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Title: Integrated Methodology for Low Carbon Sustainable Urban Transport (A case Study of Ahmedabad, Gujarat, India)

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Specialisation: Urban Environment Management

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Integrated Methodology for Low Carbon Sustainable Urban Transport

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India

Supervisor: Stelios Grafakos

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Executive Summary

Transport is one of the major sectors contributing in greenhouse gas (GHG) emissions. Along with growth in economy, demand for mobility also increases. Moreover, most of the passenger as well as freight mobility needs are met by motorized travel. It is an important concern that transport sector largely depends upon fossil fuels as a source of energy. Not only limited reserves of fossil fuels but also GHG emissions from the consumption of fossil fuels raise sustainability threats. Economic growth is based on transportation but also transportation leads to gaseous emissions which are causing serious global environmental problems. If travel and transportation is encouraged it will lead to more GHG emissions, and if transportation is discouraged it will slow down economic growth. Both the situations are undesirable as both cases lead to an unsustainable future. Challenge for planners and managers is to find solutions that minimizes GHG emissions from transport sector without compromising with mobility needs of present and future.

Low carbon transportation may be achieved by minimizing motorized travel, or by using carbon free fuel, or by increasing fuel efficiency of vehicles. However, sustainability of a clean transport solution is situation specific. Some of the solutions may be clean but not sustainable, whereas some of the solutions may be sustainable but not as clean. Thus, there is a requirement of integrated assessment frameworks where low carbon potential as well as sustainability of a solution may be examined in context of specific case or situation. In the following research an integrated methodology has been developed which combines scenario building with sustainability assessment of clean transportation solutions in context of a specific case. Scenario building methodology was a combination of various forecasting models and sustainability assessment was based on Multiple Criteria Assessment (MCA) framework. The application of integrated methodology was demonstrated with the case of Ahmedabad city, Gujarat India.

Travel demand for Ahmedabad city was forecasted for the year 2035 and 2050. Travel demand forecasting results were used to estimate CO_2 emissions under Business As Usual (BAU) scenario and CO_2 emissions under Low Carbon Sustainable Urban Transport (LCSUT) scenario. Using sustainability assessment it was found that in case of Ahmedabad, electricity may be the most suitable transportation fuel in future. It was found that motorized travel in the city would grow 1.9 times by 2035 and about 4.2 times by 2050 than that estimated in 2011. This increase in travel demand would result in increase in CO_2 emissions from the passenger transport sector of the city at the rate of 6% per annum between 2011 and 2050 under BAU scenario. Under LCSUT scenario, it was estimated that that growth rate of emissions would come down to 3% per annum between 2011 and 2050.

Thus, the study recommends that city's clean transport plans shall not count only upon electricity as a clean transport fuel for future. If targets for cleaner power generation are not achieved by the country, emissions from transport sector with electric vehicles would be much higher than that in case of having petrol and diesel vehicles. It shall also be noted that even under the most optimistic scenario of clean fuel, the city would not be able to stabilize transport CO_2 emissions at current levels. Thus, it is imperative to promote non-motorized travel in mobility plans. Another important research finding draws attention towards public transport systems in the city. It was shown that in spite of having mass transport systems in the city, public buses would carry maximum proportion of passenger travel demand. Hence, continuous strengthening of public bus services is advisable in case of Ahmedabad.

Foreword

'An essay on the Principle of Population' written in 1798 by a famous political economist Robert Malthus discusses that the way human populations are growing may result into scarcity of food in future. It shows that the concept of sustainability was realized centuries ago. However, Stockholm Convention 1972 was the first international conference truly dedicated to environmental concerns and their linkages with economic development. It played a pioneering role in bringing world's attention towards sustainable development. The Stockholm Convention helped in laying foundation for a global way of thinking about the concepts of environment and sustainable development. Thereafter, over a period of nearly four decades these concepts have evolved to a next level of understanding. Sustainable development research has now reached from 'general focus to specific actions, and has penetrated from global level to local level. It indicates the level of effort and amount of resources working collectively throughout the world in making our future more sustainable.

This research study belongs to the domain of 'Low Carbon Societies' as well as 'Sustainable Mobility Planning'. The study investigates urban transportation sector microscopically in context of mobility needs and vehicular pollution. An integrated methodology was developed as a decision making tool for low carbon sustainable urban transport planning. It integrates 'urban transport forecasting models' with 'clean fuel sustainability assessment framework'. The methodology was demonstrated with the help of a case study of Ahmedabad city, Gujarat, India. Integration of various analytical techniques helped in option analysis and in selection of a most suitable clean fuel option in a specific case. Due to limited time and scope for the study, some sections were based on assumptions which otherwise require more scientific techniques and computational methods. However, the study establishes an approach which bridges up the gap between scientific research and policy making.

Acknowledgements

In this section I would like to take the opportunity to express my gratitude towards everyone who directly and indirectly supported me in conducting this research successfully. I would like to thank my supervisor **Stelios Grafakos (IHS, Rotterdam)** who not only gave his expert inputs but also he always motivated me to do a good work. He constantly motivated me since beginning of the study and I always felt his complete involvement and consistent attention during this research.

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Not less than anything for me is the moral support, inspiration and involvement that I get from my family. It forms my confidence and the reason for anything that I am able to do.

Abbreviations

2-W	Two wheelers
3-W	Three wheelers
4-W	Four wheelers
ADB	Asian Development Bank
AMC	Ahmedabad Municipal Corporation
AMGEN	Ahmedabad Generation
AMTS	Ahmedabad Municipal Transport Services
ASI	Avoid Shift Improvement
AUA	Ahmedabad Urban Agglomeration
AUDA	Ahmedabda Urban Development Authority
BAU	Business As Usual
BAU-E	Business As Usual - Electric
BISAG	Bhaskaracharya Insitute for Space Applications and Geo-informatics
BPMC	Bombay Provincial Municipal Act
BRTS	Bus Rapid Transit System
BSNL	Bharat Sanchar Nigam Limited
CAGR	Compound Annual Growth Rate
CDM	Clean Development Mechanism
CEPT	Center for Environmental Planning and Technology
CNG	Compressed Natural Gas
CST	Clean and Sustainable Transport
CTF	Clean Technology Fund
EC-DGMT	European Commission Directorate General of Mobility and Transport
E_{CO2}	CO_2 emission
EF	Emission Factor
EU	European Union
EV	Electric Vehicles
FHWA	Federal Highway Administration
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gases

GIDB	Gujarat Infrastructure Development Board
GIS	Geographical Information System
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
HEV	Hybrid Electric Vehicles
ICF	Inner City Fund
ITDAS	Intelligent Transportation Systems Deployment Analysis System
IEA	International Energy Agency
IHS	Institute of Housing and Urban Development Studies
IIM	Indian Institute of Management
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IPT	Intermediate Public Transport
IT	Information Technology
ITeS	Information Technology Enabled Services
Km	Kilometres
Kwh	Clean and Sustainable Transport
LCD	Low Carbon Development
LCSUT	Low Carbon and Sustainable Urban Transport
LPG	Liquefied Petrolium Gas
MCA	Multiple Criteria Analysis
MCDA	Multiple Criteria Decision Assessment
MDB	Multilateral Development Banks
MLD	Million Litres per Day
MOVES	Motor Vehicle Emission Simulator
NA	Not Applicable
NAPCC	National Action Plan on Climate Change
NEEDS	New Energy Externalities Developments for Sustainability
OECD	Organization for Economic Co-operation and Development
PCTR	Per Capita Trip Rate
PHEV	Plugin Hybrid Electric Vehicles
PKm	Passenger Kilometres
SEI	Stockholm Environment Institute
SIT	State Inventory Tool

SRFDC	Sabarmati Riverfront Development Corporation
SWM	Solid Waste Management
SWOT	Strengths Weaknesses Opportunities Threats
t	Metric tons
TDM	Transport Demand Management
TTD	Total Travel Demand
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environment Protection Agency
UTEEM	Urban Transport Emission Estimation Model
VKm	Vehicle Kilometres
VTPI	Victoria Transport Policy Institute
WBCSD	World Business Council for Sustainable Development
WGA	Western Governors' Association
WRI	World Resource Institute

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Chapter 1

Introduction

1.1 Background

Transport sector is one of the major sources of Greenhouse Gas (GHG) emissions from fossil fuel combustion. The transport sector contributes for approximately 13% of overall GHG emissions and 28% of GHG emissions from combustion of fossil fuels *(ITF estimate based on IEA data and updated IMO CO_2 data for international shipping, 2006)*. It is the second largest CO_2-emitting sector after electricity production. The IEA projects that global CO_2 emissions from fossil fuel combustion will increase 45% from 28Gt in 2006 to 40Gt in 2030 – 97% of the increase occurring in non-OECD countries. Global transport emissions account for one-fifth of the overall increase and are projected to grow by 38% over the same period – 98% of the growth occurring in non-OECD countries. The projections clash with the ambitious climate stabilization objectives outlined by the IPCC, which most likely cannot be met without significant emission cuts from the transport sector (Reducing Transport GHG emissions – Opportunities and Costs, OECD, 2010, p.6-8).

As per IEA estimates, the recent growth rate (2000-2006) of CO_2 emissions from fossil fuel combustion from India's transport sector was 2.27%, which is same as that for world average but is higher than that for North America, EU-15 and Asia-Pacific. These estimates include international maritime (IEA estimate) and international aviation (Reducing Transport GHG emissions – Opportunities and Costs, OECD, 2010, p.7). India is a developing country with second largest population in the world and is maintaining a high economic growth rate (about 7.5%, 2011). Transport sector is the backbone of economic development and there are several challenges for India's transport sector. In Indian cities public transport is not adequate; condition of public transport vehicles and freight transport vehicles is poor leading to high amounts of CO_2 emissions; accessibility especially for urban poor is very low. On the other hand, India's National Action Plan on Climate Change (NAPCC) targets for reducing CO_2 emissions from various sectors including transport as a main sector.

Energy used in transport sector is carbon intensive (about 95%). It is not possible to meet climate stabilization goals outlined by IPCC without significantly reducing CO_2 emissions from transport sector. On the other hand, reduction of emissions from transport sector involves high implied costs and studies have shown that it is extremely difficult to achieve drastic emission reductions from transport sector in short run. However, findings of socio-economic analysis of abatement measures have shown that transport sector emission reduction options have low social costs making net abatement costs much lower and negative in many cases, in spite of having high implied costs.

Target for urban transportation planners is not only resolving traffic problems, but the challenge is to make urban transportation systems low carbon, more sustainable, affordable, and easily accessible in longer run. Urban transportation system in Indian cities is one of the most complex and challenging sector for urban managers and planners. With growing incomes and availability of affordable vehicles in the market, vehicular ownership in India is rising at a fast pace. On the other hand, public transport systems in Indian cities are very weak and are generally of poor quality. It leads to rapidly increasing use of personal vehicles. Moreover, most of the cities have high population density, mixed landuse and unplanned road network, which increase congestion and create difficult traffic conditions. It may be commonly seen on the roads that all the modes of transportation are running in the same lanes, pedestrians, bicycles, motorbike, car, buses, trucks and even animal carts. Traffic management measures often prove to be less effective since traffic problems are overridden by lack of adequate road and transport infrastructure.

Further, if we analyze transportation sector from supply side we find that management of urban transport is not only limited to the city. It is directly connected with state level, national level as well as international level decisions and policies. City level mobility plans provide local level interventions but are directly influenced by decisions from higher levels of governments and markets. Thus, city level transport planning actions must be flexible enough to incorporate changes in the trends which are caused due to external factors. It is very important for urban planners and urban managers that they shall have information about external factors such as cleaner technologies and policy decisions that may come in future. It would always remain unpredictable that which technological alternatives, fuel technologies or vehicle types would be promoted in the market in future. Only remedy may be a framework for urban transport planners that help them to assess the situation and help them in making adaptable plans.

Combustion of fossil fuels from vehicles is the direct cause of GHG emissions from transport sector. However, driver for fuel consumption is the need for mobility. There may be three different approaches to reduce emissions from transport sector – by increasing engine efficiency of vehicles, using alternative carbon free fuel, and by reducing vehicular travel demand. Alternative fuels and better engine efficiency may be attributed to technical innovations, whereas vehicular travel demand can be controlled through travel behaviour and transforming modal shares by improving public transportation systems. Changes in travel behaviour and increased engine efficiencies would result in reducing transport sector fuel demand and would eventually decrease the load on energy demand from transport sector. Alternative carbon free fuels would result in direct emission cuts. However, all three approaches have their own implicit challenges and limitations. Travel behaviour depends upon a number of factors such as affordability, accessibility, landuse, public transportation systems etc. Use of alternative fuels depend first upon availability and quantity of the resource, its production and marketing costs and then requirement of exclusive infrastructure fuel filling stations. Efficiency improvements in automobile engines have a limited effect on reducing emissions. In order to achieve low carbon urban transport, a hybrid approach combining reducing travel demand and introducing technological innovations may work most effectively.

Various attempts are constantly being made for making transport sector less polluting. In different approaches, some are based on socio-economic and demographic research and some are based on abatement technologies, some studies address landuse planning interventions and some studies focus on policy measures. For Indian cities, comprehensive low carbon vision studies have been carried out by experts. These studies provide scenarios for future low carbon cities. Whereas it is required to integrate different approaches and techniques in one methodology for making low carbon sustainable mobility plans more effectively implementable.

1.2 Problem Statement

Most of the scenarios for Low Carbon Development (LCD) created by experts for Indian cities were constructed with a comprehensive and holistic approach. Usually these scenarios covered all sectors with urban transportation sector as one part. This wide-ranging approach limits the scope for developing detailed and target oriented sectoral action plans. It also limits the scope for examining feasibility and effectiveness of sector specific solutions. Comprehensive LCD scenarios provide a structured vision for a low carbon future. However in some respect vision statements provide inadequate guidelines for making sector specific action plans and roadmaps. On the other hand, sector specific research, modeling and forecasting techniques unwinds an issue to such a minute level of detail that it becomes challenging to incorporate their findings in making policies and plans.

"There is a need for sector specific methodologies that provide flexibility for simulations, assessment and evaluation of solutions in context of particular policy objectives. It shall help in bridging up the gap between scientific research and policy making by binding them under a single context."

1.3 Research Objective

Main objective of the research was to develop a methodology for the integrated assessment of 'effectiveness' and 'sustainability' of potential low carbon urban transport solutions for Ahmedabad City, India.

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1.4 Research Questions

Comment [s4]: from now on do not include the provisional research questions and objectives but just the revised and final ones!

- What could be the future Business As Usual (BAU) scenario for transport sector of Ahmedbad city by 2050? What would be the level of CO_2 emissions from transport sector of the city by 2050 under BAU conditions?
- What could be the assessment framework for selection and examination of sustainability of low carbon urban transport solutions? In case of Ahmedabad, what kind of measures and or technological choices could make a low carbon transport scenario more effective?
- Under what conditions urban transport systems of Ahmedabad would be able to reach the level of emission cuts which are desired from the sector for achieving national climate goals?

1.5 Significance of the Study

The research work was a combination of exploratory research and scientific desk study. It was aimed at formulating a decision making tool for aiding the preparation of target specific roadmaps and action plans for low carbon urban transport. The integrated methodology developed in this research may also provide inputs in suitability analysis of various low carbon transport solutions in a specific context. The integrated framework may also be applied in succession to force field analysis conducted for market potential of an alternative fuel. It helps in bridging up the missing links between local area planning process and external influences from higher level governments and markets. The study advocates in bringing sustainability at the same platform with effectiveness of a solution before taking decisions and actions. Methodology developed and demonstrated in this research is a useful reference for urban transport planners and urban managers.

1.6 Scope and Limitation

Urban transport has various dimensions from transport infrastructure to travel behaviour, landuse, vehicle technology, fuel prices to external factors like climate stabilization goals. It can be seen from various perspectives and detailed research may be carried out on any of its single dimensions. However, due to limited scope of this research it was focused at developing an integrated methodology for examining effectiveness and sustainability of low carbon urban transport alternatives. Thus, it was not possible to explore every aspect of transport planning in depth due to time limitations. However, the study made an attempt to establish missing links between various aspects of urban transport planning. The study was conducted with following limitations

- Only passenger transport was taken into account and freight transport sector was excluded in all calculations, forecasts and estimates
- For running modelling simulations there was not enough time to generate all the input data through econometric methods. Some of the forecasting simulations were based on deduced and validated assumptions from expert opinions, secondary research and empirical techniques.
- Multiple criteria analysis framework developed for the sustainability assessment of clean alternative transport fuels had similar limitations as that in case modelling simulations and forecasting.
- The study did not specifically take into account local level planning interventions for clean urban transport such as landuse changes, travel behaviour and local transport networks.

Chapter 2

State of the art theories/concepts and Literature Review

*[**Keywords:** GHG emissions and Climate Change, Global warming potential, GHG abatement curves, Transportation demand management, Travel demand management plan, Economic efficiency of transport, Environmental and ecological efficiency of transport, Fuel efficiency and fuel economy, Traffic congestion costs, Marginal Abatement Curves, Cost Benefit Analysis, Stabilization Wedges in transport, Techno-economic analysis, Scenario analysis, Sustainable transport planning, transportation emission control strategies and targets.]*

2.1 Climate Change and Greenhouse Gas Emissions

2.1.1 Greenhouse gases and climate change

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The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide (CO_2), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the earth (IPCC 2001). Naturally occurring greenhouse gases include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. (U.S. EPA, 2008)

2.1.2 Global warming potential

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A global warming potential is a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse). It is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). (U.S. EPA, 2008)

2.2 Greenhouse Gas Emissions from Transport Sector

2.2.1 Transport sector and GHG emissions

Transport sector is one of the highly energy intensive sector. Moreover, most of the energy consumed by the sector is generated from the consumption of fossil fuels. Desire for mobility emanate from – how is mobility generated (S. Hanson, 2000). About two third of the travel demand accounts for personal needs and rest one third of travel demand may be accounted from the movement of freight traffic (WBCSD, 2004). More than 77% of the traffic movement (both passenger and freight) is carried by road transport (WBCSD, 2004). According to the Intergovernmental Panel on

Climate Change (IPCC) in 2004, the global transport sector was responsible for 23 per cent of world energy-related CO_2 emissions. Hence reducing these emissions from transport must be an important part of climate change mitigation programs both at local and national levels. According to the 2007 IPCC Fourth Assessment Report, the growth rate of greenhouse gas emissions in the transport sector is the highest among all the energy end-user sectors (UNEP RisØe, 2011).

2.2.2 Fuel for Transportation

Our society is currently highly dependent on oil as an energy source as it accounts for approximately 40% of the global energy supply (the rest is mainly coal and natural gas). Oil is also virtually the only energy source for transportation and is thereby the major source of greenhouse gases. Global oil resources are not, however, unlimited and at some point within the next few decades oil production will reach its maximum. Most estimates of the ultimate global oil resources are in the range of 1,800-2,200 billion barrels. Assuming that there is still another Saudi Arabia that is as yet undiscovered and will provide a total of 2,600 billion barrels, maximum production will be reached in around 2020. This future decrease in production can, however be compensated for by the production of synthetic fuels from coal and natural gas. A substitution of this kind will increase the CO_2 emissions into the atmosphere and make the global warming problem even worse. The only reasonable solution would then be to start using non-CO_2-emitting fuels like hydrogen and start the development of new vehicles and infrastructure for these new fuels (Dr. MacKenzie, WRI, 2000).

2.2.3 Sustainable Urban Transport

Sustainability of urban transport is determined by the combination of drivers, impacts and responses concerning urban transport. Together, these three factors result in a constellation that poses a serious threat to sustainable urban development, questioning the efficiency and effectiveness of current planning practice, but also its legitimacy. Major driver of the need to travel is ongoing transformation processes of society at macro-level increase the need for mobility and lead to growing transport flows concentrated on the "urban nodes" (Expert Working Group on Sustainable Urban Transport Plans, 2004).

In some countries this development is particularly acute as they face the double challenge of globalisation and transition. As an impact, transport growth implies substantial negative effects on all sectors of city life and the urban environment, thus undermining sustainability. Responses within the current institutional contexts (authorities, regulations, practices, education), the capability of the responsible stakeholders at all levels to cope with the aggravating problems appears to be limited (Expert Working Group on Sustainable Urban Transport Plans, 2004).

2.3 Transportation Planning

Comment [s7]: a paragraph or a sentence that links GHGs emissions and transport sector is missing

2.3.1 Transportation demand management (TDM)

Transportation Demand Management (TDM) is a strategy to reduce demand for single occupancy vehicle use on the regional transportation network. As a regional strategy to improve transportation system performance, TDM can reduce highway congestion and traveler delay; improve air quality; and improve access to jobs, schools, and other opportunities. (J. Rodriguez, et. al, 2009)

Comment [s8]: only the name of the first author et al. and year

2.3.2 Travel demand management plan (TDM Plan)

It is a binding agreement outlining the efforts the owner/tenants will make to reduce their traffic impact. The developer enters into the agreement with the city which extends to future owners/tenants. The TDM Plan lists strategies to be implemented over time with the goal of reducing the amount of traffic generated by the office complex. TDM Plans also have concrete goals. Typically, their stated goal is to reduce parking demand and traffic generation by 10 to 20% as compared to typical demand as documented in the Institute of Transportation Engineers' Parking Generation and Trip Generation reports. An important part of the TDM Plan is to have mechanisms in place for measuring effectiveness over time. (M. Spack, et. al, 2010)

Comment [s9]: same as above

2.3.3 Economic efficiency of transport

Maximization of benefits that users can gain from the transport system, after taking into account the resource costs of building and operating the transport system. Travel time and cost are key elements in reducing the benefits of travel, and economic efficiency is concerned with reducing these costs, whether they arise through congestion, unreliability, or inadequate services. (UNESCAP, 2006)

2.3.4 Environmental/ecological efficiency of transport

Reducing a number of adverse impacts of the transport and land use system the global, regional and local pollutants; noise and vibrations; and other environmental impacts such as visual intrusion, the fragmentation and severance of settlements and biodiversity, urban sprawl, and loss of cultural heritage and natural habitats. (UNESCAP, 2006)

2.3.5 Fuel efficiency and fuel economy

Fuel efficiency and fuel economy are terms that explain the cost component of eco-efficiency for transportation infrastructure. Fuel efficiency is the term given to the level of efficiency in converting energy contained in a carrier fuel to kinetic energy or work. Fuel economy is usually expressed in one of the following two ways (1) the amount of fuel used per unit of distance, e.g. liters/100 km; and (2) the distance traveled per unit volume of fuel used, e.g. km/liters. The efficiency becomes very important not only due to the huge cost of large-scale consumption of fossil fuels but also due to the limited nature of the available resource. (UNESCAP, 2006)

2.4 Abatement and mitigation options and assessment methods

2.4.1 GHG abatement curves

Greenhouse gas abatement cost curves depict the available mitigation measures, their abatement potential in a specific year and their cost effectiveness, relative to a business as usual scenario. In a budget-constrained environment with uncertainties such as technology, regulation, energy and carbon pricing risk, making informed decisions about the sequence and timing of greenhouse abatement investments is difficult, but critical. The development of abatement cost curves assists to evaluate the mitigation measures that could be adopted, where to prioritise resources and the timing of projects. (Carbon Price 2011 | Evaluating Carbon Abatement Options)

2.4.2 Marginal Abatement Curves (MAC)

The definition of marginal abatement costs is not exact. In principle the term marginal is defined in the context of a cost curve and means the (increasing) additional costs associated with a next step in emission reduction. A step in emission reduction, as depicted in a cost curve, can in itself already be a package of measures with differing marginal abatement costs. (R. Smokers, et.al, May 2009)

Comment [s10]: to be corrected as above comment

2.4.3 Stabilization wedges

A stabilization wedge is achieved through carbon policy by introducing the 'virtual' wedge that is achieved as a result of the continued decarbonization of the global economy even in the absence of a carbon policy. (H. J. Schellnhuber, et.al, 2006)

Comment [s11]: to be corrected

2.4.4 Abatement Cost Perspectives

Most transport abatement cost studies so far have used the economic or private approach (McKinsey, 2009; Kahn Ribeiro et al., 2007, IEA/OECD, 2009b) or a combination of the two. In some cases, only the investment costs are considered (Wright and Fulton, 2005). In the transport sector, the end-user and investor are key actors in the success of a measure, and therefore it can make sense to include taxes and subsidies. It is important to state explicitly the assumptions and perspective, as the taxes and subsidies greatly influence the abatement costs. This is not always clear in mitigation studies. (Huizenga C. and Bakker S., 2010)

Exhibit 2.1: Abatement Cost Perspectives

Perspective	Approach	Example for BRT
Economic (National)	Looks at costs from a national perspective. Policy implementation costs are considered but taxes and subsidies are not. Discount rate is set at a social level.	Costs for capital investment, implementation and operation are countered by a reduction in costs both for vehicles (fuel) as well as for users who make the shift from private vehicles (both excluding taxes). Abatement costs are usually low or negative, the latter implying that the measure yields net benefits to society. A relatively low discount rate would be used.
Financial (Private investor/ end user)	The discount rate is set at a level applicable to investment decisions common to the private sector. Taxes and subsidies for the specific investment or operations are included.	For the private investor in infrastructure and operations of transportation systems, the outcome will depend on the extent to which the investment can be recovered from passenger fares, revenues from marketing or commercial facilities in stations and public subsidies. In practice, the investment will be made only if the abatement costs for the investor are negligible or negative (generate benefits).
Social (National)	Frequently considers economic costs (as described above) and social externalities.	The abatement costs would be lower than in the economic perspective due to consideration of co-benefits.

(Source: C. Huizenga, S. Bakker, 'Climate Instruments for the Transport Sector', Asia Development Bank, 2010, p.26)

2.4.5 Incremental Cost mitigation Options

This baseline approach for the transport sector is different from that of, for example, the electricity sector, for which economic optimization models are used to determine what electricity mix will fulfil the demand in the most cost effective manner. This is because the electricity sector is very responsive to economic incentives, while non-economic considerations such as comfort or status are hardly an issue. For transport, such an approach would be very difficult to carry out, as it would require that all considerations by consumers be translated into economic parameters. Therefore, for the transport sector, the baseline approach based on historical trends is considered to be a pragmatic solution. Incremental cost (or abatement costs) represents the additional costs of reducing GHG emissions against the baseline scenario (UNEP, 1999). Cost effectiveness refers to the incremental cost relative to a policy objective—e.g., GHG emission reduction, which can be expressed in $ per ton of CO2-eq reduced and is often used to identify the least expensive way to achieve a policy objective. Anable (2008) notes, however, that cost-effectiveness is of limited value as an indicator to compare transport policies, as carbon reduction usually is not the main policy objective—i.e., transport interventions can be justified based on other considerations, such as reducing congestion or improving air quality. (Huizenga C. and Bakker S., 2010)

2.5 Emission Calculation and Forecasting Tools

2.5.1 Transportation GHG calculation tools

These tools require the user to provide transportation activity levels (e.g., VMT or fuel consumption) and vehicle fleet inputs (e.g., vehicle fleet mix, age) in order to calculate GHG emissions. They vary in terms of their sophistication, and ability to address a range of different types of inputs and types of analysis. The most commonly used of these tools include the following, EPA's MOBILE6 model, State Inventory Tool (SIT), and Motor Vehicle Emissions Simulator (MOVES), and the U.S. Department of Energy's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model. (ICF, 2006)

2.5.2 Transportation/emissions strategy analysis tools

These tools are designed to estimate travel and emissions impacts of specific types of transportation strategies, based on inputs about transportation programs or strategies (e.g., type of strategy, other parameters of specific strategies). Most of the analytical strength of these tools is in the estimation of travel impacts; the CO_2 calculation procedures are generally very simple, and often do not account for complex implications of vehicle operating characteristics on emissions. These tools include EPA's Commuter Model and the Federal Highway Administration's (FHWA) Intelligent Transportation Systems Deployment Analysis System (ITDAS). (ICF, 2006)

2.5.3 Energy/economic forecasting tools

These tools are designed to forecast energy consumption, typically based on economic factors such as economic growth and fuel prices. They include the U.S. Energy Information Administration's National Energy Modeling System (NEMS) and several other tools developed by the U.S. Department of Energy for national and international analysis of energy demand. (ICF, 2006)

2.6 Emission reduction policies and targets

2.6.1 Climate Instruments

Climate instruments and MDBs have so far mobilized limited funding for sustainable, low-carbon transport in developing countries. In addition, the transport sector has experienced difficulties in accessing these funds, especially funds related to climate instruments. However, external assistance through GEF, CTF and (especially) MDBs is increasing. The majority of GEF and CTF funding so far has been programmed as co-financing for MDB projects. The growing importance of climate change mitigation in transport among MDBs is expected to result in additional funding, which initially will be directed largely towards urban transport (see, e.g., ADB, 2010). All major MDBs have expressed support for the ASI approach. Such an increased MDB engagement in climate action in transport could also improve participation of the transport sector in climate instruments because of MDBs' growing support for knowledge management and institutional development activities that serve to lower barriers to transport involvement. (Huizenga C. and Bakker S., 2010)

2.6.2 Sectoral Crediting Mechanisms

Discussions on a possible sectoral crediting mechanism (UNFCCC, 2008) suggest crediting emissions reductions from a covered sector as a whole against a threshold below the BAU scenario. Thresholds represent country performance and can be expressed in absolute terms (e.g., GHG emissions in sector x) as well as in intensity terms (e.g., GHG emissions/ton of cement). Sectoral crediting, however, is different from CDM as credits would be issued to the respective developing country government, which would have to provide the incentives for emission reductions to take place. Sectoral crediting based on no-lose targets intends to encourage emissions reductions (orchestrated by the host country) in key emitting sectors in developing countries. (Huizenga C. and Bakker S., 2010)

2.6.3 CO_2 emission reductions from transport sector, target oriented approach

Transport emissions are caused by transport of passengers and by transport of freight. Substantially changing the trend of increased GHG emissions from transport will require the adoption of a range of available and new technologies, as well as changing people's travel patterns. Strong policies are needed to achieve this. Countries around the globe have started to realize the scale of the challenge, and many countries have now adopted policies and,—in the case of Annex I countries—have pledged targets for GHG emissions reductions. A fewer number of countries have also developed targets or goals specifically for the transport sector. Table 1 gives a broad overview of general and transport-specific targets or goals. In the case of developed countries, targets are mostly in the form of absolute reductions in GHG emissions compared to 1990 or 2005. GHG emissions reduction targets for developing countries are usually framed in reductions against BAU scenarios or in terms of reducing GHG intensity per unit of GDP. In several cases, GHG emissions reductions for developing countries are expressed in the form of a range, whereby the availability of external support determines whether the lower or higher ambition level applies. Specific sectoral targets, including for the transport sector, are often expressed in terms of improvements in energy efficiency. (Huizenga C. and Bakker S., 2010)

Exhibit 2.2: Emission Reduction Policies and Targets (as on June 2010)

Country/ region	National Target	Transport 2020 target and main policies
EU	20-30% reduction by 2020 compared to 1990 levels	Sectors such as transport and agriculture that are outside of the Emission Trading System (ETS) will have binding emission reduction targets for each member state, in line with their ability to pay, in order to reach an overall cut of 10% by 2020.b
USA	17% compared to 2005 levels by 2020a	
Japan	25% reduction by 2020 compared to 1990a	Sectoral plan for transport under preparation
South Korea	30% emissions reduction target with respect to projected baseline emissions by 2020a	33-37% below BAU by 2020, equivalent to 20-24% reduction by 2020 compared to 2005 GHG emissions
Bhutan, Costa Rica, Maldives & Papua New Guinea	Carbon neutral by 2020a	No details provided on implementation in the transport sector
Brazil	Emission reductions of 36.1-38.9% with respect to baseline by 2020a	
China	40-45% reduction of CO2 emissions/GDP below 2005 levels by 2020a	Reduction in energy consumption of commercial trucks on a per unit basis of 16% compared to 2005 Reduction in energy consumption of commercial ships on a per unit basis of 20% compared to 2005 Reduction in energy consumption of commercial buses on a per unit basis of 5% compared to 2005e
Indonesia	26-41% below BAU in 2020a	
India	Reduce by 2020 the emissions intensity of its GDP by 20-25% with respect to 2005 levelsa	
Mexico	30% reduction with respect to BAU by 2020a	Emission reductions of 11.35 MtCO2e from 2008-2012. Emissions estimates of the sector for 2020, 2030 and 2050 are 186.5 MtCO2e, 185.0 MtCO2e and 128.0 MtCO2e, respectively
Singapore	16% below BAU by 2020a	

(Source: C. Huizenga, S. Bakker, 'Climate Instruments for the Transport Sector', Asia Development Bank, 2010, p.41)

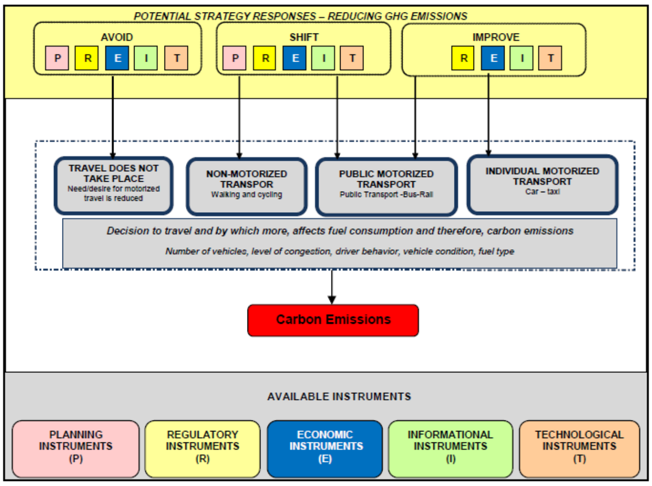
2.6.4 Traffic congestion costs

The Victoria Transport Policy Institute (VTPI) defines traffic congestion cost as the incremental delays, driver stress, vehicle costs, crash risks, and pollution resulting from interference between vehicles in the traffic stream, particularly as a roadway system approaches its capacity. Though it is an externality for individual road users, it is internal to the road users as a group. Thus while calculating total cost, it is not justified to add congestion and user costs together. The congestion costs of individuals are counted under travel time and vehicle operation costs. (UNESCAP, 2006)

2.7 Sustainable Transport Policy Measures

Transport policy measures can be implemented at different levels. Local authorities often have a large degree of autonomy when it comes to issues such as parking and public transport, while national-level institutions usually establish regulatory standards guiding fuel efficiency. The link with sustainable development is most visible at the local level—e.g., through urban air quality and congestion problems. In the particular case of logistics and freight transport, policy decisions are made at the national level, but coordination often is needed at the local level. Moving towards sustainable transport can be done through projects, programs or policies. 5 A sustainable transport approach requires comprehensive packages of interventions at all levels—national, regional, local and, if applicable, at other levels as well. (C. Huizenga, S. Bakker, 'Climate Instruments for the Transport Sector', Asia Development Bank, 2010, p.19)

Exhibit 2.3: Sustainable Transport Strategy Response



(Source: C. Huizenga, S. Bakker, 'Climate Instruments for the Transport Sector', Asia Development Bank, 2010, p.20)

2.8 Conceptual Framework

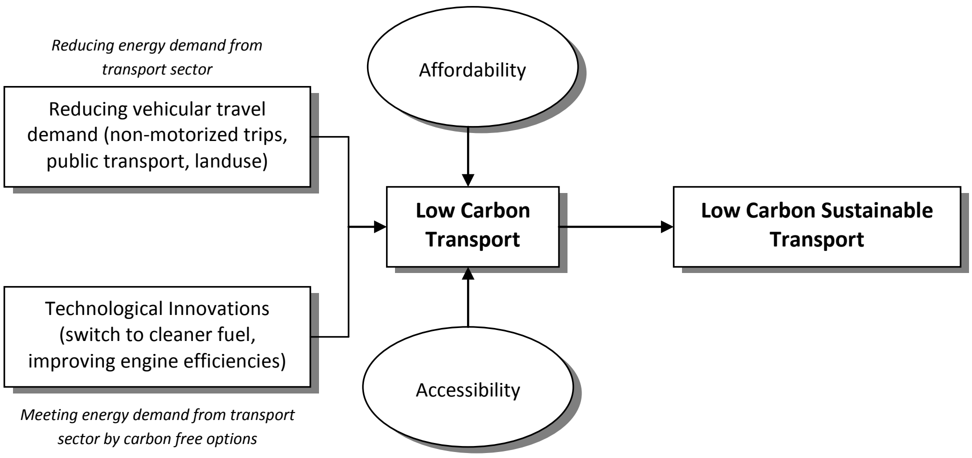
Sustainable transport policy measures vary in nature, but they generally reflect at least one of three fundamental strategies that collectively are known as the avoid-shift-improve (ASI) approach (Dalkmann and Brannigan, 2007)

- Avoid the need to travel
- Shift travel to more sustainable, lower carbon modes of transport
- Improve the efficiency of modes of transport

Transport policy instruments can further be divided into the following categories: planning, regulatory, economic, informational and technological. Transport policy measures can be implemented at different levels. Local authorities often have a large degree of autonomy when it comes to issues such as parking and public transport, while national-level institutions usually establish regulatory standards guiding fuel efficiency. The link with sustainable development is most visible at the local level – e.g., through urban air quality and congestion problems. In the particular case of logistics and freight transport, policy decisions are made at the national level, but coordination often is needed at the local level. Moving towards sustainable transport can be done through projects, programs or policies. A sustainable transport approach requires comprehensive packages of interventions at all levels—national, regional, local and, if applicable, at other levels as well. (ADB, 2010)

Transforming existing urban transportation systems in India would require a twin action involving technological changes and changes in travel behavior. Technological changes may be brought in more easily than changes in the travel behavior. A typical low carbon transport planning approach generally recommends reducing vehicular travel demand and use of cleaner fuels. A low carbon mobility planning methodology may be outlined in two folds - first to explore possibilities for making urban transport low carbon and then to examine sustainability of shortlisted low carbon technologies and practices from its socio-economic aspects (Exhibit 2.4).

Exhibit 2.4: Typical Approach for Low Carbon Sustainable Urban Transport Planning



Chapter 3

3.1 Research Approach and Techniques

Preparing city's transportation plans is a local level function. This research study recognized local level transportation planning as a part of top down planning chain which has decision making at higher levels (policy influence) as one side and scientific research (local scenario building) on another side. For example, how much fuel stations would be required in the city in future is a part of scenario building, but what type of transportation fuel would be available depends upon higher level policy decision. Similarly, electric vehicles in the city may be a choice of end users and charging stations may be provided by private or public sectors operating locally. At the same time electricity supply is coming from a carbon based plant or from a clean fuel plant is a higher level policy decision.

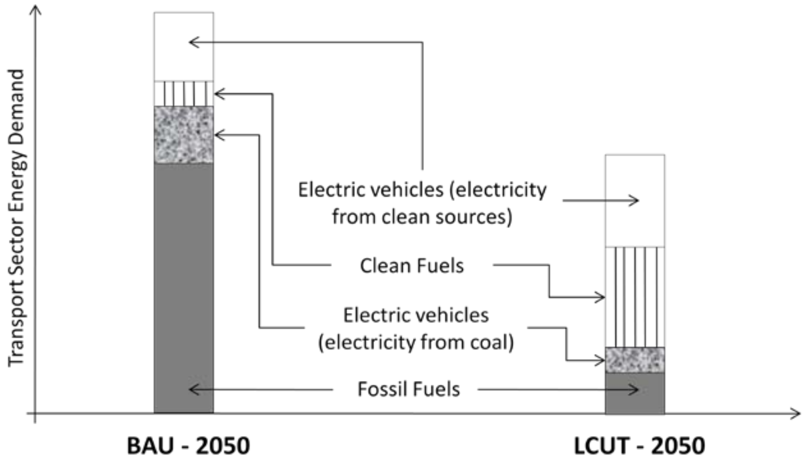
The research approach assumed that city level low carbon mobility plans may be made more sustainable and practically implementable if there are more defined targets. Invariably targets for local level transportation planning may be made more realistic if there is adequate information available on effects of external factors that may directly influence urban transport sector. In conventional approach such plans are made with overall gross targets for the whole sector, and in this research a framework for estimating residual targets for local level interventions was suggested.

Decisions like low carbon technologies and use of alternative fuels are taken at state or national level. Such decisions are many times based on international level policies and opportunities. Once a decision is taken at higher level it becomes a kind of mandate which has to be followed in local level planning. Secondly, changes in technological trends do not happen overnight, thus they are more predictable. On the other hand most of the local level low carbon interventions like changes in travel behaviour, changes in landuse and modal shift are more unpredictable due to their inherent complex characteristics. Conventional approach for low carbon mobility planning focus more at local level interventions whereas approach followed in this study emphasized on examining feasibility of low carbon technologies before linking them with local level plans.

Research framework for the research assumed that estimating upshots of technological options for low carbon transport are more predictable than bottom up planning interventions. Thus, low carbon mobility plans shall first take into account maximum potential for emission reduction by substituting conventional transport technologies and fuels with low carbon technologies and fuels and then deduce targets for local level planning interventions.

It was conceptualized that using forecasting and simulation methods, it may be possible to estimate transport sector emissions under various scenarios for future. Different scenarios were conceptualized assuming motorized travel demand as the driver for transport emissions. A conceptual illustration of comparisons between Building As Usual scenario (BAU) and Low Carbon Sustainable Urban Transport scenario (LCSUT) with fuel substitution is presented in Exhibit 3.1 below.

Exhibit 3.1: Conceptual representation comparing Low Carbon and BAU Scenarios



Note: *BAU – Building As Usual, LCUT – Low Carbon Urban Transport)*

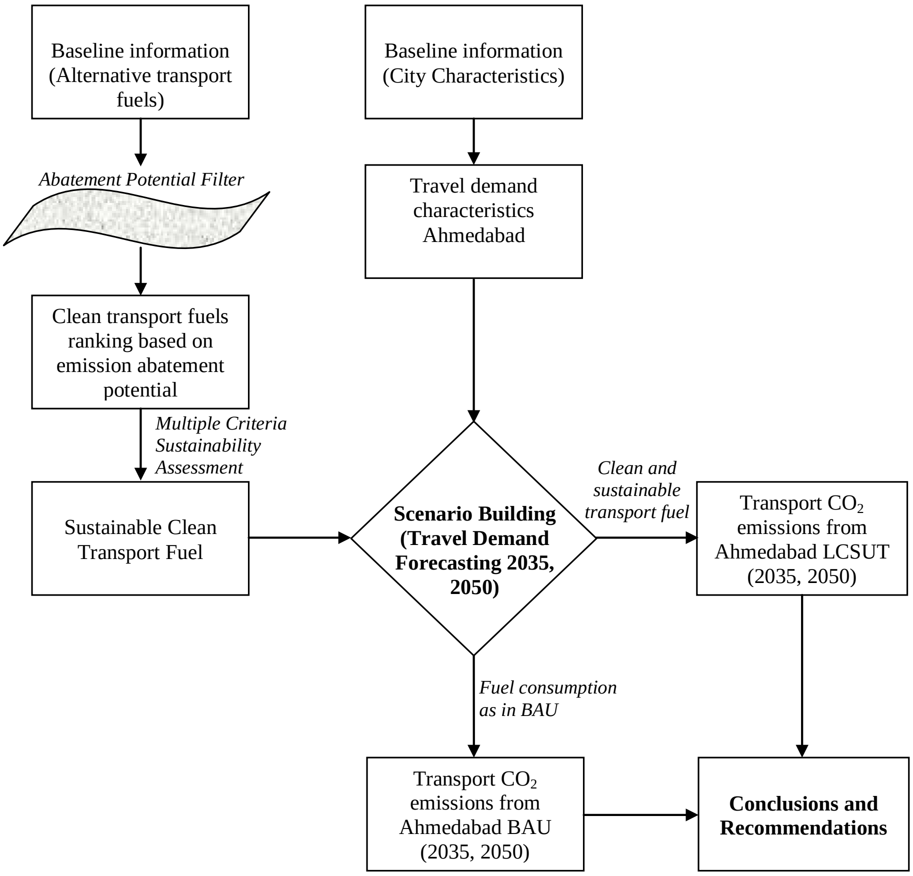
The research was conducted in following steps, (1) creating business as usual scenario for transport sector of Ahmedabad by 2050, (2) identifying low carbon alternative fuels that may become available in market in future, (3) identifying most potential clean alternative fuels using emissions abatement potential filter, (4) examining feasibility of alternatives through sustainability assessment, (5) creating a low carbon urban transport scenario by substituting most sustainable clean fuel options, (6) comparing emissions from business as usual and low carbon transport scenarios. Exhibit 3.2 provides a step by step illustration of the research approach followed in the study. Following techniques were taken in use while conducting the research –

1. **Modelling and forecasting:** Statistical and econometric methods were used for creating Business As Usual (BAU) and Low Carbon Sustainable Urban Transport (LCSUT) scenarios. The business as usual scenario provided total travel demand in passenger kilometre travel by mode. Estimated vehicular travel demand was used to derive fuel demand in both the scenarios. Combustion of estimated quantity of fuels by type was translated into CO_2 emissions from transport sector using standard conversion factors.

2. **Secondary information:** Information on certain sections of the baseline study on future transport technologies, alternative fuels and characteristics of the case study were based on information collected from secondary sources (Ahmedabad city).

3. **Multiple criteria analysis:** A multiple criteria framework was developed to assess sustainability of the low carbon alternative fuels for transport sector. Low carbon technologies and clean fuels with highest cumulative scores in multiple criteria sustainability analysis was used for building low carbon transport scenario. Under low carbon transport scenario, conventional fuel as used in building as usual scenario was substituted with most sustainable low carbon fuel as deduced from the multiple criteria sustainability assessment of alternative clean fuels.

Exhibit 3.2: Research Approach for Low Carbon Sustainable Urban Transport



3.2 Operationalization: Variables, Indicators

There were two sets of variables and indictors required at two different stages of the study. First, for travel demand forecasting and estimation of CO_2 emissions from transport sector; and second, for the sustainability assessment of clean alternative fuels using multiple criteria framework (Exhibit 3.3 and Exhibit 3.4).

Exhibit 3.3: Variables and indicators for travel demand forecasting

Variables	Indicators
• Growth of the city	Population growth rate (CAGR)
• Travel demand	Per capita trip rate
• Travel characteristic	Average trip length
• Total travel	Passenger kilometers
• Modal split	Passenger kilometer travel by mode

Exhibit 3.4: Variables and indicator strictures for multiple criteria analysis framework

Variables	Indicator stricture
• Economic	GDP, Costs, Resources (financial)
• Policy	Pro measure or anti-measure
• Social Acceptability	Awareness, Culture
• Market	Accessibility, Affordability, Willingness to pay
• Technological	Capacity, Operation and Maintenance Costs

3.3 Validity and Reliability

It was critically important to validate results of forecasting models and multiple criteria framework conducted in the study. The validity framework used involved – (1) historical evidence of forecasting models used in the study, (2) feedback from previous users and experts, (3) comparison of results with similar results drawn from other studies made by using different approach. While modeling and forecasting, reliability checks were performed by using 'test and retest' method.

3.4 Methods for data collection

Main sources of data were literature review, government records, secondary sources (reports), and discussions with experts.

Exhibit 3.5: Methods for data collection

S.no.	Topic	Method for data collection
1.	**Low carbon technologies and practices:** • Available low carbon technologies and fuels • Emission abatement potential of alternative transport fuels • Low carbon travel demand management plans • Travel behaviour for reducing emissions • Methods for measuring transport sector emissions • Assessment models and option evaluation techniques	Literature review, expert interviews, secondary sources
2.	**Modelling and forecasting:** • City's growth (population and area) • Vehicles in Ahmedabad city • Travel characteristics (trip rates, transport modes, modal share) • Total travel demand • Forecasting travel demand	Primary data collection, secondary sources (reports), expert opinion, forecasting models
3.	**Accessibility and affordability:** • Demographic characteristics of the city • Socio-economic characteristics of the city • City Landuse • Future development plan • Proposed transport infrastructure projects	Primary data collection, secondary sources (reports)

Chapter 4
Case Study, Ahmedabad, Gujarat, India

4.1 Ahmedabad City – Baseline Study

Ahmedabad was founded by Sultan Ahmed Shah Abdali in 1411A.D. along the banks of river *Sabarmati*. It is the largest city of the state of Gujarat and the seventh largest city of India. Gujarat is located along western international border of the country. International border of India along Gujarat is surrounded from north-west by a salt desert and from south-west by Arabian Sea. The city of Ahmeabad is centrally located in Gujarat and is well connected by rail, road and air transportation with other major destinations across the world and across the country.

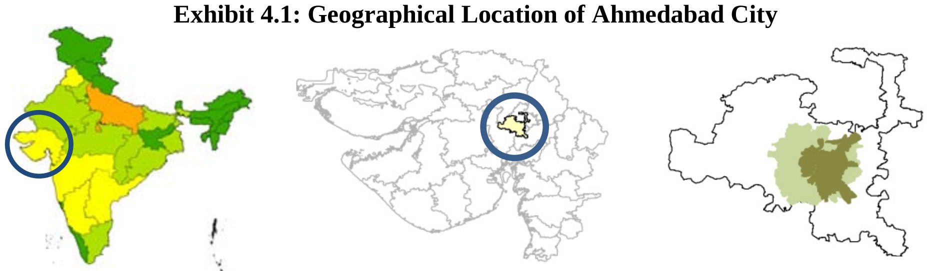
Ahmedabad is an important city for trade and commerce in India. Previously known as Manchester of India, Ahmedabad is now famous for its pharmaceutical industry and as an emerging hub for Automobile, Information Technology (IT/ITeS) and Financial Services sectors.

First textile mill in Ahmedabad was established in the year 1861. Thereafter for nearly a century textile industry contributed for a self-generated prosperity and a strong economic base for the city. By 1960 there were around 70 textile mills functioning in Ahmedabad city providing employment to nearly 1,35,000 persons. Unfortunately, during post 70s era, government's policies promoted power loom handloom sectors which resulted in decline in organized textile mill industry of the city. With its rapidly growing and diversifying economic base the city remains one of the most attractive destinations for local, national, and global investors.

Ahmedabad is a cosmopolitan city and has always witnessed a rich mix of various religions and cultures. It has complimented the city with several numbers of historically important sites and sites of special architectural interests. There are several monuments in the city exhibiting Hindu, Jain and Islamic architecture. Famous architects like Le Corbusier and Louis Kahn has also created some of the finest examples of modern architectural design in the city.

Ahmedabad has been one of the most important places during India's freedom fight movement. Father of the nation *Mahatma Gandhi* had set up his *Ashram* at the banks of river *Sabarmati* which flows through center of the city. *Sabarmati Ashram* is one of the most visited monuments in the city even today. *Gandhian* values of peace and harmony are built within the social and cultural fiber of the city.

Exhibit 4.1: Geographical Location of Ahmedabad City

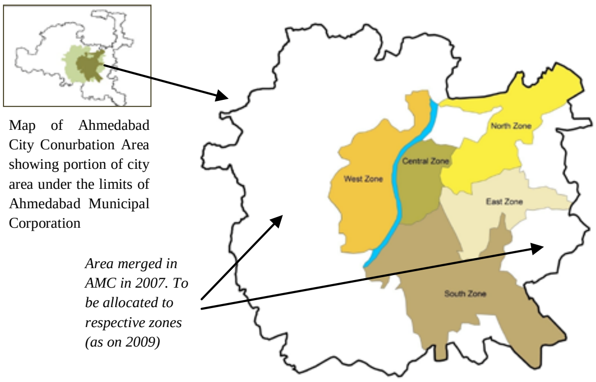


1. Map Showing State Boundaries of India 2. Map Showing Districts Boundaries of Gujarat State 3. Map Showing Boundaries of Ahmedabad City

4.1.1 City Administration

Ahmedabad city is administered by the Ahmedabad Municipal Corporation (AMC). Civic services to the city are provided by the municipal corporation whereas urbanizing new land pockets (beyond AMC limits) is a function of Ahmedabad Urban Development Authority (AUDA). Conurbation area of the city (AUDA planning area) is about 1878sq.km and jurisdiction of AMC spreads over 464sq.km. The area under Ahmedabad Municipal Corporation (AMC) is divided into six zones viz. Central, North, South, East, West and New-West Zone respectively. Most of the urban population of the city (Urban Agglomeration) is housed within the limits of Ahmedabad Municipal Corporation. River *Sabarmati* divides city into two parts with North, Central, East and South zones along its eastern banks, and West and New-West zones along its western banks.

Exhibit 4.2: City Fact Sheet, Ahmedabad



Geographical location:
$22^0$55’-$23^0$08’N, $72^0$30’-$72^0$42’E

City Governance:
Ahmedabad Municiapal Corporation

Population (2011, estimated):
4.5million

City Area (AMC): 464sqkm

Number of zones (AMC): 6

Map of Ahmedabad Municipal Corporation Area showing Municipal Zone boundaries

4.1.2 Demography

During the last decades Ahmedabad has shown high growth rate as a large metropolitan city. Observed population growth rate for the city (within municipal limits) was 2.9% during 1981-1991, during 1991-2001 it was 2.0% and is estimated to be 2.4% during 2001-2011. As there was a significantly high number of population residing in the peripheral areas of the city Ahmedabad’s city limits were expanded to 464sqkm in 2007 than 191sq.km until 2006. Most of the population residing outside municipal limits was concentrated along western periphery of the city. The larger city area known as Ahmedabad Urban Agglomeration (AUA) experienced a growth rate of 3.3% during the decade of 1981-1991 and 2.3% during the decade of 1991-2001, which is again estimated to be higher around 3.6% during 2001-2011.

Ahmedabad Urban Agglomeration (AUA) area refers to the urban population residing within the limits of conurbation area (AUDA) of the city. Apart from urban population there several villages surrounding the city which would be converted into urbanized land as per future development plan for the city prepared by the Ahmedabad Urban Development Authority (AUDA).

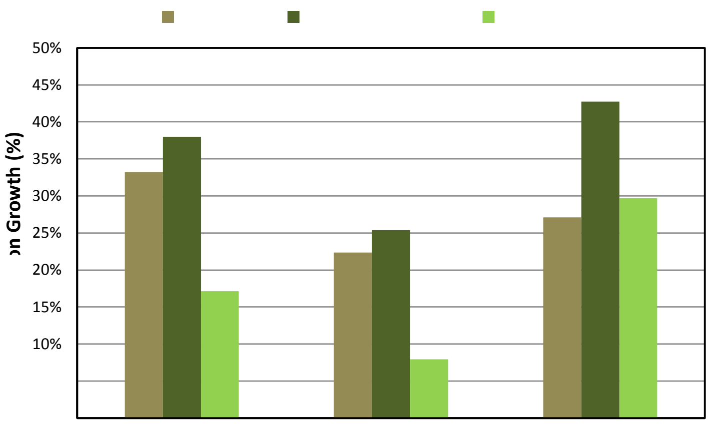
Table 4.3: Demographic profile of Ahmedabad City

S.no.	Year	Population AMC (Persons)	Population AUDA-Urban (Persons)	Population AUDA-Rural (Persons)
1.	• 1981	2159127	2721925	264555
2.	• 1991	2876710	3756246	309871
3.	• 2001	3520085	4709180	334531
4.	• 2011[1]	4475035	6722542	433924
5.	• CAGR (1981-1991)	2.91%	3.27%	1.59%
6.	• CAGR (1991-2001)	2.04%	2.29%	0.77%
7.	• CAGR (2001-2011)	2.43%	3.62%	2.64%

Source: Census of India Publications

India is not one of the most urbanized countries but it has a large number of populations living in urban areas. Due to better infrastructure and occupational opportunities there is a general preference of people to migrate and live in urban areas. Exhibit 4.4 shows that during last three decades the city has grown more in the sub-urban area and least amount of population growth was observed in the rural areas within conurbation region of Ahmedabad city. It clearly shows that in future, city of Ahmedabad might continue to remain one of the largest sprawling urban areas of India.

Exhibit 4.4: Comparison of population growth in Urban-Suburban-Rural areas of Ahemdabad City (AUDA)



[1] Population figures for 2011 were taken from 'table 2-10, p.21, City Development Plan Ahmedabad, CEPT/GIDB, 2005' since 2011 Census of India publication for Ahmedabad city were not released.

4.1.3 Civic Services

In India, Municipal Acts explicitly enunciate the functions and duties of the municipal corporations. Functions that municipal corporations are obliged to perform are called as obligatory services and some functions are facultative and are called as discretionary services. Ahmedabad Municipal Corporation is one of the urban local bodies in the country which provides high number of services to the city. It provides education, health, roads, street lighting, sanitation, water, fire fighting and drainage as its obligatory services. Generally, in other mega cities, some of the resource intensive services like water supply, drainage, education are managed by a separate board specially constituted for this purpose.

Water supply in Ahmedabad is provided by the Ahmedabad Municipal Corporation. It takes water from both surface sources and ground water sources. Ahmedabad has two water treatment plants with an installed capacity of 650MLD where surface water is treated, stored and supplied to the city. Ground water is extracted through tube-wells and French-wells maintained by the AMC. Majority of the city population is covered by piped supply except those which are living in unauthorized layouts. For the population not covered under piped supply or individual water connection, Municipal Corporation provides drinking water facility through community taps and water tankers. Water tariffs are low and water connections are not metered, this leads to leakages and misuse of water.

Sewerage also comes under one of the obligatory services of the AMC. Ahmedabad is one of the few cities in India where 100% of the waste water is collected and disposed by the underground piped network. There is no open waste water drain in the city which saves city environment from various externalities of surface drains such as bad odor, mosquitoes, flies etc. Sewerage treatment for Ahmedabad has an installed capacity of 257MLD and after treatment wastewater is disposed into the *Sabarmati* river that flows through the city. Storm water drains in Ahmedabad are also underground. Some of the storm water drains leads to lakes and ponds in the city where rain water is collected and used for recreational purpose. The Ahmedabad Development Authority (AUDA) and the Ahemdabad Municipal Corporation (AMC) has also installed several percolation wells in the city which helps in recharging ground water table.

Solid waste management (SWM) in the city is also a function of Ahmedabad Municipal Corporation. Medical waste is separately collected and is disposed through incineration. Similarly, industrial waste stream is separately managed. Waste from domestic and commercial sources is collected by municipal staff and is disposed at the municipal landfill site. The AMC has taken various initiatives to improve the situation of SWM in the city. It has partly succeeded in terms of building sanitary disposal facilities but primary collection of waste is not effective. Ahmedabad is one of the first cities in the country to have a sanitary landfill site. There is also a compost pant maintained by a private company (EXCEL Industries).

Ahmedabad is one of the few cities where fire services are provided by the municipal corporation. In most of the cities in the country, it is a function under state police department. The fire department is equipped with fire tenders, fire engines and turn table ladders. However, limitation of the fire department is to combat with fire in the buildings not more than 30m (equivalent to 10floors) high. This limitation also affects geographical expansion of the city.

The city has many slum pockets and services in the slums are the responsibility of AMC. The municipal corporation has a slum networking department which is dedicatedly working for improving living conditions in the slums. Slum networking department helps in bringing benefits of national and international schemes to slum areas in the city. However, most of the slum areas lack basic infrastructure. Water logging, heaps of waste, mud and garbage is commonly seen in many slum areas in the city. Roads are not properly built and street lighting is inadequate. Water is provided mostly through community taps and toilet facilities are pay and use.

Ahmedabad is a socially active city and there are a large number of public amenities like community halls, gardens, play grounds, libraries and open spaces in the city. Many of them are owned by the municipal corporation and several are privately owned. Mostly gardens and open spaces are municipal. The city has few number of public sports facilities like stadiums and swimming pools.

4.1.4 Infrastructure

In general urban infrastructure in Indian cities is inadequate as well as found to be much below international standards in most cases. However at a relative scale status of infrastructure in Ahmedabad city may be considered as better than that in many Indian cities. In addition to various government agencies, private sector has a significant role in providing infrastructure to the city especially in education, health and electricity. Infrastructure for telecommunication, roads and transport are mainly provided and maintained by government agencies.

Electricity to the city is provided by a private company (Torrent Power). The power company has its own coal based power plant (AMGEN) situated in North zone of the city. Total Installed capacity of the AMGEN is 500MW, out of which 400MW is coal based and 100MW is gas based. The power company is also planning to use renewable sources of energy in future. Supply of electricity to the city is uninterrupted and the service is efficiently administered. Unlike other cities in the country there are no regular power cuts experienced in Ahmedabad and even voltage fluctuations are not observed.

With the introduction of mobile phone technology telecommunication industry has penetrated at high rate in India. There are private and public companies providing telecommunication infrastructure and telecommunication services to the city. The government company providing telecommunication services to the city is Bharat Sanchar Nigam Limited (BSNL) with many other prominent private players like Vodafone, Reliance, and Idea. In mobile phones private companies are maintaining larger share but in fixed line and internet services BSNL is still the most popular.

Education facilities in the city are provided by both private and public institutions. Ahmedabad Municipal Corporation has more than 550 schools in the city where education is provided for free. Other than that there are schools owned by state and central government respectively. Additionally there are many private schools in the city. Quality of education and infrastructure in private schools is much better than that in government schools. It is a preference of people to enroll their children in private schools in spite that the study expenses in private schools are much higher than that in government schools. However, in higher education facilities government colleges are preferred over private colleges.

Health sector in the city follow similar trends as that in education sector. More number of private health facilities is preferred by people, whereas treatment and medicine is provided for free in government health facilities. There are about 70 municipal hospitals, nursing homes, dispensaries and pathological laboratories in the city. However, Ahmedabad Municipal Corporation has introduced a sound disease monitoring and surveillance system. About 14 diseases are monitored daily with a focus on 5 epidemic type including jaundice, typhoid, cholera, gastro-enteritis and malaria. The surveillance system includes 7 major hospitals, municipal clinics and mobile vans.

Roads and street lighting in the city are primarily provided by the government agencies. Most of the city road network is maintained by the Ahmedabad Municipal Corporation. There are few private roads owned by gated communities and institutions. Roads outside the boundaries of municipal area are developed by the Ahmedabad Development Authority (AUDA) and are maintained by the local municipality respectively. Condition of road surface in the city is generally good. However, there are serious issues related to road geometry and right of the way. Due to sprawling development, unplanned growth and encroachments effective road width available is much lesser than its planned right of the way. At many places only one lane is clear for the traffic.

4.1.5 Major Infrastructure Projects Ongoing

Ahmedabad city is one of the most deserving competitors among suitable destinations for national and international enterprises operating or planning to venture into the country. The city administration is constantly involved in meeting infrastructure gaps as well as in improving city infrastructure. Some of the major infrastructure plans promoted by state and central governments has already been formulated as projects and are initiated. These infrastructure projects especially *Sabarmati* Riverfront Development Project, Bus Rapid Transit System, and Metro Rail would significantly contribute in giving a new shape to city’s development in near future.

Sabarmati Riverfront Development Project is carried out under *Sabarmati* Riverfront Development Company (SRFDC) which is owned by the Ahmedabad Municipal Corporation (AMC). The SRDFC is a special purpose vehicle which was raised in 1997. The project would reclaim 185ha of land from a 10.5km long stretch along river edges. Reclaimed land would be used for the development of commercial, recreational, residential and social places. The land development would be carried out as per proposed development plan for the reclaimed land along the river. The project is also envisaged as an environmental improvement and sustainability project. Hydraulic design of the project would help in preventing flooding from the river during the incidents of heavy rainfall. The project would play a prominent role in uplifting image of the city.

Bus Rapid Transit System (BRTS) Ahmedabad is the first of its kind in the country. It is a dedicated bus corridor system. The BRTS track consist two median bus lanes (around 3.75m wide), one in each direction. A total BRTS route network of 205km will be developed under various phases. First phase of 58km is already operational and running successfully. BRTS Ahmedabad has been awarded several national and international awards for its successful planning and implementation. The BRTS project implementation would cause landuse changes along its routes. As per policy revisions, high rise building along BRTS main track would be promoted by granting permissions for extra built up area. More parking spaces would be built along the roads. Vehicles used for BRTS would be running on diesel and will have a passenger carrying capacity of 50 persons per vehicle. The system will be fully IT-enabled and would use online tracking system, online ticketing system and smart card. Plantation along BRTS routes and promoting pedestrians and cyclists through providing a dedicated track are planned integral components of the project. However, due to large amounts of encroachments, the authorities so far have not been able to clear lanes for cyclists and pedestrians. The project would increase accessibility in the city would increase the share of public transport in near future.

Exhibit 4.5: Map showing proposed BRTS and Metro routes in Ahmedabad city

Source of map: Executive Summary-Ahmedabad Bus Rapid Transit System, p.2, AUDA/GIDB/CEPT University, Ahmedabad Municipal Corporation, 2007

Metro Rail Project Ahmeabad would be a turning around project for the transport sector of Ahmedabad. The project is project is promoted by Gujarat Infrastructure Development Board which is owned by the Government of Gujarat. The proposed metro rail system would connect Ahmedabad and Gandhinagar cities. Ahmedabad is the largest city of Gujarat and is the commercial capital, and Gandhinagar is the administrative capital for the state. There will be two corridors in the first phase North-South (32.65km) which will connect the two cities and East-West corridor (10.90km) which will cut across the Ahmedabad city. The metro system will have 37 stations (11 along East-West corridor and 26 along North-South corridor). The project will be implemented in three phases. First phase of the project was expected to be operationalized by 2010. However, the work for metro has just been commenced due to delays. It is envisaged that the trains would be running at an average speed of 80km per hour. When fully operational the metro system would require a capacity of 270 coaches. It would run on a traction system voltage system of 25kv AC. It is estimated that the first phase (43km) would carry around 5.6million passenger km per day.

4.1.6 General Living Environment

In addition to infrastructure and civic services, few other aspects like pollution, crime rate, and cost of living indicate characteristics of a city. The city has witnessed few special incidents of communal disturbance in the past but in general day to day life the city is safe. Pollution levels in the city were significantly decreased after introduction of CNG as a transportation fuel in the city. It has been made mandatory that all the taxis and autorickshaws would run on CNG. Cost of living in the city is lower than that in other mega cities of India.

4.1.7 Traffic

Traffic movement in most parts of the city is not very convenient. Encroachments along roadsides and narrow effective carriageways cause mixed movement of traffic on the roads. It leads to slow movement of traffic, forms bottlenecks and causes congestion. With increasing number of vehicles in the city, traffic problems on the roads are becoming more complex.

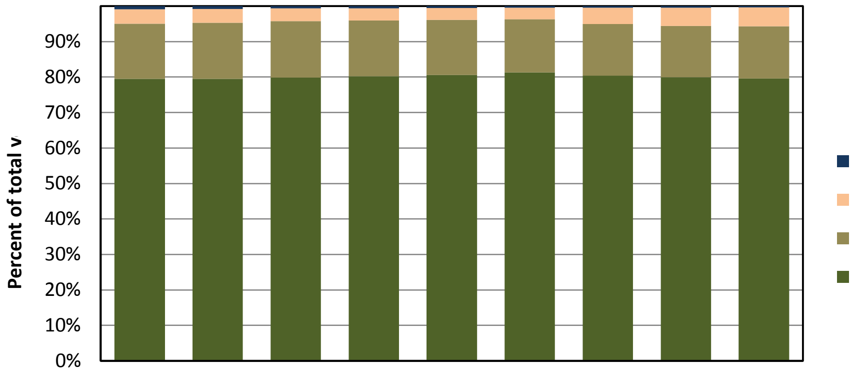
4.1.8 Modes of transport in the city

Like every Indian city, Ahmedabad has several modes of transport motorized and non-motorized. Range varies from animal carts to most luxurious cars. Vehicles sold in the city are registered with the Regional Transport Office, Ahmedabad. The vehicles are registered in 23 different categories. Depending upon the type of vehicle, type of engine and their intended use (commercial or personal) these 23 different types of vehicles may be grouped into six categories. Passenger transport vehicles may be grouped into four categories viz. two wheelers, four wheelers, three wheelers and buses. Two wheelers and most of the four wheelers are privately owned vehicles except those four wheelers which are used as commercial taxis. Two wheelers in the city are used only for personal purposes and not for commercial use. Three wheelers are commonly known as autorickshaws, which is a shared mode of transport. These autorickshaws function like three wheeler taxis. Three wheelers are a very popular mode of transport because they are lesser expensive than taxis and are available in every corner of the city. All the three-wheelers in the city use CNG as a fuel as mandated by the state Government. Buses presented in the exhibit below also includes private buses owned by private operators and are used as contract carriages or for intercity private bus service. Similarly, three wheelers used for freight transport are categorized as freight small vehicles. Tempo travelers, tractors, trailers, and trucks are grouped as freight large vehicles.

From the observed trends of number of vehicles registered in Ahmedabad city during past years it may be seen that every category of vehicle has shown a rising trend. Highest growth (1999-2000) rate was observed in case of three wheelers (15.20%).

However, highest numbers of vehicles in the city are two-wheelers. Vehicles in the category of personal vehicles 2-wheelers and 4-wheelers have grown at the rate of 11.96% and 11.27% respectively during 1999-2008. Lowest growth rate was observed in case of buses 2%, which indicates marginal role of public transport in the city. Similarly freight small vehicles had grown at the rate of 15.09% and freight large vehicles had grown at the rate off 6.65% during 1999-2008.

Exhibit 4.6: Recent Trends in growth of Passenger Transport Modes in



Source: Regional Transport Office (R.T.O.), Ahmedabad

4.1.9 Public Transport

Public transport in the city is provided by the Ahmedabad Municipal Transport Services (AMTS). AMTS is an autonomous organization formed under Bombay Provincial Municipal Act (BPMC Act) and is managed by the Transport Manager a functionary under transport committee and Ahmedabad Municipal Corporation. It started in January 1947 with its services on 29 routes in Ahmedabad city with a fleet size of 60 buses (AMTS). Before the inception of first phase of Bus Rapid Transit System (BRTS) in 2009, AMTS buses were the only mode of public transport for the city of Ahmedabad. The AMTS operates over 150 routes throughout the city with a fleet size of 540 buses and it carries around 350 thousand passengers every day (AMTS). All the buses provided by AMTS are diesel operated, however AMTS is running limited number of battery operated vehicles on experimental basis. Due to financial constraints, AMTS has tried delivering its services with private partnership on some of its routes. The new mode of public transport Bus Rapid Transit System (BRTS) for the city is a system of dedicated bus corridors.

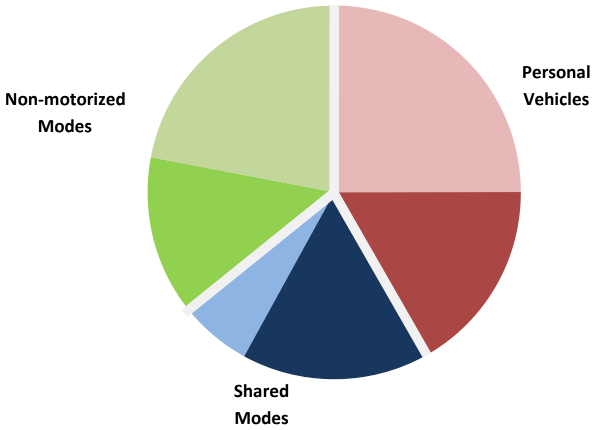
4.1.10 Travel Characteristics

Ahmedabad is a ring radial city and predominantly it has mixed landuse. Public amenities schools, colleges, hospitals, gardens, recreational areas and markets are distributed all over the city which brings down the need for long distance travel for daily needs. Ahmedabd is an industrial town and industrial areas in the city are located in East, South and North Zones. Industries in western part of the city are far from municipal boundaries are located closer to the satellite towns of Ahmedabad. Property prices in the city do not vary drastically from one zone to another. These two factors contribute for bringing down average trip lengths for occupational travel.

If we see the pattern of vehicular ownership in the city, it clearly shows that the share of personal vehicles (2-wheelers and 4-wheelers) is much more than that of public transport vehicles in the city. Further, Exhibit 4.7 shows that two wheelers have always maintained the highest share (nearly 80%) in total number of vehicles in the city. Clearly 2-wheelers are the most popular mode of transport in the city. Unfortunately, road infrastructure in Ahmedabad city is not friendly for pedestrians and bicycle riders. Traffic conditions are chaotic and dedicated lanes for non-motorized modes of transport were never included while planning the road network. Moreover, encroachments along the roadsides make it more difficult to use non-motorized modes of transport in the city.

A study released by the Ministry of Urban Development, Government of India in 2008, shows that 64% of total travel demand in the city is met by motorized travel. Out of which major share is contributed by the personal modes of transport (42%) and rest 22% by public transport and autorickshaws. Exhibit 4.5 shows the modal split for Ahmedabad city for the year 2007. The study also mentions that the per capita trip rate for the city was 1.4 (all modes) and the average trip length was 6.2km in 2007.

Exhibit 4.7: Modal Split for Passenger Travel Demand, Ahmedabad City (2007)



Source: Ministry of Urban Development, Government of India, 'Study on Traffic and Transportation Policies and Strategies in Urban Areas in India', 2008

4.2 Creating Scenario – Ahmedabad 2050 (BAU)

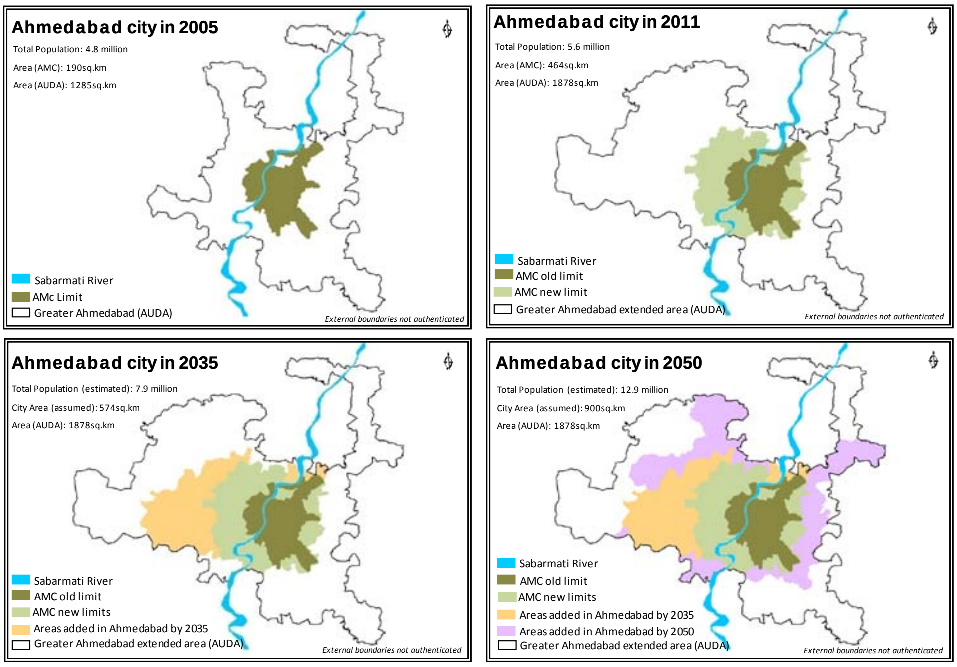
It is evident from the baseline study of Ahmedabad city that the city would keep experiencing growth on similar trends as it has experienced in past recent years. Scenario Ahmedabad 2050 Business As Usual (BAU) refers to future visualization of the city consistent with prevailing trends of growth of its various characteristic features. For creating the BAU scenario trends in spatial growth, population growth, growth of vehicles, and changes in travel characteristics were projected using various forecasting models. Projections were validated with different forecasting techniques. Input data and postulated information required for scenario building were gathered during the field work and from the study of city characteristics in baseline study. Baseline study provided important insights in understanding inter-sectoral linkages between various aspects of the city and dynamics of city growth.

4.2.1 Forecasting Spatial Growth of the City

Geographically city is growing in all directions but more along western periphery of the city. More agricultural land within conurbation area of the Ahmedabad Urban Development Authority (AUDA) would be urbanized in coming years. The city may not have a very high skyline in near or medium term future. It is also likely that in coming decades Ahmedabad Municipal Corporation may split into two urban local bodies both with multi-million populations. Based on the force field analysis of developmental forces acting on the city various areas (villages) were identified which are likely to be urbanized by 2035 and 2050 respectively.

Developmental trends, infrastructure projects, government plans and proposed development plan for the city were assumed as major forces influencing city's spatial growth. Output of the spatial growth model is shown in the Exhibit 4.8 below which provides a futuristic scenario of spread of Ahemdabad city by 2050.

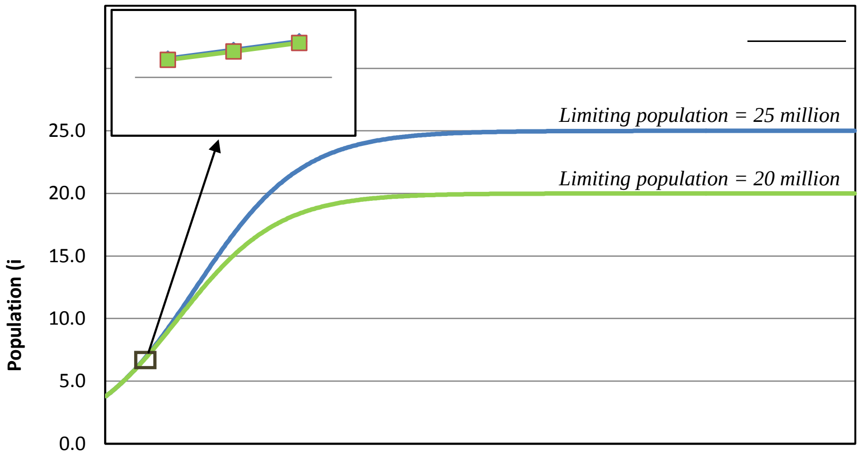
Exhibit 4.8: Spatial Growth Forecasts for Ahmedabad City



4.2.2 Population Forecasts

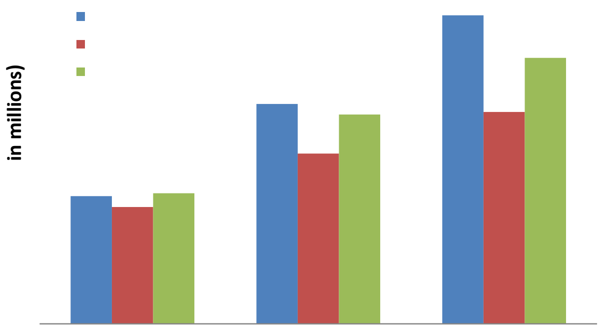
Population forecasts were made using asymptotic regression model. Yearly population growth during 1991-2001 was used as base data for projections. Ahmedabad being a mega city of India the asymptotic regression model run was carried out with a lower limit of 20million people and a higher limit of 25million people. The asymptotic limits for Ahmedabad were assumed on the basis of reported population figures and population density for other mega cities of India which are bigger than Ahmedabad. According to the regression model forecasts (with 25million limiting population), population of Ahmedabad city may reach 9.7million by year 2035 which is about 1.6 times the estimated population 2011, and the city population may double by 2050. Exhibit 4.9 shows that the city population would keep rising sharply till 2040 and after that the population growth may slow down as seen in Exhibit 4.9 below the asymptotic curve for the city population starts flattening. The population growth curve (Exhibit 4.9) also shows that the city population may reach its limits by the year 2200. Population forecasts were validated using CAGR model and spatial model.

Exhibit 4.9: Population Forecasts for Ahmedabad City using Regression Model



The Compound Annual Growth Rate (CAGR) model provides population forecasts based on observed growth rate of city population during 1991-2001. The projection method is exponential and provides exorbitantly high estimates for population growth in the longer term. Spatial growth model for the city was developed in Geographical Information System (GIS). Population density per unit developed area was taken as a control parameter in the model. Developed area refers to the gross built envelope of the city within the conurbation area of Ahmedabad. Satellite images for various time periods were analyzed to determine built envelope in the city at various points in time. Historic trends of the population density in the city were observed from the baseline study and satellite image interpretation. The model provides population forecasts by multiplication of assumed density and estimated area. Exhibit 4.10 presents a validation of population forecasts using three different models.

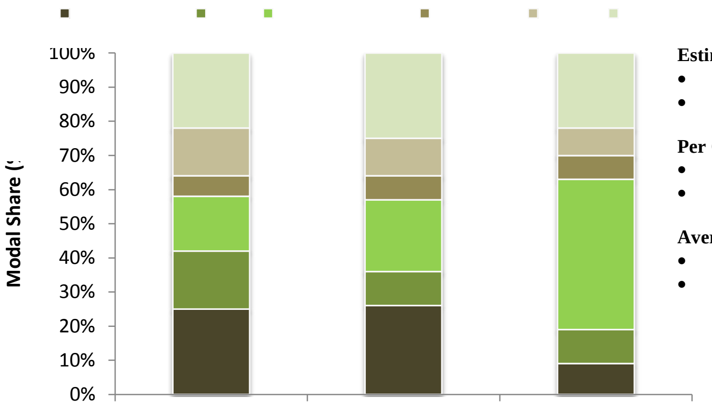
Exhibit 4.10: Comparison of population forecasts for Ahmedabad City



4.2.3 Forecasting Travel Demand

Travel demand forecasting was based on Travel Characteristics Model (Pangotra P., Sharma S., 2005). The travel characteristics model provides forecasts for vehicular travel demand as well as estimated number of vehicles in the city in future. Model computations were based on total population, per capita trip rate (PCTR), Modal Share by type of mode, and average trip length. The model took into account functional relationship between population, alternative modes of travel and mobility rates in the city. The model was used to forecast motorized travel demand for the year 2035 and 2050 in Ahmedabad city. Variables in the model were exogenously specified. Values for the variables were estimated during the baseline study. Exhibit 4.11 shows values for all the variables used for travel demand forecasting simulations.

Exhibit 4.11: Variables used in Travel Demand Forecasting Simulations



Estimated Population:
- Year 2035: 9.7 million
- Year 2050: 12.3 million

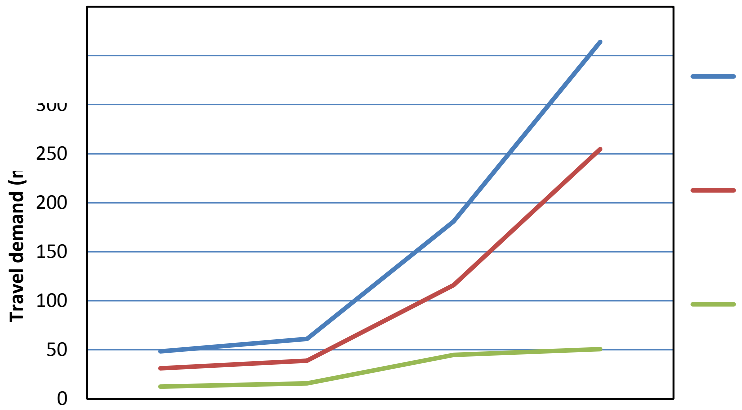
Per Capita Trip Rate (PCTR):
- Year 2035: 1.8
- Year 2050: 2.0

Average Trip Length:
- Year 2035: 10.4km
- Year 2050: 14.8km

Source: Ministry of Urban Development, Government of India, 'Study on Traffic and Transportation Policies and Strategies in Urban Areas in India', 2008

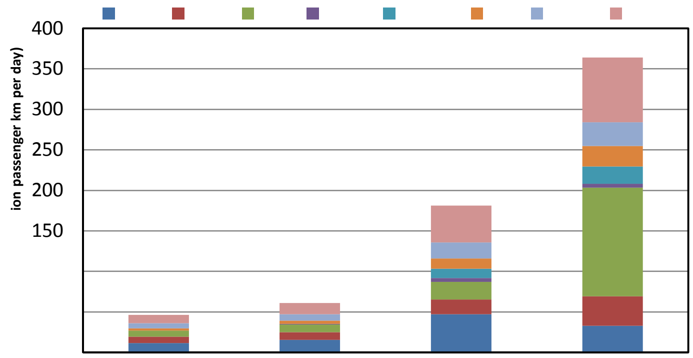
With the given set of variable it was estimated that the total passenger travel demand in Ahmedabad city would grow from 48million passenger km per day in year 2007 to 181million passenger km per day in 2035 and 364 million passenger km per day in the year 2050. Similarly, motorized travel demand would increase from 31 million passenger km per day to 116 million passenger km per day in 2035 and to 255 million passenger km per day in the year 2050. It was also forecasted that the vehicle travel in the city (all modes) would increase from 12 million equivalent vehicle km to 45 million equivalent vehicle km in 2035 and to 51 million equivalent vehicle km in 2050. It was interesting to note that whereas passenger travel demand is increasing but the vehicle travel kms nearly flatten from 2035 to 2050 (Exhibit 4.12). The trend is explained with the increase in modal share of public transport. It is a likely possibility that by 2035 Ahmedabad city would have BRTS as well as Metro systems running in the city. Moreover, by 2050 Metro is expected to be running at full scale. The expected growth in size of the city would also force people to switch from personal modes of transport to public modes of transport.

Exhibit 4.12: Travel Demand Forecasts for Ahmedabad City



If we analyze results of travel demand forecasting by mode of travel (Exhibit 4.13), we can see that within private modes of transport (2-wheelers and 4-wheelers) share of cars would increase as compared to the prevailing trends of higher usage of 2-wheelers. It indicates that in near future, market of 4-wheelers in the city would grow at a faster rate than that of 2-wheelers. Share of intermediate public transport modes (IPT, 3-wheelers) would remain same. In case of modes of public transport, it is interesting to note that in spite of having BRTS and Metro Rail systems in the city, major passenger traffic demand would remain in account of public bus systems. It is an important observation as it may provide guidelines for augmentation in planned capacity of BRTS and or Metro Rail systems if it is desirable to keep modal share of local bus system lower in future.

Exhibit 4.13: Forecasted Travel Demand by Mode



4.3 Forecasting Transport CO_2 Emissions (BAU-2050)

For estimating CO_2 emissions from the transport sector of Ahmedabad, Urban Transport Emission Estimation Model (UTEEM) was created. The model computes emissions from travel demand and follows the rational logic that emissions are a function of amount and type fuel consumed and fuel consumed is a function of motorized travel. Outputs of travel demand estimates served as input variables for UTEEM forecasting simulations. The model takes into account that various vehicles depending upon their technology and size have different fuel efficiencies. Moreover, there is a different amount of CO_2 emission per unit fuel consumed for different types of fuels respectively. However, the emissions calculated by the model accounts for only operational emissions. The model functions on equations presented in Exhibit 4.13.

Exhibit 4.13: Forecasting CO_2 Emissions from Transport Sector

$\sum E_{CO2} = \sum TTD_t \times EF_t$

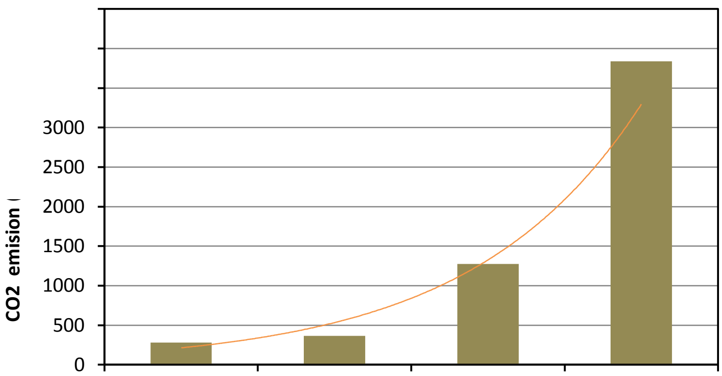
Where, E_{CO2} is the amount of CO_2 emission
TTD_t = Total vehicle kilometer travel by vehicle mode and fuel type
EF_t = emission factor in grams of CO_2 emitted per kilometer travel

It shall be noted that the emission factor (EF) is different for every type fuel and every type of vehicle. Total emission is the sum of CO_2 emission from each category of fuel by type of vehicle. In India's automobile market electric vehicles have not yet penetrated to a large extent. However, there are few numbers of electric two wheelers coming to the market. Similarly, there are small numbers of electric cars. Mostly cars in India are running on fossil fuels. Recent trend in car market is increasing popularity of CNG and LPG vehicles. In Ahmedabad it is a mandate from the state government for using CNG as a fuel for three wheelers (autorickshaws). In case of buses and other large vehicles, most of the vehicles are running on CNG but some are running on diesel.

Based on the findings of baseline study and information provided by the Regional Transport Office of Ahmedabad it was estimated that about 98% of two wheelers in the city are running on petrol and around 2% are electric. Four wheelers were observed to be using most diverse range of fuel. According to estimates made during baseline study, there may be around 64% of cars running on petrol and diesel, 35% on CNG and LPG and only 1% electric cars. Most of the three wheelers use CNG, but some of them are hybrid and also use petrol or diesel. It was estimated that three wheelers being hybrid consume petrol equivalent to 20% of three wheelers in the city. Even in case of heavy vehicles for passenger transport, it was estimated that about 20% are running on diesel and about 80% on CNG. Same proportions of vehicles by fuel type in each category were applied to the forecasts made for 2035 and 2050 BAU scenario.

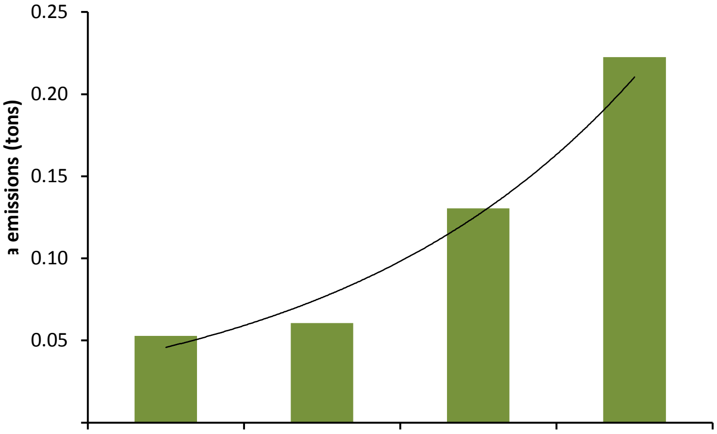
The forecasting results show that emission from transport sector of Ahmedabad may increase from 280kt per annum to 1263kt per annum by 2035 and to 2737kt per annum in 2050 under BAU. This rise in level of emissions may account for 0.22 tons CO_2 per capita emissions only from passenger transport sector of the city by 2050. Exhibit 4.14 shows that under BAU scenario, the CO_2 emissions from transport sector of the city may rise exponentially.

Exhibit 4.14: Forecasts CO_2 emissions from Ahmedabad's Transport Sector under BAU



With these levels of emissions, per capita CO_2 emissions from the passenger transport sector of Ahmedabad may increase by 2.2 times from the current levels by year 2035 and reach from 0.05 tons per capita to 0.13 tons per capita. Forecasting results also show that continuing trends till 2050 BAU may lead to 3.7 times increase in per capita CO_2 emissions than current levels from the passenger transport sector. Per capita CO_2 emissions from passenger transport sector may rise to 0.22tons by 2050 under BAU forecasts.

Exhibit 4.15: Increase in Per Capita CO_2 emission from passenger transport BAU



4.4 Clean and Sustainable Transport

The concept of clean and sustainable transport envisage a combination of two different qualities for the future transport systems viz. 'low carbon emissions' and 'sustainability'. Need for the combined approach arises from the fact that some solutions are found to be effectively clean but not sustainable and some solutions are sustainable but not clean. For planning low carbon societies in the longer run, it is imperative that planners are informed about both aspects of the solutions. Further, it is not easy to examine the effectiveness and sustainability of a solution at the same time. Sustainability depends on different factors and effectiveness may depend on entirely different factors. There are different approaches adopted by planners and researchers but it is difficult to generalize these methodologies since factors acting at a particular situation may vary entirely from factors acting in another situation or at another place. When decision has to be taken based on several variables which require evaluation at different scales and different ranges from each other, Multiple Criteria Assessment (MCA) based frameworks may be developed.

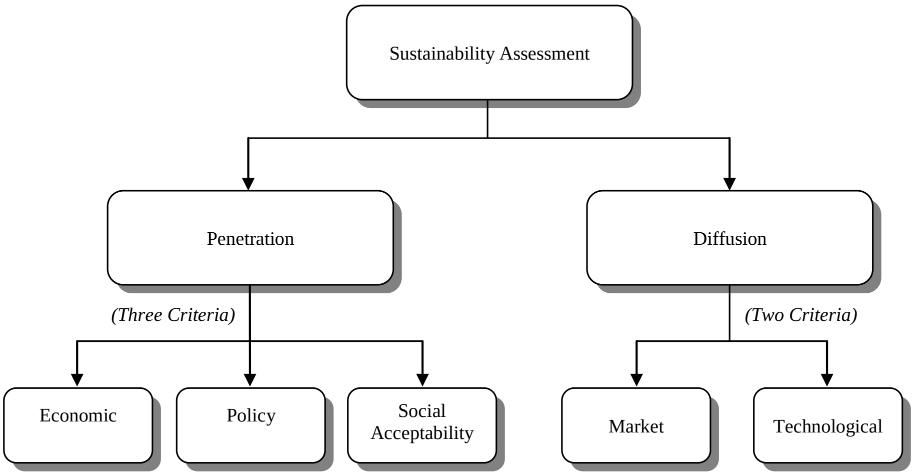
The Multiple Criteria Decision Analysis (MCDA) approach was adopted in the EU integrated project NEEDS (New Energy Externalities Developments for Sustainability). Objective of the project was to examine sustainability of advanced electricity generation in France, Germany, Italy and Switzerland in year 2050. The study mentions that MCDA approach was adopted as it combines specific technology characteristics related to sustainability with stakeholder preference in a structured way (NEEDS, 2004).

A study on clean transport fuels conducted by European Commission, Directorate General of Mobility and Transport in 2011 examines suitability and probability of future clean transport fuel through SWOT analysis. The SWOT framework developed in the report consist four parameters – technological feasibility, scalability, social acceptability, and user acceptability (EC-DGMT, 2011).

4.4.1 Clean Transport Fuel Sustainability Assessment Framework

A multiple criteria based methodology was developed to examine effectiveness and sustainability for clean fuel options. The framework assumes that sustainability of an alternative fuel in the market depends upon two basic aspects (1) Penetration of the fuel, which depends on its possibility of getting introduced in the market, and (2) Diffusion of fuel, which could be examined through its stability. In the proposed Multiple Criteria Assessment (MCA) framework, first parameter of 'Penetration' of an alternative fuel in the market was defined with three criteria viz. 'economic' examining economic and cost aspects of introducing the fuel, 'policy' which would look at influence of domestic and international policies and the third criteria 'social acceptability' is aimed at capturing chances of its acceptability by the people. The second parameter continued 'Diffusion' of fuel was defined with two criteria 'market' and 'technological'. 'Market' criteria would indicate commercial potential of the fuel and 'technological' criteria would assess capacity for technically supporting the new fuel and capacity to technically support related technological innovations required in related sectors like vehicles. Exhibit 4.16 illustrates scope and range of the framework for sustainability assessment of alternative transportation fuels.

Exhibit 4.16: MCA Framework for sustainability assessment of alternative fuels



An inventory of clean transportation fuels was created taking into account transportation fuels currently available and in use or fuels that are expected to be taken in use in near future. At first stage of the assessment framework clean transportation fuels were shortlisted on account of their abatement potential. Emission abatement potential was used as a filter to shortlist clean fuels for their sustainability assessment. Based on a study conducted by Western Governors' Association, Clifornia compares lifecycle emissions for alternative transportation fuels. The study reports that biofuels, hydrogen cell and electricity are the three transportation fuels that cause least emission of greenhouse gases if lifecycle emissions are compared (Western Governors' Association, 2008). Exhibit 4.17 shows a comparison of lifecycle GHG emissions from alternative transportation fuels.

Exhibit 4.17: Lifecycle GHG Emissions from alternative transport fuels

S.no.	Fuel	Lifecycle GHG Emission (eCO_2 g/mi)[2]
1.	Hydrogen Fuel Cell	210
2.	Plug-in Electric HEV	300
3.	All Electric Vehicles	290
4.	Vehicles Running on B20	320
5.	Vehicles Running on Fischer Tropsch Diesel	380
6.	Vehicles Running on Conventional Diesel	350
7.	Flex-fuel Vehicles on EB5 (Corn Starch)	360
8.	Flex-fuel Vehicles on E85 (Cellulosic)	150
9.	Compressed Natural Gas Vehicles	340
10.	Reformulated Gasoline	430

Source: Transportation Fuels for the Future, Western Governors' Association, California, 2008, p.24

[2] Figures estimated from graph

Due scope and limited time for the study, alternative clean transport fuels were shortlisted for sustainability assessment based on the findings shown in Exhibit 4.18. According to the study Bio-fuels (E85 Cellulosic), Hydrogen Cell and Electric vehicles were found to have minimum life cycle GHG emissions as compared to other fuels examined in the study.

In the second stage of assessment the three shortlisted fuels were analyzed under the multiple criteria assessment framework for examining their sustainability in future. The sustainability assessment framework consist two parameters, five criteria and fourteen indicators. Each criterion was given an equal weight of 20% and overall ranking of sustainability was done on cumulative relative score. The criteria score matrix for sustainability assessment of clean transport fuels is shown in Exhibit 4.18.

Exhibit 4.18: MCA Framework for Sustainability Assessment of alternative clean transport fuel – Criteria Matrix

S.no.	Aspect Examined (Parameters)	Criteria	Criteria Weight
1.	Penetration	• Economic	20%
		• Policy	20%
		• Public Acceptability	20%
2.	Diffusion	• Market	20%
		• Technology	20%
Total	-	-	**100%**

Note: Technologies for sustainability assessment were shortlisted on the basis of emission reduction potential hence it is not included among criteria for MCA framework

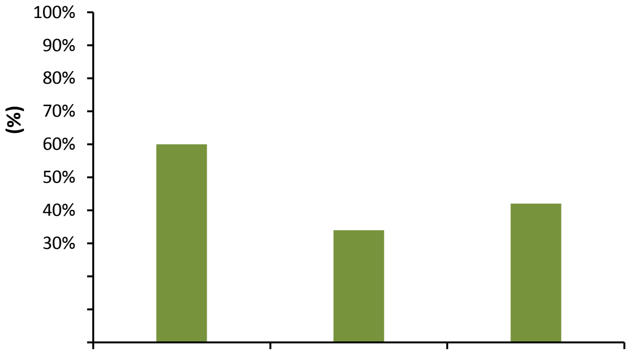
Assessment of each of the criteria was carried out through a set of systematically defined indicators. Each indicator was given a score for each of the shortlisted fuels depending upon its nature and type respectively. The economic criteria examined financial feasibility of introducing an alternative fuel. For assessing cost and economic aspects of the alternative fuel four indicators were designed - emission abatement costs (life cycle costs), cost of procurement of fuel that depends upon local availability or import, availability of governments own resources or availability of funds, and economic conditions of the country. Policy criteria is of vital importance as introduction of a fuel such as nuclear fuel depends upon national level policy decisions, or commitments made at international treaties and conventions. In some cases policies from other sectors may directly influence transport sector such as national energy policy. Social acceptability depends upon prevailing culture and social reasons. Similarly, the criteria to determine possibility of continued existence of alternative fuel depends upon demand and supply of the fuel. Market consists of availability of fuel, accessibility by people and willingness of people to pay for it. Market indicators examine sustainability from peoples' side and technology indicators examine sustainability of alternative fuel from government's side. Exhibit 4.19 shows the criteria-indicator matrix and recommended guideline for scoring each indicator.

Exhibit 4.19: Indicator Matrix for Sustainability Assessment of clean alternative fuels

S.no.	Criteria	Indicator	Scoring Method
1.	Economic	• Abatement cost per unit emission reduction	Lower the better
		• Procurement cost	Lower the better
		• Availability of internal resources (funds)	Higher the better
		• Economic conditions	Stronger the better
2.	Policy	• Sensitivity to internal political conditions	Lower the better
		• Sensitivity to international policies	Lower the better
3.	Public acceptability	• Cultural resistance	Lower the better
		• Awareness	Higher the better
4.	Market	• Affordability	Higher the better
		• Accessibility	Higher the better
		• Willingness to pay	Higher the better
5.	Technological	• Operation and Maintenance Costs	Lower the better
		• Technical Capacity	Higher the better
		• Availability	Higher the better

Results of sustainability assessment for the three shortlisted clean transportation fuels show that clean electricity as an alternative fuel may be more sustainable than hydrogen cell and ethanol in case of Ahmedabad. On both the parameters of sustainability assessment framework electricity weights higher than the other two fuels. It was found that on all criteria except that on the criteria of policy influence weights of clean electricity were higher than that for hydrogen cell and ethanol. The reason for relatively lower weight of clean electricity at policy criteria is that expected contribution of nuclear fuel in India's clean energy plans is quiet high. At the same time decision of continuing usage of nuclear technology in power generation is highly sensitive to national and international policies. Further, on demand and supply criteria, clean electricity gets higher weight than other alternative fuels shortlisted. Exhibit 4.20 present the results of MCA for sustainable clean transport fuels. It may be seen that electricity scores highest (60%), followed by ethanol (42%) and then hydrogen cell (34%).

Exhibit 4.20: Cumulative sustainability score of clean alternative transport fuels



Scores for each indicator were given as judgment made on the basis of recently published research studies. The judgment approach has been adopted due to limitations for the study. However, it is recommended that scoring shall be more scientifically based on data. Exhibit 4.21 shows weights obtained by the three shortlisted fuels under each criterion.

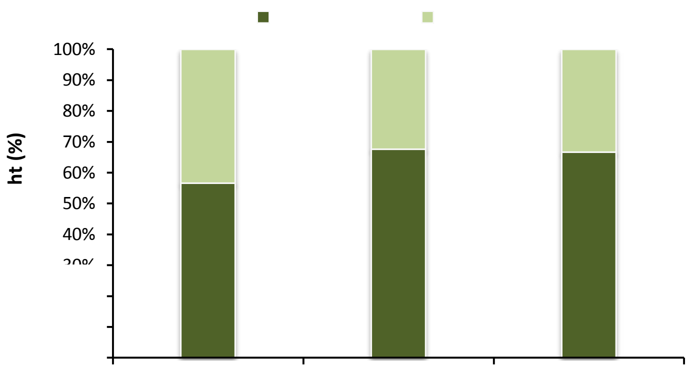
Exhibit 4.21: Relative sustainability scores under each criterion

S.no.	Criteria	Electricity	Hydrogen Cell	Ethanol (E85)
1.	Economic	13%	5%	8%
2.	Policy	10%	12%	12%
3.	Social acceptability	11%	6%	8%
4.	Market	14%	5%	6%
5.	Technological	12%	6%	8%
-	**Overall weight**	**60%**	**34%**	**42%**

Hydrogen cell scores minimum as a sustainable alternative fuel due to production challenges, low performance, technological barriers and high costs. Ethanol has similar challenges as it requires large amounts harvesting and transportation of biomass which is a significant economic challenge. Further, increasing cultivation of energy crops may raise concerns for soil and water systems. Infrastructure and education for the production of ethanol (E85) are also limited (WGA, California, 2008). In case of electricity, greater unpredictability remains in case of getting clean energy generation, which largely depends upon policy decisions. On all other criteria, electricity as a transport fuel is expected to be more sustainable than biofuels and hydrogen cell.

Looking at sustainability analysis more broadly (Exhibit 4.22), it may be seen that although possibility of penetration of hydrogen cell is high but it gets lower score on diffusion criteria. Similarly, ethanol weights higher on penetration but looses score on the diffusion criteria. On the contrary, electricity weights relatively higher on diffusion than penetration. It may help in identifying areas of interest for fuel policies and investments in future action plans and roadmaps.

Exhibit 4.22: Penetration Vs. Diffusion of alternative clean fuels



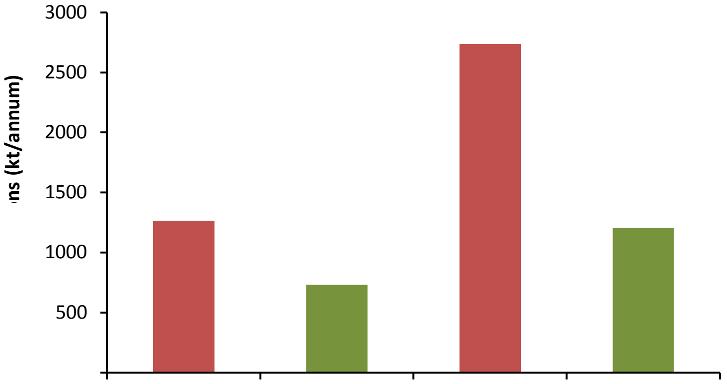
4.4.2 Low Carbon and Sustainable Urban Transport Scenario 2050 Emissions

Having chosen clean electricity and sustainable alternative fuel for transport sector in case of Ahmedabad, Low Carbon and Sustainable Urban Transport (LCSUT) 2050 Scenario was created by substituting emission factors from conventional fuel with emission factors from the selected clean fuel. Under the LCSUT scenario it was assumed that there will be very high proportion of electric vehicles on roads. Major shift would come from high usage of electric vehicle in public transport sector by 2035 and having high number of electric two wheelers and four wheelers by 2050.

It was assumed that by 2035, 50% of buses, 25% of two wheelers and 25% of four wheelers would be running on electricity. By 2050, 40% of two wheelers, 40% of four wheelers and 70% of buses would be running on electricity. It was assumed that metro system would be running on electricity since beginning. Cleanliness of electricity as a fuel depends upon nature and type of fuel used for electricity production. It is estimated that for India's power generation mix is highly CO_2 intensive about 803gm of CO_2 is generated per unit (Kwh) of electricity produced (R.T. Doucette, M.D. McCulloch, 2011). According to the estimates of International Energy Agency (IEA) the emission factor would come down to 60gm of CO_2 emissions per unit (Kwh) of electricity produced by 2050 (IEA ETP 2010, IEA 2010).

For the Sustainable Clean Transport Scenario 2050 CO_2 emissions were forecasted using emission factors for clean electricity as transport fuel. Travel demand characteristics under the LCSUT scenario were kept same as that in case of BAU scenario. Forecasting simulations were carried out emission forecasting model with same calibrations to know how much what could be the possible CO_2 emissions reduction potential if clean electricity is used as transport fuel in future. The model forecasts show that by 2035 CO_2 emissions from transport sector under LCSUT scenario may reduce by 42% of that expected under BAU and by 2050 the emissions could reduce to 56% of that expected under BAU scenario. Exhibit 4.23 shows a comparison of CO_2 emissions from transport sector Ahmedabad under BAU and LCSUT scenario.

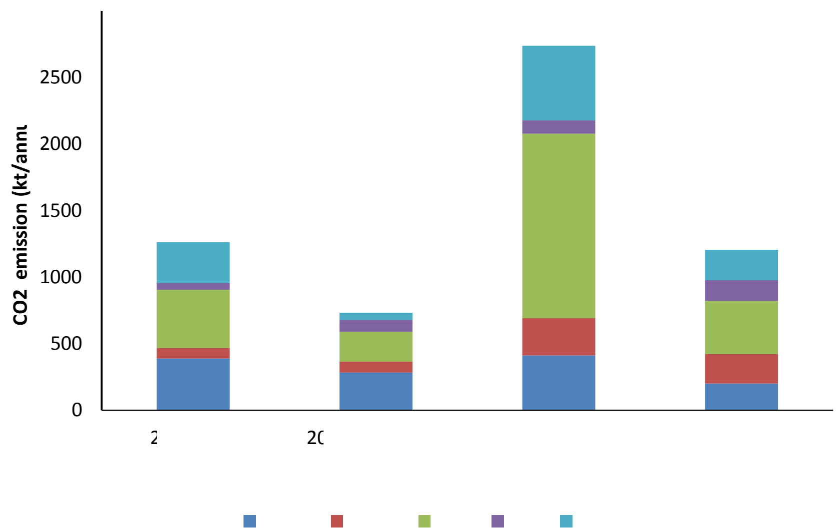
Exhibit 4.23: CO_2 emissions under BAU and LCSUT



Forecasting results also show that maximum proportion of these emissions would come from CNG based vehicles but proportion of emissions on account of electric vehicles would also increase relatively in 2050 than that compared to 2035. It may be because of the fact that it is assumed that population of electric vehicles would increase by 2050 than that by the year 2035.

Exhibit 4.24 shows contribution of emissions by type of fuel used. It may be seen that under BAU scenario major proportion of emissions is coming from CNG based vehicles which is because of expected high share of public transport and most of the public transport travel demand would be served by buses.

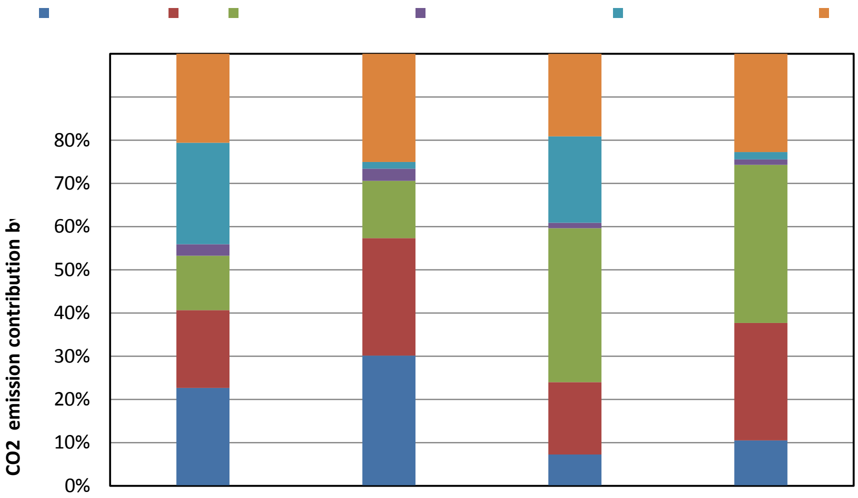
Exhibit 4.24: Forecasted CO_2 emissions by type of fuel used



Another simulation was carried out to know which category of vehicle may be contributing for highest proportion of emissions under LCSUT scenario and how these proportions vary than that under BAU. Exhibit 4.25 shows that under LCSUT scenario most of the emissions may be attributed to the use of four wheelers and buses.

It is interesting to note that by 2035 it is likely that two wheelers remain highest polluting mode of transport but by 2050 the relative share of CO_2 emissions would decrease considerably due to the use of high number of electric two wheelers. Relative proportion of emissions from public transport is also likely to decrease by 2050 under LCSUT as compared to that in case of BAU. It is because of the fact that travel demand served by metro rail under BAU scenario is based on conventional electricity and under LCSUT scenario it forecasted with clean electricity parameters.

Exhibit 4.25: Contribution of vehicular emissions by type - BAU and LCSUT



Chapter 5
Conclusions and Recommendations

Research process went through various stages of exhaustive data analysis, developing complex assessment frameworks and their application on a case study. The research findings were sufficiently able to answer all the three research questions. Research questions were related to the case study and were answered in Chapter 4 of the report. Section 4.2 and Section 4.3 of the report answers the first research question about visualization of transport sector of Ahmedabad city by 2050 under building as usual scenario (BAU) and estimating corresponding CO_2 emissions. Second research question was aimed at developing a framework for the selection of sustainable low carbon transport solution and its application in case Ahmedabad city, it was answered in section 4.4 of the report. Third research question was answered in section 5.1 through a comparison of BUA scenario forecasts (section 4.3) and LCSUT scenario forecasts (section 4.4).

There were several interesting observations and discussions that came out from the research findings. Conclusions of the study were grouped into two categories presented below. First set of conclusions (section 5.1 and section 5.2) relates to the case study and provide policy recommendations for a low carbon sustainable urban transport planning for Ahmedabad city. Second set of conclusions are methodological recommendations and explanations which are based on observations made during the application of various techniques and forecasting methods used in the study.

5.1 Discussion

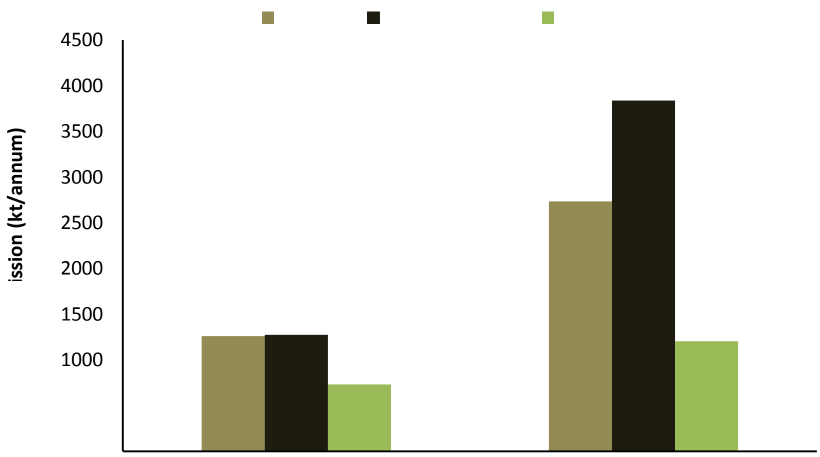
Under Building As Usual (BAU) scenario forecasts it was seen that if Ahmedabad's travel characteristics keep growing along the same trends as of today, by 2035 per capita CO_2 emission from the passenger transport of the city may rise upto 0.13gm per capita and by 2050 it would reach upto 0.22gm CO_2 emission per capita. It may result in an increase in CO_2 emissions at the rate of 6% per annum between 2011 and 2050 and the estimated rise in per capita emission would be 3% per annum. Here it shall be noted that the BAU scenario 2035 and 2050 it was assumed that there will be same mix of vehicles by type of fuel used with same values of fuel efficiency as that in existing situation (2011). Thus, rise motorized travel demand may be accounted for estimated rise in emissions from the passenger transport sector of Ahmedabad.

As a result of sustainability assessment for alternative fuels it was found that electricity could be the most feasible transport fuel in future for Ahmedabad city. Thus, a clean fuel transport scenario was created assuming electricity as a major fuel for passenger transport in the city. Thus, clean transport envisages a large number of electric vehicles running in the city by 2035 and it was assumed that the share of electric vehicles would increase by 2050. Under the clean transport scenario, it was estimated that the rate of growth of emissions from passenger transport sector may drop down to 3% per annum as compared to 6% per annum than that in case of BAU scenario. However, it is an important conclusion that even in the most optimistic scenario of clean fuel the city would not be able to stabilize CO_2 emissions from the transport sector at current levels. Thus, mobility plans and travel demand management plans for the city must give high priority to promoting non-motorized travel.

It is important to note that low carbon emissions from transport sector using electricity depend upon the power generation mix for the country. According to current estimates, power generation mix for India is estimated as 803gmCO_2/Kwh (Reed T. Doucette, Malcolm D.McCulloch, 2010). A lower value of the emission factor is expected in future based on ongoing clean energy initiatives in India including renewable sources of energy (solar, wind, hydro), nuclear power and smart grid. On the other hand, Indian Government, transport planners and markets are already inclined at pushing electric vehicles in Indian automobile market. A report on Technology Roadmap (IEA) for EV and PHEV reports that India is one of the growing centers for the production of electric vehicles and electric vehicles have already achieved a mass production scale in India. The Indian Government is aiming at releasing a full policy by 2012 for the promotion of electric vehicles (EV) and plug-in electric vehicles (PHEV) in the country (IEA, 2011). Various governments have announced to produce and supply about 1.5 million electric vehicles (EV/PHEV) by 2015 and 7 million by 2020, India is expected to be one among the largest market of buyers for these vehicles (IEA, 2011).

Rapidly increasing supply of electric vehicles in Indian market and poor power generation mix makes low carbon transport scenario with electricity as a fuel questionable. Thus, a third scenario was created BAU-Electric, in which CO_2 emissions from the passenger transport sector of Ahmedabad were estimated using integrated methodology (developed under this research). Results were compared with that from BAU and LCSUT scenarios. It was found that if Ahmedabad city has more electric vehicles in (as in case of LCSUT) without achieving clean electricity goals, the emissions from transport sector in future would be much higher that using fossil fuels (BAU). Exhibit 5.1 shows a comparison of total CO_2 emissions from passenger transport sector of Ahmedabad under three different scenarios.

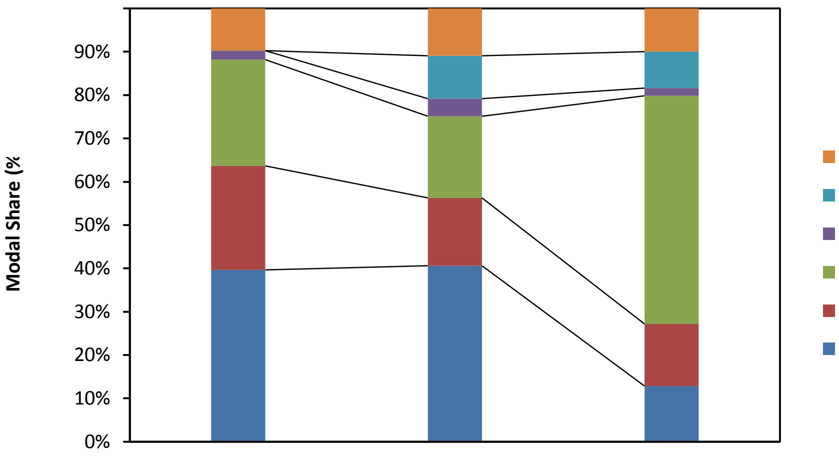
Exhibit 5.1: Estimated CO_2 emissions from passenger transport under three scenarios



A comparison of three scenarios indicate that low carbon sustainable transport planning for Ahmedabad city shall not entirely depend upon the assumption of electricity as a clean fuel option. However, it is equally important for the planners to keep a focus on other fuels and efficiency improvements. Unforeseen pushing of electric vehicles in Indian market may not lead to achieving the goal of clean transport. Moreover, it is also important for guiding infrastructure investment decisions as every new technology or fuel would require specific infrastructure and market support.

Results of travel demand forecasting shows that there would be a noticeable change in travel behaviour by 2050. Public transport would have much larger share by 2050 than that in 2035 or in 2011. Exhibit 5.2 shows that in existing situation there is significantly high usage of personal modes of transport (4-w and 2-w). With the expected introduction of metro and increased capacity of BRTS, by 2050 the share of public transport would increase considerably with respect to that of personal modes of transport. However, it may be seen that share of 2-w travel demand doesn't change much by 2035 whereas, more shift to public transport is seen from buses and cars. As seen in inter-modal comparison of travel demand forecasts between 2-w and 4-w, by 2050 popularity of four wheelers would rise and usage of two wheelers may drop down (Exhibit 5.2).

Exhibit 5.2: Passenger Travel Demand Forecasts by Mode



It shall be noticed that according to the forecasts the modal share of Mass transport in the city (BRTS and Metro) increases by 2035 but it decreases in 2050. It is on account of the fact that mass transport systems like BRTS and Metro have a limited augmentation capacity due to high requirements of heavy and dedicated infrastructure. The remaining load for public transport again spills over to the bus system in longer run. It is a very important observation in case of Ahmedabad that the city transportation authority (Ahmedabad Municipal Transport Services) shall not count upon mass transit systems to meet future mobility needs of the city. However, the authority shall take it as an opportunity to strengthen their capacity for meeting future needs since in short to medium term upcoming mass transit projects would share a major load of public transport.

5.2 Policy Recommendations

It shall also be understood from the analysis and discussion above that ultimately bus system would remain as the major mode of public transport in case of Ahmedabad, thus in future maximum CO_2 emissions from public transport would remain on account of buses. Thus, it is advisable that cleaner fuel and efficient buses shall remain a priority of public transportation authority.

India's National Action Plan for Climate Change (NAPCC) mentions a target reduction in emissions intensity of India's economy (per unit GDP) by 20 percent between 2007-08 and 2016-17, which is also articulated in the 12^{th} Five Year Plan (2007-12) of India (SEI, 2009). However, there is no specific target reduction mentioned in the NPACC in terms of quantity of emissions to be reduced particularly from the urban transport sector. Thus, research result may not comment upon contribution of LCSUT scenario in achieving national emission reduction goals (ref. Research question 3). However, it may be said that introduction of clean fuel (clean electricity) would significantly reduce emissions from city's transport sector but it is advisable to give equal importance to alternative clean fuels and promoting non-motorized travel in the city. It would help in hedging the risks of failure of investments and efforts in case the country doesn't reach its clean electricity goals.

5.3 Integrated Methodology as a Tool for Planning

Planning exercises are aimed at meeting needs for the future and at the same time fulfilling certain pre-determined objectives. It is thus imperative to visualize scenarios for future so that solutions may be identified which are relevant and applicable in future. Use of forecasting techniques and assessment methods in combination under a single framework brought forward some important observations from methodological point of view. Conclusions presented below are more in the form of important lessons learned and points for discussion rather than recommendations for planning methodologies.

5.3.1 Forecasting and scenario building

For population projections, three methods were used Compound Annual Growth Rate (CAGR), Spatial modelling (based on density), and Asymptotic Regression (with assumed limits). It was found that in short term projections, all the methods give similar results. However, for longer term projections, forecasts made by CAGR method gave much higher estimates than other two methods. It was also examined that results given by CAGR method were not realistic for longer term forecasts in case of population. Spatial modelling technique was based on assumed population density in the city. Population density in the city depends upon several exogenous factors like building height restrictions, availability of land, city administration limits etc. Further, development plan for the city is prepared with a maximum horizon of ten years, thus assumption of population density in the city becomes hypothetical for a longer term like fifty years. However, it was found that regression model with asymptotic limits provides more realistic estimates since the assumption of city's limiting growth may be compared with other cities of similar character in the country. For example, asymptotic limit for Ahmedabad (being a mega city) was assumed to be 25 million people. According to provisional reports from Census of India, by 2011 there were already three out of seven mega cities Mumbai (18million), Delhi (16million) and Kolkata (14million) whose population is approaching 20 million people. Thus, validation of assumption is more reliable in case of regression method than that for other two forecasting methods in case of long term projections. However, limitation of the regression method is that it requires historic yearly data for population for at least ten years. Unfortunately, in practice actual population counts are released at an interval of five or ten years in most of the countries. In such case implicit CAGR method may be used to cover up data gaps for missing years.

Integrated approach was also more helpful in comparing more consistently Business As Usual (BAU) scenario with Low Carbon Sustainable Urban Transport (LCSUT) scenario as both the simulations were carried out under same analytical framework.

The integrated approach provides higher flexibility to simulate outcomes of a solution before making recommendations. In the integrated approach, most of the parameters and variables remain fixed during different simulations hence, for creating different scenarios it requires calibration of only selected parameters. Thus, it may be a more efficient and quicker decision making tool than modelling every aspect separately while scenario building. It shall be noted that independent scenario building has its own importance that may not be replaced with integrated methodologies. However, integrated methodologies were found to be helpful in contextualizing different methods which are applicable in a planning process.

Integrated model may also minimize probability of mathematical compounding of errors during computations because in an integrated approach assumptions for each parameter are made only once. It also helps in preventing repetitive assumptions for the same parameter and decreases the risk for mistakes and computational errors.

5.3.2 Multiple Criteria Framework for Sustainability Assessment

The Multiple Criteria Assessment (MCA) framework was used to determine sustainability of low carbon alternative fuels for urban transport sector in future. Sustainability of an alternative fuel is a broad term and it requires insights on various forces acting upon penetration and diffusion of the fuel in future. The MCA framework helps in taking into account various aspects under a single framework through a systematically developed set of deterministic parameters. However, it has its own limitations. There is enormous amount of data required in determining weight for a particular parameter or criteria. In many cases, enough information is not available and as a result allocating weight to a parameter may become subjective and judgemental. MCA framework was found to be a flexible and quicker method for assessment. It is easier to adjust weights for any parameter if desired. Effects of adjustments are rapidly reflected in the results.

Integrating MCA framework in the methodology unintentionally influenced selection of the alternative fuel since information on forecasted scenarios was available at the same place. It may be considered as an advantage as it helps in making a selection decision more relevant. When such an assessment is carried out separately, it sometimes misses a link between relevance and need of a particular alternative.

5.4 Future Scope of the Study

Low carbon transport planning and sustainable development are vast domains of research. Both the research areas are multi-dimensional in nature and hence there is a wide scope of research in both topics. This research thesis explores both the dimensions of transport planning – low carbon as well as sustainability. Due to limited time frame for the research was conducted as a demonstrative model methodology for low carbon and sustainable transportation planning. There are several new areas of research that may be derived from this research work, as well as there are several areas where scope of this research may be extended.

The study takes into account only passenger travel demand in the city by surface modes. The scope of study may be extended to addressing total travel demand in the city including freight traffic as well as commuting through other modes of transport like airways and waterways.

There were some sections in the research which required more extensively obtained input data for example – information on vehicles in the city by type of fuel used, abatement potential of alternative fuels, actual fuel efficiency of vehicles etc. Due to time limitations such data requirements were fulfilled by information from secondary sources. However, with extensive surveys, workshops, structured interviews and experiments actual data for such parameters may be generated.

The study only examined outcomes of fuel substitution as a solution for low carbon transport approach. In principal, it is only one part of low carbon transport approach. Solutions aiming at minimizing transport emissions with effects from changes in travel behaviour may also be examined using the same methodology. It would require creation of another scenario for low carbon transport.

Further, in low carbon sustainable transport (LCSUT) scenario described in the study only electricity as clean alternative fuel was taken into account. However, it is required to apply a combination of alternative fuels to different type of vehicles for making more comprehensive scenarios.

It was recognized in the study that effectiveness of electricity as a clean fuel depends upon power generation mix for the country. It may be a very interesting research idea to explore the possibilities for achieving a cleaner energy production in future. The research may also be conducted as sensitivity analysis of sustainable solutions.

Low carbon transport scenarios are not only related to emissions and environment but also they may have significant effects on the economy of a place. It may be interesting to conduct a research on the economic impacts of low carbon transport scenarios.

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Annexure

A.1: Research Instruments Used and Referred

S.no.	Instrument	Description
1.	Travel demand forecasting model (used)	Excel based model for calculating future passenger travel demand by mode
2.	Transport emissions assessment model (used)	Excel based instrument, calculates fuel demand by transport sector and emissions from transport sector in future
3.	Extended Snapshot Model (referred)	GAMS based model, for building Low carbon city scenarios
4.	Definite MCA tool (referred)	Multiple Criteria Assessment tool

A.2: Observed Population Growth Rates of Ahmedabad City (AMC, AUDA-Urban, AUDA-Rural)

S.no.		AMC	AUDA-Urban	AUDA-Rural
1.	1981	2159127	2721925	264555
2.	1991	2876710	3756246	309871
3.	2001	3520085	4709180	334531
4.	2011*	4475035	6722542	433924
5.	Population Growth (1981-1991)	717583	1034321	45316
6.	Population Growth (1991-2001)	643375	952934	24660
7.	Population Growth (2001-2011)	954950	2013362	99393
8.	Populaiton Growth (1981-2001)	1360958	1987255	69976
9.	Population Growth (1981-1991)	33%	38%	17%
10.	Population Growth (1991-2001)	22%	25%	8%
11.	Population Growth (2001-2011)	27%	43%	30%
12.	Populaiton Growth (1981-2001)	63%	73%	26%
13.	CAGR (1981-1991)	2.91%	3.27%	1.59%
14.	CAGR (1991-2001)	2.04%	2.29%	0.77%
15.	CAGR (2001-2011)	2.43%	3.62%	2.64%
16.	CAGR (1981-2001)	2.47%	2.78%	1.18%

Source: City Development Plan, p.9, CEPT/GIDB 2005
***Source:** City Development Plan, p.21, CEPT/GIDB 2005

A.3: Population Forecasts for Ahmedabad City using various models

S.no.		Population (in millions)			
		CAGR Model	**Spatial Model**	**Regression Model (high limit, 25million)**	**Regression Model (low limit, 20million)**
1.	2001	4.71	4.71	4.71	4.71
2.	2002	4.82	4.77	4.94	4.94
3.	2003	4.93	4.84	5.05	5.05
4.	2004	5.04	4.91	5.17	5.16
5.	2005	5.15	4.97	5.29	5.28
6.	2006	5.27	5.04	5.41	5.40
7.	2007	5.39	5.11	5.53	5.52
8.	2008	5.52	5.18	5.65	5.64
9.	2009	5.64	5.25	5.78	5.76
10.	2010	5.77	5.33	5.91	5.89
11.	2011	5.90	5.40	6.04	6.01
12.	2012	6.04	5.49	6.17	6.14
13.	2013	6.18	5.57	6.30	6.27
14.	2014	6.32	5.66	6.44	6.40
15.	2015	6.46	5.75	6.57	6.53
16.	2016	6.61	5.84	6.71	6.66
17.	2017	6.76	5.93	6.85	6.80
18.	2018	6.92	6.03	7.00	6.93
19.	2019	7.07	6.12	7.14	7.07
20.	2020	7.24	6.22	7.29	7.21
21.	2021	7.40	6.32	7.44	7.35
22.	2022	7.57	6.42	7.59	7.49
23.	2023	7.74	6.52	7.74	7.63
24.	2024	7.92	6.62	7.89	7.77
25.	2025	8.10	6.73	8.05	7.91
26.	2026	8.29	6.84	8.20	8.06
27.	2027	8.48	6.94	8.36	8.20
28.	2028	8.67	7.05	8.52	8.35
29.	2029	8.87	7.17	8.68	8.50
30.	2030	9.07	7.28	8.84	8.64
31.	2031	9.28	7.40	9.01	8.79
32.	2032	9.49	7.51	9.17	8.94
33.	2033	9.71	7.63	9.34	9.09
34.	2034	9.93	7.75	9.51	9.24
35.	2035	10.16	7.88	9.67	9.39
36.	2036	10.39	7.99	9.84	9.54
37.	2037	10.63	8.11	10.02	9.69
38.	2038	10.87	8.23	10.19	9.84
39.	2039	11.12	8.35	10.36	9.99
40.	2040	11.37	8.47	10.53	10.14
41.	2041	11.63	8.59	10.71	10.29
42.	2042	11.90	8.72	10.88	10.44
43.	2043	12.17	8.85	11.06	10.59
44.	2044	12.45	8.98	11.23	10.74
45.	2045	12.73	9.11	11.41	10.89
46.	2046	13.03	9.24	11.59	11.04
47.	2047	13.32	9.38	11.77	11.19
48.	2048	13.63	9.52	11.94	11.34
49.	2049	13.94	9.66	12.12	11.48
50.	2050	14.26	9.80	12.30	11.63

A.4: Vehicles Registered in Ahmedabad City (Cumulative)

Sr.No.	Type of Vehicles	Upto 2000-01	Upto 2001-02	Upto 2002-03	Upto 2003-04	Upto 2004-05	Upto 2005-06	Upto 2006-07	Upto 2007-08
1.	Motor Cycle/Scooters	357643	408134	473266	553762	658871	757561	868441	968322
2.	Moped	97689	106467	114104	121696	128910	134499	139178	143864
3.	Autorickshaws	15176	15952	17684	20173	22776	41972	54994	62462
4.	Jeep	7728	8257	9070	10099	10943	11609	12241	13562
5.	Three wheelers M/Car	979	985	987	991	998	1000	1000	1000
6.	Four wheelers M/Car	79997	91035	102960	116170	130780	145948	165174	186905
7.	Taxi	2641	2707	2856	3017	3291	3702	3979	4282
8.	Private Service Vehicle	260	267	279	291	314	356	394	443
9.	Other light Vehicle	6058	6318	6682	7048	7498	7979	8970	10399
10.	Ambulance Van	199	216	244	273	306	323	357	378
11.	Maxi-Cab	322	365	394	624	925	1165	1456	1779
12.	Police Van	165	181	181	181	197	203	205	206
13.	Others	2020	2315	2527	2912	3355	3926	4440	5285
14.	Contract Carriages	1157	1198	1286	1432	1524	1608	1701	1828
15.	Stage Carriages	2526	2250	2249	2249	2249	2599	2821	2901
16.	School Bus	46	55	60	92	121	188	218	260
17.	AMTS Buses	886	801	687	601	540	540	540	540
18.	Tempo	8010	9034	10315	11712	14290	17362	21450	24738
19.	Truck/Lorries	7979	8549	9056	9605	10204	10893	11768	12529
20.	Tankers	1109	1135	1188	1238	1279	1313	1347	1380
21.	Transport-Trailors	6784	7095	7427	7683	8138	8841	9656	10700
22.	Non-Transport-Trailors	17	17	17	17	17	17	17	17
23.	Tractors	10301	11226	12569	13297	14558	16040	17587	19211
24.	**Total**	**608805**	**683757**	**775400**	**884561**	**1021543**	**1169103**	**1327393**	**1472450**

A.5: Estimated growth rate of vehicles in Ahmedabad city by category

Sr.No.	Year (Upto)	2-W	4-W	Autorickshaws	Buses
1.	1999-00	402279	78629	20678	4627
2.	2000-01	455332	90825	22213	4615
3.	2001-02	514601	102482	23255	4304
4.	2002-03	587370	115409	25353	4282
5.	2003-04	675458	129850	28212	4374
6.	2004-05	787781	145634	31272	4434
7.	2005-06	892060	161938	50951	4935
8.	2006-07	1007619	182145	64964	5280
9.	2007-08	1112186	205570	73861	5529
10.	**CAGR (1999-2008)**	**11.96%**	**11.27%**	**15.20%**	**2.00%**

A.6: Public Transport in Ahmedabad

S.no.	Year-ending 31st March	Fleet-size	(Buses) No. of Routes	Service kms per day	Buses per lakh of population	No. of passengers per day
1.	1948	205	38	15000	26	109024
2.	1951	188	57	19755	21	153004
3.	1961	337	100	44038	27	333865
4.	1971	525	164	75757	33	541096
5.	1981	610	205	96685	30	786301
6.	1991	756	248	111452	24	619726
7.	1995	705	180	115123	19	625479
8.	1996	724	170	119563	19	683607
9.	1997	820	164	134192	21	800822
10.	1998	882	166	141726	22	791370
11.	1999	882	132	150134	22	799321
12.	2000	942	144	155675	22	757852
13.	2001	886	140	151245	21	678861
14.	2002	801	136	124375	18	574257
15.	2003	687	115	81802	15	385682
16.	2004	601	110	76028	13	325378
17.	2005	540	117	77411	11	349653

Source: Bus Rapid Transit System, Ahmedabad, p.5-2, GIDB

Original Source: Ahmedabad Municipal Transport Service, Ahmedabad

A.7: Travel Characteristics for Ahemdabad City

S.no.	Parameter	2007*	2035-BAU*	2050-BAU*	Implicit CAGR** (2005-35)	2011**
1.	Per Capita Trip Rate (all modes)	1.4	1.8	2.0	0.82%	1.48
2.	Per Capita Trip Rate (motorized)	0.9	1.2	1.4	0.96%	0.95
3.	Per Capita Trip Rate (non-motorized)	0.5	0.6	0.6	0.54%	0.53
4.	Average Trip Length	6.2	10.4	14.8	1.74%	6.88
5.	**Modal Split (all modes)**					
	Two Wheeler	25%	26%	9%	0.13%	25%
	Car	17%	10%	10%	-1.75%	15%
	Public Transport	16%	21%	44%	0.91%	17%
	IPT (3-W)	6%	7%	7%	0.52%	6%
	Cycle	14%	11%	8%	-0.80%	13%
	Walk	22%	25%	22%	0.43%	23%
6.	**Modal Split (motorized modes)**					
	Two Wheeler	39%	41%	13%	0.13%	39%
	Car	27%	16%	14%	-1.75%	24%
	Public Transport	25%	33%	63%	0.91%	26%
	IPT	9%	11%	10%	0.52%	10%

*Source: Ministry of Urban Development, Government of India, 'Study on Traffic and Transportation Policies and Strategies in Urban Areas in India', 2008

** Estimated by interpolation method

A.8: Projected Travel Demand for Ahmedabad City (Passenger km per day)

S.no.	Mode of Passenger Transport	2011	2035	2050
1.	Two Wheeler	15483240	47089376	32767629
2.	Car	9394514	18111299	36408477
3.	Public Transport - Bus	9562699	21852346	134225051
	Public Transport - BRTS	818679	4680000	4680000
	Public Transport - Metro	0	11501381	21292246
4.	IPT	3802382	12677909	25485934
5.	Cycle	8197777	19922428	29126781
6.	Walk	13868877	45278247	80098648
Total	-	**61128168**	**181112986**	**364084766**

Source: Results of Travel Demand Forecasting Model Simulations

A.9: Estimated Vehicle Travel Demand in Ahmedabad City (Vehicle km per day)

S.no.	Mode of Passenger Transport	2011	2035	2050
1.	Two Wheeler	10322160	31392918	21845086
2.	Car	3131505	6037100	12136159
3.	Public Transport - Bus	239067	546309	3355626
	Public Transport - BRTS	20467	117000	117000
	Public Transport - Metro	0	57507	106461
4.	IPT	1901191	6338955	12742967
Total	-	**15614390**	**44489787**	**50303299**

Source: Results of Travel Demand Forecasting Model Simulations

A.10: Estimated CO_2 emissions from the passenger transport sector of Ahmedabad under BAU scenario (tons/annum)

S.no.	Mode of Passenger Transport	2011	2035	2050
1.	Two Wheeler	94029	285970	198995
2.	Car	118217	227905	458149
3.	Public Transport - Bus	69425	158648	974472
	Public Transport - BRTS	5944	33977	33977
	Public Transport - Metro	N.A.*	296631	549146
4.	IPT	77913	259778	522222
Total	-	**365527**	**1262908**	**2736961**

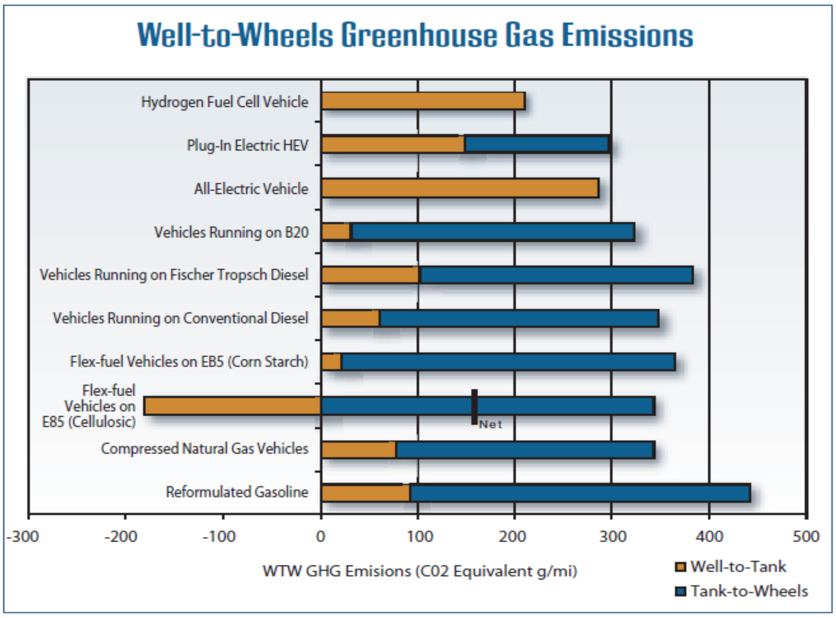
*N.A.: Not Applicable

A.11: Weight criteria and scoring guidelines for sustainability assessment of alternative clean fuels

S.no.	Parameter	Indicator	Judgement Criteria	Scoring guidelines
1.	Economic	Abatement cost per unit emission reduction	Lower the better	If possible Life Cycle Cost of the technology shall be considered
		Procurement cost	Lower the better	Depends upon whether the technology is partly or fully produced within the country or needs import
		Availability of internal resources (funds)	Higher the better	May be decided upon part or full funds available from own resources, grants, loans or source of funding unknown
		Economic conditions	Stronger the better	Factors like trends in inflation, GDP may be taken into consideration
2.	Policy	Sensitivity to internal political conditions	Lower the better	Controversial technologies like Nuclear Power
		Sensitivity to international policies	Lower the better	Effect of various treaties and conventions e.g. promotion of solar and wind technology
3.	Social Acceptability	Cultural resistance	Lower the better	More relates to local business enterprises that may get affected by introduction of new technologies
		Awareness	Higher the better	Determines potential of penetration
4.	Market	Affordability	Higher the better	May be determined on the basis of per capita income or SEC characteristics of the city
		Accessibility	Higher the better	Considers landuse and condition of infrastructure
		Willingness to pay	Higher the better	Sometimes people prefer using personal vehicles in spite of having good public transport systems
5.	Technologica l	Operation and Maintenance Costs	Lower the better	Must remain within the reach of concerned local level authorities
		Technical Capacity	Higher the better	Preferably repair and maintenance of every component of the technology shall be locally available
		Availability	Higher the better	Taking into account dependence on imports

Note: Emission reduction potential of alternative fuels was used as a filter for short listing hence it is not included among criteria for MCA framework

A.12: Lifecycle emissions from alternative transport fuels



Source: Transportation Fuels for the Future, Western Governors' Association, California, 2008, p.24

A.13: Sustainability Assessment Scores for Shortlisted Alternative Clean Fuels

S.no.	Parameter	Indicator	Criteria Weight	Percent Score Obtained		
				Electricity	Hydrogen Cell	Ethanol
1.	Economic	Abatement cost per unit emission reduction	5%	3%	1%	2%
		Procurement cost	5%	4%	1%	2%
		Availability of internal resources (funds)	5%	4%	1%	2%
		Economic conditions	5%	2%	2%	2%
2.	Policy	Sensitivity to internal political conditions	10%	5%	6%	6%
		Sensitivity to international policies	10%	5%	6%	6%
3.	Social Acceptability	Cultural resistance	10%	5%	4%	4%
		Awareness	10%	6%	2%	4%
4.	Market	Affordability	8%	6%	1%	1%
		Accessibility	6%	4%	2%	2%
		Willingness to pay	6%	4%	2%	3%
5.	Technological	Operation and Maintenance Costs	8%	4%	2%	4%
		Technical Capacity	6%	4%	2%	2%
		Availability	6%	4%	2%	2%
Total	-	-	**100%**	**60%**	**34%**	**42%**

A.14: Estimated CO_2 emissions from the passenger transport sector of Ahmedabad under BAU-Electric scenario (tons/annum)

S.no.	Mode of Passenger Transport	2011	2035	2050
1.	Two Wheeler	94029	299531	214586
2.	Car	118217	252105	540419
3.	Public Transport - Bus	69425	314619	2313051
	Public Transport - BRTS	5944	67380	80648
	Public Transport - Metro	N.A.*	296631	549146
4.	IPT	77913	266460	552492
Total	-	**365527**	**1496726**	**4250343**

A.15: Estimated CO_2 emissions from the passenger transport sector of Ahmedabad under Low Carbon Sustainable Urban Transport scenario (tons/annum)

S.no.	Mode of Passenger Transport	2011	2035	2050
1.	Two Wheeler	91948	220468	126559
2.	Car	116995	199307	328148
3.	Public Transport - Bus	69425	96911	440914
	Public Transport - BRTS	5944	20755	15373
	Public Transport - Metro	N.A.*	44331	82069
4.	IPT	77913	183305	273886
Total	-	**362225**	**765078**	**1266949**

*N.A.: Not Applicable