kits, high cost of CNG buses, inadequate resources (availability of fuel), inadequate infrastructure (CNG filling stations), poor knowledge of the advantages of this technology, lack of awareness, lack of enforcing mechanism, high operating costs due to the new fuel, reduced life of the vehicles, possible rise in transportation costs, increase in noise pollution, unreliability of technology and so on. In case of CNG cars, most of the above barriers may also be there but some barriers may not because of the difference in operating conditions, number and the ownership. Hence, the set of barriers to CNG bus and CNG cars would differ. In case of 2-wheelers the list of barriers could include availability of technology, reliability of technology, additional cost on the owner, lack of awareness about the benefits of this option, lack of enforcing mechanism, affordability, political, market based barriers and so on. Many people may not be aware that 4-stroke two wheelers are energy efficient and result in lesser emissions and hence may not go in for these. It is also possible that due to higher cost involved in 4-stroke 2-wheelers affordability may be another barrier. Manufacturers may not go for more production of 4-stroke 2-wheelers due to the fact that they are expensive and so there is a possibility of fall in their acceptability in the market. Moreover, 2-stroke 2-wheelers have their minimum demand to be met.

Hence, selection of barriers to each option has to be done by considering that particular option, its merits and demerits. Following section presents the list of barriers identified for each option under consideration.

For the case of Mumbai three options were considered viz. CNG cars, CNG 3-wheelers and BOV 3-wheelers. Mumbai traffic is clearly dominated by 3-wheelers and cars. 2-wheeler population is not high. On the other hand, Mumbai has one of the best public transport systems that include a very efficient metro system and a bus network. The bus system could not qualify as an alternative option because of the reason that it is already a very efficient system both for energy use and emission control. Other option showed considerable difference in energy efficiency and emission mitigation with alternative fuels compared to buses. Mumbai, has very different set of alternatives from Delhi. This presents a very different scenario for barriers. Mode of transport determines the importance of the barrier to a great extent. In the case of CNG cars, the list of barrier may be the same as that of Delhi. However, the high congestion on roads and character of uni-directional flow of traffic may be a barrier to implement CNG cars in Mumbai. Infrastructure barriers to CNG cars could be more prominent in Mumbai than in Delhi as the road network is entirely different and poses severe constraints in establishing an efficient network of CNG stations. In the case of CNG 3-wheelers (popularly known as autos), the significance of barriers would differ from that of CNG cars. Among cars, private cars dominate the taxis population where 3-wheelers population contributes mainly to the public transport. Hence the character of ownership would lead to a very different scenario of barriers. A list of barriers selected based on these considerations is presented for the case of Mumbai, in the next section.

3. TYPE OF BARRIERS

Based on the above discussion and conditions prevailing in the respective cities, the following barriers have been selected for different options under consideration for Delhi and Mumbai.

Delhi

3.1 Technological Option 1: Conversion of conventional buses to CNG buses -

Barrier 1: Availability of Efficient Technology/Conversion Kits
Barrier 2: Additional Costs
Barrier 3: Inadequate Resources and Infrastructure
Barrier 4: Absence of Enforcing Mechanism

This technical option presents a set of barriers encompassing technical, financial, resource, infrastructure, administrative and management barriers. At present CNG conversion kits for buses are imported and hence the cost is high. Indigenous production of CNG conversion kits for the buses would certainly make adoption of CNG buses easier. Additional cost is a financial barrier. CNG conversion kit adds to the cost of vehicle. That is extra financial burden to implement the introduction of CNG buses. Even the factory made CNG buses cost higher than that of conventional vehicles and hence entails additional financial burden. As and when this barrier fades away the implementation of CNG buses would be better.

Inadequate resources and infrastructure could be a major barrier especially for CNG technology. For the option of CNG bus inadequate infrastructure may not be a problem as most of the buses are run by one or the other corporation who posses their own refueling stations. However, the lack of CNG availability would pose a severe constraint for the penetration of CNG buses. In fact this barrier has influence on many other issues. The possible future needs for CNG imports would put additional burden on the user and create financial barriers depending on international CNG prices and exchange rates. Absence of enforcing mechanism is another major barrier for the implementation of CNG buses. This barrier is in the category of Management and Administration barriers. With many barriers prevailing for the alternative technology there is always a tendency for the user to try escape from CNG conversion. Mechanism to administer this option is of great importance. Hence this was chosen as an important barrier for this alternative option.

3.2 Technological Option 2: Conversion of conventional cars to CNG cars -

Barrier 1: Availability of Efficient Technology/Conversion Kits
Barrier 2: Additional Costs
Barrier 3: Inadequate Resources and Infrastructure
Barrier 4: Lack of Awareness

From the above list of barriers, first, second, third and fourth barriers represent technological, financial, resource & infrastructure and awareness barriers, respectively. CNG technology has a few common barriers to buses as well as cars. However there exists a difference among some of the barriers as explained below. For example, conversion kits for CNG cars are not indigenously made and importing them is putting a lot more burden on the users. Unlike the buses, where the burden on passengers is marginal, cars are individual units and put strong burden on the owner on its implementation compared to buses. Currently, available retrofits have problems, giving rise to serious safety issues. The availability of efficient retrofits and their easy accessibility is an important barrier for greater penetration of CNG cars in Delhi.

Additional cost is another very important barrier for CNG cars. Retrofitting kits are imported and hence are considerably expensive. Factory made CNG vehicles are available from Maruti and Bajaj but they cost more than the conventionally fueled vehicles. This puts an additional burden on the average car owner and hence for more penetration of this cleaner option in Delhi. Bringing down the difference between the prices of conventional and CNG vehicles would certainly make this option more penetrating.

Infrastructure and resource availability are of great importance for CNG technology as it is relatively a new option which needs considerable efforts to establish itself. Resource availability is a barrier and its consequences have been explained in the previous paragraph. Unlike CNG buses, infrastructure is a very important barrier in the case of CNG cars. Due to lack of wide spread network of filling stations CNG car owners face many problems and this makes them not to prefer CNG vehicles to the conventional one. Removing this barrier would certainly make a way for its smooth implementation. Unlike CNG buses, lack of awareness is a major barrier for CNG car option. Cars, having a character of individual ownership need much more awareness campaign than do buses. Lack of awareness about the benefits of CNG cars over conventional cars is a major reason why people are not opting for this energy efficient and cleaner option.

3.3 Technological Option 3: Replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers -

Barrier 1: Availability of Alternative Technology
Barrier 2: Additional Costs
Barrier 3: Lack of Awareness
Barrier 4: Absence of Mechanism for its Implementation

Delhi roads are clearly dominated by 2-stroke 2-wheelers. They are known for their hydrocarbon emissions. Hence, replacing 2-stroke vehicles by 4-stroke vehicles was considered as an option for Delhi and the above four barriers have been identified as major barriers to its implementation. They represent technological, financial, awareness and management & administration barriers, respectively. Availability and easy accessibility of technology is a major barrier to this alternative option. Most of the 4-stroke 2-wheelers on the roads are manufactured by foreign collaborations. Easy accessibility of technology certainly make this option more easy to penetrate and this would also have implications for other related barriers. Additional cost for 4-stroke 2-wheelers in comparison to 2-stroke 2-wheelers is a financial barrier. This certainly holds back people from switching over even though there are clear advantages of the 4-stroke vehicles. Moreover, lack of awareness is also a major barrier to this option. If advantages of this option are made clear, the option will become widespread in spite of the financial barrier.

Lack of mechanism to enforce this change is another challenge as the vehicle population is very high and difficult to monitor. Unlike buses, it is a major barrier in the case of 2-wheelers.

Mumbai

Having discussed the above in the context of Delhi and also in general for India, we now look at the barriers to Mumbai. For the option of CNG vehicles, the barriers are similar for Delhi and Mumbai. However, the importance (ranking) of barrier may change, as the conditions are very different in Mumbai from those in Delhi. For instance, absence of policy and enforcement mechanism as a barrier may have more significance in Mumbai than in Delhi where policy decision has already been taken despite the fact that the city geography and the nature of existing traffic are favourable in Mumbai. Similarly CNG availability and additional costs may differ from Delhi due to the fact that Mumbai has easy access to CNG compared to Delhi due to its proximity to the oil fields. Hence, difference in priority on barriers is expected in the case of CNG options in Delhi and Mumbai.

3.4 Technological Option 1: Conversion of conventional cars to CNG cars -

Barrier 1: Availability of Efficient Technology/Conversion Kits
Barrier 2: Additional Costs
Barrier 3: Inadequate Resources and Infrastructure
Barrier 4: Absence of Enforcing Mechanism

Barriers to penetration of CNG cars in Mumbai represent technical, financial, resource & infrastructure and management & administrative barriers.

3.5 Technological Option 2: Conversion of conventional 3-wheelers to CNG 3-wheeler -

Barrier 1: Availability of Efficient Technology/Conversion Kits
Barrier 2: Additional Costs
Barrier 3: Inadequate Resources and Infrastructure
Barrier 4: Absence of Enforcing Mechanism

This option presents a very different case of Mumbai traffic and clearly emphasizes the importance for public transport in Mumbai. Barrier for this option represents technical, financial, resource & infrastructure and administration barriers in their order. 3-wheelers are used as means of public transport though it is a kind of personalized transportation mode. It presents a special case, which stands between buses and cars. Hence, this mode presents a very special scenario for all these barriers identified. Barriers to CNG technology for different modes may be similar but the importance of barriers would differ to a considerable extent. Technology availability may not have similar impact on CNG 3-wheelers implementation compared to CNG cars due to the difference in the character of ownership. But the same barrier may show much more indirect influence by means of reduced cost due to easy availability of technology. Factors like the safety and increase in noise may not influence the implementation of CNG 3-wheelers.

Additional cost as a barrier is very important for reason that it not only influences the owner of the vehicle but also the user. Though the operating cost is less in the case of CNG 3-wheelers, higher capital cost creates some friction for its implementation. Bajaj has been producing CNG 3-wheelers indigenously. However, the price has to be made reasonable to attract prospective buyers of 3-wheeler owners. Financing agencies have a major role to play in removing this barrier. The other two barriers viz. lack of resources and infrastructure and lack of enforcing mechanism presents similar argument as that of CNG cars. In the recent past Delhi has witnessed a severe problem of scarce CNG filling stations with CNG 3-wheelers lining up for a kilometer or two to fill their tanks. This is certainly a prominent barrier to this alternative option. The authorities are assuming that this will be a short-term problem till more stations are set up. However, the availability of CNG itself could be a serious problem.

3.6 Technological Option 3: Conversion of conventional 3-wheelers to BOV 3-wheeler -

Barrier 1: Availability of Alternative Technology
Barrier 2: Additional Costs
Barrier 3: Lack of Awareness
Barrier 4: Absence of Mechanism for its Implementation

This option qualified in the case of Mumbai, presents a very special case and shows the importance that advanced technologies like BOV are going to receive in future transportation systems. Barriers to this alternative option represent technological, financial, awareness and administrative barriers, respectively. Battery operated vehicles are still under examination for various facts and hence the specifics of technological parameters are yet to be determined. This is going to be a very important barrier. Though the technology has been proven in many places, it is yet to reach the developing world and hence is a major barrier to its implementation. Additional cost may not be stronger as its maintenance cost is supposed to be negligible making it more economic. However, the initial investment would certainly be a barrier. This alternative option has very distinct advantages such as zero maintenance cost, low operating cost and absolutely emission free ride. A strong awareness campaign is needed to convince people about this very effective option.

4. RANKING OF BARRIERS

Not just the barriers and their nature but their importance should be considered while assessing them. A proper ranking of barriers with due consideration to all factors and actors involved should be done to identify most important barriers so that possible policy suggestions and action to alleviate them can be taken up. In this part of the report, the previously identified barriers to all alternative options for Delhi as well as Mumbai are ranked based on a systematic analysis using multiple criteria decision making tools, analytic hierarchy process in particular (AHP).

4.1 Construction of Hierarchy In Analytic Hierarchy Process

Priority setting exercise is well established with considerable literature support to it. Usually ranking is done by using quantitative approach with various optimization techniques. There are many methodologies documented even for qualitative technique based priority setting. However, the problem takes a different form altogether when it involves group aggregation. For priority setting from a group of members and based on qualitative and or quantitative criteria, Analytic Hierarchy process was found to be one of the most widely applied methods. The AHP (Analytical Hierarchical Process) Model is a suitable tool for this because AHP combines deductive approach and systems approach of solving problems into one integrated logical framework. The three principles of guidance in AHP are decomposition, comparative judgement and synthesis of priorities. This method is simple, practical, systematic and effective. It has been widely used for conducting such undertakings as analysis of energy planning, distribution of resources planning, conflict resolution, selection of projects, etc. and useful results have been obtained.

Analytic Hierarchy Process, well known as AHP was developed by Thomas L. Saaty in 80s. It is one of those specialised tools based on priority theory that are applied for decision making process both for individual decision-making and group decision-making. AHP, unlike other decision-making tools, has the capability of handling both qualitative and quantitative parameters in its process. Integrated multi-criteria decision-making system with other methods viz. goal programming, linear programming etc are also proposed (Ramanathan and Ganesh, 1995). Unlike quantitative criteria, qualitative criteria are difficult to judge and AHP provides a platform for such situations. Figure 4.1 shows the general principle of AHP schematically. The fundamental principle of AHP is the “pair-wise comparison of different variables that are given numerical values for their subjective judgements on relative importance of each of the variables following a hierarchy and coming out with assigning relative weightage to those variables”. This process breaks down a complex and unstructured situation into components forming a hierarchy. Then the scale developed by Thomas L. Saaty (Table 4.1) is used to make pair-wise comparisons which are subsequently synthesizes to get the final priorities of the alternatives.

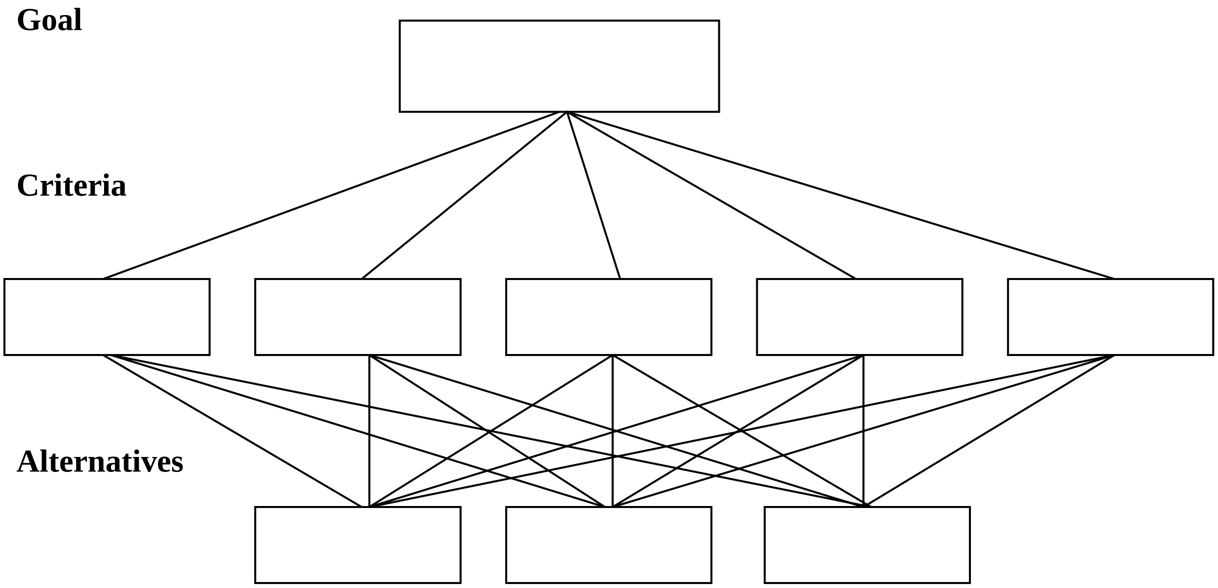


Figure 4.1 General Principle of AHP

Table 4.1 Pair-wise Comparison Scale for AHP Preferences

Verbal Judgement of Ranking	Numerical Rating	Explanation
Equal important	1	Two activities contribute equally to the objective.
Moderate importance of one over the other	3	Experience and judgement slightly favor one activity over another.
Essential or strong importance.	5	Experience and judgement strongly favor on activity over another.
Very strong importance.	7	An activity is strongly favored and its dominance demonstrated in practice.
Extreme importance.	9	The evidence favoring one activity over another is of the highest possible order of affirmation.
Intermediate values between the two adjacent judgements	2,4,6,8	When compromise is needed.

Saaty (1989)

The hierarchy system would be formulated with objectives (termed as the focus), criteria and the different options (the barriers). Information is collected by means of personal interviews with a specially designed questionnaire. Interviews are conducted to find their opinions regarding the constraints and barriers against implementing the feasible alternative options in the transport sector. This information is then used to rank the barriers to each of the alternative options, analyzed in objective 2. Data collected through questionnaire survey is analysed using Expert Choice to arrive at priorities. Expert Choice is a software developed based on analytic hierarchy process.

4.1.1 Formulation of the Problem

Objective:

The overall objective is to rank the barriers to energy efficiency improvement of Delhi and Mumbai transport systems.

Actors:

Different actors have different perceptions about the barriers and the effect of barriers. The following actors are identified as having influence over the ranking of barriers:

A. Energy/Environment Experts
B. Policy Makers
C. Users (General public)
D. Manufacturers of equipment
E. Retailers of equipment
F. Business Community (investors/lenders)

Criteria:

In order to rank the barriers we must define the attributes or criteria by which it will be ranked. These attributes are based on the characteristics of barriers. Barriers obstruct n adoption of a technology and range from minor obstruction to major ones. Some barriers are easy to understand while others are not. Barriers may be incidental i.e. created or exist without knowledge of the person taking the decision. At times, barriers may be intentionally created to achieve certain other goal or to restrict the access. Following criteria are selected based on which the priority of barrier is set.

Criteria 1: Monetary Cost to Remove the Barrier
Criteria 2: Level of Political/Bureaucratic Efforts
Criteria 3: Impact on Adoption
Criteria 4: Life of Barrier

Level of efforts to create awareness was not considered under the category of criteria as it is a barrier by itself. As lack of awareness is a major barrier for many options under consideration viz. replacing 2-S 2-W by 4-S 2-W and BOV 3-W, it was considered as a barrier. This resulted in ignoring it as a criterion.

Criteria are very important in setting the priorities of barriers. Pair wise comparison differs to a great extent from the criteria based on which the comparison was made. Hence, the definition of criteria needs to be very clear and easily understandable to the respondents. Criteria listed above are defined as follows:

Criteria 1: Monetary Cost to Remove the Barrier

"Monetary efforts, direct or indirect, that are required from Government and/or other agencies to overcome a particular barrier". Cost of removing the barriers varies with the type and nature of barriers. Cost in the form of subsidy can be used to remove the barrier related to high initial cost and the high cost of capital. Similarly, barriers of information and awareness could be overcome through financing in internet facilities, TV/local paper advertisements and public campaign programs.

Criteria 2: Level of Political/Bureaucratic Efforts

"Level of political/bureaucratic efforts or lobbying required at various levels of hierarchy to overcome any particular barrier". It is believed that political and bureaucratic efforts could play a major role in removing the barriers. Such efforts may be in the form of lobbying by the politician, bureaucratic initiatives, and clear instruction of the policy makers.

Criteria 3: Impact on Adoption

"Level of ease in implementing a particular option by removing this barrier". Different barriers have different levels of impact on the adoption of efficient options. Removing a particular barrier could result in a higher level of introduction of efficient options than some other barriers. This feature implicitly recognizes the importance and complexity of barriers. Barrier that is easy to overcome may have less impact in terms of adoption of options. On the other hand, barrier that is difficult to remove may have larger impact in adoption of options.

Criteria 4: Life of Barrier

"Time span over which the barrier remains a barrier". Each barrier has its own life, i.e., the time it takes to cease. Without any external intervention, some barriers tend to last long compared to other barriers. Normally, barriers with shorter life would be preferable to longer ones.

Decision Alternatives:

Barriers to be ranked are the decision alternatives in the present case of study. The barriers to be ranked are those identified in the previous section. This whole exercise of setting priorities is done for all three options in the case of Delhi and Mumbai, respectively.

Delhi:

Figure 4.2 and 4.3 shows the representative hierarchy tree (for option 1 respectively) employed in the present study for Delhi and Mumbai, respectively. The similar trees have been generated for all options and their priority derivation exercise.

The next step is to establish priorities of different actors, criteria and alternatives and this is done based on pair wise comparison scale shown in Table 4.1. Inconsistencies of all pair wise judgement should be less than or equal to 10%.

Figure 4.2 AHP Hierarchy tree for the ranking of barriers to alternative options in Delhi transport sector

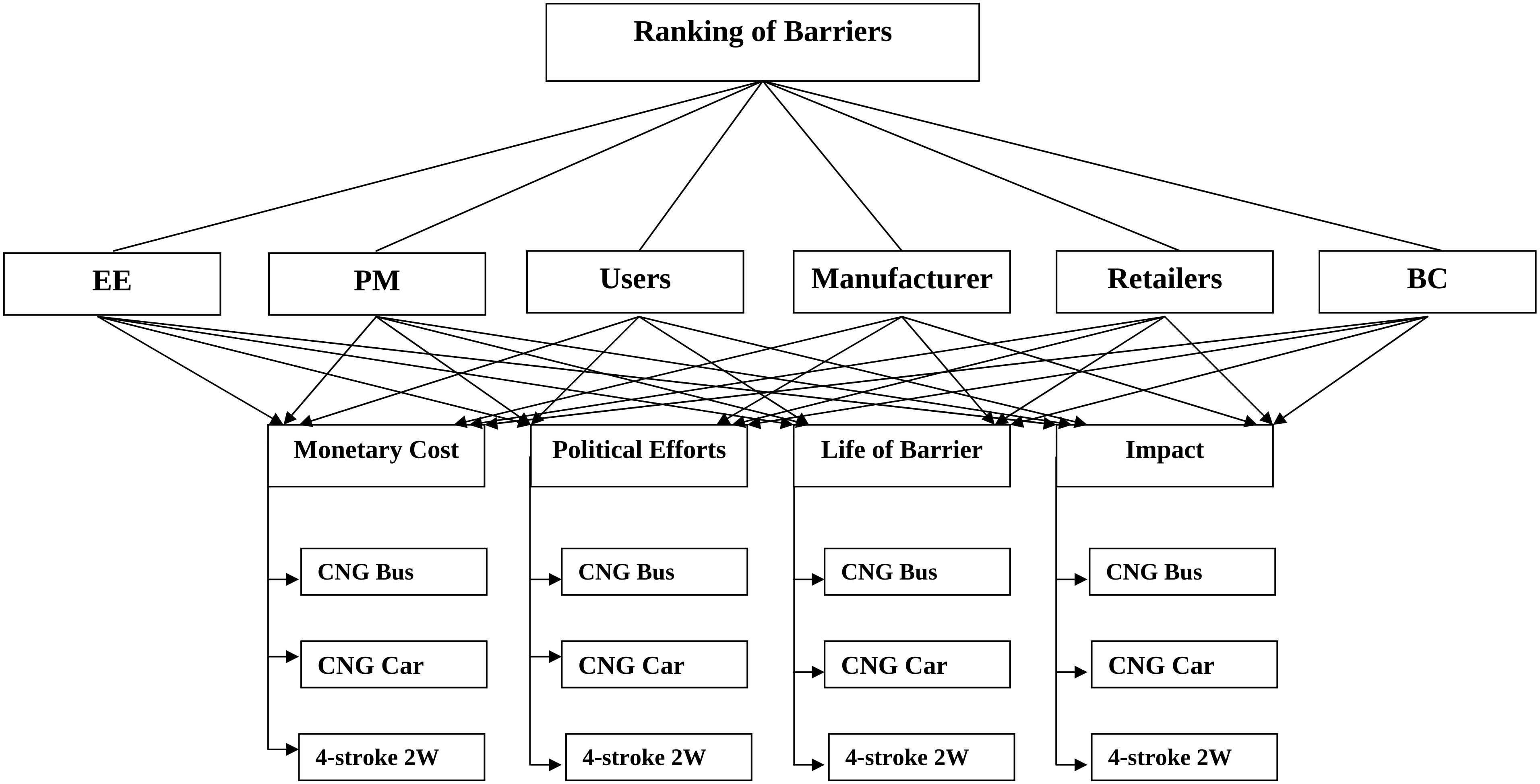
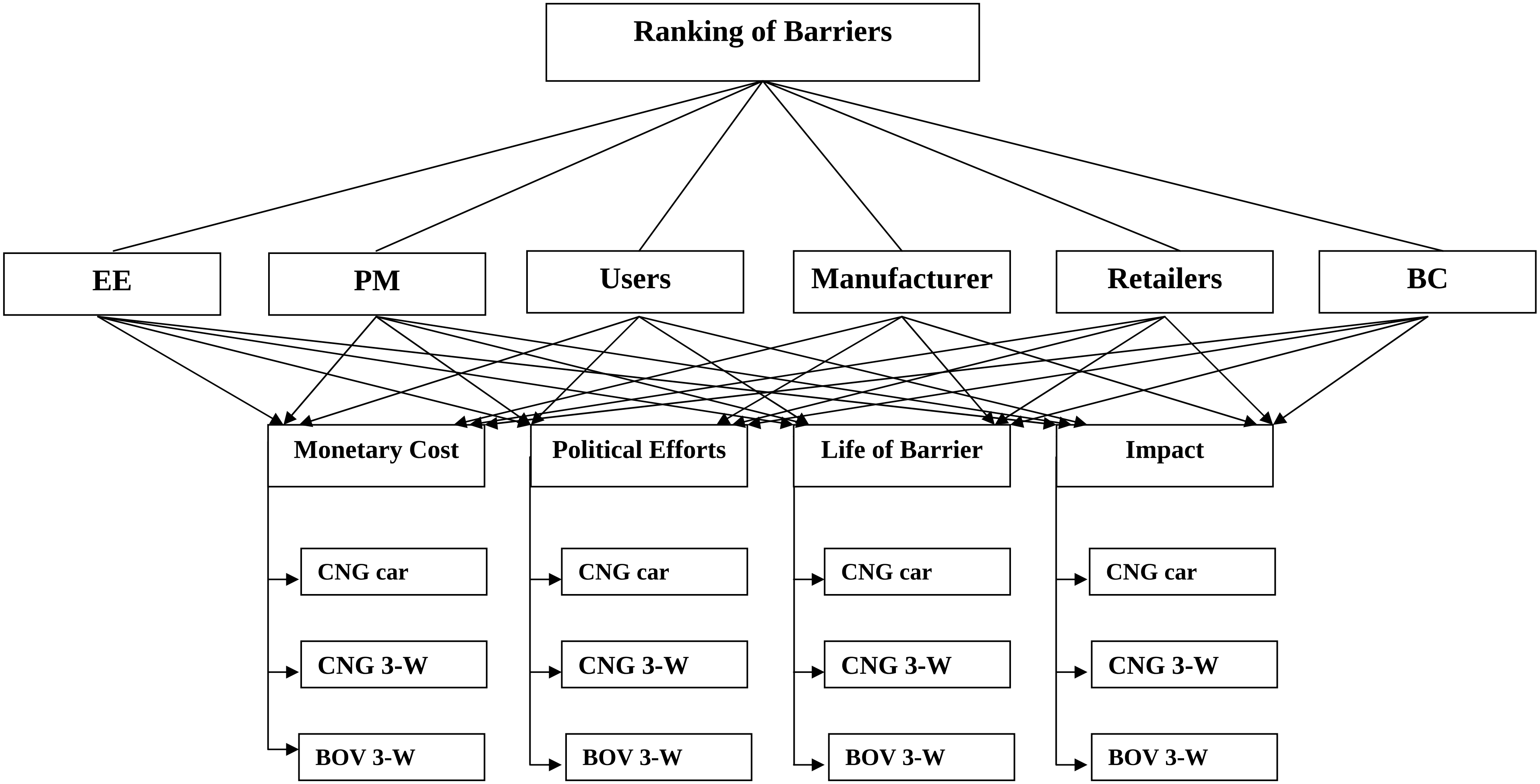


Figure 4.3 AHP Hierarchy tree for the ranking of barriers to the alternative option in Mumbai transport sector



4.1.2 Pair wise Comparison Matrix

Pair wise comparisons are fundamental building blocks of the AHP. Scale for pair wise comparison matrix was provided by Saaty (shown in Table 1) for quantifying the qualitative priorities given by the respondent. A specimen table showing pair wise matrix is given here for 6 element (6 x 6 matrix):

Factor	Barrier 1	Barrier 2	Barrier 3	Barrier 4	Barrier 5	Barrier 6
Barrier 1	1					
Barrier 2		1				
Barrier 3			1			
Barrier 4				1		
Barrier 5					1	
Barrier 6						1

After getting pair wise matrices for all cases from all individuals, final matrix was arrived at using Geometric mean method. This is a widely adopted methodology for group aggregation in AHP.

4.2 Design of Questionnaire

Survey questionnaire was designed and defined clearly so that it doesn’t create any confusion among the respondents. Due importance was given to the selection of respondents. While selecting the respondents from different sectors, their knowledge of all the criteria and factors affecting the concerned issue was given significance without which, accurate and unique solutions are difficult to obtain. Number of respondents from each sector was kept uniform. The goal of the research study is highlighted in the questionnaire. The sample questionnaire is given in Appendix A. The questionnaire is very similar in both cases of Delhi and Mumbai. This questionnaire is designed for ranking the barriers to all three options individually. Sample size was kept at 40 and was arrived at with due consideration to all influencing factors.

5. DESCRIPTION OF SURVEY METHODOLOGY

This survey was conducted by means of specially designed questionnaire with personal interviews as the mode of data collection. Any questionnaire survey faces the problem of heterogeneity in the team that conducts the interviews. The responses would be influenced to great a extent by the way the questions were put. Hence, care was taken to avoid heterogeneity in the present case of survey. Following are a few points taken into consideration while conducting questionnaire survey:

- The interviewers were thoroughly trained and appraised of the project as they need to brief the respondents with the back ground of this questionnaire
- Number of interviewers per day was kept low to minimize the heterogeneity factors
- Questionnaire was prepared in interviewer as well as respondent friendly manner
- Questionnaires have been filled up by the interviewer in stead of respondents. This minimizes the risk of mistake due to unfamiliarity with the questionnaire
- Number of respondents from different categories was kept uniform so as to minimize the channeling effect
- Maximum number of interviews per day were kept at 4 so as to avoid any inconsistency in conducting interviews due to exhaustion

Total sample size for Delhi and Mumbai was 40 respectively with almost equal representation from different sectors. Some respondents did not prefer to reveal their identity and hence only those who were willing to disclose their identity have been listed below:

- Ministry of Environment and Forests, Govt. of India, New Delhi
- Ministry of Petroleum and Natural gas, Govt. of India, New Delhi
- Ministry of Urban Development, Govt. of India, New Delhi
- Central Pollution Control Board, New Delhi
- Indian Institute of Technology, Delhi
- Development Alternatives, New Delhi
- Confederation of Indian Industries (CII), New Delhi
- TERI, New Delhi
- Society of Indian Automobile Manufacturers (SIAM), New Delhi
- Centurion Bank, New Delhi
- Kotak Mahindra Financing Agency, New Delhi
- Center for Science and Environment (CSE), New Delhi
- Users
- Taxi Drivers
- Bank of India, New Delhi
- Delhi Financing Agency, New Delhi

Following are the responding agencies in the case of Mumbai:

- ARAI
- TELCO
- BAJAJ
- MSPCB
- Indian Institute of Technology, Bombay
- BEST
- Road Transport Office
- Users
- Bank of India
- Bank of Maharasthra
- Tata-AIG Risk Management Services
- Sai service (motors)
- Arun Motors and so on.

6. RESULTS AND ANALYSIS

Analysis of data and presentation and discussion of results has been reported separately for Delhi and Mumbai for the sake of clarity. Expert Choice has been used for the analysis of data collected using the questionnaire survey.

Delhi

Three alternative options were tried for Delhi and the respective barriers have been identified. Following are the barriers under consideration and the ranking was done based on the list of criteria.

6.1 Alternative option I: Conversion of conventional fueled buses to CNG buses –

Criteria:	Monetary Cost	(C1)
	Level of Political/Bureaucratic Efforts	(C2)
	Impact on Adoption	(C3)
	Life of Barrier	(C4)
Barriers:	Availability of Alternative Technology/ Conversion Kits	(B1)
	Additional Cost	(B2)
	Inadequate Resources and Infrastructure	(B3)
	Lack of Enforcing Mechanism	(B4)

As a first exercise, weights were calculated for all actors in the group. Entire data set of the questionnaire survey has been distributed into different actor categories and geometric mean method (GMM) was employed to arrive at a common pair wise matrix and weights were derived using that matrix by employing Expert Choice software. Derived weights for all actors in case of Delhi are presented in Table 6.1. Graphical representation of these weights is given in Figure 6.1.

Table 6.1. Weights for various actors (after group aggregation)

Energy & Environmental Experts	Policy Makers	User	Manufacturers	Retailers	Business Community
0.226	0.185	0.278	0.125	0.057	0.129

Inconsistency = 0.05

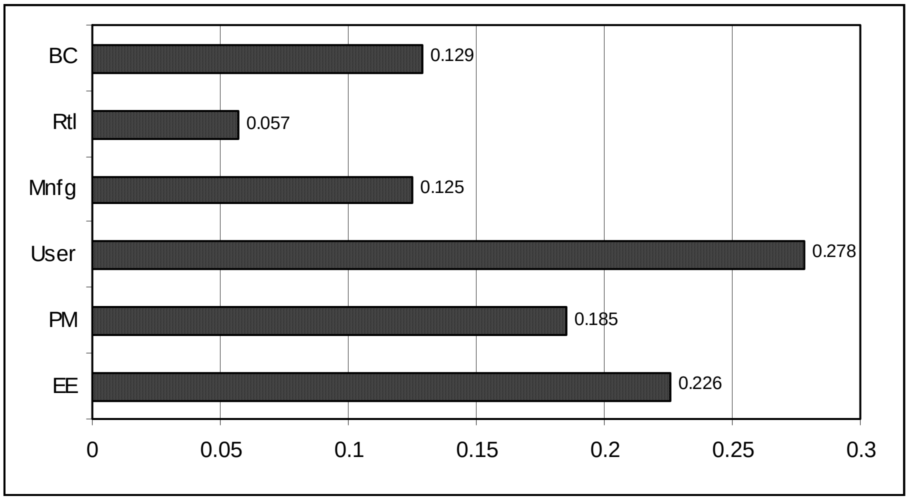


Figure 6.1. Derived weights for various actors (after group aggregation)

Over all consensus of the group showed that users' opinion should be given maximum priority in ranking the barriers to implementation of alternative options in Delhi transportation. Users are followed by Energy & Environmental Experts (EE), Policy Makers (PM). Retailers were given the least priority. Distinct feature of this weight derivation is that all individuals were asked to give priority for all actors in the group including themselves. It is a sensible set of weights for Indian conditions. Many new technologies failed due to the poor response of user and hence, users' opinion should be given top priority in handling the barriers. During the interview it was also mentioned that even for identification of barriers users and EE should play a major role. In the case of Delhi, policy makers input has already been given in for the Delhi transport sector in the form of Supreme Court Directives and others for the implementation of CNG vehicles. This must be the reason for less weight was given for policy makers.

Inconsistency index of this group assessment was as good as 0.05. The allowed inconsistency level in AHP is 0.10. These weights have been used further in ranking the set of barriers i.e. importance given to the actors and their judgement was taken from these derived weights.

Table 6.2. Weights for Criteria

	Energy & Environmental Experts **(0.226)**	Policy Makers **(0.185)**	User **(0.278)**	Manufacturers **(0.125)**	Retailers **(0.057)**	Business Community **(0.129)**
Monetary Cost	0.222	0.294	0.215	0.311	0.300	0.520
Political/Bureaucratic Efforts	0.413	0.215	0.266	0.115	0.118	0.158
Impact on Adoption	0.234	0.239	0.280	0.199	0.048	0.149
Life of Barrier	0.130	0.251	0.239	0.375	0.534	0.173

Criteria provide a reference line for the comparison of barriers and arrive at a final ranking. Any one to one comparison should base on a particular criteria and comparison of any two barriers would differ based on different criteria. Some criteria show more importance than others in ranking a particular barrier. For instance, availability of technology as a barrier may be given more priority with reference to monetary cost involved but may demand less priority with reference to level of political efforts required.

Hence, all criteria have been subjected to pair wise comparison and their weights were arrived at with a common consensus from the entire group. Weights given by each group of individuals for different criteria are presented in Table 6.2.

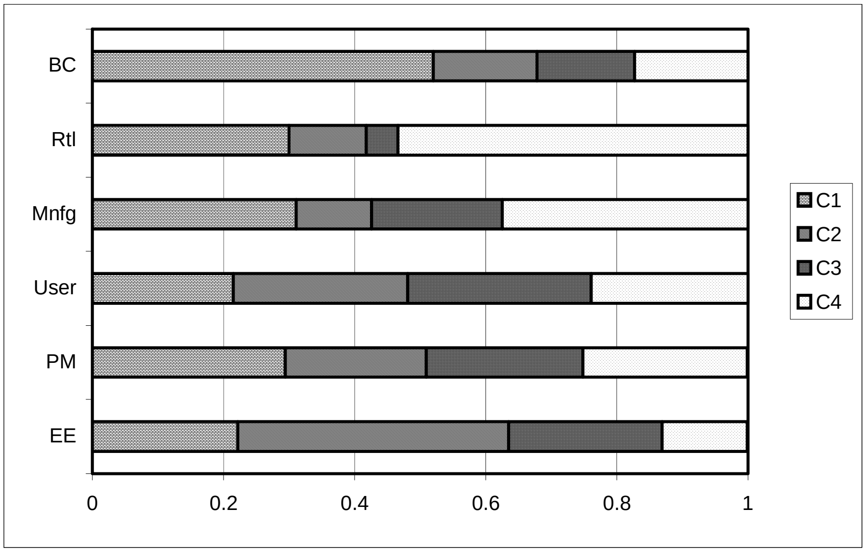


Figure 6.2. Weights for criteria

Weights given for criteria by different actors presents a mixed scenario as presented in Figure 6.2. It is interesting to note that the user, who got the maximum weight in the group of actors gave almost equal weights for all criteria. Energy and environmental experts (EE) gave more weight for the criteria of political/bureaucratic efforts. It may be reflecting the fact that the technology is not reaching the user due to the influence of policy makers as they are the channel between the technology and the user. Where as policy maker (PM) felt that EE should be given slightly more weight than others. Manufacturers and Retailers gave almost similar weights for all criteria. Impact on adoption as criteria got almost similar weights from EE, PM, Users and Manufacturers. Business community showed more importance for EE and almost equal importance for all other criteria.

Based on the weights given for the criteria, ranking of barrier was done by each actor group. Single pair wise comparison matrix was calculated for each actor group by employing GMM for group aggregation. Based on the individual matrix for each actor group ranking of barriers was done which is shown in Table 6.3.

As it can be observed from the table and Figure 6.3, most of the actor groups gave more importance for barrier 3 (Lack of resources and infrastructure) for the implementation of the option of CNG bus in Delhi. Importance of level of political and bureaucratic efforts is clearly emphasized by the user group. This consensus is in perfect agreement with the general opinion of users that more needs to be done about the additional cost on users.

Table 6.3. Ranking of barriers to CNG bus implementation in Delhi, given by various actors (after group aggregation)

	Energy & Environmental Experts	Policy Makers	User	Manufacturers	Retailers	Business Community
Availability of Efficient Technology/ Conversion Kits **(B1)**	0.183	0.187	0.143	0.134	0.191	0.171
Additional Cost **(B2)**	0.14	0.233	0.351	0.122	0.085	0.215
Lack of Resources/ Infrastructure **(B3)**	0.474	0.442	0.276	0.544	0.522	0.398
Lack of Enforcing Mechanism **(B4)**	0.202	0.139	0.23	0.2	0.202	0.216
Inconsistency	0.06	0.06	0.07	0.25	0.05	0.15

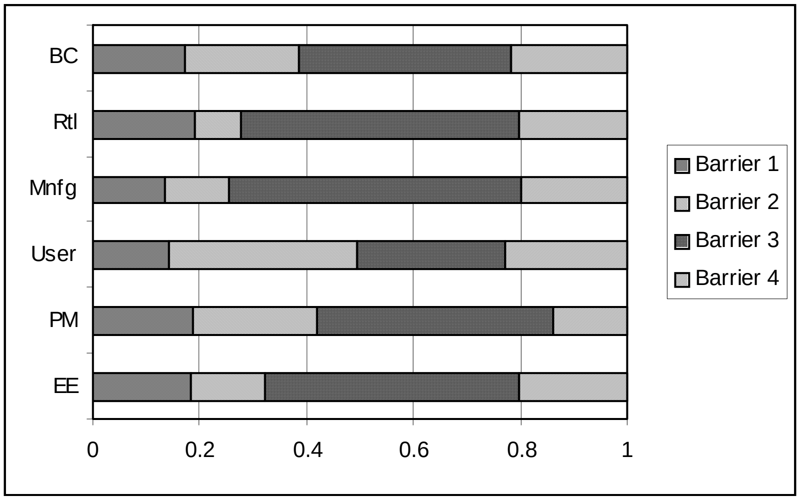


Figure 6.3. Ranking of barriers to CNG bus implementation in Delhi, given by different users groups (after group aggregation)

More understandably, policy makers feel that lack of resources and infrastructure needs to be emphasized more for better implementation of alternative option of CNG buses. Lack of enforcing mechanism is a common priority among all actor groups as far as CNG bus option is concerned. Inconsistency levels of all these pair wise matrix operations are within the limit except in one case which may be due to the group aggregation.

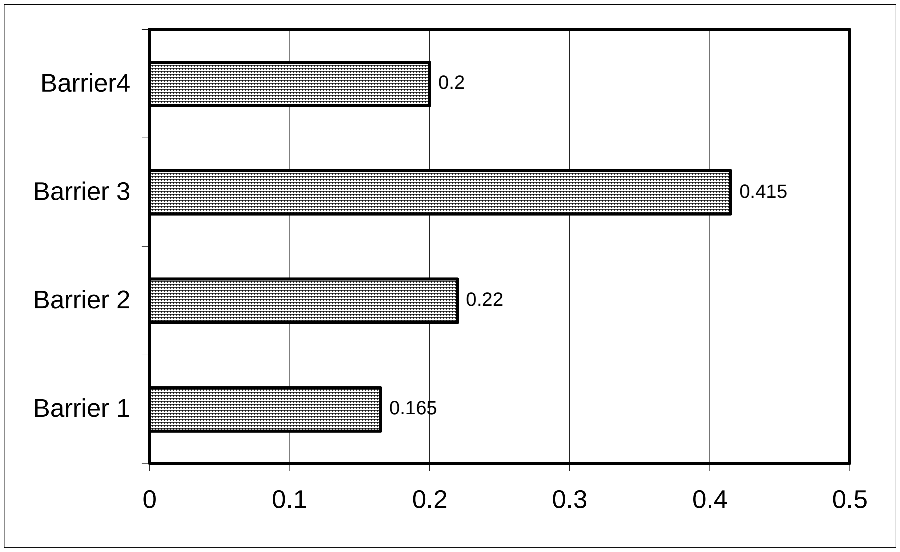
Table 6.4. Ranking of barriers to CNG bus implementation in Delhi, given by the entire sample (after group aggregation)

Availability of Efficient Technology/ Conversion Kits **(B1)**	Additional Cost **(B2)**	Lack of Resources/Infrastructure **(B3)**	Lack of Enforcing Mechanism **(B4)**
0.165	0.22	0.415	0.2

Inconsistency = 0.10

With all actor groups in to one group, a common pair wise matrix was arrived at using GMM method and final ranking of barriers was carried out using EC software. The results are shown in Table 6.4 and Figure 6.4. The over all group consensus reflects the consensus of individual actor groups. Barrier 3 (lack of resources and infrastructure) was identified as the most important barrier to the implementation of CNG bus option in Delhi. Users' consensus to the barrier 2 was reflected in the overall ranking of barriers. Barrier 2 (Additional cost) got the second highest priority as a barrier to the implementation of CNG bus in Delhi which is followed by 'lack of enforcing mechanism'.

Figure 6.4. Ranking if barriers to CNG bus implementation in Delhi, given by the



entire group (after aggregation)

It is indeed surprising to see the barrier 1 (availability of efficient technology/ conversion kits) getting the least priority. But, similar opinion was observed among the individual actor groups. It implies that the availability of technology is no more a problem for the implementation of CNG bus option in Delhi.

Final ranking of barriers to the option of CNG bus in Delhi is as follows:

B3 > B2 > B4 > B1

6.2 Alternative option II: Conversion of conventional fueled cars to CNG cars –

Following is the list of criteria and barriers to this alternative option of CNG cars in Delhi:

Criteria:	Monetary Cost	(C1)
	Level of Political/Bureaucratic Efforts	(C2)
	Impact on Adoption	(C3)
	Life of Barrier	(C4)
Barriers:	Availability of Alternative Technology/ Conversion Kits	(B1)
	Additional Cost	(B2)
	Inadequate Resources and Infrastructure	(B3)
	Lack of awareness	(B4)

Derivation of weights for actors and criteria is common for all alternative option as they represent the same group of actors.

Ranking of barriers by the individual actor groups was carried out as it was done in the previous section. Results are presented in Table 6.5 and Figure 6.5. As it can be observed from the figure clearly, Barrier 3 (lack of resources and infrastructure) was given top priority by all actor groups. Barrier 2 (additional costs) was the next important barrier in most of the actor groups except in the case of retailer group.

It is interesting to observe that additional cost has only 50% weight of the barrier 3 (lack of resources and infrastructure). In spite of the individual ownership factor, user chose barrier 3 as an important barrier than that of additional cost due to the conversion. It clearly indicates that public is aware of the advantages of the alternative option. It is further demonstrated by the least priority for barrier 4 (lack of awareness). Availability of technology showed some priority in the case of EE, Users and retailers. It is certainly a cause for retailers as there exist some hazards due to poor technology of CC.

Table 6.5. Ranking of barriers to CNG car implementation in Delhi, given by various actors (after group aggregation)

	Energy & Environmental Experts	Policy Makers	User	Manufacturers	Retailers	Business Community
Availability of Efficient Technology/ Conversion Kits **(B1)**	0.186	0.16	0.192	0.116	0.191	0.162
Additional Cost **(B2)**	0.21	0.323	0.238	0.135	0.085	0.223
Inadequate Resources and Infrastructure **(B3)**	0.483	0.411	0.448	0.653	0.522	0.407
Lack of awareness **(B4)**	0.122	0.106	0.122	0.096	0.202	0.208
Inconsistency	0.05	0.06	0.13	0.15	0.058	0.14

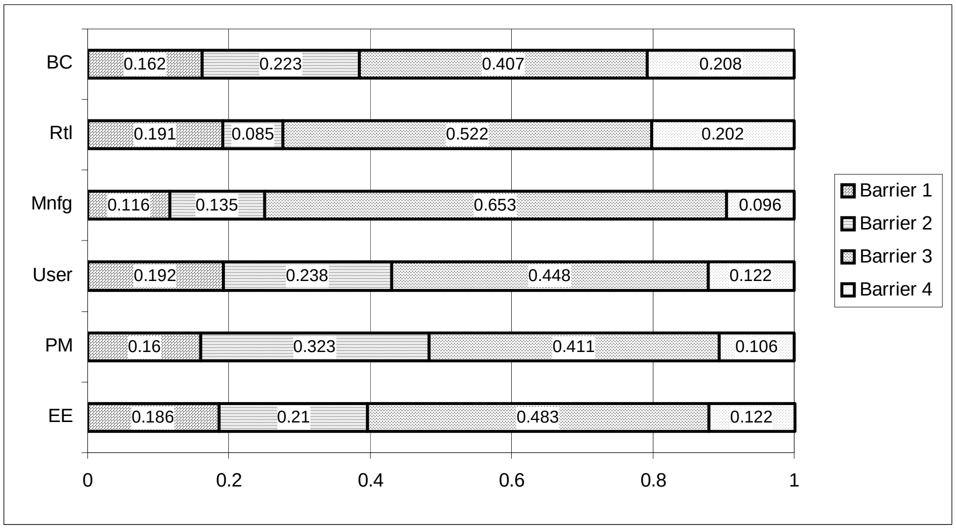


Figure 6.5. Ranking of barriers to CNG car implementation in Delhi, given by different users groups (after group aggregation)

Ranking of barriers was done for the entire group. The aggregation of pair wise comparison matrix was done by adopting GMM. The combined pair wise comparison matrix was used for the ranking of barriers using EC software. Results are presented in Table 6.6 and Figure 6.6.

The ranking of barriers from the entire group consensus is very much in agreement with the individual actor group consensus. Barrier 3 (lack of resources and infrastructure) was rated as the most important barrier hampering the implementation of the alternative option, CNG cars. In support to the result in the earlier case the intensity of priority for the final ranking is very close to that of users. Priority for barrier 3 by the user group was 0.448 and by the overall group was 0.474.

Table 6.6. Ranking of barriers to CNG car implementation in Delhi, given by the entire sample (after group aggregation)

Availability of Efficient Technology/ Conversion Kits **(B1)**	Additional Cost **(B2)**	Lack of Resources/Infrastructure **(B3)**	Lack of Awareness **(B4)**
0.171	0.224	0.474	0.131

Inconsistency = 0.10

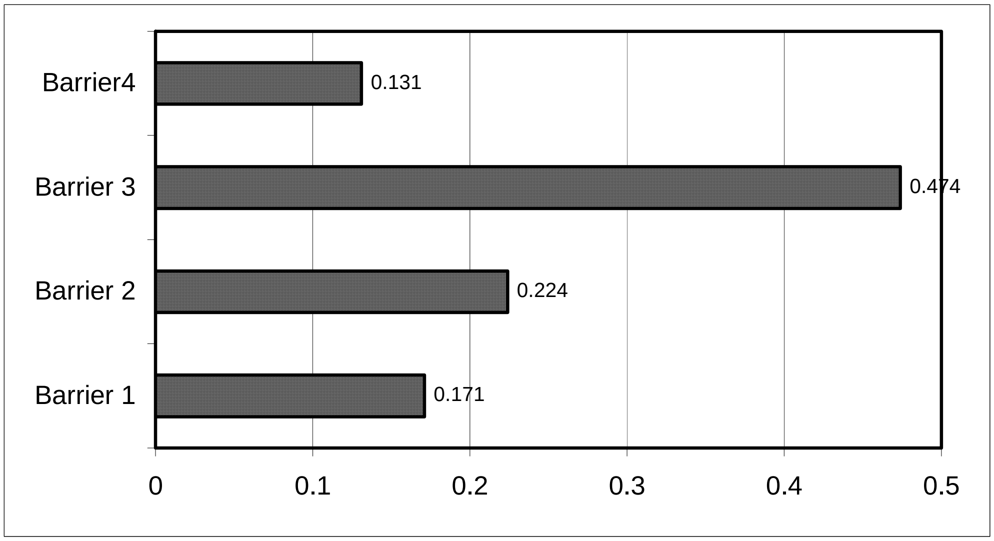


Figure 6.6. Ranking of barriers to CNG car implementation in Delhi, given by the entire group (after aggregation)

Additional cost as barrier occupied the second spot followed by the availability of technology. Lack of awareness stood the last as far as importance of barriers is concerned. For this option of CNG cars, Delhi public seems to be well aware of the alternative technology. This may not be the case in Mumbai where the awareness for this alternative transport options is very poor. Additional cost was of more importance in the case of CNG cars than that of CNG buses. Ownership has a role to play in this. The reason for more importance for availability of technology this case of CNG cars may be due to the fact that people are well aware that availability of alternative technology and conversion kits would reduce the additional cost factor for the user. Hence, both additional cost and availability of technology as barriers stood almost equally rated.

Final ranking of barriers to the option of CNG car in Delhi is as follows:

B3 > B2 > B1 > B4

6.3 Alternative option III: Replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers –

Criteria:	Monetary Cost	(C1)
	Level of Political/Bureaucratic Efforts	(C2)
	Impact on Adoption	(C3)
	Life of Barrier	(C4)
Barriers:	Availability of Alternative Technology/ Conversion Kits	(B1)

Additional Cost	(B2)
Lack of awareness	(B3)
Lack of Enforcing Mechanism	(B4)

This option presents a deviation in the approach for the improvement mechanism. Option I & II presents a case of switching to cleaner fuels and option III presents a case of cleaner technology. Hence, the set of barriers chosen is slightly deviated from the previous set. As this option of replacing 2-stroke 2-wheelers by 4-stroke 2-wheelers needs no infrastructure, barrier 3 of the previous set has been replaced by awareness barrier and the barrier 4 has been the lack of enforcing mechanism.

Weights for actors and criteria remain the same as in the case of option I and II.

With the weights for actors and criteria, ranking of barriers was determined for all individual actor groups. Results are presented in Table 6.7 and Figure 6.7. Unlike the other two options, barrier 2 (additional cost) gained more priority than the other three barriers. It is indeed a logical choice as the additional cost involved in 4-stroke 2-wheelers is the major controlling factor in this option. Lack of enforcing mechanism followed the additional cost. At the moment there exists no mechanism to support such an alternative option. Hence, it was chosen as the second most important barrier to the implementation of this alternative option. Lack of awareness about the benefits of this option as a barrier stood above the availability of technology as a barrier. Except in the case of manufactures group no other actor felt the importance of this barrier.

Table 6.7. Ranking of barriers to 4-stroke 2-wheelers implementation in Delhi, given by various actors (after group aggregation)

	Energy & Environmental Experts	Policy Makers	User	Manufacturers	Retailers	Business Community
Availability of Efficient Technology/ Conversion Kits **(B1)**	0.141	0.107	0.08	0.388	0.083	0.152
Additional Cost **(B2)**	0.446	0.329	0.433	0.255	0.53	0.314
Lack of Awareness **(B3)**	0.108	0.188	0.25	0.15	0.289	0.244
Lack of Enforcing Mechanism **(B4)**	0.305	0.376	0.236	0.208	0.098	0.291
Inconsistency	0.05	0.05	0.06	0.14	0.20	0.12

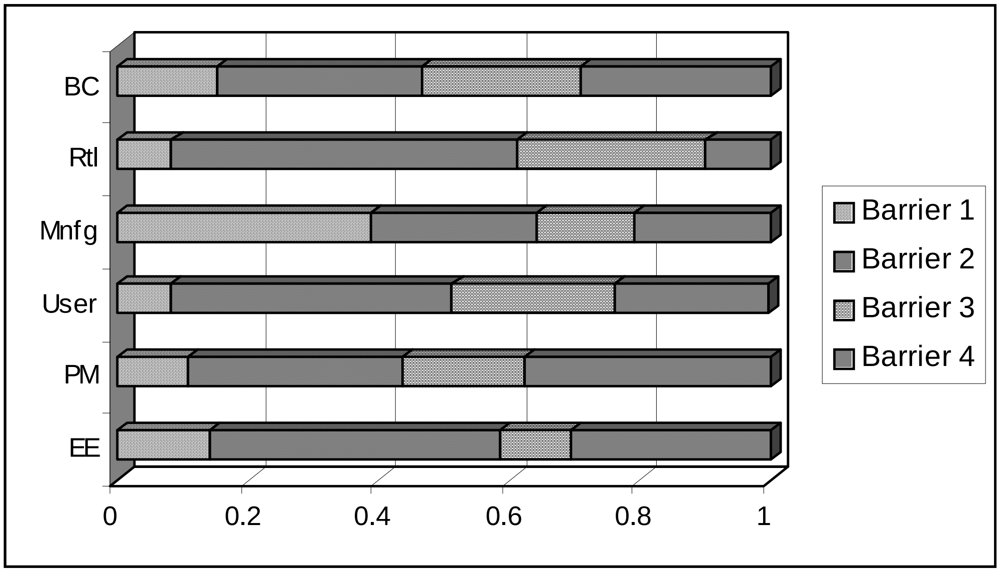


Figure 4.7. Ranking of barriers to 4-stroke 2-wheelers implementation in Delhi, given by different users groups (after group aggregation)

Final ranking of barriers with group aggregation was done using the weights derived for actors and criteria. Pair wise comparison matrix for the group aggregation was determined by employing GMM and this has been used to arrive at final ranking of barrier for the implementation of this option.

Table 6.8. Ranking of barriers to 4-stroke 2-wheelers implementation in Delhi, given by the entire sample (after group aggregation)

Availability of Efficient Technology/ Conversion Kits	Additional Cost	Lack of Resources/Infrastructure	Lack of Enforcing Mechanism
0.147	0.385	0.195	0.273

Inconsistency = 0.07

Overall group ranking is in good agreement with individual actor group ranking. Barrier 2 (additional cost) was found to be dominating in this option of 2-wheelers. Lack of enforcing mechanism followed Barrier 2. Lack of awareness proved more important as a barrier than the availability of technology as a barrier. This is a good illustration of group aggregation technique and its efficiency in following a few social choice axioms viz. Pareto Optimality axiom.

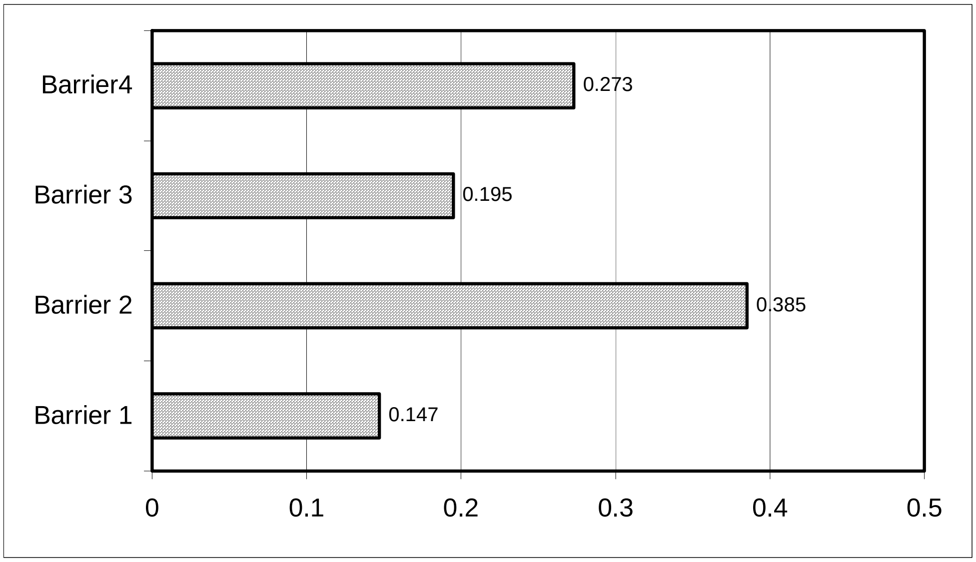


Figure 6.8. Ranking if barriers to 4-stroke 2-wheelers implementation in Delhi, given by the entire group (after aggregation)

For this option, Additional cost involved is more important and hence, policies should be formulated and action needs to be taken to come over this barrier for the better implementation of 4-stroke 2-wheelers in Delhi transport system.

Final ranking of barriers to the option of CNG bus in Delhi is as follows:

B2 > B4 > B3 > B1

Ranking of barrier for all three options for the case of Delhi are presented in the following table for cross comparison.

Table 6.9. Barriers ranking for all three alternative options in Delhi

	B1	B2	B3	B4
CNG Bus	0.165	0.22	0.415	0.2
CNG car	0.171	0.224	0.474	0.131
4-stroke 2-wheeler	0.147	0.385	0.195	0.273

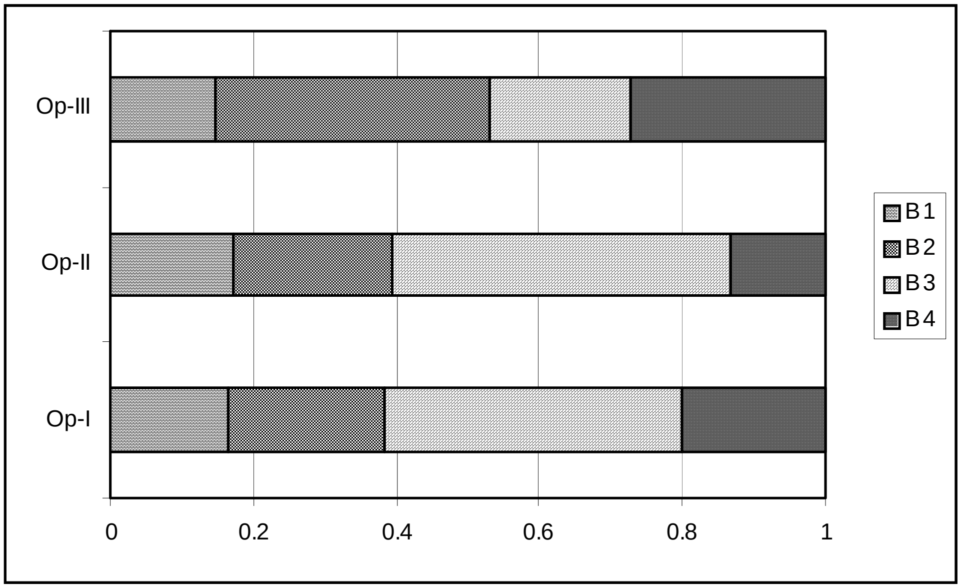


Figure 6.9. Ranking of barriers to all three alternative options in Delhi

As it can be observed from the above figure, barrier 3 (lack of resources and infrastructure) is dominating in the case of option I & II. Both options are CNG options and as it is a well known fact that resource and infrastructure availability is a problem. Hence, for the implementation of CNG option whether it is CNG bus or CNG car lack of resources and infrastructure is a major barrier and policy measure needs to be taken to remove this barrier for better implementation of CNG option. Barrier 2 (additional cost) is a major barrier in the case of option III. Additional cost appeared to be the second important barrier for the implementation of CNG option. It has been very clearly observed that the cost of CNG kits has not come down considerably over the past 10 years. Hence, measures need to be taken to bring down additional cost on the user to make this option more penetrating in Delhi transport system.

Lack of enforcing mechanism as a barrier has caught more attention than the availability of technology as a barrier. It clearly implies that in the opinion of various actors involved in Delhi transport system, availability of technology is not a problem at all for the implementation of various alternative options. It is only the resources and infrastructure along with enforcing mechanism, which needs to be taken care of . Removing the additional cost burden on the user would also make the options more adaptable.

Mumbai

Three alternative options were tried for Mumbai and a domain of barriers has been identified. Barriers to each option and their respective ranking have been explained separately.

As it was explained in the case of Delhi, all actors involved in the decision making process, and also various criteria are weighed based on subjective comparison made by the individuals in the group. These derived weights are used for the final ranking of barriers. Entire data set of the questionnaire survey has been distributed into different actor categories and geometric mean method (GMM) was employed to arrive at a common pair wise matrix and weights were derived using that matrix by employing *Expert Choice* software. Derived weights for all actors for the case of Mumbai are presented in Figure 6.10. The inconsistency has been checked for all calculations and in this case it was found to be 0.09, well within the limits if inconsistency for AHP.

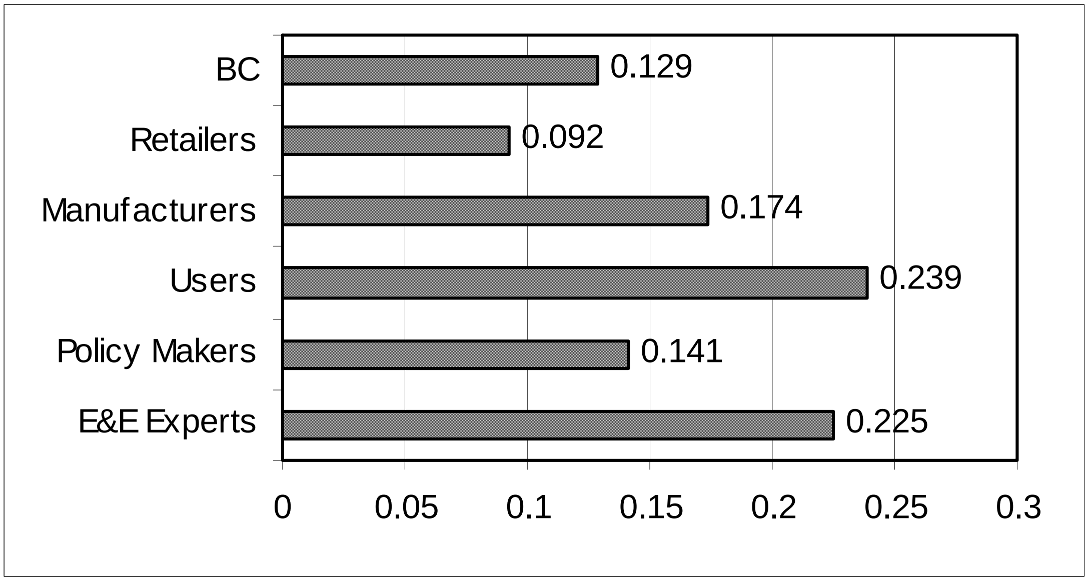


Figure 6.10. Derived weights for various actors (after group aggregation)

Over all consensus of the group showed that users' opinion should be given maximum priority in ranking the barriers to the implementation of alternative options in Mumbai transportation. Users are followed by Energy & Environmental Experts (EE) and Manufacturers (M). As in the case of Delhi, Retailers were given the least priority. It is an interesting result to observe that like in Delhi, Mumbai also gave maximum weight to the opinion of users in handling the barriers. This strongly supports the general feeling that everybody shares the view that most of the advanced technological options fail due to the poor user participation and inefficient strategic policy making and penetration. During the interview it was also mentioned that even for identification of barriers users and EE should play a major role. As Mumbai involved advanced alternative options viz. BOVs, manufacturer's opinion was given more weight than the policy makers. Unlike cities like Delhi where technology is almost available, Mumbai with an alternative option of BOV, depends more on manufacturers opinion than that of policy makers whose role comes in at a later stage.

These weights have been used further in ranking the set of barriers i.e. importance given to the actors and their judgement was taken from these derived weights.

All criteria have been subjected to pair wise comparison and their weights were arrived at with a common consensus from the entire group. Weights given by each group of individuals for different criteria are presented in Table 6.10.

Table 6.10. Weights for Criteria

	Energy & Environmental Experts **(0.226)**	Policy Makers **(0.185)**	User **(0.278)**	Manufacturers **(0.125)**	Retailers **(0.057)**	Business Community **(0.129)**
Monetary Cost	0.137	0.132	0.238	0.142	0.078	0.195
Political/Bureaucratic Efforts	0.132	0.134	0.413	0.218	0.446	0.499
Impact on Adoption	0.465	0.492	0.161	0.353	0.417	0.141
Life of Barrier	0.266	0.243	0.188	0.287	0.059	0.165

Impact on adoption as a criterion was given more weight in general followed by the criteria of political/bureaucratic efforts required. It is very interesting to observe that the criteria of “monetary cost to remove barriers” was not given much weight which may mean that in the opinion of the whole group, these new technologies may not demand higher monetary efforts but bureaucratic efforts. Energy experts, policy makers, manufacturers and retailers feel that impact on adoption as criterion is more important closely followed by life of barrier. Users, Retailers and business community expressed an opinion that bureaucratic efforts are of higher importance.

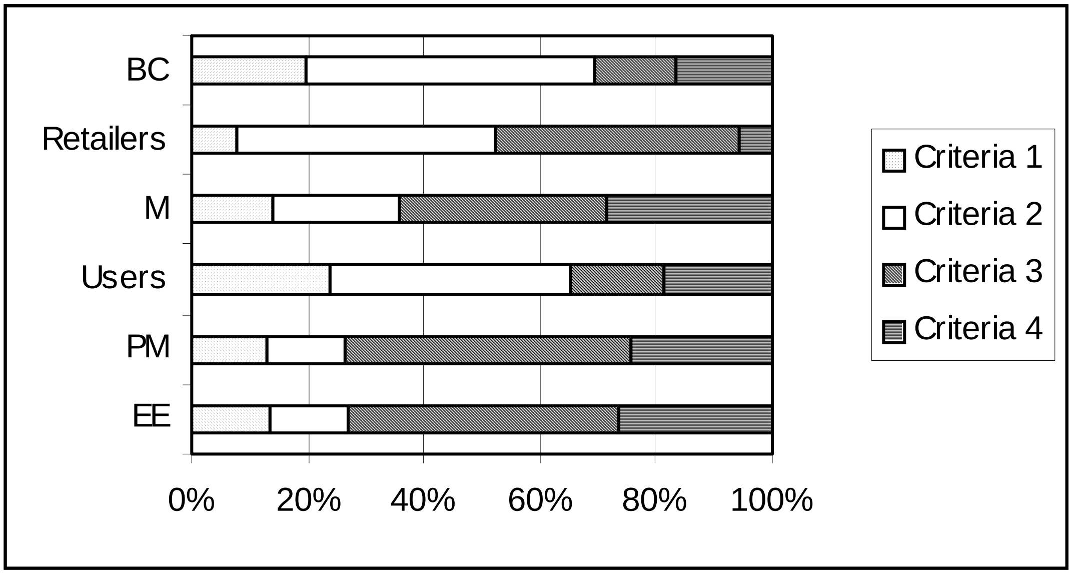


Figure 6. 11. Weights for criteria given by different actor groups

6.4 Alternative option I: Conversion of conventional fueled cars to CNG cars –

Criteria:	Monetary Cost	(C1)
	Level of Political/Bureaucratic Efforts	(C2)
	Impact on Adoption	(C3)
	Life of Barrier	(C4)
Barriers:	Availability of Alternative Technology/ Conversion Kits	(B1)
	Additional Cost	(B2)
	Inadequate Resources and Infrastructure	(B3)
	Lack of Enforcing Mechanism	(B4)

Based on the criteria with varying weights, ranking of barriers was done by each actor group. Individual pair wise comparison matrices from each actor group were aggregated by employing GMM and combined pair wise matrix was calculated for each actor group. Based on the aggregated matrix for each actor group, ranking of barriers was done as shown in Table 6.11. The ranking of barriers by individual actors groups is presented in Figure 6.12

Table 6.11. Ranking of barriers to CNG car implementation in Mumbai, given by various actors (after group aggregation)

	Energy & Environmental Experts	Policy Makers	User	Manufacturers	Retailers	Business Community
Availability of Efficient Technology/ Conversion Kits **(B1)**	0.121	0.141	0.102	0.091	0.050	0.281
Additional Cost **(B2)**	0.139	0.144	0.138	0.202	0.359	0.150
Lack of Resources/ Infrastructure **(B3)**	0.529	0.567	0.525	0.511	0.407	0.418
Lack of Enforcing Mechanism **(B4)**	0.211	0.147	0.235	0.196	0.185	0.152

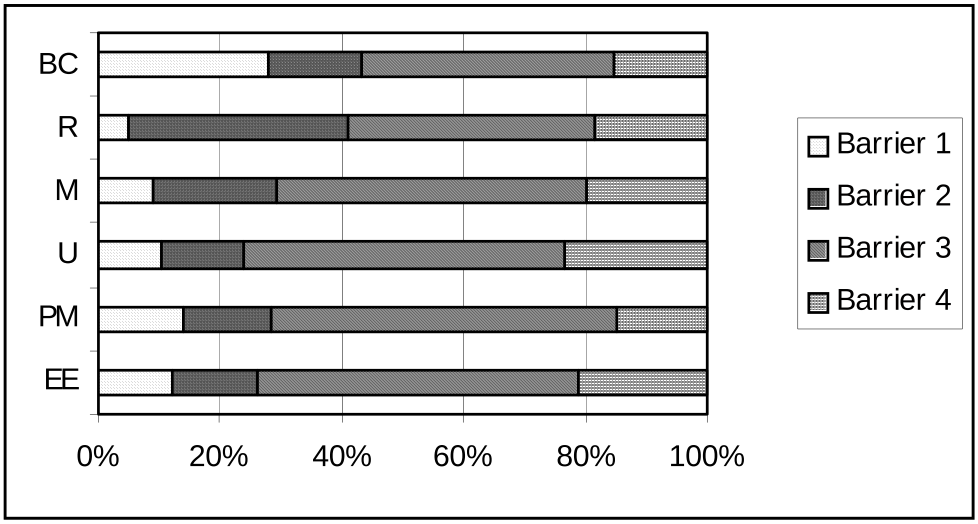


Figure 6.12. Ranking of barriers to CNG car implementation in Mumbai, given by different users groups (after group aggregation)

All actor groups unanimously gave the highest importance to barrier 3 (Lack of resources and infrastructure) for the implementation the option of CNG car in Mumbai. The recent developments in Delhi regarding CNG technology must have provided considerable inputs in arriving at this unanimous selection of barrier and its importance. The one closely following this is the lack of enforcing mechanism. Business community is genuinely bothered about the technological barrier and retailers are showing more concern for cost next to the barrier 3.

Inconsistency levels of all these pair wise matrix operations were well within the limit.

With all actor groups into one group, a common pair wise matrix was arrived at using GMM method and final ranking of barriers was carried out by using EC software. The results are shown in Figure 6.13. The over all group consensus is very much in agreement with the consensus of individual actor groups. Barrier 3 (lack of resources and infrastructure) was identified as the most important barrier to the implementation of CNG car option in Mumbai. Users' consensus for the barrier 4 was reflected in the overall ranking of barriers. Barrier 4 (lack of enforcing mechanism) got the second highest priority as a barrier to the implementation of CNG car in Mumbai, which is followed by cost barrier. It is interesting to note that cost as a barrier is taking back seat which may be due to the Delhi-episode. This further strengthens the view that with more awareness technological options and their respective barriers take a different levels of success.

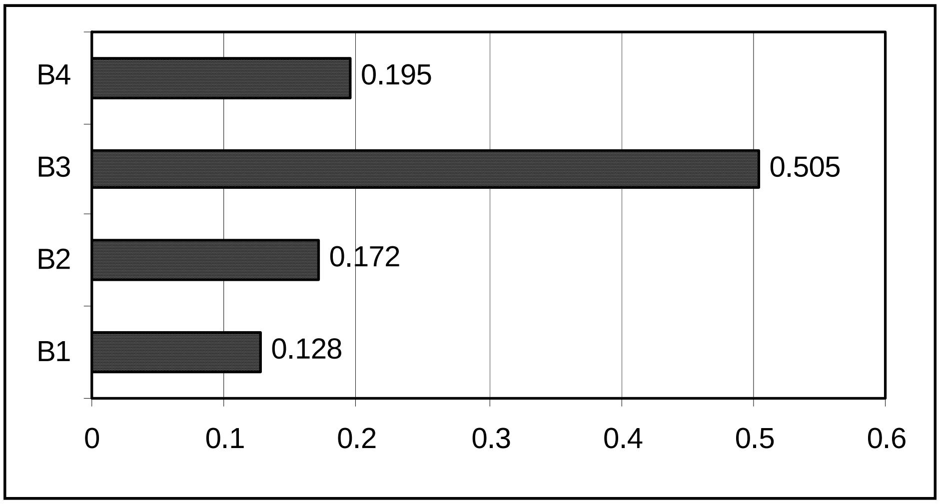


Figure 6.13. Ranking if barriers to CNG car implementation in Mumbai, given by the entire group (after aggregation)

Final ranking of barriers to the option of CNG car in Mumbai is as follows:

B3 > B4 > B2 > B1

6.5 Alternative option II: Conversion of conventional fueled 3-Wheelers to CNG 3-Wheelers –

List of criteria and barriers to this option of CNG 3-Wheelers is very identical to the CNG cars option. Ranking of barriers by the individual actor groups was carried out as it was done in the previous option. Results are presented in Figure 6.14. Though the list of barriers is the same for these two CNG based options, their ranking is very different. This could be attributed mostly to the ownership differences. Unlike in the case of CNG car, ranking of barriers to this option is a mix of opinions from the group of actors. Ranking of barriers 1, 2 and 3 are very close to each other though barrier 3 stands narrowly above the other two. Lack of resource is shared as a common concern for both the options. It is interesting to see the cost barrier gaining priority in the case of 3-Wheelers. Manufacturers' opinion is very similar to the one on CNG cars with more weights given to technology barrier and cost barrier. Retailers are apparently more conscious about the cost as a barrier.

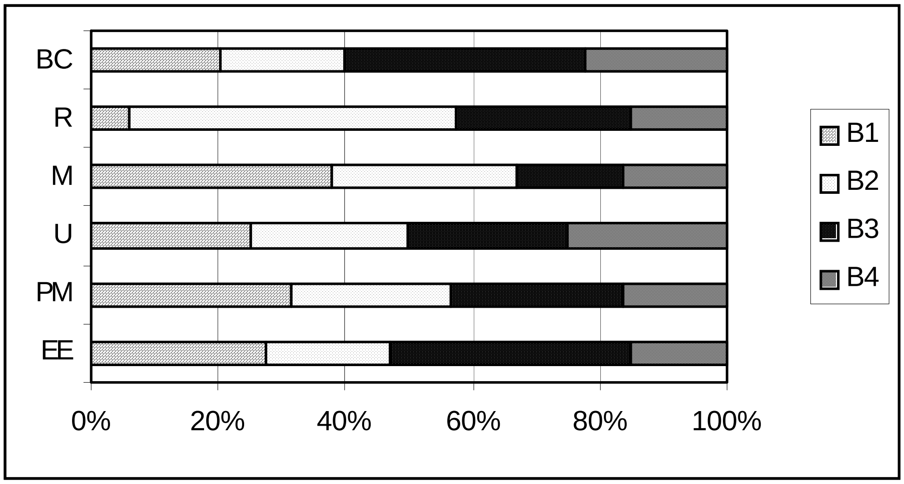


Figure 6.14. Ranking of barriers to CNG 3-Wheeler implementation in Mumbai, given by different users groups (after group aggregation)

Aggregated pair wise comparison matrices are used for the ranking of barriers by the entire group. Results are shown Figure 6.15. Inconsistency was found to be 0.10, exactly on the limiting line.

The ranking of barriers from the entire group consensus is very much in agreement with the individual actor group consensus. Barrier 3 (lack of resources and infrastructure) was rated as the most important barrier hampering the implementation of the alternative option, CNG 3-Wheeler.

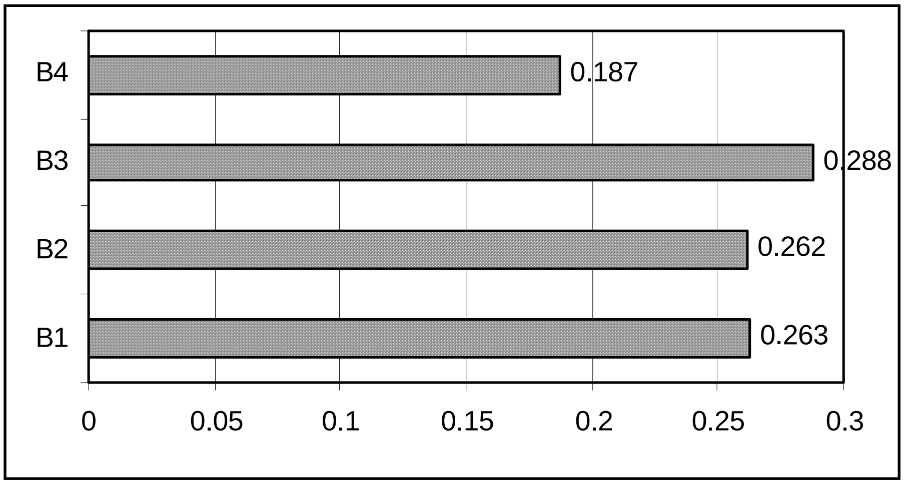


Figure 6.15. Ranking of barriers to CNG 3-Wheeler implementation in Mumbai, given by the entire group (after aggregation)

Additional cost as barrier occupied the second spot followed by ‘lack resources and infrastructure’. Additional cost was of more importance in the case of CNG 3-Wheelers than that of CNG cars. Ownership has a role to play in this. The reason for more importance to the availability of technology in this case of CNG 3-wheelers may be due to the fact that people are well aware that availability of alternative technology and conversion kits would reduce the additional cost factor on the user. Hence, both additional cost and availability of technology as barriers stood almost equally rated.

Final ranking of barriers to the option of CNG 3-Wheelers in Mumbai is as follows:

B3 > B1 > B2 > B4

6.6 Conversion of conventional fueled 3-W to BOV 3-W –

Criteria:	Monetary Cost	(C1)
	Level of Political/Bureaucratic Efforts	(C2)
	Impact on Adoption	(C3)
	Life of Barrier	(C4)
Barriers:	Availability of Alternative Technology/ Conversion Kits	(B1)
	Additional Cost	(B2)
	Lack of awareness	(B3)
	Lack of Enforcing Mechanism	(B4)

This option presents a deviation in the approach for the improvement mechanism. Option I & II presents a case of switching to cleaner fuels and option III presents a case of cleaner technology. Hence, the set of barriers chosen is slightly deviated from the previous set. As this option of BOV 3-Wheelers needs no major infrastructure, barrier 3 of the previous set has been replaced by awareness barrier and the barrier 4 has been the lack of enforcing mechanism.

Weights for actors and criteria remain the same as in the case of option I & II.

With the weights for actors and criteria, ranking of barriers was determined for all individual actor groups. Results are presented in Figure 6.16. Unlike the other two options, barrier 2 (additional cost) gained more priority than the other three barriers. This may be due to the fact that people are not aware of the cost effectiveness of the option. General feeling of any advanced technology being expensive must be the reason behind this opinion. Technology availability followed the additional cost very closely. Users gave almost equal weight to all barriers, which shows the awareness level about this new option. Technological availability is a common concern and unlike CNG options, most actors gave it a better ranking. Hence, it was chosen as the second most important barrier for the implementation of this alternative option.

It is interesting to note that lack of awareness did not gain much of importance compared to barriers like technology availability and cost. This may mean that once the technology is available at least cost, awareness would not remain a barrier at all.

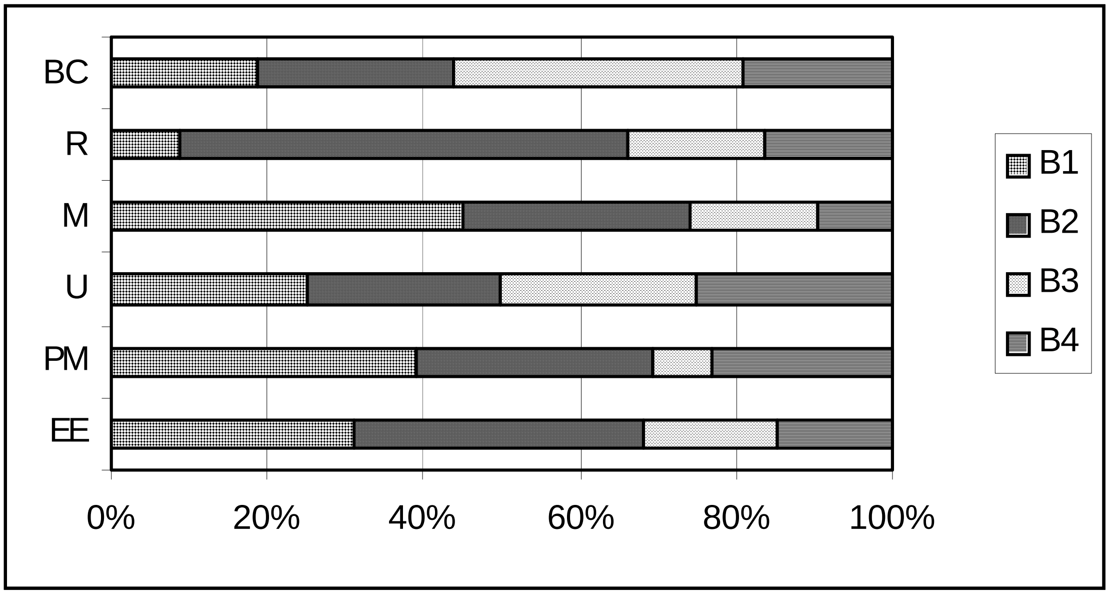


Figure 6.16. Ranking of barriers to BOV 3-Wheelers implementation in Mumbai, given by different users groups (after group aggregation)

Final ranking of barriers with group aggregation was done using the weights for actors and criteria. Pair wise comparison matrix for the group aggregation was determined by employing GMM and this has been used to arrive at final ranking of barrier for the implementation of this option. The inconsistency level was at 0.07. Ranking of barriers to the option of BOV 3-Wheelers is given in Figure 6.17.

Group ranking is in good agreement with individual actor group ranking. Barrier 2 (additional cost) was found to be dominating in this option of BOV 3-wheelers. Availability of alternative technology followed Barrier 2. Lack of awareness proved more important as a barrier than lack of enforcing mechanism as a barrier.

For this option, technology development and additional cost are more important and hence, policies should be formulated and action needs to be taken to come over these barriers to the better implementation of BOV 3-Wheelers in Mumbai transport system.

Final ranking of barriers to the option of BOV 3-Wheelers is as follows:

B2 > B1 > B3 > B4

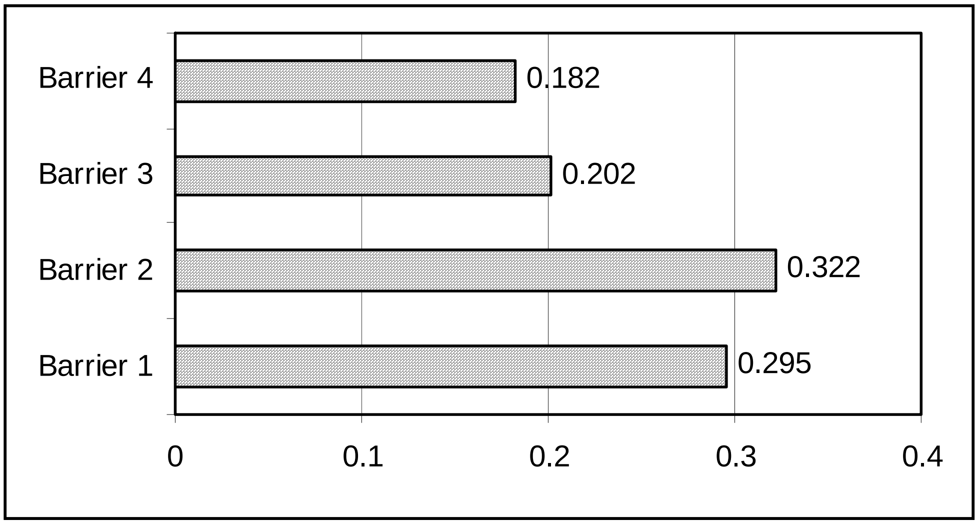


Figure 6.17. Ranking if barriers to BOV 3-wheelers implementation in Mumbai, given by the entire group (after aggregation)

Ranking of barriers for all three options for the case of Mumbai are presented in the following table for cross comparison.

Table 6.12. Barriers ranking for all three alternative options in Mumbai

	B1	B2	B3	B4
CNG car	0.128	0.172	0.505	0.195
CNG 3-W	0.263	0.262	0.288	0.187
BOV 3-W	0.295	0.322	0.202	0.182

As can be observed from the above figure, barrier 3 (lack of resources and infrastructure) is dominating in the case of option I & II. Both are CNG options and as it is a well known fact that resource and infrastructure availability is a problem. Hence, for the implementation of CNG option whether it is CNG car or CNG 3-wheeler or even CNG bus, lack of resources and infrastructure is a major bottleneck and policy measures needs to be taken to remove this barrier for better implementation of CNG option. Barrier 2 (additional cost) is a major barrier in the case of option III and to some extent in option II. Additional cost appeared to be the second important barrier for the implementation of CNG option. Availability of technology is a second major barrier for option III. Hence, measures need to be taken to overcome this barrier to make this option more penetrating in Mumbai transport system. 3-Wheelers showed some concern about the cost as a barrier. This was not the case with CNG cars. This could be due to the ownership constraint.

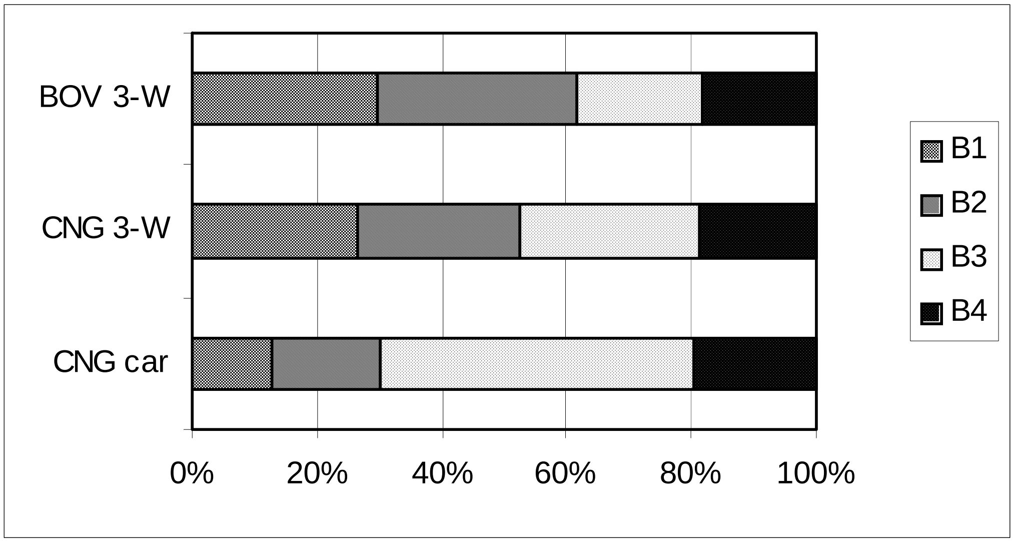


Figure 6.18. Ranking of barriers to all three alternative options in Mumbai

Lack of enforcing mechanism as a barrier did not gain much importance. This could be due to the fact that Mumbai, unlike Delhi, is driven by commercial activity with millions of people pursuing their interest everyday. Once proved of its potential, no option needs to be promoted in this kind of a fast moving metro. It is only the resources and infrastructure, which needs to be taken care of. Removing the additional cost burden on the user would also make the options more adaptable.

7. CONCLUSIONS

Delhi

Three options viz. conversion of conventional fuel buses to CNG buses (option – I), conversion of conventional fuel cars to CNG cars (option – II) and replacing 2-stroke 2-wheelres by 4-stroke 2-wheelrs (option – III) were chosen for energy efficiency and emission reduction from the Delhi transport system. Based on various influencing factors, traffic conditions, vehicle stock, information on modes that are dominating the road, geographical conditions barriers to option chosen were identified and they are availability of efficient technology/conversion kits, additional costs, lack of resources and infrastructure, lack of enforcing mechanism and lack of awareness.

Ranking of the above barriers was carried out by employing geometric mean method to arrive at pair wise comparison matrix for the group. Ranking of barriers by the individual actor groups was also determined to make comparison with the group ranking. It was found that the group consensus is in good agreement with the individual actor group consensus. Following are the final ranking of barriers to all three options:

Option I:	lack of resources and infrastructure > additional costs > lack of enforcing mechanism > availability of efficient technology/conversion kits **B3 > B2 > B4 > B1**
Option II:	lack of resources and infrastructure > additional costs > availability of efficient technology/conversion kits > lack of awareness **B3 > B2 > B1 > B4**
Option III:	additional costs > lack of enforcing mechanism > lack of awareness > availability of alternative technology **B2 > B4 > B3 > B1**

Resource availability and infrastructure as a barrier is dominating in the case of option I & II. Both options are CNG options and as it is a well known fact that resource and infrastructure availability is a major problem for CNG option. Hence, for the implementation of CNG option whether it is CNG bus or CNG car lack of resources and infrastructure is a major barrier and policy measure needs to be taken to remove this barrier for better implementation of CNG option. Additional cost was found to be a major barrier in the case of 4-stroke 2-wheelers. Hence, by bringing down the additional cost burden on users, 4-stroke 2-wheelers can be made more prominent on Delhi roads. Additional cost appeared to be the second important barrier for the implementation of CNG option. It is very clearly observed that cost of CNG kits has not come down considerably over last 10 years. Hence, measures are needed to bring down the additional cost on the user to make this option more penetrating in Delhi transport system.

Lack of enforcing mechanism as a barrier caught more attention than the availability of technology as a barrier, in view of the Supreme Court of India's decision taken in this regard. It clearly implies that in the opinion of various actors involved in Delhi transport system, availability of technology is not a problem for the implementation of various alternative options. However, availability of technology may show some influence on cost as well as the safety of the alternative option. It is only the resources and infrastructure along with enforcing mechanism, which need to be handled. Removing the additional cost burden on the user would also make the options more adaptable.

Mumbai

Three options viz. conversion of conventional fuel cars to CNG cars (option – I), conversion of conventional fuel 3-Wheeelrs to CNG 3-Wheelers (option – II) and conversion of conventional fuel 3-Wheeelrs to BOV 3-Wheelers (option – III) were chosen for energy efficiency and emission reduction from Mumbai transport system. Based on various influencing factors, traffic conditions, vehicle stock, information on modes that are dominating the road, geographical conditions barriers were identified for each option under consideration. They are availability of efficient technology/conversion kits, additional costs, lack of resources and infrastructure, lack of enforcing mechanism and lack of awareness.

Ranking of barriers by the individual actor groups was also determined to make comparison with the group ranking. It was found that the group consensus is in good agreement with the individual actor group consensus. Following are the final ranking of barriers to all three options:

Option I: lack of resources and infrastructure > lack of enforcing mechanism > additional cost > availability of efficient technology/conversion kits
B3 > B4 > B2 > B1

Option II: lack of resources and infrastructure > availability of efficient technology/conversion kits > additional costs > lack of awareness
B3 > B1 > B2 > B4

Option III: additional costs > availability of alternative technology > lack of enforcing mechanism > lack of awareness
B2 > B1 > B3 > B4

Lack of resources and infrastructure have come out to be a dominating barrier for options I & II. Both options are CNG options and lack of resource and infrastructure has proved a problem in many countries. CNG conversion has been initiated in Mumbai in late 90's and till now the conversion has been marginal. Hence, for the implementation of CNG option whether it is CNG car or CNG 3-wheeler, lack of resources and infrastructure is a major bottleneck and policy measures need to be taken to remove this barrier for better implementation of CNG option. Barrier 2 (additional cost) is a major barrier in the case of option III and to some extent in option II. Additional cost appeared to be the second important barrier to the implementation of CNG option. Availability of technology is a second major barrier to the option III. Hence, measures need to be taken to overcome this barrier to make this very potential option for emission mitigation more widespread in Mumbai transport system. 3-Wheelers showed some concern about the cost as a barrier. This was not the case with CNG cars. This could be due to the ownership constraint. 3-Wheelers are used for public transport and most of them are sources of livelihood. Unlike cars, any capital investment in 3-wheelers needs some financing and that certainly burdens the user. Removing the additional cost burden on the user would also make the options more adaptable.

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Appendix – I

DELHI

Table A1. PKM supplied by each technology for the base case as well as mitigation case

	2W		**Car**			**Bus**		
	2S	**4S**	**P**	**D**	**CNG**	**Diesel**	**CNG**	**total pkm in yr (bill)**
Base	10230.53	1089.467	10248.55	7921.449	0	43630	0	73.12
2005	8700.015	7179.985	12503.29	15928.09	1158.62	10146.53	44183.47	99.8
2010	8495.929	14644.07	12083.89	20053.66	2722.452	15899.03	59980.97	133.88
2015	5238.031	25581.97	18376.72	21902.52	5350.755	19779	63031	159.26
2020	4190.422	38549.58	30930.46	24663.73	10315.81	25984.12	89195.88	223.83
MS I -								
Base	10230.53	1089.467	10248.55	7921.449	0	43630	0	73.12
2005	8700.015	7179.985	12503.29	15928.09	1158.62	10146.53	44183.47	99.8
2010	8495.929	14644.07	12083.89	20053.66	2722.452	15899.03	59980.97	133.88
2015	5238.031	25581.97	18376.72	21902.52	5350.755	19779	63031	159.26
2020	4190.422	38549.58	50214.25	5379.941	10315.81	25984.12	89195.88	223.83
MS – II								
Base	10230.53	1089.467	10248.55	7921.449	0	43630	0	73.12
2005	8700.015	7179.985	12503.29	15928.09	1158.62	10146.53	44183.47	99.8
2010	8495.929	14644.07	12083.89	20053.66	2722.452	15899.03	59980.97	133.88
2015	5238.031	25581.97	35870.12	4409.121	5350.755	19779	63031	159.26
2020	4190.422	38549.58	54438.63	1155.558	10315.81	25984.12	89195.88	223.83
MS – III								
Base	10230.53	1089.467	10248.55	7921.449	0	43630	0	73.12
2005	8700.015	7179.985	13008.35	15423.03	1158.62	10146.53	44183.47	99.8
2010	8495.929	14644.07	30331.96	1805.59	2722.452	15899.03	59980.97	133.88

2015	5238.031	25581.97	38834.78	1444.464	5350.755	19779	63031	159.26
2020	4190.422	38549.58	54438.63	1155.558	10315.81	25984.12	89195.88	223.83
MS – IV								
Base	10230.53	1089.467	15348.77	2821.225	0	43630	0	73.12
2005	8700.015	7179.985	26174.41	2256.972	1158.62	10146.53	44183.47	99.8
2010	8495.929	14644.07	30331.96	1805.59	2722.452	15899.03	59980.97	133.88
2015	2953.527	27866.47	40206.23	73.01938	5350.755	19779	63031	159.26
2020	4099.272	38640.73	55594.19	0	10315.81	25984.12	89195.88	223.83
MS – V								
Base	0	11320	18170	0	0	43630	0	73.12
2005	8700.015	7179.985	15973.87	0	1158.62	22604.04	44183.47	99.8
2010	8495.929	14644.07	32137.55	0	2722.452	15899.03	59980.97	133.88
2015	2953.527	27866.47	40279.25	0	5350.755	19779	63031	159.26
2020	4099.272	38640.73	55594.19	0	10315.81	25984.12	89195.88	223.83

Table A2. CO_2 emission by each technology for base case as well as mitigation cases (‘000 t)

CO_2 emission

BAU

	2-W		**Car**			**Bus**		Total CO_2	% change
	2-S	4-S	P	D	CNG	D	CNG		
Base	697.92698	44.5955	795.7699	1170.511	0	740.5308	0	3449.334	
2005	593.515	293.9007	970.8439	2353.609	64.77366	172.2167	216.1408	4665	
2010	579.5923	599.4306	938.2781	2963.224	152.2011	269.8539	293.4204	5796	
2015	357.33846	1047.155	1426.898	3236.42	299.1387	335.7084	308.3408	7011	
2020	285.87059	1577.963	2401.659	3644.428	576.7144	441.0277	436.3366	9364	
MS I -									
Base	697.92698	44.5955	795.7699	1170.511	0	740.5308	0	3449.334	0
2005	593.515	293.9007	970.8439	2353.609	64.77366	172.2167	216.1408	4665	0

2010	579.5923	599.4306	938.2781	2963.224	152.2011	269.8539	293.4204	5796	0
2015	357.33846	1047.155	1426.898	3236.42	299.1387	335.7084	308.3408	7011	0
2020	285.87059	1577.963	3898.989	794.9655	576.7144	441.0277	436.3366	8011.866	14.4397
									2.88794
MS – II									
Base	697.92698	44.5955	795.7699	1170.511	0	740.5308	0	3449.334	0
2005	593.515	293.9007	970.8439	2353.609	64.77366	172.2167	216.1408	4665	0
2010	579.5923	599.4306	938.2781	2963.224	152.2011	269.8539	293.4204	5796	0
2015	357.33846	1047.155	2785.21	651.5125	299.1387	335.7084	308.3408	5784.404	17.49531
2020	285.87059	1577.963	4227	170.7508	576.7144	441.0277	436.3366	7715.663	17.60292
									7.019646
MS – III									
Base	697.92698	44.5955	795.7699	1170.511	0	740.5308	0	3449.334	0
2005	593.515	293.9007	1010.06	2278.98	64.77366	172.2167	216.1408	4629.587	0.759127
2010	579.5923	599.4306	2355.187	266.8025	152.2011	269.8539	293.4204	4516.488	22.07577
2015	357.33846	1047.155	3015.407	213.4407	299.1387	335.7084	308.3408	5576.529	20.46029
2020	285.87059	1577.963	4227	170.7508	576.7144	441.0277	436.3366	7715.663	17.60292
									12.17962
MS – IV									
Base	697.92698	44.5955	1191.787	416.8775	0	740.5308	0	3091.718	10.36767
2005	593.515	293.9007	2032.366	333.5008	64.77366	172.2167	216.1408	3706.414	20.54848
2010	579.5923	599.4306	2355.187	266.8025	152.2011	269.8539	293.4204	4516.488	22.07577
2015	201.48963	1140.668	3121.895	10.78969	299.1387	335.7084	308.3408	5418.03	22.72101
2020	279.65236	1581.694	4316.725	0	576.7144	441.0277	436.3366	7632.15	18.49476
									18.84154
MS – V									
Base	0	463.3653	1410.847	0	0	740.5308	0	2614.743	24.1957
2005	593.515	293.9007	1240.324	0	64.77366	383.6577	216.1408	2792.312	40.14337
2010	579.5923	599.4306	2495.386	0	152.2011	269.8539	293.4204	4389.884	24.2601
2015	201.48963	1140.668	3127.565	0	299.1387	335.7084	308.3408	5412.91	22.79404
2020	279.65236	1581.694	4316.725	0	576.7144	441.0277	436.3366	7632.15	18.49476

Table A3. TSP emission by each technology for base case as well as mitigation cases ('000 t)

TSP

BAU

	2-W		**Car**			**Bus**		Total TSP	% change
	2-S	4-S	P	D	CNG	D	CNG		
Base	5.0511553	0.075536	1.249118	1.652507	0	2.216876	0	10.24519	
2005	4.2954872	0.497812	1.523931	3.322787	0	0.515553	0	10.15557	
2010	4.1947235	1.015322	1.472812	4.18343	0	0.807843	0	11.67413	
2015	2.5861904	1.773683	2.239798	4.569124	0	1.004987	0	12.17378	
2020	2.068951	2.672771	3.769878	5.145144	0	1.320274	0	14.97702	
MS I -									
Base	5.0511553	0.075536	1.249118	1.652507	0	2.216876	0	10.24519	0
2005	4.2954872	0.497812	1.523931	3.322787	0	0.515553	0	10.15557	0
2010	4.1947235	1.015322	1.472812	4.18343	0	0.807843	0	11.67413	0
2015	2.5861904	1.773683	2.239798	4.569124	0	1.004987	0	12.17378	0
2020	2.068951	2.672771	6.120231	1.122319	0	1.320274	0	13.30455	11.16692
									2.233384
MS – II									
Base	5.0511553	0.075536	1.249118	1.652507	0	2.216876		10.24519	0
2005	4.2954872	0.497812	1.523931	3.322787	0	0.515553		10.15557	0
2010	4.1947235	1.015322	1.472812	4.18343	0	0.807843		11.67413	0
2015	2.5861904	1.773683	4.371935	0.919794	0	1.004987		10.65659	12.46279
2020	2.068951	2.672771	6.635109	0.241063	0	1.320274		12.93817	13.61319
									5.215195
MS – III									
Base	5.0511553	0.075536	1.249118	1.652507	0	2.216876	0	10.24519	0
2005	4.2954872	0.497812	1.585488	3.217426	0	0.515553	0	10.11177	0.431321
2010	4.1947235	1.015322	3.69693	0.376667	0	0.807843	0	10.09149	13.55685
2015	2.5861904	1.773683	4.733275	0.301332	0	1.004987	0	10.39947	14.57489
2020	2.068951	2.672771	6.635109	0.241063	0	1.320274	0	12.93817	13.61319
									8.43525

MS – IV									
Base	5.0511553	0.075536	1.870745	0.588541	0	2.216876	0	9.802853	4.317531
2005	4.2954872	0.497812	3.190198	0.470831	0	0.515553	0	8.969882	11.67525
2010	4.1947235	1.015322	3.69693	0.376667	0	0.807843	0	10.09149	13.55685
2015	1.4582549	1.932075	4.900429	0.015233	0	1.004987	0	9.310979	23.51614
2020	2.0239474	2.67909	6.775951	0	0	1.320274	0	12.79926	14.54064
									13.52128
MS – V									
Base	0	0.784853	2.214602	0	0	2.216876	0	5.216331	49.08508
2005	4.2954872	0.497812	1.946933	0	0	1.148529	0	7.888762	22.32084
2010	4.1947235	1.015322	3.917	0	0	0.807843	0	9.934889	14.89826
2015	1.4582549	1.932075	4.909329	0	0	1.004987	0	9.304647	23.56816
2020	2.0239474	2.67909	6.775951	0	0	1.320274	0	12.79926	14.54064
									24.88259

Table A4. CO emission by each technology for base case as well as mitigation cases (‘000 t)

CO
BAU

	2-W		**Car**			**Bus**			
	2-S	4-S	P	D	CNG	D	CNG	**Total CO**	**% change**
Base	83.208337	7.836897	109.4786	3.028789	0	14.03235	0	217.585	
2005	70.760119	51.64803	133.5646	6.090151	8.12E-06	3.263343	5.35E-05	265.3263	
2010	69.100226	105.3397	129.0843	7.667577	1.91E-05	5.113473	7.26E-05	316.3054	
2015	42.602651	184.0196	196.3066	8.374494	3.75E-05	6.361354	7.63E-05	437.6649	
2020	34.082099	277.3	330.4101	9.430249	7.23E-05	8.357054	0.000108	659.5797	
MS I -									
Base	83.208337	7.836897	109.4786	3.028789	0	14.03235	0	217.585	0
2005	70.760119	51.64803	133.5646	6.090151	8.12E-06	3.263343	5.35E-05	265.3263	0
2010	69.100226	105.3397	129.0843	7.667577	1.91E-05	5.113473	7.26E-05	316.3054	0
2015	42.602651	184.0196	196.3066	8.374494	3.75E-05	6.361354	7.63E-05	437.6649	0

2020	34.082099	277.3	536.4063	2.057036	7.23E-05	8.357054	0.000108	858.2027	-30.1136
									-6.02271
MS – II									
Base	83.208337	7.836897	109.4786	3.028789	0	14.03235	0	217.585	0
2005	70.760119	51.64803	133.5646	6.090151	8.12E-06	3.263343	5.35E-05	265.3263	0
2010	69.100226	105.3397	129.0843	7.667577	1.91E-05	5.113473	7.26E-05	316.3054	0
2015	42.602651	184.0196	383.1773	1.68584	3.75E-05	6.361354	7.63E-05	617.8469	-41.169
2020	34.082099	277.3	581.5327	0.441831	7.23E-05	8.357054	0.000108	901.7138	-36.7104
									-15.5759
MS – III									
Base	83.208337	7.836897	109.4786	3.028789	0	14.03235	0	217.585	0
2005	70.760119	51.64803	138.9598	5.897042	8.12E-06	3.263343	5.35E-05	270.5284	-1.96063
2010	69.100226	105.3397	324.0167	0.690373	1.91E-05	5.113473	7.26E-05	504.2605	-59.4221
2015	42.602651	184.0196	414.8468	0.552295	3.75E-05	6.361354	7.63E-05	648.3829	-48.146
2020	34.082099	277.3	581.5327	0.441831	7.23E-05	8.357054	0.000108	901.7138	-36.7104
									-29.2478
MS – IV									
Base	83.208337	7.836897	163.961	1.078704	0	14.03235	0	270.1173	-24.1433
2005	70.760119	51.64803	279.6043	0.86296	8.12E-06	3.263343	5.35E-05	406.1388	-53.0714
2010	69.100226	105.3397	324.0167	0.690373	1.91E-05	5.113473	7.26E-05	504.2605	-59.4221
2015	24.022022	200.4528	429.4971	0.027919	3.75E-05	6.361354	7.63E-05	660.3613	-50.8829
2020	33.340749	277.9556	593.8768	0	7.23E-05	8.357054	0.000108	913.5304	-38.5019
									-45.2043
MS – V									
Base	0	81.42853	194.0984	0	0	14.03235	0	289.5592	-33.0787
2005	70.760119	51.64803	170.6385	0	8.12E-06	7.269947	5.35E-05	300.3167	-13.1877
2010	69.100226	105.3397	343.3046	0	1.91E-05	5.113473	7.26E-05	522.8581	-65.3017
2015	24.022022	200.4528	430.2771	0	3.75E-05	6.361354	7.63E-05	661.1134	-51.0547
2020	33.340749	277.9556	593.8768	0	7.23E-05	8.357054	0.000108	913.5304	-38.5019
									-40.2249

Table A5. NOx emission by each technology for base case as well as mitigation cases ('000 t)

	2-W		Car			Bus			
	2-S	4-S	P	D	CNG	D	CNG	Total NOx	% change
NOx									
BAU									
Base	1.0094126	0.36824	8.198841	4.622398	0	1.639073	0	15.83796	
2005	0.8584014	2.426835	10.00263	9.294508	0.00016	0.38118	0	22.96372	
2010	0.838265	4.949696	9.667108	11.7019	0.000375	0.597288	0	27.75463	
2015	0.516819	8.646706	14.70138	12.78077	0.000738	0.743049	0	37.38946	
2020	0.413455	13.02976	24.74437	14.39201	0.001422	0.97616	0	53.55718	
MS I -									
Base	1.0094126	0.36824	8.198841	4.622398	0	1.639073	0	15.83796	0
2005	0.8584014	2.426835	10.00263	9.294508	0.00016	0.38118	0	22.96372	0
2010	0.838265	4.949696	9.667108	11.7019	0.000375	0.597288	0	27.75463	0
2015	0.516819	8.646706	14.70138	12.78077	0.000738	0.743049	0	37.38946	0
2020	0.413455	13.02976	40.1714	3.139354	0.001422	0.97616	0	57.73155	-7.79424
									-1.55885
MS – II									
Base	1.0094126	0.36824	8.198841	4.622398	0	1.639073	0	15.83796	0
2005	0.8584014	2.426835	10.00263	9.294508	0.00016	0.38118	0	22.96372	0
2010	0.838265	4.949696	9.667108	11.7019	0.000375	0.597288	0	27.75463	0
2015	0.516819	8.646706	28.6961	2.572852	0.000738	0.743049	0	41.17626	-10.128
2020	0.413455	13.02976	43.55091	0.674302	0.001422	0.97616	0	58.646	-9.50167
									-3.92594
MS – III									
Base	1.0094126	0.36824	8.198841	4.622398	0	1.639073	0	15.83796	0
2005	0.8584014	2.426835	10.40668	8.999793	0.00016	0.38118	0	23.07305	-0.4761
2010	0.838265	4.949696	24.26557	1.053615	0.000375	0.597288	0	31.70481	-14.2325
2015	0.516819	8.646706	31.06783	0.842887	0.000738	0.743049	0	41.81802	-11.8444
2020	0.413455	13.02976	43.55091	0.674302	0.001422	0.97616	0	58.646	-9.50167
									-7.21093

MS – IV

Base	1.0094126	0.36824	12.27902	1.646268	0	1.639073	0	16.94201	-6.9709
2005	0.8584014	2.426835	20.93953	1.317009	0.00016	0.38118	0	25.92311	-12.8873
2010	0.838265	4.949696	24.26557	1.053615	0.000375	0.597288	0	31.70481	-14.2325
2015	0.2914147	9.418868	32.16498	0.042609	0.000738	0.743049	0	42.66166	-14.1008
2020	0.4044615	13.06057	44.47535	0	0.001422	0.97616	0	58.91796	-10.0095
									-11.6402

MS – V

Base	0	3.82616	14.536	0	0	1.639073	0	20.00123	-26.2866
2005	0.8584014	2.426835	12.7791	0	0.00016	0.849179	0	16.91367	26.34611
2010	0.838265	4.949696	25.71004	0	0.000375	0.597288	0	32.09566	-15.6407
2015	0.2914147	9.418868	32.2234	0	0.000738	0.743049	0	42.67747	-14.1431
2020	0.4044615	13.06057	44.47535	0	0.001422	0.97616	0	58.91796	-10.0095
									-7.94676

Table A6. SOx emission by each technology for base case as well as mitigation cases (‘000 t)

BAU

	2-W		**Car**			**Bus**			
	2-S	4-S	P	D	CNG	D	CNG	**Total SOx**	**% change**
Base	0.4774249	0.030534	0.843998	2.564685	0	2.782886	0	6.699529	
2005	0.4060007	0.201231	1.029683	5.156953	0	0.647184	0	7.441051	
2010	0.3964767	0.410424	0.995143	6.492668	0	1.014101	0	9.308813	
2015	0.2444414	0.716977	1.513377	7.091264	0	1.26158	0	10.82764	
2020	0.195553	1.080416	2.547215	7.985244	0	1.657365	0	13.46579	

MS I -

Base	0.4774249	0.030534	0.843998	2.564685	0	2.782886	0	6.699529	0
2005	0.4060007	0.201231	1.029683	5.156953	0	0.647184	0	7.441051	0
2010	0.3964767	0.410424	0.995143	6.492668	0	1.014101	0	9.308813	0
2015	0.2444414	0.716977	1.513377	7.091264	0	1.26158	0	10.82764	0

2020	0.195553	1.080416	4.135291	1.741835	0	1.657365	0	8.810461	34.57154
									6.914309
MS – II									
Base	0.4774249	0.030534	0.843998	2.564685	0	2.782886	0	6.699529	0
2005	0.4060007	0.201231	1.029683	5.156953	0	0.647184	0	7.441051	0
2010	0.3964767	0.410424	0.995143	6.492668	0	1.014101	0	9.308813	0
2015	0.2444414	0.716977	2.95401	1.427518	0	1.26158	0	6.604526	39.00308
2020	0.195553	1.080416	4.483181	0.374129	0	1.657365	0	7.790645	42.14492
									16.2296
MS – III									
Base	0.4774249	0.030534	0.843998	2.564685	0	2.782886	0	6.699529	0
2005	0.4060007	0.201231	1.071276	4.993434	0	0.647184	0	7.319125	1.638563
2010	0.3964767	0.410424	2.497926	0.584586	0	1.014101	0	4.903514	47.32396
2015	0.2444414	0.716977	3.198158	0.467666	0	1.26158	0	5.888823	45.61305
2020	0.195553	1.080416	4.483181	0.374129	0	1.657365	0	7.790645	42.14492
									27.3441
MS – IV									
Base	0.4774249	0.030534	1.264017	0.913413	0	2.782886	0	5.468275	18.37822
2005	0.4060007	0.201231	2.15554	0.730728	0	0.647184	0	4.140683	44.35352
2010	0.3964767	0.410424	2.497926	0.584586	0	1.014101	0	4.903514	47.32396
2015	0.1378313	0.781004	3.311101	0.023641	0	1.26158	0	5.515157	49.06409
2020	0.1912994	1.082971	4.578345	0	0	1.657365	0	7.509981	44.2292
									40.6698
MS – V									
Base	0	0.317262	1.496353	0	0	2.782886	0	4.596501	31.39068
2005	0.4060007	0.201231	1.315495	0	0	1.441771	0	3.364498	54.78464
2010	0.3964767	0.410424	2.646622	0	0	1.014101	0	4.467623	52.00652
2015	0.1378313	0.781004	3.317114	0	0	1.26158	0	5.497529	49.22689
2020	0.1912994	1.082971	4.578345	0	0	1.657365	0	7.509981	44.2292
									46.32759

Table A7. HC emission by each technology for base case as well as mitigation cases ('000 t)

HC
BAU

	2-W		**Car**			**Bus**			
	2-S	4-S	P	D	CNG	D	CNG	**Total HC**	**% change**
Base	52.332588	0.679827	23.49691	0.770151	0	0.680982	0	77.96046	
2005	44.503475	4.480311	28.66637	1.548585	0	0.158368	0	79.35711	
2010	43.459511	9.1379	27.70479	1.949688	0	0.248154	0	82.50005	
2015	26.794274	15.96315	42.13242	2.129441	0	0.308713	0	87.32799	
2020	21.435405	24.05494	70.91445	2.397895	0	0.405563	0	119.2083	
MS I -									
Base	52.332588	0.679827	23.49691	0.770151	0	0.680982	0	77.96046	0
2005	44.503475	4.480311	28.66637	1.548585	0	0.158368	0	79.35711	0
2010	43.459511	9.1379	27.70479	1.949688	0	0.248154	0	82.50005	0
2015	26.794274	15.96315	42.13242	2.129441	0	0.308713	0	87.32799	0
2020	21.435405	24.05494	115.1265	0.523057	0	0.405563	0	161.5455	-35.5153
									-7.10307
MS – II									
Base	52.332588	0.679827	23.49691	0.770151	0	0.680982	0	77.96046	0
2005	44.503475	4.480311	28.66637	1.548585	0	0.158368	0	79.35711	0
2010	43.459511	9.1379	27.70479	1.949688	0	0.248154	0	82.50005	0
2015	26.794274	15.96315	82.23965	0.42867	0	0.308713	0	125.7345	-43.9795
2020	21.435405	24.05494	124.8118	0.112347	0	0.405563	0	170.82	-43.2955
									-17.455
MS – III									
Base	52.332588	0.679827	23.49691	0.770151	0	0.680982	0	77.96046	0
2005	44.503475	4.480311	29.82432	1.499482	0	0.158368	0	80.46595	-1.39728
2010	43.459511	9.1379	69.54226	0.175546	0	0.248154	0	122.5634	-48.5616
2015	26.794274	15.96315	89.03673	0.140436	0	0.308713	0	132.2433	-51.4329
2020	21.435405	24.05494	124.8118	0.112347	0	0.405563	0	170.82	-43.2955
									-28.9374

MS – IV

Base	52.332588	0.679827	35.19023	0.274289	0	0.680982	0	89.15791	-14.363
2005	44.503475	4.480311	60.01022	0.219431	0	0.158368	0	109.3718	-37.8223
2010	43.459511	9.1379	69.54226	0.175546	0	0.248154	0	122.5634	-48.5616
2015	15.108277	17.38868	92.18105	0.007099	0	0.308713	0	124.9938	-43.1314
2020	20.969145	24.11181	127.4611	0	0	0.405563	0	172.9476	-45.0803
									-37.7917

MS – V

Base	0	7.06368	41.65847	0	0	0.680982	0	49.40313	36.63054
2005	44.503475	4.480311	36.62339	0	0	0.352806	0	85.95998	-8.32045
2010	43.459511	9.1379	73.68194	0	0	0.248154	0	126.5275	-53.3666
2015	15.108277	17.38868	92.34846	0	0	0.308713	0	125.1541	-43.315
2020	20.969145	24.11181	127.4611	0	0	0.405563	0	172.9476	-45.0803
									-22.6904

Table A8. Pb emission by each technology for base case as well as mitigation cases (‘000 t)

Pb

BAU

	2-W		**Car**			**Bus**			
	2-S	4-S	P	D	CNG	D	CNG	**Total Pb**	**% change**
Base	0.0341018	0.002179	0.060286	0	0	0	0	0.096566	
2005	0.029	0.01436	0.073549	0	0	0	0	0.116909	
2010	0.0283198	0.029288	0.071082	0	0	0	0	0.12869	
2015	0.0174601	0.051164	0.108098	0	0	0	0	0.176722	
2020	0.0139681	0.077099	0.181944	0	0	0	0	0.273011	

MS I -

Base	0.0341018	0.002179	0.060286	0	0	0	0	0.096566	0
2005	0.029	0.01436	0.073549	0	0	0	0	0.116909	0
2010	0.0283198	0.029288	0.071082	0	0	0	0	0.12869	0
2015	0.0174601	0.051164	0.108098	0	0	0	0	0.176722	0

2020	0.0139681	0.077099	0.295378	0	0	0	0	0.386445	-41.5492
									-8.30985
MS – II									
Base	0.0341018	0.002179	0.060286	0	0	0	0	0.096566	0
2005	0.029	0.01436	0.073549	0	0	0	0	0.116909	0
2010	0.0283198	0.029288	0.071082	0	0	0	0	0.12869	0
2015	0.0174601	0.051164	0.211001	0	0	0	0	0.279625	-58.2283
2020	0.0139681	0.077099	0.320227	0	0	0	0	0.411294	-50.6512
									-21.7759
MS – III									
Base	0.0341018	0.002179	0.060286	0	0	0	0	0.096566	0
2005	0.029	0.01436	0.07652	0	0	0	0	0.11988	-2.54122
2010	0.0283198	0.029288	0.178423	0	0	0	0	0.236031	-83.4113
2015	0.0174601	0.051164	0.22844	0	0	0	0	0.297064	-68.0964
2020	0.0139681	0.077099	0.320227	0	0	0	0	0.411294	-50.6512
									-40.94
MS – IV									
Base	0.0341018	0.002179	0.090287	0	0	0	0	0.126568	-31.0681
2005	0.029	0.01436	0.153967	0	0	0	0	0.197327	-68.7872
2010	0.0283198	0.029288	0.178423	0	0	0	0	0.236031	-83.4113
2015	0.0098451	0.055733	0.236507	0	0	0	0	0.302085	-70.9377
2020	0.0136642	0.077281	0.327025	0	0	0	0	0.41797	-53.0964
									-61.4602
MS – V									
Base	0	0.02264	0.106882	0	0	0	0	0.129522	-34.1279
2005	0.029	0.01436	0.093964	0	0	0	0	0.137324	-17.4625
2010	0.0283198	0.029288	0.189044	0	0	0	0	0.246652	-91.6645
2015	0.0098451	0.055733	0.236937	0	0	0	0	0.302515	-71.1808
2020	0.0136642	0.077281	0.327025	0	0	0	0	0.41797	-53.0964
									-53.5064

Table A9. Total cost for each case including BAU

Percentage of CO_2 reduction (%)	**0**	**5**	**10**	**15**	**20**	**25**
Total cost (USD)	**16021277**	**16106383**	**16234043**	16340426	16553192	16893617
MAC (USD/ton)	0	35.68	44.59	49.08	66.94	115.87

MUMBAI

Table A10. Passenger-kilometer supplied by each technology for the base case as well as mitigation cases

BAU					**PKM in mill**				
	3-W			**Car**			**Bus**		
	Diesel	**CNG**	**BOV**	**P**	**D**	**CNG**	**Diesel**	**CNG**	**total pkm in yr (bill)**
Base	0	3600	0	2770.45	692.6078	1936.942	21398.62	1.37901	30.4
2005	4639.621	1360.379	0	4854.73	3166.265	279.0049	43400	0	57.7
2010	2081.673	3091.829	1626.498	9637.07	443.2766	719.6531	44738.58	11961.42	74.3
2015	5297.033	4402.906	0.060317	12486.8	354.6175	1458.581	68000	0	92
2020	10675.44	3124.559	0	13242.96	2913.334	2543.708	93200	0	125.7
MS I -									
Base	0	3600	0	3049.327	692.6078	1658.065	19383.14	2016.859	30.4
2005	4639.621	1360.379	0	7466.909	554.0862	279.0049	43400	0	57.7
2010	2081.673	3091.829	1626.498	9637.07	443.2766	719.6531	36187.73	20512.27	74.3
2015	3572.334	4402.906	1724.759	12486.8	354.6175	1458.581	68000	0	92
2020	10675.44	3124.559	0	15604.95	551.3457	2543.708	93200	0	125.7
MS – II									
Base	0	3600	0	3755.275	692.6078	952.1171	19383.14	2016.859	30.4
2005	4367.573	1360.379	272.0478	7466.909	554.0862	279.0049	43400	0	57.7
2010	2081.673	3091.829	1626.498	9637.07	443.2766	719.6531	27636.88	29063.12	74.3
2015	1665.338	4402.906	3631.755	12486.8	354.6175	1458.581	68000	0	92
2020	7550.882	3124.559	3124.559	15872.6	283.6902	2543.708	88488.36	4711.641	125.7

MS – III									
Base	0	3600	0	4461.223	692.6078	246.1693	19383.14	2016.859	30.4
2005	3279.242	1360.379	1360.379	7466.909	554.0862	279.0049	42572.88	827.1205	57.7
2010	2081.673	3091.829	1626.498	9637.07	443.2766	719.6531	19086.03	37613.97	74.3
2015	1665.338	4402.906	3631.755	12486.8	354.6175	1458.581	56818.26	11181.74	92
2020	7550.882	3124.559	3124.559	15872.6	283.6902	2543.708	63642.44	29557.56	125.7
MS – IV									
Base	0	3600	0	4707.392	692.6078	0	17213.3	4186.698	30.4
2005	3279.242	1360.379	1360.379	7466.909	554.0862	279.0049	33855.83	9544.168	57.7
2010	1823.621	3091.829	1884.549	9637.07	443.2766	719.6531	12405.95	44294.05	74.3
2015	1665.338	4402.906	3631.755	12486.8	354.6175	1458.581	44314.94	23685.06	92
2020	7550.882	3124.559	3124.559	15872.6	283.6902	2543.708	43131.76	50068.24	125.7
MS – V									
Base	0	3600	0	4707.392	692.6078	0	13881.71	7518.286	30.4
2005	3279.242	1360.379	1360.379	7466.909	554.0862	279.0049	25138.79	18261.21	57.7
2010	644.1228	3091.829	3064.048	9637.07	443.2766	719.6531	12405.95	44294.05	74.3
2015	1665.338	4402.906	3631.755	12486.8	354.6175	1458.581	31811.62	36188.38	92
2020	7550.882	3124.559	3124.559	15872.6	283.6902	2543.708	24234.63	68965.37	125.7

Table A11. CO_2 emission by each technology for base case as well as mitigation cases ('000 t)

BAU -	**3-W**			**Car**			**Bus**		**Total CO2**	**% change**
	Diesel	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**		
Base	0	222	0	213.6095	101.6256	107.5274	353.6404	0.006568	998.4095	
2005	395.6566	83.89003	0	374.3133	464.5828	15.48868	717.2421	0	2051.174	
2010	177.5204	190.6628	0	743.0451	65.04152	39.95084	739.364	56.97411	2012.559	
2015	451.7192	271.5125	0	962.7674	52.03266	80.97168	1123.789	0	2942.793	
2020	910.3779	192.6811	0	1021.069	427.4705	141.2114	1540.253	0	4233.063	
MS I -										
Base	0	222	0	235.1117	101.6256	92.04585	320.3319	9.606619	980.7217	1.771597
2005	395.6566	83.89003	0	575.7196	81.3005	15.48868	717.2421	0	1869.298	8.866924

2010	177.5204	190.6628	0	743.0451	65.04152	39.95084	598.0499	97.70316	1911.974	4.997866
2015	304.6407	271.5125	0	962.7674	52.03266	80.97168	1123.789	0	2795.715	4.997922
2020	910.3779	192.6811	0	1203.185	80.89838	141.2114	1540.253	0	4068.607	3.885041
										4.90387
MS – II										
Base	0	222	0	289.5422	101.6256	52.85585	320.3319	9.606619	995.9622	0.245114
2005	372.457	83.89003	0	575.7196	81.3005	15.48868	717.2421	0	1846.098	9.997966
2010	177.5204	190.6628	0	743.0451	65.04152	39.95084	456.7359	138.4322	1811.389	9.995733
2015	142.0164	271.5125	0	962.7674	52.03266	80.97168	1123.789	0	2633.09	10.52411
2020	643.9225	192.6811	0	1223.822	41.62557	141.2114	1462.387	22.44229	3728.092	11.92922
										8.538429
MS – III										
Base	0	222	0	343.9728	101.6256	13.66585	320.3319	9.606619	1011.203	-1.28137
2005	279.6465	83.89003	0	575.7196	81.3005	15.48868	703.5729	3.939706	1743.558	14.99706
2010	177.5204	190.6628	0	743.0451	65.04152	39.95084	315.4218	179.1613	1710.804	14.9936
2015	142.0164	271.5125	0	962.7674	52.03266	80.97168	938.9965	53.26041	2501.558	14.99377
2020	643.9225	192.6811	0	1223.822	41.62557	141.2114	1051.775	140.7873	3435.825	18.83359
										12.50733
MS – IV										
Base	0	222	0	362.9531	101.6256	0	284.4725	19.9419	990.9931	0.742816
2005	279.6465	83.89003	0	575.7196	81.3005	15.48868	559.5122	45.46038	1641.018	19.99614
2010	155.5144	190.6628	0	743.0451	65.04152	39.95084	205.0246	210.9796	1610.219	19.99147
2015	142.0164	271.5125	0	962.7674	52.03266	80.97168	732.3627	112.8157	2354.479	19.99169
2020	643.9225	192.6811	0	1223.822	41.62557	141.2114	712.8092	238.4829	3194.555	24.53325
										17.05107
MS – V										
Base	0	222	0	362.9531	101.6256	0	229.4136	35.81078	951.8031	4.668059
2005	279.6465	83.89003	0	575.7196	81.3005	15.48868	415.4515	86.98105	1538.478	24.99523
2010	54.92936	190.6628	0	743.0451	65.04152	39.95084	205.0246	210.9796	1509.634	24.98933
2015	142.0164	271.5125	0	962.7674	52.03266	80.97168	525.7289	172.371	2207.401	24.98961
2020	643.9225	192.6811	0	1223.822	41.62557	141.2114	400.5091	328.493	2972.265	29.78453
										21.88535

Table A12. TSP emission by each technology for base case as well as mitigation cases ('000 t)

BAU

	3-W			**Car**			**Bus**		**Total TSP**	**% change**
	Diesel	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**		
Base	0	0	0	0.335302	0.143473	0	1.058669	0	1.537444	
2005	1.315848	0	0	0.587558	0.65589	0	2.147158	0	4.706455	
2010	0.590386	0	0	1.166356	0.091825	0	2.213383	0	4.061948	
2015	1.502298	0	0	1.511253	0.073459	0	3.364211	0	6.45122	
2020	3.027674	0	0	1.602769	0.603496	0	4.610947	0	9.844886	
MS I -										
Base	0	0	0	0.369054	0.143473	0	0.958955	0	1.471483	4.290321
2005	1.315848	0	0	0.903705	0.114779	0	2.147158	0	4.48149	4.779919
2010	0.590386	0	0	1.166356	0.091825	0	1.790341	0	3.638906	10.41476
2015	1.013154	0	0	1.511253	0.073459	0	3.364211	0	5.962076	7.582191
2020	3.027674	0	0	1.888636	0.114211	0	4.610947	0	9.641468	2.06623
										5.826684
MS – II										
Base	0	0	0	0.454494	0.143473	0	0.958955		1.556922	-1.26692
2005	1.238692	0	0	0.903705	0.114779	0	2.147158		4.404334	6.41928
2010	0.590386	0	0	1.166356	0.091825	0	1.367298		3.215864	20.82951
2015	0.472308	0	0	1.511253	0.073459	0	3.364211		5.421231	15.9658
2020	2.141514	0	0	1.92103	0.058766	0	4.377845		8.499155	13.66934
										11.1234
MS – III										
Base	0	0	0	0.539933	0.143473	0	0.958955	0	1.642362	-6.82416
2005	0.93003	0	0	0.903705	0.114779	0	2.106237	0	4.054751	13.84703
2010	0.590386	0	0	1.166356	0.091825	0	0.944256	0	2.792822	31.24427
2015	0.472308	0	0	1.511253	0.073459	0	2.811008	0	4.868029	24.54096
2020	2.141514	0	0	1.92103	0.058766	0	3.148626	0	7.269936	26.1552
										17.79266
MS – IV										
Base	0	0	0	0.569726	0.143473	0	0.851605	0	1.564805	-1.77965
2005	0.93003	0	0	0.903705	0.114779	0	1.674973	0	3.623486	23.01028

2010	0.517199	0	0	1.166356	0.091825	0	0.613768	0	2.389147	41.18223
2015	0.472308	0	0	1.511253	0.073459	0	2.192423	0	4.249444	34.12961
2020	2.141514	0	0	1.92103	0.058766	0	2.133887	0	6.255198	36.46247
										26.60099

MS – V

Base	0	0	0	0.569726	0.143473	0	0.68678	0	1.399979	8.941125
2005	0.93003	0	0	0.903705	0.114779	0	1.243708	0	3.192222	32.17353
2010	0.18268	0	0	1.166356	0.091825	0	0.613768	0	2.054629	49.41766
2015	0.472308	0	0	1.511253	0.073459	0	1.573838	0	3.630859	43.71827
2020	2.141514	0	0	1.92103	0.058766	0	1.198976	0	5.320287	45.95888
										36.04189

Table A13. CO emission by each technology for base case as well as mitigation cases ('000 t)

BAU

	2-W		**3-W**			**Car**			**Bus**			
	2-S	**4-S**	**Diesel**	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**	**Total CO**	**% change**
Base	636048400	0	0	2.24E-05	0	29.38749	0.262964	1.35E-05	6.701147	1.63E-09	36.35163	
2005	0	0	32.21959	8.46E-06	0	51.49644	1.202145	1.94E-06	13.59105	0	98.50924	
2010	0	0	14.45606	1.92E-05	0	102.225	0.1683	5.01E-06	14.01024	1.41E-05	130.8596	
2015	0	0	36.78495	2.74E-05	0	132.4535	0.134639	1.02E-05	21.29474	0	190.6678	
2020	0	0	74.13501	1.94E-05	0	140.4744	1.106114	1.77E-05	29.18632	0	244.9018	

MS I -

Base	0	0	0	2.24E-05	0	32.34567	0.262964	1.15E-05	6.069984	2.38E-06	38.67865	-6.40142
2005	0	0	32.21959	8.46E-06	0	79.20506	0.210372	1.94E-06	13.59105	0	125.2261	-27.1212
2010	0	0	14.45606	1.92E-05	0	102.225	0.1683	5.01E-06	11.33247	2.42E-05	128.1819	2.046281
2015	0	0	24.80788	2.74E-05	0	132.4535	0.134639	1.02E-05	21.29474	0	178.6907	6.281645
2020	0	0	74.13501	1.94E-05	0	165.5291	0.209331	1.77E-05	29.18632	0	269.0598	-9.86434
												-7.0118

MS – II

Base	0	0	0	2.24E-05	0	39.83399	0.262964	6.63E-06	6.069984	2.38E-06	46.16697	-27.0011
2005	0	0	30.33037	8.46E-06	0	79.20506	0.210372	1.94E-06	13.59105	0	123.3369	-25.2034
2010	0	0	14.45606	1.92E-05	0	102.225	0.1683	5.01E-06	8.654708	3.43E-05	125.5041	4.092562
2015	0	0	11.56485	2.74E-05	0	132.4535	0.134639	1.02E-05	21.29474	0	165.4477	13.22725
2020	0	0	52.43668	1.94E-05	0	168.3683	0.107709	1.77E-05	27.71083	5.55E-06	248.6235	-1.51966
												-7.28086

MS – III

Base	0	0	0	2.24E-05	0	47.32232	0.262964	1.71E-06	6.069984	2.38E-06	53.65529	-47.6008
2005	0	0	22.77252	8.46E-06	0	79.20506	0.210372	1.94E-06	13.33203	9.75E-07	115.52	-17.2682
2010	0	0	14.45606	1.92E-05	0	102.225	0.1683	5.01E-06	5.976942	4.43E-05	122.8264	6.138843
2015	0	0	11.56485	2.74E-05	0	132.4535	0.134639	1.02E-05	17.79309	1.32E-05	161.9461	15.06376
2020	0	0	52.43668	1.94E-05	0	168.3683	0.107709	1.77E-05	19.93013	3.48E-05	240.8429	1.657395
												-8.40179

MS – IV

Base	0	0	0	2.24E-05	0	49.93355	0.262964	0	5.390481	4.94E-06	55.58703	-52.9148
2005	0	0	22.77252	8.46E-06	0	79.20506	0.210372	1.94E-06	10.60222	1.13E-05	112.7902	-14.4971
2010	0	0	12.66404	1.92E-05	0	102.225	0.1683	5.01E-06	3.88502	5.22E-05	118.9424	9.106864
2015	0	0	11.56485	2.74E-05	0	132.4535	0.134639	1.02E-05	13.87757	2.79E-05	158.0306	17.11733
2020	0	0	52.43668	1.94E-05	0	168.3683	0.107709	1.77E-05	13.50705	5.9E-05	234.4198	4.280101
												-7.38152

MS – V

Base	0	0	0	2.24E-05	0	49.93355	0.262964	0	4.347168	8.86E-06	54.54372	-50.0447
2005	0	0	22.77252	8.46E-06	0	79.20506	0.210372	1.94E-06	7.872409	2.15E-05	110.0604	-11.726
2010	0	0	4.473075	1.92E-05	0	102.225	0.1683	5.01E-06	3.88502	5.22E-05	110.7515	15.36621
2015	0	0	11.56485	2.74E-05	0	132.4535	0.134639	1.02E-05	9.96206	4.27E-05	154.1151	19.1709
2020	0	0	52.43668	1.94E-05	0	168.3683	0.107709	1.77E-05	7.589265	8.13E-05	228.502	6.696484
												-4.10742

Table A14. NOx emission by each technology for base case as well as mitigation cases ('000 t)

	3-W			Car			Bus			
BAU	**Diesel**	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**	**Total NOx**	**% change**
Base	0	0.000246	0	2.200825	0.401324	0.000265	0.782739	0	3.385399	
2005	0.262912	9.3E-05	0	3.856561	1.834658	3.82E-05	1.587526	0	7.541789	
2010	0.117961	0.000211	0	7.655617	0.256852	9.85E-05	1.63649	0	9.66723	
2015	0.300165	0.000301	0	9.919422	0.205479	0.0002	2.487368	0	12.91294	
2020	0.604942	0.000214	0	10.52011	1.6881	0.000348	3.409158	0	16.22287	
MS I -										
Base	0	0.000246	0	2.422363	0.401324	0.000227	0.709015	0	3.533175	-4.36508
2005	0.262912	9.3E-05	0	5.931657	0.321059	3.82E-05	1.587526	0	8.103285	-7.44514
2010	0.117961	0.000211	0	7.655617	0.256852	9.85E-05	1.323709	0	9.354449	3.235478
2015	0.202432	0.000301	0	9.919422	0.205479	0.0002	2.487368	0	12.8152	0.756861
2020	0.604942	0.000214	0	12.39645	0.319471	0.000348	3.409158	0	16.73059	-3.12964
										-2.1895
MS – II										
Base	0	0.000246	0	2.983162	0.401324	0.00013	0.709015	0	4.093878	-20.9275
2005	0.247496	9.3E-05	0	5.931657	0.321059	3.82E-05	1.587526	0	8.087869	-7.24073
2010	0.117961	0.000211	0	7.655617	0.256852	9.85E-05	1.010928	0	9.041668	6.470956
2015	0.094369	0.000301	0	9.919422	0.205479	0.0002	2.487368	0	12.70714	1.59372
2020	0.427883	0.000214	0	12.60908	0.164381	0.000348	3.236811	0	16.43871	-1.3305
										-4.2868
MS – III										
Base	0	0.000246	0	3.543962	0.401324	3.37E-05	0.709015	0	4.654581	-37.4899
2005	0.185824	9.3E-05	0	5.931657	0.321059	3.82E-05	1.557271	0	7.995942	-6.02182
2010	0.117961	0.000211	0	7.655617	0.256852	9.85E-05	0.698147	0	8.728887	9.706434
2015	0.094369	0.000301	0	9.919422	0.205479	0.0002	2.078352	0	12.29812	4.761214
2020	0.427883	0.000214	0	12.60908	0.164381	0.000348	2.327974	0	15.52988	4.271699
										-4.95447

MS – IV

Base	0	0.000246	0	3.739517	0.401324	0	0.629644	0	4.770732	-40.9208
2005	0.185824	9.3E-05	0	5.931657	0.321059	3.82E-05	1.238411	0	7.677082	-1.79391
2010	0.103339	0.000211	0	7.655617	0.256852	9.85E-05	0.453796	0	8.469913	12.38531
2015	0.094369	0.000301	0	9.919422	0.205479	0.0002	1.620994	0	11.84076	8.303075
2020	0.427883	0.000214	0	12.60908	0.164381	0.000348	1.577715	0	14.77962	8.896399
										-2.62598

MS – V

Base	0	0.000246	0	3.739517	0.401324	0	0.507778	0	4.648866	-37.321
2005	0.185824	9.3E-05	0	5.931657	0.321059	3.82E-05	0.91955	0	7.358221	2.434008
2010	0.0365	0.000211	0	7.655617	0.256852	9.85E-05	0.453796	0	8.403075	13.0767
2015	0.094369	0.000301	0	9.919422	0.205479	0.0002	1.163636	0	11.38341	11.84494
2020	0.427883	0.000214	0	12.60908	0.164381	0.000348	0.886477	0	14.08838	13.15728
										0.638376

Table A15. SOx emission by each technology for base case as well as mitigation cases (‘000 t)

BAU

	2-W		3-W			Car			Bus			
	2-S	**4-S**	**Diesel**	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**	**Total SOx**	**% change**
Base	636048400	0	0	0	0	0.226556	0.22267	0	1.328967	0	1.778193	
2005	0	0	0.66759	0	0	0.396999	1.017939	0	2.695368	0	4.777897	
2010	0	0	0.29953	0	0	0.788078	0.142511	0	2.778502	0	4.008621	
2015	0	0	0.762184	0	0	1.021117	0.114008	0	4.223158	0	6.120467	
2020	0	0	1.536077	0	0	1.082952	0.936623	0	5.788211	0	9.343863	

MS I -

Base	0	0	0	0	0	0.249361	0.22267	0	1.203795	0	1.675826	5.756776
2005	0	0	0.66759	0	0	0.610612	0.178136	0	2.695368	0	4.151706	13.10599
2010	0	0	0.29953	0	0	0.788078	0.142511	0	2.247449	0	3.477568	13.24777
2015	0	0	0.514019	0	0	1.021117	0.114008	0	4.223158	0	5.872302	4.054675
2020	0	0	1.536077	0	0	1.276105	0.177255	0	5.788211	0	8.777648	6.059753

												8.444992
MS – II												
Base	0	0	0	0	0	0.30709	0.22267	0	1.203795	0	1.733555	2.510256
2005	0	0	0.628445	0	0	0.610612	0.178136	0	2.695368	0	4.112562	13.92527
2010	0	0	0.29953	0	0	0.788078	0.142511	0	1.716396	0	2.946515	26.49554
2015	0	0	0.239624	0	0	1.021117	0.114008	0	4.223158	0	5.597906	8.53792
2020	0	0	1.086488	0	0	1.297993	0.091205	0	5.495593	0	7.971279	14.68969
												13.23173
MS – III												
Base	0	0	0	0	0	0.36482	0.22267	0	1.203795	0	1.791285	-0.73626
2005	0	0	0.471847	0	0	0.610612	0.178136	0	2.644	0	3.904594	18.27797
2010	0	0	0.29953	0	0	0.788078	0.142511	0	1.185343	0	2.415462	39.74331
2015	0	0	0.239624	0	0	1.021117	0.114008	0	3.528713	0	4.903461	19.8842
2020	0	0	1.086488	0	0	1.297993	0.091205	0	3.952531	0	6.428217	31.20386
												21.67461
MS – IV												
Base	0	0	0	0	0	0.38495	0.22267	0	1.069037	0	1.676657	5.710041
2005	0	0	0.471847	0	0	0.610612	0.178136	0	2.102625	0	3.36322	29.60878
2010	0	0	0.262399	0	0	0.788078	0.142511	0	0.770475	0	1.963463	51.01899
2015	0	0	0.239624	0	0	1.021117	0.114008	0	2.752191	0	4.126939	32.57149
2020	0	0	1.086488	0	0	1.297993	0.091205	0	2.67871	0	5.154396	44.83657
												32.74917
MS – V												
Base	0	0	0	0	0	0.38495	0.22267	0	0.862127	0	1.469748	17.34597
2005	0	0	0.471847	0	0	0.610612	0.178136	0	1.561251	0	2.821845	40.93959
2010	0	0	0.092682	0	0	0.788078	0.142511	0	0.770475	0	1.793746	55.25278
2015	0	0	0.239624	0	0	1.021117	0.114008	0	1.975669	0	3.350418	45.25879
2020	0	0	1.086488	0	0	1.297993	0.091205	0	1.505098	0	3.980784	57.39681
												43.23879

Table A16. HC emission by each technology for base case as well as mitigation cases ('000 t)

	2-W		**3-W**			**Car**			**Bus**			
BAU												
	2-S	**4-S**	**Diesel**	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**	**Total HC**	**% change**
Base	636048400	0	0	0	0	6.307305	0.066866	0	0.325203	0	6.699374	
2005	0	0	10.20717	0	0	11.05245	0.305678	0	0.659566	0	22.22486	
2010	0	0	4.579681	0	0	21.9401	0.042795	0	0.679909	0	27.24248	
2015	0	0	11.65347	0	0	28.4279	0.034236	0	1.033421	0	41.14903	
2020	0	0	23.48597	0	0	30.14939	0.281259	0	1.416395	0	55.33301	
MS I -												
Base	0	0	0	0	0	6.942207	0.066866	0	0.294573	0	7.303645	-9.01982
2005	0	0	10.20717	0	0	16.99943	0.053493	0	0.659566	0	27.91966	-25.6235
2010	0	0	4.579681	0	0	21.9401	0.042795	0	0.549958	0	27.11253	0.477014
2015	0	0	7.859136	0	0	28.4279	0.034236	0	1.033421	0	37.35469	9.220966
2020	0	0	23.48597	0	0	35.52678	0.053228	0	1.416395	0	60.48237	-9.30612
												-6.8503
MS – II												
Base	0	0	0	0	0	8.549393	0.066866	0	0.294573	0	8.910831	-33.0099
2005	0	0	9.608662	0	0	16.99943	0.053493	0	0.659566	0	27.32115	-22.9306
2010	0	0	4.579681	0	0	21.9401	0.042795	0	0.420008	0	26.98258	0.954028
2015	0	0	3.663744	0	0	28.4279	0.034236	0	1.033421	0	33.1593	19.41657
2020	0	0	16.61194	0	0	36.13613	0.027388	0	1.34479	0	54.12025	2.191755
												-6.67563
MS – III												
Base	0	0	0	0	0	10.15658	0.066866	0	0.294573	0	10.51802	-57
2005	0	0	7.214333	0	0	16.99943	0.053493	0	0.646996	0	24.91425	-12.1008
2010	0	0	4.579681	0	0	21.9401	0.042795	0	0.290057	0	26.85263	1.431042
2015	0	0	3.663744	0	0	28.4279	0.034236	0	0.863488	0	32.98936	19.82954
2020	0	0	16.61194	0	0	36.13613	0.027388	0	0.967198	0	53.74266	2.874155

												-8.99322
MS – IV												
Base	0	0	0	0	0	10.71702	0.066866	0	0.261597	0	11.04548	-64.8733
2005	0	0	7.214333	0	0	16.99943	0.053493	0	0.51452	0	24.78178	-11.5047
2010	0	0	4.011967	0	0	21.9401	0.042795	0	0.188538	0	26.1834	3.887623
2015	0	0	3.663744	0	0	28.4279	0.034236	0	0.67347	0	32.79935	20.29132
2020	0	0	16.61194	0	0	36.13613	0.027388	0	0.655489	0	53.43095	3.437487
												-9.75232
MS – V												
Base	0	0	0	0	0	10.71702	0.066866	0	0.210966	0	10.99485	-64.1175
2005	0	0	7.214333	0	0	16.99943	0.053493	0	0.382043	0	24.6493	-10.9087
2010	0	0	1.41707	0	0	21.9401	0.042795	0	0.188538	0	23.5885	13.41281
2015	0	0	3.663744	0	0	28.4279	0.034236	0	0.483453	0	32.60933	20.7531
2020	0	0	16.61194	0	0	36.13613	0.027388	0	0.368303	0	53.14376	3.956502
												-7.38076

Table A17. Pb emission by each technology for base case as well as mitigation cases ('000 t)

BAU

	2-W		**3-W**			**Car**			**Bus**			
	2-S	**4-S**	**Diesel**	**CNG**	**BOV**	**P**	**D**	**CNG**	**D**	**CNG**	**Total Pb**	**% change**
Base	636048400	0	0	0	0	0.016183	0	0	0	0	0.016183	
2005	0	0	0.019332	0	0	0.028357	0	0	0	0	0.047689	
2010	0	0	0.008674	0	0	0.056291	0	0	0	0	0.064965	
2015	0	0	0.022071	0	0	0.072937	0	0	0	0	0.095008	
2020	0	0	0.044481	0	0	0.077354	0	0	0	0	0.121835	
MS I -												
Base	0	0	0	0	0	0.017811	0	0	0	0	0.017811	-10.0661
2005	0	0	0.019332	0	0	0.043615	0	0	0	0	0.062947	-31.995
2010	0	0	0.008674	0	0	0.056291	0	0	0	0	0.064965	0

2015	0	0	0.014885	0	0	0.072937	0	0	0	0	0.087822	7.56384
2020	0	0	0.044481	0	0	0.09115	0	0	0	0	0.135631	-11.3241
												-9.16428
MS – II												
Base	0	0	0	0	0	0.021935	0	0	0	0	0.021935	-35.5475
2005	0	0	0.018198	0	0	0.043615	0	0	0	0	0.061813	-29.6181
2010	0	0	0.008674	0	0	0.056291	0	0	0	0	0.064965	0
2015	0	0	0.006939	0	0	0.072937	0	0	0	0	0.079876	15.92716
2020	0	0	0.031462	0	0	0.092714	0	0	0	0	0.124176	-1.92152
												-10.232
MS – III												
Base	0	0	0	0	0	0.026059	0	0	0	0	0.026059	-61.0288
2005	0	0	0.013664	0	0	0.043615	0	0	0	0	0.057279	-20.1091
2010	0	0	0.008674	0	0	0.056291	0	0	0	0	0.064965	0
2015	0	0	0.006939	0	0	0.072937	0	0	0	0	0.079876	15.92716
2020	0	0	0.031462	0	0	0.092714	0	0	0	0	0.124176	-1.92152
												-13.4265
MS – IV												
Base	0	0	0	0	0	0.027496	0	0	0	0	0.027496	-69.9143
2005	0	0	0.013664	0	0	0.043615	0	0	0	0	0.057279	-20.1091
2010	0	0	0.007598	0	0	0.056291	0	0	0	0	0.06389	1.655071
2015	0	0	0.006939	0	0	0.072937	0	0	0	0	0.079876	15.92716
2020	0	0	0.031462	0	0	0.092714	0	0	0	0	0.124176	-1.92152
												-14.8726
MS – V												
Base	0	0	0	0	0	0.027496	0	0	0	0	0.027496	-69.9143
2005	0	0	0.013664	0	0	0.043615	0	0	0	0	0.057279	-20.1091
2010	0	0	0.002684	0	0	0.056291	0	0	0	0	0.058975	9.220039
2015	0	0	0.006939	0	0	0.072937	0	0	0	0	0.079876	15.92716
2020	0	0	0.031462	0	0	0.092714	0	0	0	0	0.124176	-1.92152
												-13.3596

Table A18. Total cost for each case including BAU

Percentage of CO2 reduction (%)	**0**	**5**	**10**	**15**	**20**	**25**	**30**
Total cost (USD)	4276,596	**4297,872**	**4302,128**	4319,149	4340,426	4361,702	4425,532
MAC (USD/ton)	0	17.48	--	19.51	21.44	24.02	47.51

Appendix II: Sample Questionnaire

Survey Questionnaire

INSTRUCTIONS

There are eight tables in the following questionnaire. For each table, please compare factor in column I to that in column II to indicate the more important one and the degree of importance .

If you think factor in column I is more important than factor in column II, please tick the appropriate column in the left area to indicate the degree of importance.

If you think factor in column II is more important than factor in column I, please tick the appropriate column in the right area to indicate the degree of importance.

If both factors are of equal importance, then tick “equal” column.

For intermediate values between the two adjacent judgments, please tick in between two columns.

OBJECTIVE:

Ranking the listed barriers to energy efficiency improvement of urban transport system in Delhi

Options under consideration:

1. Conversion of Diesel Buses to CNG Buses

2. Conversion of Petrol/diesel cars to CNG cars

3. 4-stroke 2-wheelers in place of 2-stroke 2-wheelers

Name of the respondent :

Organization and Address :

Respondent category :

Table 1: Pair wise comparison of Actors

1. **Energy/Environment Experts (NGOs)**
2. **Policy Makers (Government, Implementing Agency)**
3. **Users (General public)**
4. **Manufacturers of equipment**
5. **Retailers of equipment**
6. **Business Community (investors/lenders)**

Question: **From the perspective of overall objective which actor is more important**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Actor 1																		Actor 1
Actor 1																		Actor 2
Actor 1																		Actor 3
Actor 1																		Actor 4
Actor 1																		Actor 5
Actor 1																		Actor 6
Actor 2																		Actor 1
Actor 2																		Actor 2
Actor 2																		Actor 3
Actor 2																		Actor 4
Actor 2																		Actor 5
Actor 2																		Actor 6
Actor 3																		Actor 1
Actor 3																		Actor 2
Actor 3																		Actor 3
Actor 3																		Actor 4
Actor 3																		Actor 5
Actor 3																		Actor 6
Actor 4																		Actor 1
Actor 4																		Actor 2
Actor 4																		Actor 3
Actor 4																		Actor 4
Actor 4																		Actor 5
Actor 4																		Actor 6
Actor 5																		Actor 1
Actor 5																		Actor 2
Actor 5																		Actor 3
Actor 5																		Actor 4
Actor 5																		Actor 5
Actor 5																		Actor 6

Table: Pair wise comparison of Criterion

Criterion 1: Monetary Cost to Remove
Criterion 2:Level of Political/Bureaucratic Effort to Remove
Criterion 3:Impact on Adoption
Criterion 4:Life of Barrier

Question: **From the perspective of overall objective, which criterion is more important**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Criterion 1																		Criterion 1
Criterion 1																		Criterion 2
Criterion 1																		Criterion 3
Criterion 1																		Criterion 4
Criterion 2																		Criterion 1
Criterion 2																		Criterion 2
Criterion 2																		Criterion 3
Criterion 2																		Criterion 4
Criterion 3																		Criterion 1
Criterion 3																		Criterion 2
Criterion 3																		Criterion 3
Criterion 3																		Criterion 4
Criterion 4																		Criterion 1
Criterion 4																		Criterion 2
Criterion 4																		Criterion 3
Criterion 4																		Criterion 4

Option I: Conversion of diesel buses to CNG buses

Barrier I : Availability of efficient technology/conversion kits
Barrier II : Additional Costs
Barrier III : Inadequate resource and infrastructure
Barrier IV : Absence of enforcing mechanism

Table: Pair wise comparison of alternative barriers from the **Criterion of Monetary Cost to Remove**

Question: **From the perspective of monetary cost to remove the barriers which barrier requires higher cost**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Level of Political/Bureaucratic Effort to Remove**

Question: **From the perspective of level of political/bureaucratic effort to remove the barriers which barrier requires higher effort**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Barrier I : Availability of efficient technology/conversion kits
Barrier II : Additional Costs
Barrier III : Inadequate resource and infrastructure
Barrier IV : Absence of enforcing mechanism

Table: Pair wise comparison of alternative barriers from the **Criterion of Life of Barrier**

Question: **From the perspective of life of barriers which barrier has longer life**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Impact on Adoption**

Question: **From the perspective of impact on Adoption which barrier has higher impact on adoption**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Option II: Conversion of petrol/diesel cars to CNG cars

Barrier I : Availability of efficient technology/conversion kits
Barrier II : Additional Costs
Barrier III : Inadequate resource and infrastructure
Barrier IV : Lack of awareness

Table: Pair wise comparison of alternative barriers from the **Criterion of Monetary Cost to Remove**

Question: **From the perspective of monetary cost to remove the barriers which barrier requires higher cost**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Level of Political/Bureaucratic Effort to Remove**

Question: **From the perspective of level of political/bureaucratic effort to remove the barriers which barrier requires higher effort.**

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Barrier I : Availability of efficient technology/conversion kits
Barrier II : Additional Costs
Barrier III : Inadequate resource and infrastructure
Barrier IV : Lack of awareness

Table: Pair wise comparison of alternative barriers from the **Criterion of Life of Barrier**

Question: **From the perspective of life of barriers which barrier has longer life**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Impact on Adoption**

Question: **From the perspective of impact on Adoption which barrier has higher impact on adoption**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Option III: Conversion of 2-stroke 2-wheelers to 4-stroke 2-wheelers

Barrier I	:	Availability of alternative technology
Barrier II	:	Additional costs
Barrier III	:	Lack of awareness
Barrier IV	:	Absence of mechanism for its implementation

Table: Pair wise comparison of alternative barriers from the **Criterion of Monetary Cost to Remove**

Question: **From the perspective of monetary cost to remove the barriers which barrier requires higher cost**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Level of Political/Bureaucratic Effort to Remove**

Question: **From the perspective of level of political/bureaucratic effort to remove the barriers which barrier requires higher effort.**

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Barrier I : Availability of alternative technology
Barrier II : Additional costs
Barrier III : Lack of awareness
Barrier IV : Absence of mechanism for its implementation

Table: Pair wise comparison of alternative barriers from the **Criterion of Life of Barrier**

Question: **From the perspective of life of barriers which barrier has longer life.**

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Table: Pair wise comparison of alternative barriers from the **Criterion of Impact on Adoption**

Question: **From the perspective of impact on Adoption which barrier has higher impact on adoption**.

Column 1	Absolute		Very Strong		Strong		Moderate		Equal		Moderate		Strong		Very Strong		Absolute	Column II
Barrier 1																		Barrier 1
Barrier 1																		Barrier 2
Barrier 1																		Barrier 3
Barrier 1																		Barrier 4
Barrier 2																		Barrier 1
Barrier 2																		Barrier 2
Barrier 2																		Barrier 3
Barrier 2																		Barrier 4
Barrier 3																		Barrier 1
Barrier 3																		Barrier 2
Barrier 3																		Barrier 3
Barrier 3																		Barrier 4

Background of the National Research Institute (NRI)

Indira Gandhi Institute of Development Research (IGIDR), Mumbai, INDIA

Indira Gandhi Institute of Development Research (IGIDR) is an advanced research institute in Mumbai, established by the Reserve Bank of India in December 1987 for the study of national and global issues relating to economic development.

The Institute is located on a 14-acre site on a hillside 20 minutes drive from Mumbai's national and international airports.

Current research activities at IGIDR cover the following areas:

a) macroeconomic, trade, monetary and fiscal policies, pace and sequence of reforms and applied general equilibrium modeling.

b) poverty, employment and redistribution.

c) energy systems.

d) technology assessment.

e) environment and development – sustainable transportation, sustainable development, natural resource accounting, greenhouse effects and global negotiations.

f) agricultural and rural development.

g) comparative studies.

h) industrial structure, conduct and performance.

To facilitate dissemination of its policy oriented research the Institute encourages work in collaboration with government departments and international agencies. Some work done in the past has involved studies for the economic advisory council to the Prime Minister, Planning Commission, Department of Energy, Ministry of Environment and Forests, UNCED, UNDP, UNCTAD, ESCAP, The Asian Development Bank, Sida and the World Bank.

The Institute frequently hosts national and international conferences. The Institute is a deemed university and conducts M.Phil/Ph.D. programmes in development policy. It is designed to create professionals who are capable of conducting policy analysis, relating to national and global development issues, in a quantitative and inter-disciplinary manner. The Institute has at present some 37 faculty members and 50 M.Phil/Ph.D. students.

IGIDR Personnel Involved in the Project

Prof. Jyoti K. **PARIKH**, Senior Professor (jp@igidr.ac.in)
Project Coordinator

Dr. Sudhakar **YEDLA**, Assistant Professor (sudhakar@igidr.ac.in)
Project investigator

Dr. Anjana **DAS**, Assistant Professor (Currently with the University of Stuttgart, Germany)
Project investigator (for Issue # 1)

Ms. Sarika **KANSAL**, Ph.D. Scholar
Research Associate

Mr. Sanjay Kumar **SINGH,** Ph.D. Scholar
Research Associate

For further information, please contact:

Dr. Sudhakar Yedla
Assistant Professor
Indira Gandhi Institute of Development Research
Gen. Vaidya Marg, Goregaon (E), Mumbai 400 065, India
Tel: +91-22-2840 0919 x 546, Fax: +91-22-2840 2752
Email: sudhakar@igidr.ac.in
http://www.igidr.ac.in/proj/arrpeec-I