TOWARDS LOW CARBON DEVELOPMENT: URBAN ACCESSIBILITY BASED PLANNING SUPPORT FOR EVALUATING LOW CARBON TRANSPORT PLANS FOR KATHMANDU METROPOLITAN CITY (KMC)

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FEBRUARY, 2012

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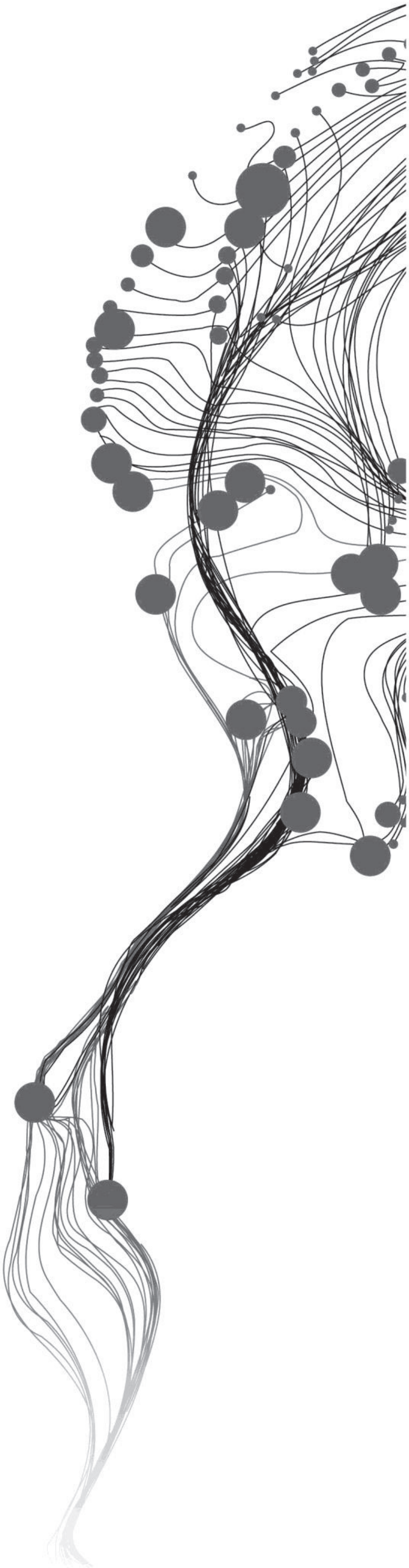

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REHANA SHRESTHA
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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EXECUTIVE SUMMARY

Climate change is a global issue and all the countries, both developing and developed, are required to address it through climate policy. But since the major concern of developing countries is for development policy rather than climate change, the new notion of Low Carbon Development (LCD) has emerged, which follows a development-first approach and henceforth addresses both issues. Among many sectors where LCD can be pursued, transport is regarded as one of the important sectors, which needs to be addressed urgently. It is mainly because of two reasons. The transport sector is regarded as the backbone for economic growth of cities while most of the cities-especially developing cities are facing problems of unsustainable transport and its related negative externalities, both locally and globally. Transport accounts for 23% of total energy related GHG emission, which directly exerts pressure to climate change. To address the issue of unsustainable transport and its national and global externalities, another notion of Low Carbon Transport (LCT) plans has emerged, which adopt avoid-shift-improve (ASI) strategies, which are regarded as key to LCT. However, considering accessibility as one of the performance indicators for sustainable development, LCT plans besides minimizing emissions, should address accessibility issues, as such paving a pathway towards LCD.

Due to the complexity and uncertainty involved in the long range planning, scenario-based planning support systems have been regarded as a useful tool in exploring future impacts of plans. But the lack of research on its use in evaluating LCT plans for their accessibility and emission impact, has stemmed the research problem as; how are urban accessibility and LCT related and how can planning support system (PSS) be used to derive accessibility scenarios of LCT plans. Thus, the main objective of this research is to evaluate LCT plans and their potential contribution in LCD for Kathmandu Metropolitan City (KMC), a case study in this research, by developing an urban accessibility based planning support system.

This research combines an accessibility analysis and activity-structure-intensity-fuel (ASIF) framework as the modelling approach, which has been applied in the open GIS-based modelling platform of Community Viz. The semi-automatic model has been developed in Community Viz; in which output from accessibility analysis in the form of potential population and distance travelled by the mode are used as input in ASIF model as activity in passenger kilometre (pkm). With the modal share of each mode, average occupancy, fuel efficiency and emission factor, $CO2$ emissions are calculated.

From the interviews and documents of Kathmandu Sustainable Urban Transport (KSUT) project, three plans have been identified as LCT plans; public transport (PT) improvement plans, renewal of trolley bus system and the combination of both plans that is penetration of trolley bus system along with PT improvement plans. Two scenarios have been constructed, high population growth of 7.6% and low population growth of 4.56% as external drivers to the scenarios. In combination with the chosen LCT plans and baseline scenario without interventions, eight alternative scenario have been constructed, four in each high and low population growth, that have been evaluated for their potential to LCD.

The scenario results show that the baseline scenarios even with 20% improvement in fuel efficiency; are clearly not a desirable future under both high and low population growth. PT improvement and combination of PT with trolley buses show an increase in accessibility in both scenarios whereas trolley bus renewal plans show a decrease in accessibility. The underlying assumptions on mode share, average occupancy, fuel efficiency of those plans have shown a reduction in emissions against the base year during low population growth whereas emission would still be high in the case of high growth. The sensitivity analysis shows that only 5% shift from private to public in combination plans of penetration of trolley bus renewal along with PT improvement plans, result in an emission reduction gain. It can be concluded that under the given assumptions, the combined package of penetration of trolley bus renewal with PT improvement plans has a great potential towards LCD. However, the final choice of mode depends on people's preferences, attitudes and behaviour, hence the modal split. The results show that there is a need to have a shift from private to public transport in all LCT plans. Thus a package of policies that addresses 'push and pull' effects are required to get substantial shift from private to public mode to realize the LCD in transport.

Keywords: Low Carbon Development, Low Carbon Transport, planning support system, urban accessibility, Kathmandu Metropolitan City, Community Viz.

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Rehana Shrestha
February 13

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ADB	Asian Development Bank
ASI	Avoid-Shift-Improve
ASIF	Activity Structure Intensity Fuel
BRT	Bus Rapid Transit
CAI-Asia	Clean Air Initiatives-Asia
CBS	Central Bureau of Statistics
CEN	Clean Energy Nepal
CANN	Clean Air Network Nepal
DoR	Department of Road
DoTM	Department of Transport Management
EREC	European Renewable Energy Council
GHG	Greenhouse gas
GIS	Geo-Information System
g/km	Gram per kilometre
l/km	Litre per kilometre
IEA	International Energy Annual
ICE	Institution of Civil Engineers
IPCC	Intergovernmental Panel for Climate Change
ICT	Information and Communications Technology
KMC	Kathmandu Metropolitan City
Kph	Kilometre per hour
KSUT	Kathmandu Sustainable Urban Transport
KVTDC	Kathmandu Valley Town Development Committee
LCD	Low Carbon Development
LCT	Low Carbon Transport
MoE	Ministry of Environment
MoPPW	Ministry of Physical Planning and Works
MoLD	Ministry of Local Development
MoLTM	Ministry of Labour and Transport Management
NAC	Nepal Airlines Corporation
NADA	Nepal Automobile Dealers Association
NEA	Nepal Engineers' Association
NEC	Nepal Engineering College
NTDRC	Nepal Transportation Development and Research Center
pkm	Passenger kilometre
PSS	Planning Support System
PT	Public Transport
SDTS	Sustainable Development of Transport System
STI	Sustainable Transport Initiative
SUT	Sustainable Urban Transport
TDM	Transport Demand Management
TSM	Transport Supply Management
TOD	Transit Oriented Development
UNFCCC	United Nations Framework Convention on Climate Change

VKT	Vehicles kilometre travelled
2W	Two wheeler

1. INTRODUCTION

1.1. General Introduction

In today's world, climate change is one of the greatest threats. Many institutions have been formed to address the challenges of climate change. In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was established to provide a framework for policy making to mitigate climate change. In 1997, Kyoto Protocol was made as an international climate change policy document(UNFCCC, 1997).

According to the Intergovernmental Panel for Climate Change (IPCC), "*Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change*" (Rübbelke, 2011). Under, the UNFCCC and the Kyoto framework, developed countries are required to support mitigation actions and adaptation to global warming in developing countries. Thus climate policy comprises of two different pillars; mitigation and adaptation (Rübbelke, 2011).

Though this issue of climate change needs to be addressed by both developing and developed countries together through climate policy, it is being overlooked mostly in developing countries due to their urgent need to give preferences to development activities (Halsnæs & Verhagen, 2007). However, development activities will be less effective if climate change adaptation and mitigation are not taken into account in the long run. According to authors (Halsnæs & Verhagen, 2007), relating development to Amartya Sen's capability approach, advocates that climate change pose constraints to the freedoms and rights of individuals to achieve their needs such as food, energy, health, education. Therefore, the notion of 'Low Carbon Development (LCD)' has emerged as a new area of challenges.

Different countries and organizations have formed different interpretations for the concept of LCD. For example European Renewable Energy Council (EREC) has defined it as substituting fossil fuels by low-carbon energy without hampering economic growth and promoting residential welfare (Yuan et al., 2011). According to DFID's White Paper (2009), the common notion accepted by different countries regarding LCD is utilizing less carbon for enhancing economic growth (Mulugetta & Urban, 2010). Despite differences in understandings, there is common view regarding LCD: reducing GHG emission, exploiting low carbon energy, ensuring economic growth and poverty reduction. Thus, in any case the main essence of LCD is reducing GHG emission while ensuring development.

In order to achieve the purpose of LCD, there is a need for effective policies that enhance mitigation through sustainable development. Thus, there is the emergence of LCD strategies in 2009 under the UNFCCC. The 2011 Durban Climate Conference, COP17, has restated the importance and potential of LCDS (UNFCCC, 2011). The objective of LCDS is to take national climate change policy and development policy together in co-ordinated manner. It further helps the developed countries to prioritize their assistance in developing countries as co-benefits and hence help in mitigation of CO2.

Among many sectors such as industry, agriculture, household where LCD pathway could be followed, one of the main sectors is transport which shares considerable portion of greenhouse gas (GHG) emission. According to International Energy Annual (IEA), transport sector accounted for 26% of world's energy use and 23% of energy-related GHG emission in 2004 (IPCC, 2007). Presently, developed countries are responsible for 70% of transport induced GHG which will decrease in future and developing countries and industrializing countries such as China, India, Latin American countries, and South Africa will then takeover (Rothengatter, 2010). This has been accounted to rapid urbanization and motorization that is happening in most of the developing countries.

In the face of global urbanization, the rate of urbanization in the developing world is at an alarming rate. The total urban population of developing world which was 2.3 billion in 2005 is estimated to be 5.3 billion in 2050 with much of the growth taking place in Asia (Dimitriou & Gakenheimer, 2011). Along with its increasing population, the economic growth of cities of Asia is also at rapid pace (Dimitriou, 2011). Thus, as reported by ADB (2011) rising incomes, urban expansion and dispersion of activity have increased the demand for and dependence on motorized transportation with the rate doubling every 5 to 7 years for Asian countries.

Though motorization is perceived as headway towards development, the manifested problems as described by Dimitriou (1992), such as air pollution, congestion, accidents locally, GHG emission globally and increased marginalization of urban poor ultimately lead to inhibition of sustainable development (Dimitriou & Gakenheimer, 2011). Thus, concerned about this dilemma, the concept of Low Carbon Transport has emerged, which explicitly addresses sustainability priorities while mitigating GHG emission (Sakamoto et al., 2010).

The notable contribution of Dalkmann & Brannigan (2007) on the three pillars of transport intervention strategies-avoid-shift-improve (ASI) and their adoption by the Asian Development Bank (ADB) can be taken as potential strategies for developing cities towards Low Carbon Transport. The ASI strategy has been a new paradigm shift in this field which helps nations to deal with unsustainable transport and GHG emissions. Thus, any response that can avoid or reduce travel, can encourage shift to more sustainable and environmentally friendly modes or that can improve the efficiency of modes can be regarded as Low Carbon Transport plans.

According to Geurs & Ritsema van Eck (2001), earlier transport plans were usually geared towards increasing mobility. However, concern on the three pillars of sustainability, i.e. economic, social and environmental sustainability, has raised the concept of accessibility and makes it a performance indicator for sustainable development(Ha, 2011). Moreover, accessibility has been used as a key criterion in transport planning to assess the interaction of land use and transport in plans and policies (Bertolini et al., 2005; Geurs & Van Wee, 2004).

Planning support systems (PSS) as argued by Geertman & Stillwell (2009), are valuable tools enabling the planners to handle complexity of planning process by evaluating alternatives of futures. Pettit (2005) has claimed PSS as an effective way of integrating social, economical and environmental aspects, helping planners to develop spatial planning scenarios. There are a number of researchers which have appreciated the use of planning support system for exploring different alternatives of plans and hence help in decision making. It has been used in the appraisal of many transport policies, plans for exploring its impact in long run (Hickman & Banister, 2007).

1.2. Background and justification

Kathmandu, the capital city of Nepal is situated in South Asia. It has been facing rapid urbanization over the last decade with an estimated population of 2.18 million and annual urban growth rate of 6.6 %, which according to ADB/ICIMOD(2006) is among the highest in Asia and Pacific region (Thapa & Murayama, 2010). With the increasing urbanization, the vehicle numbers are also increasing.

The use of two wheelers, private cars, vans, jeeps, lower occupancy vehicles are contributing most to the share of motorized passenger modes as compared to mass transit such as public buses. According to Dhakal (2006) private cars and motorcycles take 71 % share of the total operational vehicles population while high occupancy public transport such as buses and minibuses, have only a 1.4% vehicle share. Thus, the number of private vehicles has increased by 8-7 fold since 1989 and is estimated to rise by three times in 2025. Moreover, among passenger transport modes, private vehicles meet only 41% of travel demand and are consuming 53% of total energy whereas public transport meets 57% of travel demand with 13% energy use by buses and minibuses and 28% by microbuses.

The transport sector is considered as the backbone for economic development. But with this trend of increasing motorization of private vehicles, the city is facing many problems of air pollution, congestion, health impact, social inequity (MoPPW & ADB, 2010). This has further led to the highest share of CO2 emission as compared to other sectors such as industry and household; which according to Shrestha & Rajbhandari (2010) accounts to 34% of the total emissions. Thus, urban transport of the city is unsustainable which is causing ever increasing growth in CO2 emission and its negative impact on development is hence undebatable.

Therefore, it has become necessary to combat this non-trivial situation in a carbon-friendly manner through proper strategies and plans in order to prevent the city to move on the pathways typical for many developed cities. So there is a need for the city to 'leapfrog' by developing sustainable Low Carbon Transport plans addressing avoid-shift-improve strategy (Leather & CAI-Asia, 2009); which must not only provide mobility as of traditional transport plans, but to larger extent good accessibility in order to achieve sustainable development as a whole.

According to Kojima and Lovei (2001), further challenges in dealing with this problem remains in the lack of realization of policy makers about the co-benefits of GHG mitigation measures on development (Dhakal, 2006). This knowledge gap as argued by Dhakal (2003) is due to lack of scientific studies on the impact of various mitigating measures on emission reduction and development.

Hence with this argument, the need of developing cities including Kathmandu Metropolitan City (KMC) to pursue LCD pathway has become indispensible by developing Low Carbon Development strategy (LCDS) as it has many benefits; helps to align development priorities with climate change policy and it facilitates the transfer of financial resources from developed countries (Clapp et al., 2010). The unprecedented growth of transport posing threat on sustainable development has made this sector of more concern in KMC. So there is general consent on the effectiveness of Low Carbon Transport to deal with this problem in developing cities.

Since accessibility as argued by (Geurs & Van Wee, 2004) is a good indicator for assessing the integration of land use and transport policies, and the access it provides to economic opportunity; thus socio-economic development, this study on the evaluation of Low Carbon Transport plans on urban accessibility for KMC is sensible and relevant. Using scenario based urban accessibility planning support, development and assessment of various scenarios on the accessibility impact of different plans to some extent can fill the knowledge gap as addressed by (Dhakal, 2006). Further evaluation of these plans with respect to LCD can help in strengthening LCD.

1.3. Research Problem

To pursue a LCD pathway by developing LCT has manifold benefits especially for developing cities like KMC. Firstly, preparing a Low Carbon Development strategy for LCD helps nations to realize their development priorities by minimizing adverse effect on global climate. Secondly it helps developed countries to prioritize their financial assistance in developing nations. Last but not the least, LCT besides reducing GHG emission also helps the cities in tackling other negative externalities such as local pollution, congestion, social inequity etc.

Several researches have been done on cause and effect of unsustainable transport (Dimitriou & Gakenheimer, 2011). A number of researches have advocated various measures to mitigate CO2 emission ranging from an urban planning perspective to technology improvement (Cervero & Kockelman, 1997; Chapman, 2007; Dulal et al., 2011; Wright & Fulton, 2005). ASI strategy is widely agreed and also accepted by ADB for most of the developing cities including KMC.

Dhakal (2003) has analyzed CO2 emissions for different scenarios for 20 years time horizon with the implication of packages of policies such as public transportation, electric vehicles, and improvement of traffic management, using Long-range Energy Alternative Planning System (LEAP), which is an integrated energy-environment and scenario based accounting model. Pradhan et al. (2006) have analyzed the scenarios of potential effects of electric trolley bus system in the valley on fuel consumption and greenhouse gas emissions till 2025. Both studies show that considerable reduction can be obtained using these responses.

Despite this number of studies, the study of the impact of Low Carbon Transport plans on urban accessibility and hence its contribution to strengthening of Low Carbon Development is scanty. For the case of KMC, no studies have been done so far on the assessment of various Low Carbon Transport plans for its impact on urban accessibility. Various literatures on the potential of scenario based planning support for future impacts and alternatives of plans could be found (Geertman & Stillwell, 2003; Ludin et al., 2006), but, the scientific study on the use of planning support on assessing urban accessibility of Low Carbon Transport plans is virtually not available especially for KMC.

Thus, with this argument the research problem basically addresses these two questions; how are urban accessibility and Low Carbon Transport related and how can a planning support system be used to derive accessibility scenarios of Low Carbon Transport plans for the case of KMC.

1.4. Research Objective

The main objective is to evaluate Low Carbon Transport plans and their potential contribution in Low Carbon Development of Kathmandu Metropolitan City (KMC) by developing urban accessibility based planning support system.

1.4.1. Sub-Objectives

- To define concept of Low Carbon Development and Low Carbon Transport in general and specific for KMC
- To identify Low Carbon Transport plans for KMC
- To develop urban accessibility and emission scenarios of selected Low Carbon Transport plans with planning support system
- To assess the potential contribution of these scenarios in Low Carbon Development for KMC

1.4.2. Research Questions

To define the concept of Low Carbon Development and Low Carbon Transport in general and specific for KMC

1. How are Low Carbon Development (LCD) and Low Carbon Transport (LCT) being defined?
2. How are LCD and LCT being translated for the case of KMC?

To identify Low Carbon Transport plans for KMC

1. How to identify current Low Carbon Transport plans for KMC?
2. What are the physical interpretations of the identified plans in terms of their influence in land use and transport component (spatial location, speed, emission)?

To develop urban accessibility scenarios of identified Low Carbon Transport plans with planning support system

1. What are the factors to be considered in qualitative description of scenario?
2. What modelling approach can be applied for developing alternative scenarios of Low Carbon Transport plans?
3. Which activity based accessibility measure can be used for analyzing accessibility impacts of identified Low Carbon Transport plans?
4. What is the result of quantitative assessment of constructed scenarios regarding urban accessibility and emissions?

To assess the potential contribution of the constructed scenarios to Low Carbon Development for KMC

1. What is the result of qualitative analysis of the constructed scenarios for their potential contribution in Low Carbon Development for KMC?

1.5. Conceptual Framework

The conceptual model, as explained below in figure 1, has been designed to show the major components and their interactions. The contribution of Dalkmann & Braningan (2007) on potential strategies for Low Carbon Transport, avoid-shift-improve (ASI), was adapted from the literature which can be used to identify Low Carbon Transport plans. The measures under ASI have effect on either transport demand or transport supply or both by reducing need to travel, encouraging use of mass transit or environment friendly mode or improving the transport mode through technology. Transport demand arises from the physical separation of people from activities which are satisfied by transport supply such as road infrastructure and different types of modes. Moreover, transport supply, in turn, has made this separation possible. Thus, responses under ASI address either transport demand management by promoting high-density, mixed land use, transit oriented development (TOD) or transport supply management by parking policy, traffic calming and restraining, developing pedestrian and cycling infrastructure.

The model focuses on the influence of Low Carbon Transport plans on two components of accessibility (Geurs & Ritsema van Eck, 2001); land use component on characteristics and spatial distribution of activities and transport component and its characteristics such as speed, travel costs. This effect of Low Carbon Transport plans on land use and transport component ultimately have an influence on accessibility of potential population to opportunities affected by those plans. Those people who are served by the transport mode within certain time, costs and efforts, have been considered as potential user of the mode and hence referred as potential population.

Good accessibility facilitates people to reach the opportunities with ease and hence, enhance socio-economic development. So Low Carbon Transport plans should not only minimize carbon emission but also provide good accessibility to opportunities which together influence Low Carbon Development.

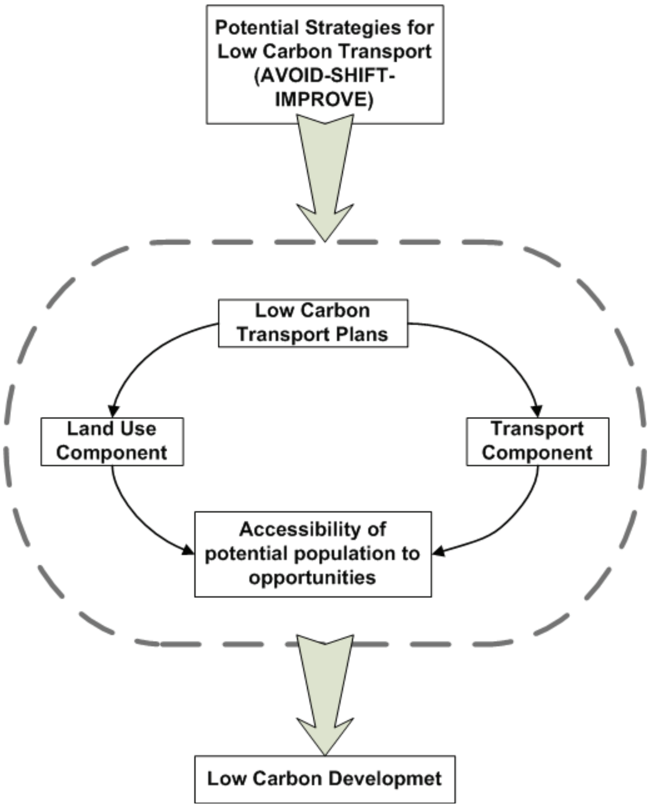


Figure 1 Conceptual framework

1.6. Research Methodology

Figure 2 outlines the research methodology adopted. The methodology has been divided into three phases with five stages.

The first phase involves the establishment of theoretical concept on Low Carbon Development and Low Carbon Transport along with exploring the concept of avoid-shift-improve strategies for Low Carbon Transport. It relies largely on literature review, supervised discussions with relevant persons. General overview of the study area further helps in scoping and identification of data need for the second phase.

The second phase is the data collection and survey during which required data is collected from different ministries and other data that are pertinent. The data are collected from different government offices such as Department of Road, Department of Transport Management, Central Bureau of Statistics, National Planning Commission, Kathmandu Metropolitan Office, Metropolitan Traffic Office, Kathmandu Valley Town Development Committee, Ministry of Physical Planning and Works, Ministry of Local Development. The insight on the concept of LCD and LCT for the case of KMC is gathered by interviewing relevant people. The completion of first phase and second phase helps in fulfilling the sub-objective 1.

The third phase is the data processing, data analysis and result generation which has been divided into three stages. The first stage is the identification of Low Carbon Transport plans (sub-objective 2) from the collected plans and visions that address the potential strategies of Low Carbon Transport (LCT); avoid-shift-improve and have influence on the either/or land use and transport component of accessibility to opportunities. The influences of selected plans on opportunities and/or transport system such as speed, emission, spatial location are interpreted.

The second stage is development of alternative scenarios of Low Carbon Transport plans (sub-objective 3) which follows sequence of steps (Mahmoud et al., 2009). The first step is the formation of qualitative description of scenario. It includes defining time horizon, driving forces such as population, existing policy measures etc., assumptions, uncertainties. The second step is scenario construction which includes the choice of model or development of model for generation of scenarios. Business as usual scenario and alternative scenarios with identified Low Carbon Transport plans are generated. Using selected activity based accessibility measure; accessibility to opportunities of generated scenarios is computed in terms of potential population demand in planning support.

The third stage is the qualitative analysis of each scenario (sub-objective 4) for Low Carbon Development of KMC by analysing the accessibility of potential demand population and the contribution of each alternative scenario on carbon emission.

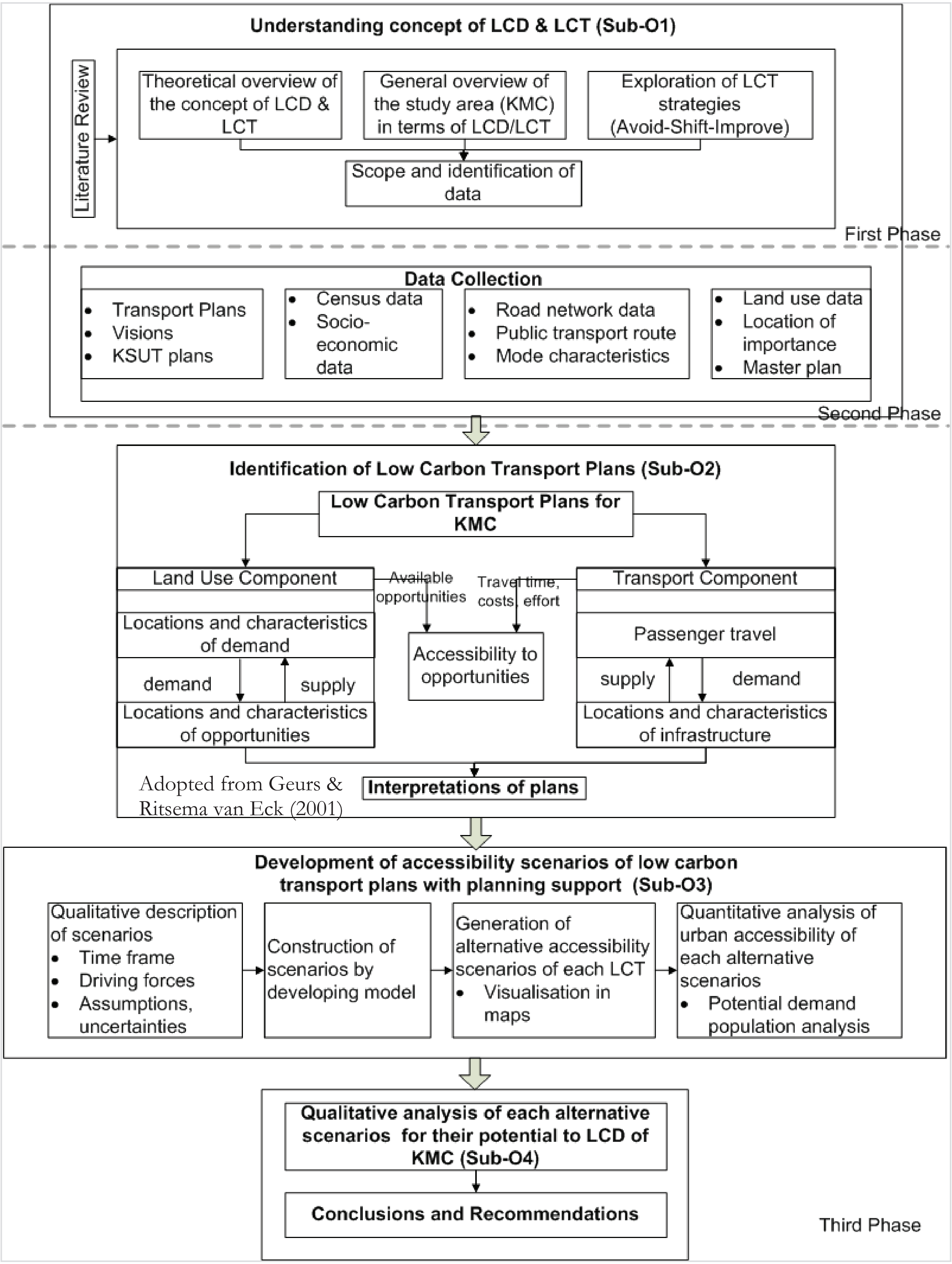


Figure 2 Research Methodology

1.7. Research Matrix

The following research matrix shows the research questions to meet each research sub-objectives, data required and their source, the method to be adopted.

Research Objective	Research Questions	Data Required	Data Source	Method adopted & expected output
To define concept of Low Carbon Development and Low Carbon Transport in general and specific for KMC	How are Low Carbon Development (LCD) and Low Carbon Transport (LCT) being defined?	Secondary data	Literature, discussion	Reviewing literatures and discussion with concerned person
	How are LCD and LCT being translated for the case of KMC?	Secondary data, governmental reports	Government documents, interview	Reviewing and analysing documents, government reports, interviewing with concerned person
To identify current Low Carbon Transport plans for KMC	How can Low Carbon Transport plans for KMC be identified?	LCT strategies, plans, visions	Literature review, secondary data, interview with concerned person	Transport plans are selected those responding LCT strategies
	What are the physical interpretations of the identified plans in terms of their influence in land use and transport component (spatial location, speed, emission)?	Result from question 1, spatial data for different plans, non spatial data on the system	Secondary	Identifying spatial location of the plans, characteristics of the system like emission, speed
To develop urban accessibility scenarios of identified Low Carbon Transport plans with planning support	What are the factors to be considered in qualitative description of scenario?	Census data, population growth rate, socio-economic data, income rate,	Secondary	Qualitative description of each scenario
	What modelling approach can be applied for developing alternative scenarios of Low Carbon Transport plans?	Planning support system with modelling platform	-	Developing model showing interrelations between different drivers and interpretations of LCT plans for generating alternative scenarios.

	Which activity based accessibility measure can be used for analyzing accessibility of identified Low Carbon Transport plans?	Accessibility measures, available data	Literature, secondary data	Selecting measure based on the data. Using the selected measure accessibility of each alternative scenario is computed and visualized using indicators.
	What is the result of quantitative assessment of constructed scenarios regarding urban accessibility and emissions?	Result from question 3	-	Each alternative scenario is compared with BAU scenario for the accessibility as well as to each other in terms of affected potential population and for different socio-economic groups
To assess potential contribution of the constructed scenarios to Low Carbon Development for KMC	What is the result of qualitative analysis of the constructed scenarios for their potential contribution in Low Carbon Development for KMC?	Result from question 4 of third objective and interpretation of plans regarding emission	-	Comparative and qualitative analysis of each alternative scenario regarding its contribution in CO2 emission and analysis of accessibility in terms of potential population and different socio-economic groups.

Table 1 Research matrix

1.8. Research Outlines

The thesis comprises of 8 chapters as per the following sequence:

Chapter 1: Introduction
This includes the general introduction of the context, background and justification for this research followed by research objectives, sub-objectives and research questions leading to research methodology with research matrix

Chapter 2: Literature Review
This chapter includes the theoretical background on Low Carbon Development and Low Carbon Transport from the literatures; gives overview on different accessibility measures as performance indicator for assessing transport planning, scenario development and planning support system

Chapter 3: Case Study Area: Kathmandu Metropolitan City
This chapter presents the general introduction on context of the system and transport system

Chapter 4: Methodology
This chapter describes the data collection methods, data collected and the modelling framework in for developing scenarios of LCT

Chapter 5: Interview Results and Document Analysis
This chapter presents the qualitative description on the interview undertaken during fieldwork with concerned people and the qualitative description on the document of Kathmandu Sustainable Urban Transport Project

Chapter 6: Scenario Development
This chapter includes the qualitative description of formed scenarios on chosen plans or policies that are addressing strategies of Low Carbon Transport plans, 'avoid-shift-improve'. It also includes the quantitative interpretations of those scenarios to be used in developed model in community viz.

Chapter 7: Results and Discussions
This includes the results of those scenarios followed by discussions on those results.

Chapter 8: Conclusion and recommendations
This includes the summary of the findings and the methodology followed in the research as well as the recommendations on the quality of data and further research directions.

2. LITERATURE REVIEW

2.1. Low Carbon Development and Low Carbon Transport

2.1.1. Emergence of Low Carbon Development in climate change

The realisation of the need for support from developed countries on finance, technology and capacity building on the mitigation actions by developing countries has been founded in 2007 in the Bali Action Plan. This realisation was then concretely defined after two years in COP15 conference in Copenhagen. In this context "low carbon-development strategy (LCDS)", first appeared as an important lexicon in an arena of climate change in April 2009 after its EU submission in the UNFCCC which emphasized the implementation of Nationally Appropriate Mitigation Action (NAMA). Finally it was adopted into the Copenhagen Accord (UNFCCC, 2009a) as 'low-emission development strategy'. In contrast to this EU proposal, the Cancun Agreements (UNFCCC, March 2011) acknowledged the need of Low Carbon Development strategy for sustainable development. Thus, aligning low carbon-development more towards general development and national priorities of socio-economic and poverty eradication, it acknowledged the need of developed countries and encouraged the developing countries to pursue Low Carbon Development pathway (Tilburg et al., 2011).

2.1.2. Concept on Low Carbon Development (LCD)

Many authors, organizations and countries have their own interpretation regarding the definition as well as the concept on Low Carbon Development. However, Yuan et al. (2011) have to some extent filled the gap by summarizing various concepts into common understanding. According to them, the three common discourses for Low Carbon Development are: reducing CO2 emission, intensive use of low-carbon energy and ensuring economic growth. Tilburg, et al.(2011) in addition define 'low carbon' as reducing emissions trajectory below business as usual i.e. in the absence of additional policy interventions; further address the Low Carbon Development as reducing emissions in sectors such as energy, industry and agriculture and increasing carbon sequestration through forest management. Thus as shown in figure 3 Low Carbon Development explicitly reconciles the mitigation and development priorities of the country.

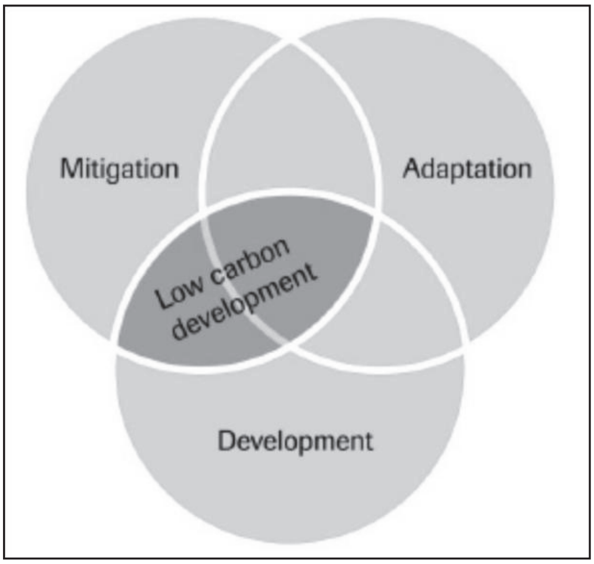


Figure 3 Overlaps between development and mitigation (Source: van Tilburg et.al., 2011)

The importance of following a Low Carbon Development pathway is highlighted by Mulugetta & Urban (2010) emphasizing it as the cornerstone to achieve sustainable development. Clapp, et al. (2010) has further argued on the importance of preparation of LCDS for developing countries. According to the authors (Clapp et al., 2010) Low Carbon Development strategy not only helps countries to take development priorities and climate change policy together in coordinated manner but also helps international community to prioritize their assistance through LCDS in developing countries. Moreover, in contrast to climate-first approach, the development first approach as addressed by LCD pathway ensures a more structured solution through alternative infrastructure and spatial planning with lower emissions (Tilburg et al., 2011). But, each country need to develop their own approach of LCDS depending on the national prospects and capacities (Mulugetta & Urban, 2010).

2.1.3. **Low Carbon Transport**

Transport sector has been indicated as one of the major concern areas where there is a need of Low Carbon Development strategy especially in developing cities to make their transport sector sustainable. Qureshi & Lu (2007) arguing that the definition of sustainable transport forms around the definition of sustainable development and hence crediting Spaethling(1996), defined it as *"Sustainable transportation infrastructure and travel policies that serve multiple goals of economic development, environment stewardship and social equity, have the objective to optimize the use of transportation systems to achieve economic and related social and environmental goals, without sacrificing the ability of future generations to achieve the same goals"*

Several studies have been carried out to tackle the problem of unsustainable transport and its negative externalities such as increasing CO2 emission, congestion, and air pollution. Dulal et al. (2011) reviewed the role of urban design forms, settlement density, housing and employment activities and their effects on reducing travel demand, vehicle dependency and reduction on GHG emissions. They concluded that though urban planning instruments have less effect on short term, but in the long run they can be very effective by reducing need to travel and shift to public modes and environmental friendly modes such as walking and cycling. Grazi & Van den Bergh (2008) have studied on the relation between spatial organization, transport and climate change comparing wide range of spatial planning and policy instruments such as physical planning, pricing policies, command-and-control, market based instruments, arguing further on their choice and effectiveness depending on the spatial context. Wright & Fulton (2005) and Chapman (2007) have reviewed on technology implication for answering climate change problem. Though differentiated, but they all concluded on technology alone cannot achieve substantial emission reduction. But, mode shift, land use, technology, behavioural change complementing each other in an integrated way can be effective. Within this variety of research, a new paradigm shift- avoid-shift-improve have emerged as potential strategies, which have been argued as coherent measure to reduce CO2 emission (Dalkmann & Brannigan, 2007).

From the literatures, various responses can be identified which can be categorized under 5 policy instruments, planning, regulatory, economic, information and technology. Different measures that are categorized into these instruments address either of the ASI strategies as given in table 2 and hence is characterized as Low Carbon Transport plans which influence transport demand management (TDM) by bringing behaviour change and/or transport supply management (TSM) by improving quality or quantity of transport system.

Strategy		**Possible responses**
AVOID **(reduce travel or need to travel)**	TDM	Compact mixed land use (density, diversity), parking policy, transit oriented design, ICT
	TSM	Traffic calming measures(restricted entry to urban centre), prioritize pedestrians,

SHIFT (non motorized transport or public motorized transport)	TDM	Incentives, pricing policies,
	TSM	BRT, mass transit, development of cycling and pedestrian infrastructure, increasing efficiency of public transport system, route reorganization
IMPROVE (individual motorized transport)	TSM	Improving load factors of vehicles, fuel efficiency, vehicle standards, speed limits

Table 2 Potential Low Carbon Transport strategies with examples of responses

2.2. Measuring carbon emissions from transport

Measuring CO2 from transport sector has become an important task in the present context where the transport sector contributes to the large share of GHG emission. According to Schipper et.al.(2009) "measuring CO2" comprises of three major tasks that includes the gathering and analysing information regarding changes in transport activity and changes in vehicles, vehicle technology as well as fuel use by those vehicles. Thus, the task as mentioned by the authors (Schipper et al., 2009) has been divided into three steps as; 1) analyzing and monitoring present transport activity, fuel use, pollutant emissions and hence CO2 emissions, 2) projecting future transport activity due to change in variables such as transport costs, incomes, land uses and the resulting outcome in fuel use and CO2 emissions, and 3) evaluating the impact of different policies targeted on both transport activities and CO2 emissions.

There are basically two approaches that can be found discussed in various literatures. Schipper et al.(2009) has presented an overview on these approaches, the data need as well as the situation of many countries in carrying out such measures. Two approaches as discussed by the authors are the top-down approach proposed by IPCC which is based on fuel use or fuel sales and the bottom up approach that considers transport activity and characteristics data.

The top down approach during national communications of government submitted to UNFCCC used the following equation:

Emissions= activity data x emission factor

where, fuel consumption as the activity data and the mass of CO2 emitted per unit of fuel consumed is the emission factor.

The bottom up approach as described by many authors (Schipper et al., 2009) follows the following equation:

$$G = A * Si * Ii * F\,i,j$$

where, G is the carbon emissions from transport, A is the total activity of passenger travel in passenger km (pkm) or vehicle km (vkm), Si is the modal structure which is percentage share of pkm or vkm by each travel mode, Ii is the modal energy intensity in l/km or l/pkm and Fij is the carbon content of fuels in g/l or g/pkm. Land use and the form of city, income have an effect on travel distances or transport demand.. The number of vehicles of a given type multiplied by distance travelled each year, multiplied by occupancy factor gives the total passenger km produced by that vehicle in a year or the structure of the mode (S). The modal energy intensity is highly dependent on the vehicle occupancy. The energy used by a mode divided by the number of people travelling and distance covered by them gives the modal intensity. Other factors affecting modal intensity are the vehicle fuel intensity influenced by vehicle characteristics and the technological efficiency and road conditions such as congestion, speed. F or carbon content in fuel has changed very little worldwide. However, depending on type of fuels, the carbon content in the fuel is different.

Since the main purpose of measuring CO2 is to link the transport activity with energy use, among the two approaches the bottom up approach provides the relationship between different parameters of complex transport system and hence permits estimation of the impact of policy and measures on these parameters. But as advocated by Schipper et.al. (2009) the major challenges with this approach are the lack of intensive data on transport activity and transport characteristics especially in developing countries.

2.3. Development and accessibility

The need of addressing sustainable development by Low Carbon Transport to move the cities towards Low Carbon Development has been discussed earlier. The wider discourse of sustainable development as defined in Brundtland report (1987) is "*condition to fulfil the needs of the present without compromising the ability of future generation to meet their own needs*". But, crediting Sen (2002), Grasso & Di Giulio (2003), argue that there is a need to view sustainable development in a broader perspective - enhancing human freedoms in a sustainable way, instead of merely defining it only in terms of fulfilment of basic needs.

According to Amartya Sen development is enhanced by broadening human potential which can be materialized through expanding the opportunities and individual choices and providing freedoms to an individual to live the desired life (Grasso & Di Giulio, 2003). Thus, it is the expansion of individual's capabilities. Robeyns (2006) argue that development of a community or country should not focus on the resources but on the availability of effective opportunities to people to lead the lives they value.

Transport is a means to an end and that mobility and accessibility are at the hearth of development (Czuczman, 2008). Many literatures distinguish accessibility from mobility as, the former is about an ease to reach to goods, services, activities or opportunities whereas latter is an ease of network for people to move from one place to another which merely comprises of level of service, road capacity, design speed.

Accessibility within its diversified meaning includes "the amount of effort for a person to reach a destination" or "the number of opportunities that are available to people" (Geurs & Ritsema van Eck, 2001). In this regard accessibility can be considered as an enabler for enhancing the capabilities of people to reach to wide number of opportunities. In line with Amartya Sen's capability approach it can be argued that better accessibility provides freedom to people to choose the opportunities they desire. Grasso & Di Giulio (2003) has further summed up Amartya Sen's capability approach and Bruntland's sustainable development as, "*if the enlargement of the space of choices is expected to hold in future without compromising capabilities of future generation then it can be referred as sustainable development*". Referring accessibility as an enabler to enlarge that space of choices, it can be argued that it is one of the performance indicators for sustainable development

Several studies have used accessibility to employment as an indicator for assessing and valuing the benefits of proposed land use and transport plans and policies on economic development of people since employment is one of the sources of income generation which helps in development of people (Bertolini et al., 2005; Cervero & Kockelman, 1997). After the contribution of Amartya Sen's capability approach there are growing numbers of literatures that advocate the need to broaden the perspective of looking over the development of country as improvement in all dimensions of human needs such as health, education instead of only growth per capita income (Mazumdar, 2003; Saito, 2003). Hoffman (2006) has further emphasized on the access to education and equitable access to education as basic foundation for developing other capabilities for human development.

Thus, following wider horizon of development, this research has considered physical accessibility to education as an enabler for young generation to develop capabilities and hence contribute in economic development of country in the future.

2.4. Measures of accessibility

Geurs & Ritsema van Eck (2001) discusses the various accessibility measures as economic and social indicator. Changes in the transport system and land uses due to transport plans or projects have impact on accessibility which may have different economic or social impacts and can be analysed by using accessibility measures. Further, the authors (Geurs & Ritsema van Eck, 2001) argued on three dimensions of social evaluations; spatial equity, social equity and economic equity which can be evaluated using accessibility by region, accessibility for population groups separated by socio-demographic characteristics and accessibility for income groups respectively. There are mainly three types of accessibility measures as indicated by Geurs & Ritsema (2001).

- **Infrastructure based accessibility** measures analyses the performance of the system considering infrastructure characteristics and is especially used in transport geography for evaluating transport policies, plans or projects. Some of the measures mentioned were "average speed on the road network", "level of congestion" or "average delays".
- **Activity-based accessibility measures** analyses the number of opportunities available with respect to their distribution and space and time considering travel impedance between origins and destinations. This is further divided into geographical accessibility measures and time-space accessibility measures.
  - **Geographical accessibility measures or location-based accessibility measures** takes into account the location and evaluates spatial distribution of services or activities. The general indicator is "the number of jobs within 30 minutes travel time". The wider application of such measure is often in urban planning.
  - **Time-space measures or person-based measures** analyse the accessibility at individual level. Indicators such as "number of people travelling in one destination at a specific time" or "number of activities that people can participate in a specific time" are found to be relevant.
- **Utility based accessibility measure** uses utility theory which assumes an individual as utility maximizer and chooses the highest utility alternatives. Thus, indicators such as "travel cost between destinations and origins"

The choice of measure should be done according to the accessibility needs of the actors as well as should be easy to understand and communicate (Bertolini et al., 2005). Geurs & Van Wee (2004) reviewed the advantages and disadvantages of the above mentioned accessibility measures on the basis of four criteria: theoretical basis, operationalization, interpretability and communicability and application in social and economic evaluations . Infrastructure-based accessibility measures are widely used measures in current transport policies. The advantage of this measure lies on its easy operationalization and communicability with easy availability of required data and transport models. However, the serious disadvantage remains in its theoretical basis with shortcoming in handling land-use component and its inability to provide insight into the variation of accessibility among different groups and land use patterns. Person-based accessibility measure though overcome the shortcoming of all the other measures with strong theoretical basis but its major disadvantage remains in operationalization and communicability which required detailed individual activity-travel data. Utility based accessibility measure has been appraised for its ability to compute transport-user benefit of both land-use and transport projects since as accessibility changes may be due to transport-changes or land-use changes or both. However, its usability is lessened by its complexity in interpretability and communicability due to complex theories. With all this argumentations, location based-accessibility measures of activity based measures are preferable due to its undemanding nature of data requirement, easy to interpret and communicate and is not dependent on person's perception of transport, land-use and their interaction though some of the location measures still do not satisfy much of the theoretical criteria

Location based-accessibility measures are further divided into following types as described by Geurs and Van Wee (2004);

- Contour measures also called as cumulative opportunity, isochronic measure, proximity count or daily accessibility measure; counts the number of opportunities that can be reached within a given time, distance or cost. On the other hand, it measures the time, distance or cost required to reach the fixed number of opportunities (Cerda & El-Geneidy, 2009; Geurs & Ritsema van Eck, 2001; Geurs & Van Wee, 2004). This measure has been used in many transport planning, urban and geographical studies as a simple and easy to understand measure for measuring equity or impact on accessibility brought about by change in infrastructure (Cerda & El-Geneidy, 2009; Geurs & Van Wee, 2004). The simplicity in understanding, interpreting with less data need has made this measure acceptable in criteria of operationalization, interpretability and communicability. The greatest shortcoming of this measure lies in theoretical base. Geurs & Van Wee (2004) have argued that this measure is unable to evaluate combined effect of land use and transport and do not take people's perception under consideration and measure desirability of all opportunities falling within same isochrones of time or distance equally.

- Potential accessibility measures or gravity based measures overcome some of the shortcomings of contour measure. Though similar to contour measure, this measure takes into account the distance decay function to reach the opportunities. Hence more distant the opportunities less will be the attractiveness of those opportunities. According to Geurs & Van Wee (2004) this measure takes into account people's perceptions by using distance decay function. So it is usable to evaluate accessibility of different socio-economic groups to social and economic opportunities. However, the disadvantage lies in difficulty in interpretation and communicability (Geurs & Van Wee, 2004).

- Potential accessibility with competition in addition to distance decay function, takes into account the competition effects at origins and/or at destinations (Geurs & Van Wee, 2004). The effect of competition is expressed by dividing the available number of opportunities for zone under consideration by the demand potential from the same zone.

- Balancing factors in addition to distance decay function, as described by Geurs and van Wee (2004) takes into account competition at both origins and destinations . Hence, it considers the magnitude of flow to and from a zone equals the number of activities in that zone. Though easy to operationalize according to authors, its difficulty lies in interpretability and communicability.

With many types of location based accessibility measures, the choice of measure should be in balance with data availability, accessibility need of actor and purpose of use. Leather & CAI-Asia (2009) have addressed that there is a lack of robust data on transport characteristics in most of the Asian cities including the case study city. So for this research location based accessibility measure is preferable for the evaluation of Low Carbon Transport plans.

2.5. Scenario development

The need to follow Low Carbon Development path through sustainable Low Carbon Transport plans have been discussed in the previous section.

Shiftan et al. (2003) argued on the complexity associated with sustainable transportation planning due to large number of alternative potential policy packages, number of implementation ways and difference in response for each policy package. In this respect the authors have argued on the shortcomings of traditional approach in accommodating change and unexpected events for evaluating transportation planning that usually applies statistical and behavioural models. Thus, scenario planning has been agreed as a useful tool in long range planning to check the robustness of strategies and plans under different set of possible futures (O'Brien, 2004; Shiftan et al., 2003). Hickman et al. (2012) highlighted on the importance of scenario analysis in transport field as a way to '*think the unthinkable*'.

Several researchers have used scenario planning approaches for examining potentials of different mitigation strategies to reduce CO2 emission in transport sector. Ramanathan & Parikh (1999) have used scenario analysis approach to analyse the effects of different policy options aimed at reducing CO2 emission under annual average growth of passenger km and freight km for sustainable development in India. Banister et al. (2000) developed three images of future and demonstrated that range of policy options can be opted to achieve targets for sustainable mobility. Dhakal (2003) constructed business as usual scenario (BAU) and analysed potentials of alternative scenarios of different transport policies against BAU for the case of Kathmandu Valley. Similarly, there are growing numbers of literatures that have used scenario analysis approaches to identify range of options that can contribute in Low Carbon Development of countries (Johnson et al., 2010).

According to the Intergovernmental Panel on Climate Change (IPCC), a scenario is defined as *"a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold"* (Mahmoud et al., 2009). Borjeson, et al.(2006) has described various typologies of scenarios based on the need of user to know *what will happen, what can happen* and/or *how a predefined target can be achieved.* Based on these questions the authors suggested three main typologies as predictive scenarios, explorative scenarios and normative scenarios respectively.

In order to develop scenarios Mahmoud et al. (2009) have proposed a formal approach for scenario development consisting of 5 consecutive steps. This approach has been proposed for developing environmental scenario. Nevertheless, out of 5, the following sections describe 4 main steps which could be applied to any scenario development task.

Scenario Definition: This phase includes the identification of characteristics of scenario, spatial and temporal scales with time horizon. It includes the identification of key driving forces that are external force which cannot be controlled and the policies that are under control of actors. The definition includes the scenario themes, uncertainties, storyline which are qualitative descriptions and should be plausible.

Scenario Construction: This consists of three steps; system conceptualization, model selection or development and data collection and processing. During system conceptualization, the key assumptions and the decision factors are identified to build a connection between scenario definition and model. A model is used to generate the outcomes of potential futures and data collection; and processing in model-based approach refers to gathering and processing of model input-data, running the model for each scenario and processing model output data.

Scenario analysis: During scenario analysis, the outcomes of the interactions among boundary conditions, driving forces and system components are interpreted using variety of statistical and other analytical techniques. It includes model outputs interpretations, inspection of data consistency and quantification of the uncertainties.

Scenario assessment: This includes the identification of risks, mitigation opportunities and tradeoffs and helps stakeholders to plan for management strategies. This includes the description of results from the outcomes of the scenario analysis phase in the form of narration.

2.6. Planning Support Systems

The large number of alternatives and number of possible ways of implementation increase the complexity in planning task and so there is a need of scenario planning approach to explore the impact of those planning tasks on sustainable development which has been discussed in section 2.5.

The use of model in developing different energy consumption and CO2 emission scenario is increasing. Cai et al. (2007) have used integrated energy-environment and scenario based accounting modelling platform called LEAP (Long-range Energy Alternative Planning System) to generate energy consumption and CO2 emission in different scenarios. Dhakal (2003).has used this model for constructing future scenarios up to year 2020 to analyze their implications in transport sector. However, this model does not include the spatial component.

LCT plans have influence on spatial component of land use and transport which influence the accessibility of potential population as shown in figure1. Geospatial technologies have been appreciated as useful tools for performing analysis of spatial relationships, manage spatial information and model processes. Thus it provides the platform for managing and organizing spatial data and related information for analysis and visualization (Heywood et al., 2006). But its effective use in planning and stakeholders participation is inhibited due to lack of system transparency and need of expert training. Thus planning support systems (PSS) have been evolved that respond to the need of actors and facilitates the planning task more actively.

A PSS integrates different elements such as theory, data, information, knowledge, methods and instruments in a graphical user interface (Geertman & Stillwell, 2003). Batty (2007) defines PSS as collective set of tools that support different steps of planning process like problem identification, analysis, and generation of alternative plans, evaluation, choice and implementation. Thus PSS has been regarded as useful tool which is capable of incorporating social, economic and environmental aspects and provides platform for generating spatial planning scenarios for improving knowledge and information in planning processes (Pettit, 2005).

Different PSS tools have been developed recently. Community Viz, which was developed for community decision making, is a planning support system which is easy to use in GIS environment. It has been appreciated for its dynamic attributes that respond immediately to the change made in spatial component, facilitates transparency in assumptions made in generating scenarios and results into on the fly changes in ultimate results (indicators) and visualization of those results in charts and graphs.

2.7. Conclusions

After reviewing the above literatures, it is clear that an overlap exists between mitigation and development priorities of nation which form the core concept of LCD and as such different co-benefits are associated with development-first approach of LCD. Therefore, pursuing LCD pathway entails win-win situation for the nation as well as global community, provided that it is formulated according to nations' capabilities and local context. LCD can be realized in many sectors as such transport forms central theme since the majority of countries are facing problem of unsustainable transport resulting in negative externalities of air pollution, health impacts, accidents locally and GHG emission globally.

The review of literature has shown that sustainability in transport revolves around the accepted definition of sustainable development. Though there are many researches on measures of transport demand and transport supply management to deal with the problems of unsustainable transport, it has been concluded that there is a need of a paradigm shift. Recent studies show that the avoid-shift-improve are the paradigm and the indicators are widely accepted strategies for Low Carbon Transport to induce CO2 emission reductions from road transportation. Measuring emissions from transport has become important in current trend as it is growing rapidly from transport. Amongst two approaches; top down and bottom up approach, the later has been used by many authors since it considers transport activity and characteristics. However, the use of this approach needs intensive data which is generally lacking in most of the developing countries.

Amartya Sen's capability approach has given new direction to view the development of the country as the availability of opportunities to people to broaden their potential and capability to lead the lives they value. In this respect, accessibility as an ease to reach to opportunities or number of opportunities that are available to people, can be regarded as an enabler to develop capability of people. Further it has been advocated that there is a need to expand the horizon of accessibility which usually considers jobs and employment as opportunities, to include accessibility to education as education is important in the development of human capital and their capability which ultimately leads to development. There are different measures of accessibility having their own advantages and limitations. For this research location based measure of activity based accessibility measures is found to be suitable due to its easiness in interpretability and communicability. Among many types of location based measures, contour measure is found to have advantage with its undemanding data need, easy to interpret and communicate.

Scenario analysis is generally seen as a useful tool in the long range planning when there are uncertainties and complexities associated with it. It is useful in sustainable transportation planning to check the robustness of number of alternatives with number of implementation ways. Several studies have used this approach to analyse CO2 mitigation potential of a range of options and their potential to contribute in Low Carbon Development of countries. Scenarios could be policy driven or driven by external variables or drivers of scenarios, which are usually not under the control of actors. As a platform for developing these scenarios, Community Viz has been chosen as a planning support system. .

3. CASE STUDY AREA: KATHMANDU METROPOLITAN CITY

This chapter gives an overview on the case study city regarding urban form and current urban transport system.

3.1. Introduction

Nepal is located in South Asia. The total area of the country is 147,181 square kilometres with the current population of approximately 26.6 million and has the growth rate of 1.4 percent (CBS, 2011). The national GDP as of 2011 census is $642 per capita with an annual average growth rate of 3.48 %.

The Kathmandu Valley comprises of three districts, Kathmandu, Lalitpur and Bhaktapur with an area of 899 square kilometres. Out of total area of the valley, Kathmandu district comprises of 85% with the population of more than 1.5 million and is the major urban concentration centre, 50% by Lalitpur district and remaining by Bhaktapur district. The valley consists of five major cities or municipalities, which form the core urban areas of the valley. Those five municipalities as shown in figure 4 are Kathmandu Metropolitan City, Lalitpur Sub-metropolitan City, Bhaktapur municipality, Kirtipur municipality and Madhyapur Thimi municipality.

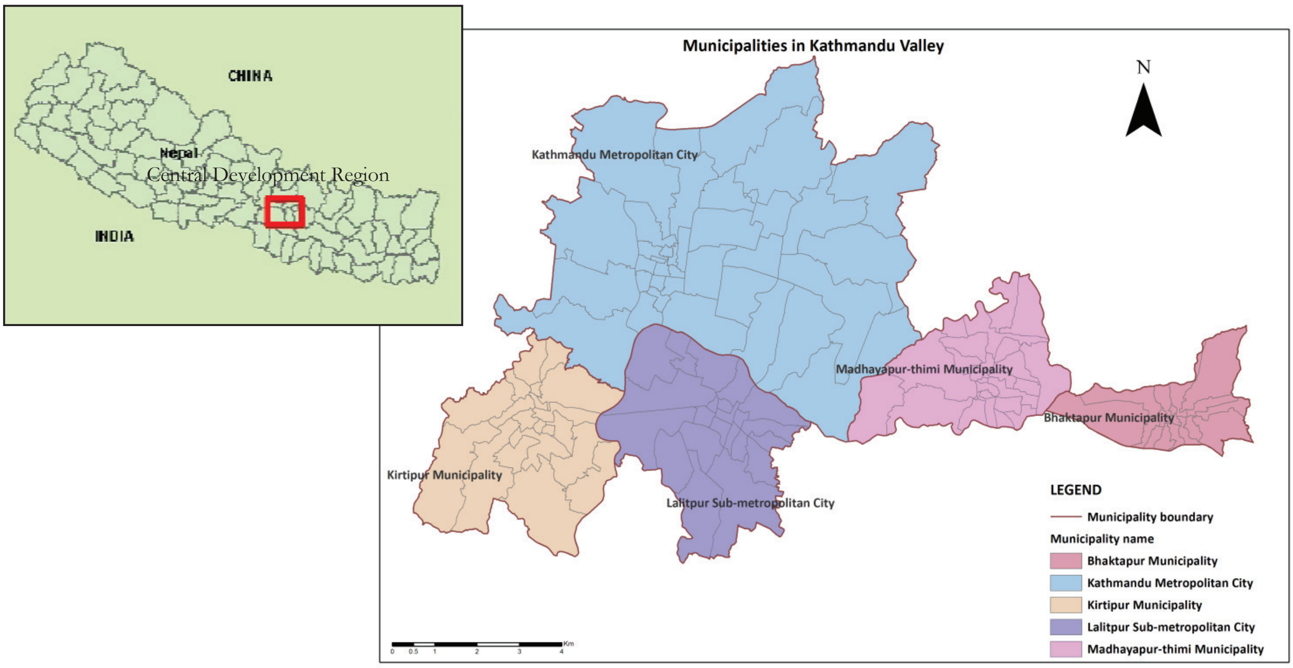


Figure 4 Municipalities of Kathmandu Valley in Central Development Region

3.2. Kathmandu Metropolitan City (KMC)

Kathmandu is the largest metropolitan and capital city of Nepal. It is the largest urban agglomeration in the country accommodating around 20% of urban population in an area of 50.67 square kilometres. Apart from being the capital city, it is headquarter of Central Development Region. There are five development regions constituting 14 administrative zones in the country and Central Development Region is located at the central part of the country and constitutes three zones, namely, Bagmati, Narayani and Janakpur. Kathmandu is located in Bagmati Zone and consists of 35 wards.

3.2.1. Population and Population Density

According to Central Bureau of Statistics (CBS) of 2001, the total population of KMC was 671,846 with most of the wards in periphery having the population density between 3,233 and 13,983 per square kilometres as shown in figure 5. The historic core area has maximum population density of 44,000 to 101,129 per square kilometres.

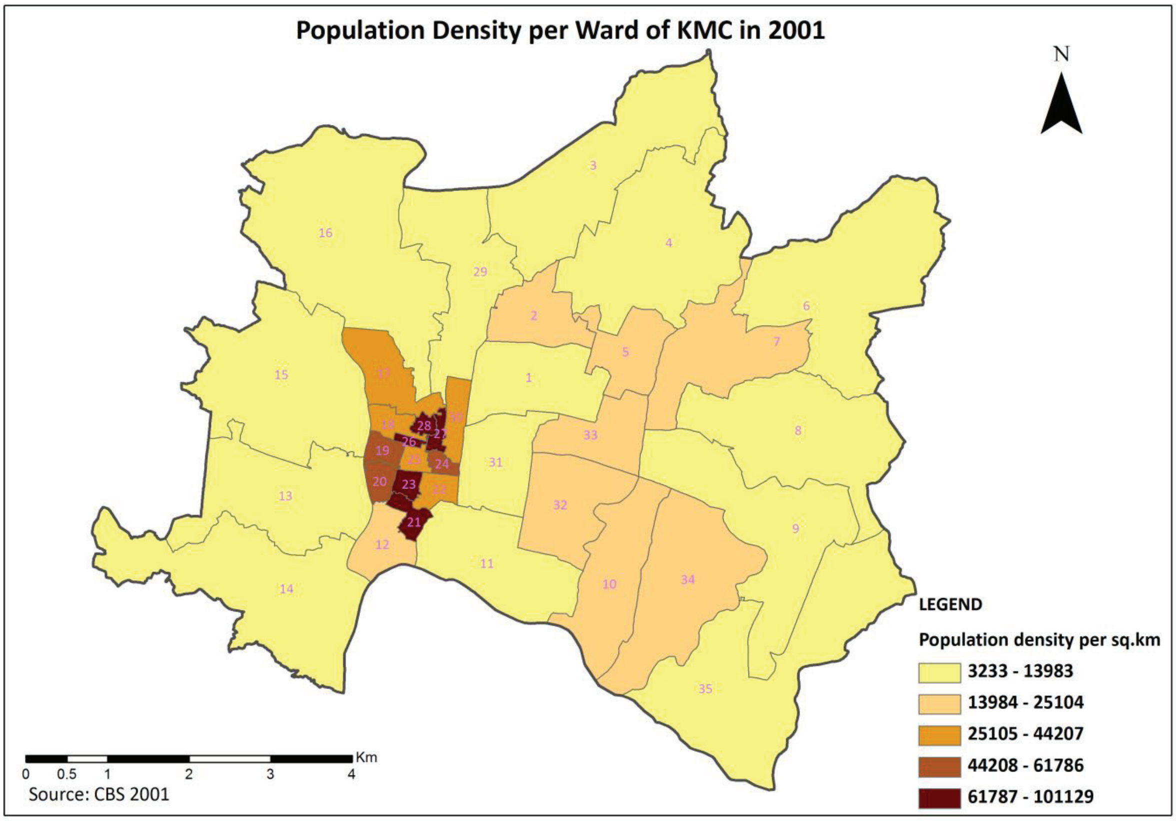


Figure 5 Map of population density for 2001 in 35 wards of KMC

3.2.2. Urban Form and Road Network

The analysis of trends of urbanisation in KMC shows that urbanization has occurred as a function of travel distance to the city centre of Kathmandu and is influenced by main roads. As per the land use of 2008 as shown in figure 6, mixed land use with residential and mostly commercial activities covers nearly 50% of the area with only about 27% being used as open area, cultivation and parks. The road network forms about 7% of the area.

The development of the city has often been undertaken in haphazard and unplanned manner without any formal planning. The fringe area of the city without proper access to roads has remained as agricultural land. Open spaces and agriculture land around the core area is under pressure of urbanization.

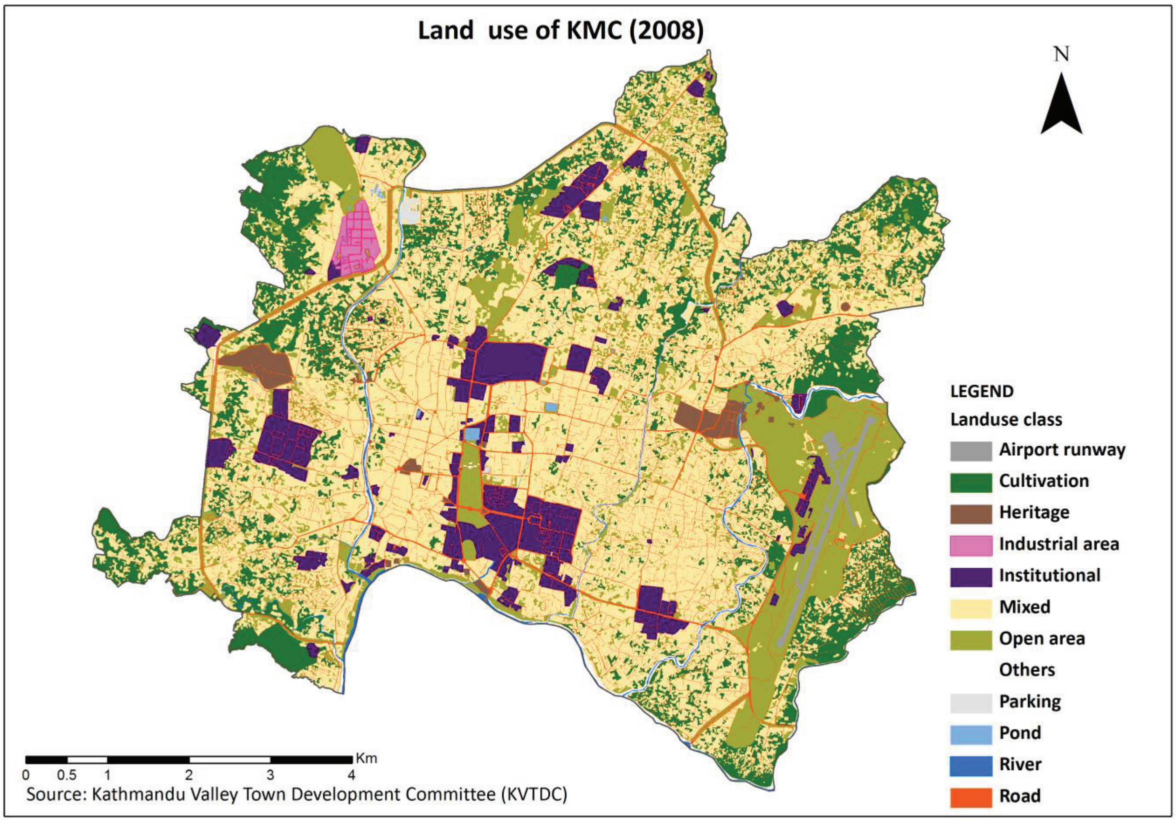


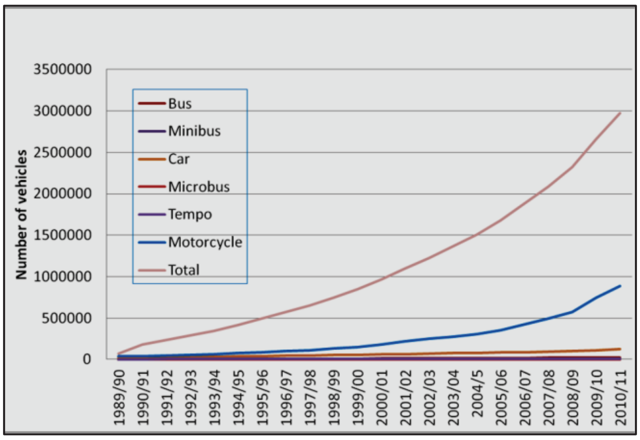
Figure 6 Map of land use of KMC for 2008

The city transport is predominantly based on roadways which form only about 7% of total land area in the city. The road network of the city follows the radial pattern.

3.2.3. Transport system in KMC

3.2.3.1. Vehicle composition

There has been a substantial growth in vehicle registration in the city in past decades. The passenger transportation in the city is mainly fulfilled by two categories of vehicles; public transport and private transport. Public transport includes bus, minibus, microbus and tempos whereas motorcycle, car/jeep/van are being used as private ownership. Graph 1 shows vehicle growth in Nepal. Though it is for national context, most of this growth has been taken place in Kathmandu Valley.



Source: Department of Transport Management

Graph 1 Vehicular growth in Nepal

It shows an increasing trend in the total number of passenger vehicles for the last two decades with average growth of 15%. As shown in graph 1 motorcycle show highest growth trend whereas minibus, microbus, bus and tempo show insignificant growth. This increase in two wheelers has been attributed to increase in income per capita, easy affordability and easy to use.

3.2.3.2. Route Network

The public transport system in the city is broadly classified into three groups; city services serving within the built up area, valley routes that are connecting towns and villages within Kathmandu valley and long distance routes connecting Kathmandu to throughout Nepal (MoPPW & ADB, 2010). Though the majority of these long distance routes do not penetrate the city and use the terminal on north-western part of the city, few of them linking east of Kathmandu use old terminal in the centre of the city and thus penetrate the core area of the city.

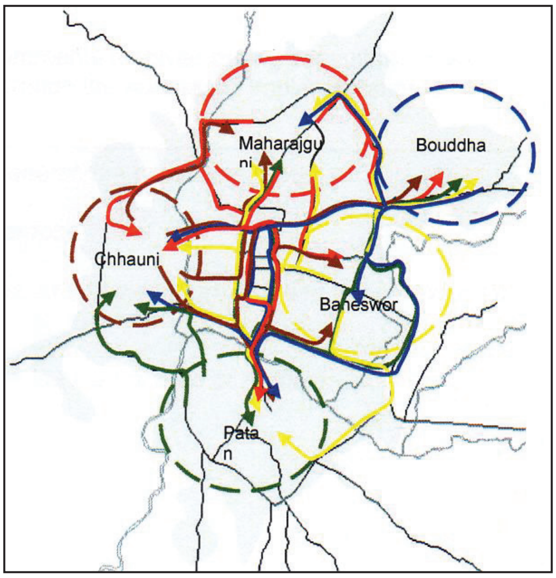


Figure 7 Conceptual diagram of the existing public vehicle routes

The complexity of public transport system in KMC is in three folds (MoPPW & ADB, 2010). Firstly, there are many overlapping routes of public vehicles. Secondly, there is mix of higher occupancy large vehicles and lower occupancy small vehicles. Thirdly, large numbers of public vehicles routes originate and terminate in the central city area as shown in figure 7. The central area has number of terminals, Old Bus Park, Bhaktapur Bus Park, Shahid Gate, Ratnapark and NAC which is increasing vulnerability to road users as well as causing inefficient transport system.

Thus, with the growing population and increasing vehicle growth, especially two wheelers, the transport system of KMC is facing problem of congestion, pollution, health impact. Moreover, unplanned and haphazard urbanization, complex overlapping of route networks with mix of both higher and lower occupancy small vehicles originating and terminating in the central city area are all increasing vulnerability to road users. Further elaboration on problems of the city would be discussed in chapter 5 along with identification of LCT plans for the city followed by their evaluation on their potential in LCD for KMC.

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4. METHODOLOGY

A general approach was discussed in research methodology in chapter 1. This chapter discusses in detail the fieldwork data collection approach, data collected and the conceptual model in community viz.

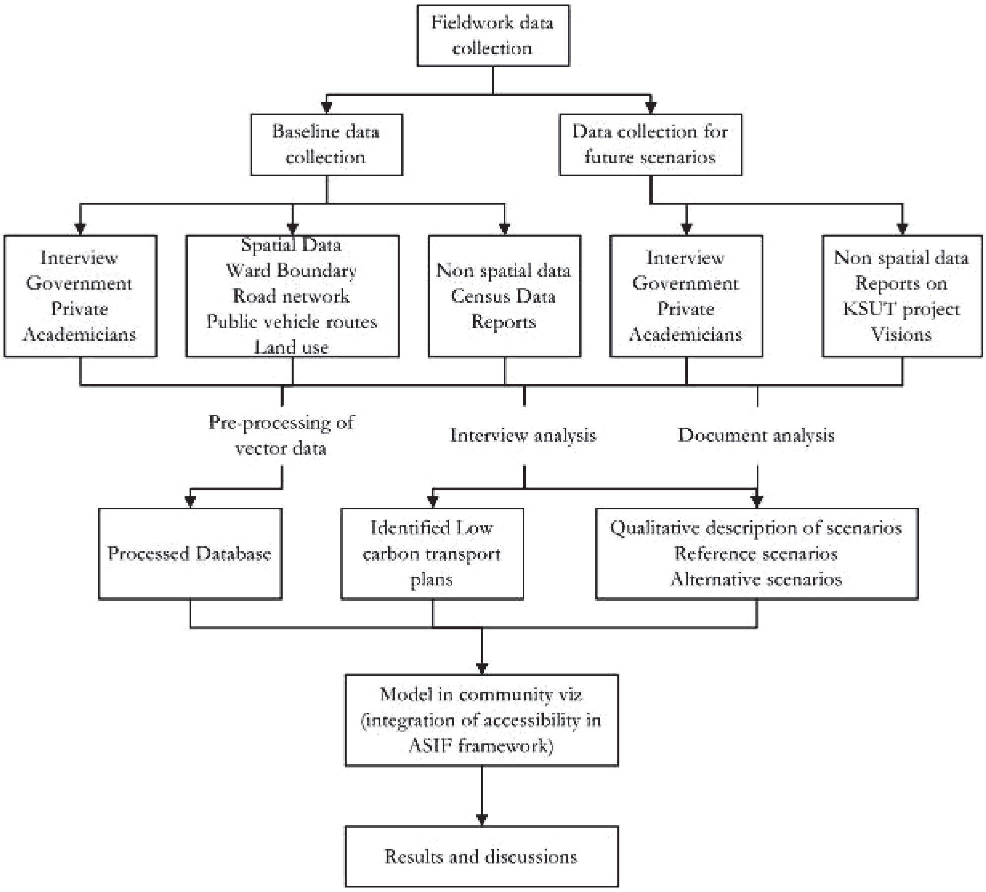


Figure 8 Methodology flowchart

4.1. Fieldwork Data Collection

A fieldwork of 4 weeks starting from 4th of October to 2nd of November, 2011, was carried out in the case study area, Kathmandu Metropolitan City (KMC). The research was based on data collected from primary and secondary sources. For the primary data, interviews with the relevant people from government and private offices, academicians were carried out. The secondary data were collected in the form of spatial and non spatial data from different government, private offices and consultancies. The collection of data was categorized into two: baseline data collection and data collection for developing future scenarios.

4.1.1. Baseline Data Collection

To do the analysis of future scenarios, good representation of baseline situation is necessary. Hence, the first task involved was the collection of baseline data to represent the current transport system in the city and to understand different problems, issues and challenges associated with the transport sector of the city. The baseline data was collected from both primary and secondary sources according to the type of data to be collected and the availability of data. The following sections discuss the type of data collected and the sources.

4.1.1.1. Secondary data and sources

The secondary data mostly consists of spatial data in GIS format and non spatial data in the form of reports. A brief description of data and their sources are given below. All the spatial data has Modified UTM as the projection system with local datum, Modified Everest 1830 with 84 degree meridian.

Kathmandu Metropolitan City Ward Boundary: This data in GIS format is from 2008 and was obtained from Kathmandu Valley Town Development Committee (KVTDC). The only information available in this spatial data is the ward number which is 35 in numbers.

Road Network: The road network of 2008 was also obtained from KVTDC in GIS format. The road is classified according to type of construction material. The road network data is available as road centre line and road edges.

Public Vehicle Route: The current public vehicles routes with stops and terminals was obtained from SOFTWEL P. (Ltd) which worked as GIS specialists under the Kathmandu Sustainable Urban Transport (KSUT) Project in 2009. The public vehicles are categorised as micro bus, electric tempo, gas tempo, mini bus and bus. There is the system of giving route permit from transport office. So the data consists of route name i.e. according to places, route number and the type of vehicles that are in operation in current situation.

Building points: The building layer consists of point features on the location of different building types. The building points are categorised into different classes as schools, hospitals, government offices, hotels, tourism etc. This is also from 2008 and was obtained from KVTDC.

Land use map: The GIS data on land use map of 2008 was also obtained from KVTDC. The data consists of land use with 18 classes.

Census Data: The non spatial data on population was obtained from Central Bureau of Statistics (CBS) which conducts census for every 10 years. The latest census data as per ward is available for 2001. Though 2011 census had been completed, but the data was not disseminated. So, for census 2011, the preliminary report on total population in municipality level is available with present growth rate. Besides total population, the census data of 2001 consisted of information on population distribution according to gender, number of households and average household size in ward level.

Kathmandu Sustainable Urban Transport Project Report: This report presents the recommendations from an Asian Development Technical Assistance for Sustainable Urban Transport in Kathmandu. This assistance was the part of Sustainable Transport Initiative (STI) which was launched in 2006 for supporting transport sector of Asian Development Bank (ADB). The main aim of STI was to incorporate energy efficiency, inclusive transport infrastructure and services to explicitly reduce transport sector green house gas emissions by encouraging different interventions. Among five pilot cities for undertaking SUT project under STI, Kathmandu, Nepal was also one of them.

This report is divided into two volumes. The first part consists of the present situation as well as the vision (strategy) for sustainable urban transport and the second part is the annexes on the data regarding bus route, bus stops, survey results on vehicle traffic counts, vehicle occupancy and parking demand, width and condition of roads, vehicle numbers and types. Thus, the report presents the initial comprehensive study on the framework for the Sustainable Urban Transport for the city.

Performance of the existing vehicles: For this research, data on the performance of the existing vehicles particularly focussed on the types of vehicles currently operated in the city and their performance in terms of average speed, fuel efficiency and emission factor. The Clean Energy Nepal (CEN), secretariat for Clean Air Network Nepal (CANN) under CAI-Asia had been working on GHG quantification for Kathmandu Valley. So the data on emission factor according to type of vehicles and type of fuel used, average speed of the public transport for the city was obtained from CEN.

4.1.1.2. Primary Data Source

To meet the first objective, the data and information were collected from primary data source that is interviewing concerned people. Semi-structured interviews were conducted with the people that were involved in developing policies, strategies or the academicians having knowledge and experience on the issues and challenges of transport system of the city or involved in developing the strategies of sustainable transport for the city. Thus, the interviewees were grouped into three categories as: government personals, academicians and private consultants. The interviews were recorded and focussed on the following three aspects; the results from the interviews are discussed in the next chapter.

- Understanding the current situation and problems of transportation in the city
- Understanding the concept on Low Carbon Development (LCD) for the city
- Understanding the concept on Low Carbon Transport (LCT) plans and policies for the city

During the fieldwork, the "International Conference on Sustainable Development of Transport System" was held in the city in cooperation of university (from 20^{th} Oct -22^{nd} Oct, 2011); Nepal Engineering College (NEC), ministries; Ministry of Physical Planning and Works (MoPPW), Ministry of Local Development (MoLD), Ministry of Environment (MoE) and organisations; Nepal Engineer's Association (NEA), Institution of Civil Engineers (ICE). The conference was helpful in understanding the local and international context in sustainable development of transport system in the country. Though in national context, the presentations during conference were focussed on rural road development; however, few presentations on the Kathmandu Sustainable Urban transport were relevant for understanding the present situation of city and the LCT plans. Further, the conference had been useful in identifying some of the interviewees. Besides SDTS conference, participation during interaction program between Nepal Automobile Dealers Association (NADA) and the government on draft transport policy had been useful in understanding the transport policy for the country. The list of interviewees with semi-structured interview questionnaires is made available in annexe.

4.1.2. Data collection for developing future scenarios

Among various definitions of scenarios, the accepted definition of scenarios for this research is "*The robustness of the chosen policy measures can be tested by imposing effects on the system that in the real world are beyond his control. These effects are called scenarios"* (Engelen, 2000).Thus, the effects that are imposed are the external driving forces such as population growth or change in income which has an effect on the affected population and the socio-economic structure. The internal variables will be the selected Low Carbon Transport plans and policies. With each of these plans and policies different scenarios were produced. Both primary source and secondary sources were used for developing scenarios on Low Carbon Transport.

Kathmandu Sustainable Urban Transport Project Report: The secondary source for developing future scenarios is the KSUT project report. Besides the existing situation of transport in Kathmandu and Kathmandu Metropolitan City, the report presents the framework for Sustainable Urban Transport. The main aim of this report was to provide support to Government of Nepal for developing and implementing the vision (strategy) for sustainable transport. In a broad aspect, the report includes the following short term measures to:

- Improve operations of public transport
- Implement a traffic management plan for the central area of Kathmandu
- Introduce pedestrian areas with the old town of Kathmandu, with links to transport facilities
- Improve the air quality within the city

The report provides the preliminary report on the spatial location on the improved route network, possible routes for revived services, specification of proposed public vehicles under the above measures as a short term and long term measures.

Interviews: Besides understanding the current situation of transport system in the city and the concept of Low Carbon Development and Low Carbon Transport for the city, the interviews had aimed on identifying long term visions on Low Carbon Transport plan for the city other than those mentioned in the KSUT project.

4.2. Pre-processing of vector dataset

Data to be preserved in vector format include the city ward boundary, road network, public vehicles routes and stops, building points of schools and colleges. The extent of data includes the whole Kathmandu Valley. Hence first task involved was to extract case study area for which Kathmandu Metropolitan City ward boundary was used to clip the required area from other layers.

4.2.1. Road network

The road network layer consists of road type categorized into 10 classes according to construction material used during construction. As far as possible all the road types have been considered. However, while observing the data road type such as stairs was found to be used for the temples and only few roads type with stone paving were not considered in the analysis. Processing of road network data to render usable topology was done in ArcGIS.

4.2.2. Public vehicle routes and stops

The data on public vehicles routes consists of total 129 routes for all public vehicles; bus, minibus, microbus, gas tempo and electric tempo. As in the existing condition where different types of public vehicles are using the same routes, the data also represents the overlapping of routes. So, for topology rectification, these routes are stored as separate layers according to the vehicle type.

The stops layer consists of location of stops according to vehicles. While observing the data, it was found that not all stops had been located. Thus, with reference to the location of stops from the KSUT report, stops were digitized manually where necessary.

4.2.3. Census data

The census data of 2001 which was obtained in the form of non-spatial data were geo-referenced as per ward which was 35 in numbers. The census data consisted of total population and population according to gender (male or female) in ward level. So in order to extract the potential population of higher schools and colleges, percentage of population between ages 15-29 was obtained for KMC. Thus this percentage was used for each ward to acquire subset of potential population of higher schools and colleges.

4.2.4. **Facilities or services**

For this study higher schools and colleges were considered as facilities. Referring to Amartya Sen's capability approach which has been discussed in section 2.3 access to schools and colleges has been considered as proxy for broadening the capabilities of young generation to seek socio-economic opportunities and hence contribute in future development of the city.

The building points consist of all types of schools and colleges, from pre-primary level to higher education. As per the requirement, the schools and colleges were extracted and resulted into 151 facilities. These 151 had no specific information such as whether it is government owned or private owned, whether higher secondary education or graduate level education or both was provided. Thus, for this research it was assumed that population going to higher schools and colleges would be served by either one of these facilities.

4.2.5. **Private and public vehicles**

For the study, public vehicles considered were minibus, microbus, electric tempo and gas tempo since these were the dominant types of public vehicles in current situation. According to graph 1 in chapter 3, it could be seen that two wheelers form 80% of total passenger transport. Besides, due to its affordability and usability, it is becoming popular among young people. Thus, this research had used two wheelers as representative of private mode.

4.2.6. **Network dataset**

For network analysis data was prepared to represent intermodal network. Boile (2000) has stated intermodal network as an integrated transportation system consisting of two or more modes. The procedure for developing intermodal network dataset is presented in the figure below:

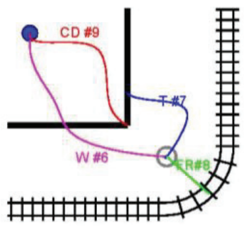


Figure 10 Intermodal connectors
(Source: (Boile, 2000)

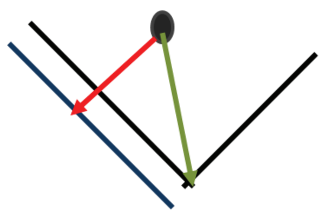


Figure 9 Intermodal connectors for vehicle route and road

Figure 9 shows the procedure of connecting two different modes. Here, solid line represents road network, and rail line represents the transit network. The solid circle represents origin/destination and open circle represents intermodal transfer point. CD represents a connector of origin/destination to road network. T represents a transfer link connector transfer point to road network, FR a fare link connecting to rail mode which can be used to denote fare for travelling and W is walking link from an origin to destination. This procedure was adopted for developing intermodal network for this research as shown in figure 10 which represents the following form.

Total travel time by public vehicle= walk time to stop+ waiting time for vehicle + travel time in vehicle + walk time to destination

Thus, in figure 10, blue line represents vehicle route coded with average speed of vehicle and black line represents road network coded with walking speed. Solid circle represents stop and red line represents connection between stop and vehicle route which was coded with waiting time whereas green line represents connector between stop and road network. As such, people are allowed to get on the bus and get off to required point only through stops.

4.3. Modelling framework

To derive scenarios on urban accessibility of Low Carbon Transport plans for KMC as well as to demonstrate the application of planning support system for generating and evaluating those scenarios, the following modelling framework as presented in figure 11 was adopted.

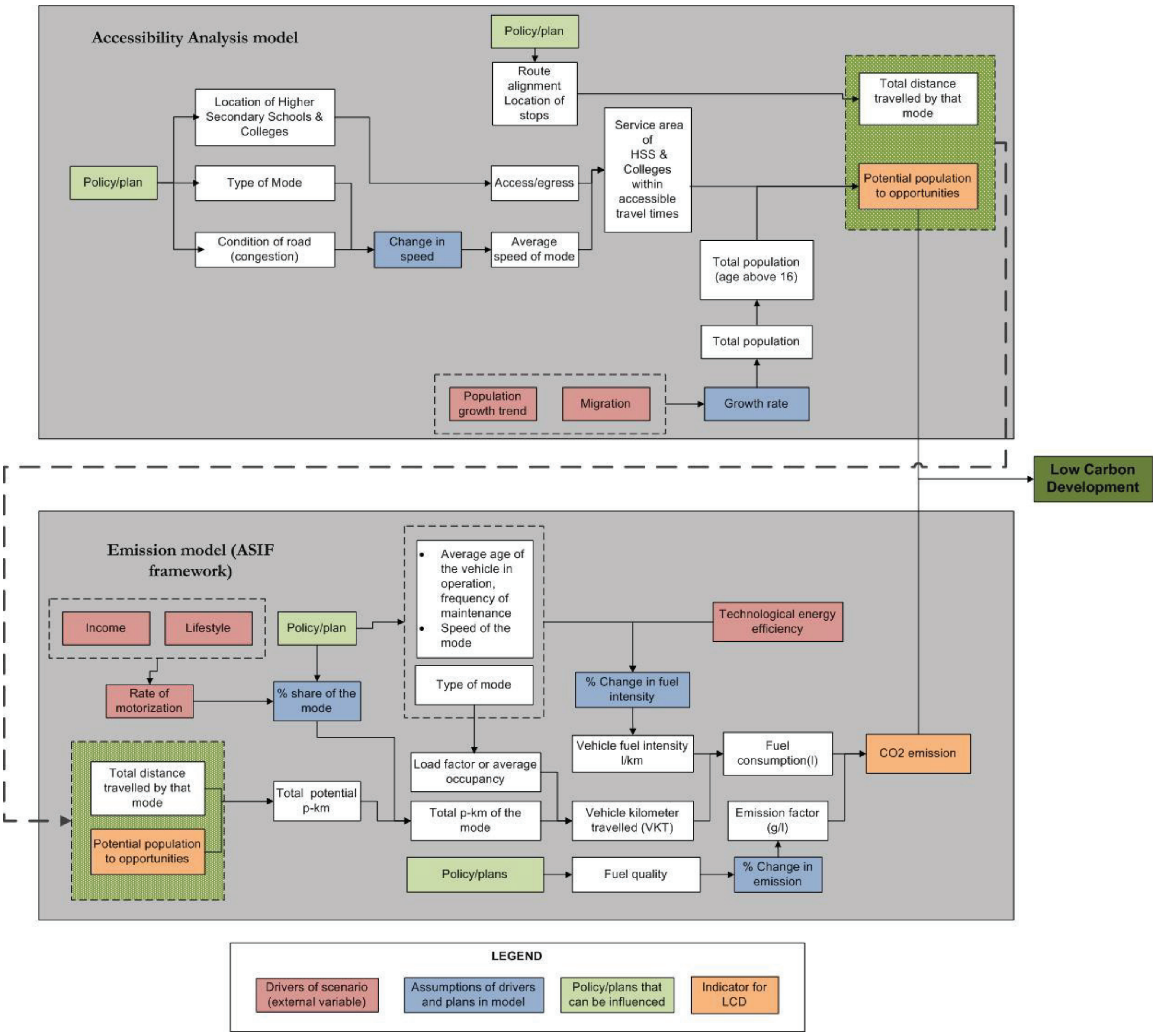


Figure 11 Modelling framework

The main concept on the modelling framework was the integration of accessibility analysis with carbon emission model. Here, integration was defined as output obtained from accessibility analysis in terms of potential population and distance travelled by mode under consideration to reach the facilities; were used as input as passenger km in emission model for calculating carbon emission while seeking those facilities. With the help of interviews with relevant people and the document on transportation plans for KMC, different drivers and Low Carbon Transport plans were identified. The choice of those drivers as mentioned in modelling framework in figure 11 would be discussed in subsequent chapter 6.

Considering the effects of drivers which are the external variables, likely future scenarios were constructed with certain time horizon. These scenarios had both qualitative description followed by quantitative interpretations. Scenarios could be formed without policy interventions also called as reference scenarios or with interventions of selected LCT plans/policies. These interventions have interpretations in the form of spatial and quantitative measure. The quantitative measures of those scenarios were the assumptions that affect different components of model and hence change the potential population serviced and the carbon emissions during that service provision. Finally, with the indicators of potential service population and related emissions during that service provision or how many people were serviced with green transport, qualitative assessment to Low Carbon Development was undertaken. The following sections describe in detail each part of the framework (accessibility analysis and emission model).

4.3.1. **Accessibility analysis**

As discussed in chapter 2, there is abundant literature on application of different measures of accessibility. Geurs & van Wee (2004) have categorized these measures in three main categories; infrastructure based accessibility measure, activity based measure and utility based measures; and discussed their advantages and disadvantages in terms of theoretical basis, operationalization and interpretability, communicability and usability in social and economic evaluations. From the literatures, location-based activity measure was found to be appropriate. But, with many types of location based measure having their own pros and cons, complexity still remains in choice of measure and its operationalization.

As argued by Bertolini, et.al. (2005) with no best approach, choice of measure and approach are governed by situations and purpose of use. Referring to practicality of chosen measure in policy implication, the authors have discussed two basic requirements to maintain balance between developments of suitable indicator with respect to their practical application in policy making. According to authors (Bertolini et al., 2005), the chosen measure and indicator should reflect accessibility need of actors and should be understandable to those involved in plan making process. With this argument, in this research, contour measure of location-based activity measure had been chosen as simple measure of accessibility analysis. Moreover, by crediting Handy and Niemeier (1997) for three issues in selecting accessibility measure, Bertolini, et.al.(2005) have argued on choice of measure in relation to interpretation, specification and calibration. Following this ground, choice of contour measure in this research is also discussed and argued in relation to the above three issues as following

The choice of contour measure stems from one of the important issues which are interpretability. The contour measure has been appraised for its easiness in understanding to policy makers while dealing with trade-offs and interdependencies between transport and land use component. One of the objectives of this research was to demonstrate application of PSS in dealing with accessibility impact of LCT plans, thus easiness in conceptualization, operationalization and interpretability with undemanding data need has made this measure suitable for this research.

The level of disaggregation, defining origins and destinations and selecting travel impedance are required to be determined in specification. In the absence of traffic analysis zone (TAZ), the unit of analysis for the case study area was chosen to be wards which are only 35 in the area. With no available information on number of jobs, spatial locations of schools and colleges were chosen as facilities. However, referring to Amartya Sen's capability approach and considering accessibility to education as an enabler to expand capabilities and potential of young generation so that they can contribute in economic development of the city, the choice of schools & colleges as facilities hold importance. Further, educational trips of the city constitute large share of daily trips besides work trips. Moreover, it has been observed that students give preference to educational quality rather than distance and hence are willing to travel farther distance for seeking education. In addition to this, students of these ages are also being more attracted to two wheelers.

The data for KMC city lack information on travel demand such as origin and destination of people, individual choice on mode and spatial travel behaviour of people in the city; other measures of accessibility such as potential measure, potential measure with competition, which considers people's perception on land use and transport, hold difficulty in their operationalization as well as in interpretation and communication as argued by Geurs and van Wee (2004). Thus considering travel time as impedance and generating service area around facilities by connecting all points that could be reached within given travel time for various modes and conditions; it is easy to operationalize with less data. With this approach, computing the number of people that fell inside those isochrones was considered as the potential users of the modes and the definition of accessibility for this research was directed as- the more the number of people serviced by LCT plans; the more is the accessibility. This increase could be the result in either change in transport component (transport network, speed and cost) or change in land use component (distribution of facilities).

The third key issue to be considered for contour measure is calibration in choice of cut-off travel time. For this research, travel time of 30 min had been set. Without any rule on determining cut-off travel time; Bertolini, et.al.(2005) have argued on two reasons for the choice of contour measure in their study. One reason is empirical base through the study of travel behaviour of people and other being purpose of their study. Since, there was no study on travel time spend by students of KMC for going to schools and colleges, arguments on choice of 30min travel time stems from purpose of the study which was to evaluate the accessibility impact of LCT plans and related emission during that service against the scenario when there would be no interventions. Thus, consideration of same cut-off travel time should be seen more as a benchmark against which to assess all the scenarios rather than taking it as absolute value. The accessibility analysis was carried out in network analyst of GIS in Community Viz using model builder which is further discussed in section 4.5.

4.3.2. **Emission model**

As discussed in chapter 2, the recommended framework for measuring carbon emission from transport is the ASIF framework. This framework considers transport activity in the form of trip generation and distance travelled choice of mode and mode structure for those trips, fuel efficiency and carbon content of the fuel used.

For this research due to lack of intensive transport activity and behavioural data, the concept followed was the population that were given services (population by age qualified for receiving higher education and the service locations are higher schools & colleges) within the travel time are the potential user of the mode. Thus, calculating the distance travelled to those locations by different mode and the serviced potential population as output from accessibility analysis, total travel demand in passenger-km was calculated. Based on the mode share, pkm was estimated for each which was then assigned to vehicles km travelled (VKT) according to occupancy factor of that mode. With VKT and the fuel intensity (l/km) of the mode, total fuel consumed was calculated which was further converted into carbon emission (ton) according to emission factors (g/l). The emission model was built in open modelling framework of Scenario 360 of Community Viz which is further discussed in section 4.5

4.4. Calculation of estimated user of the mode

The applied definition of potential user of the mode was explained in section 4.3.1. Depending on mode choice and preference, even though people are provided with good accessibility, it is likely that all of them might not use the mode. Thus, the following figure 13 shows the concept of accessibility for two modes. The outside circle represents universe of discourse or the whole population in the area whereas circle with population A is the catchment area of mode A and circle encircling pop B is the catchment area for mode B which also includes catchment area of mode A. Then,

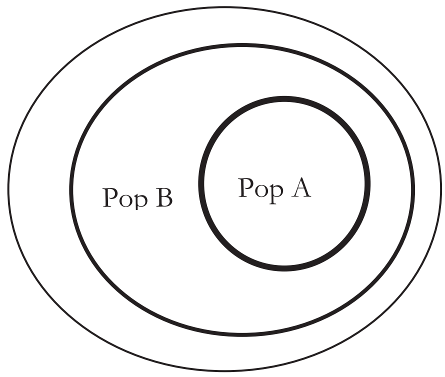


Figure 12 Catchment area of mode A and mode B

If Pop A is the population served by mode A then,

Potential user of mode A= Pop A

If M_A is the percentage of population using the mode A or mode share then,

Assumed user of mode A = M_A ** Potential user of mode A*

If Pop B is the population served by mode B

Potential user of mode B= (Pop B- Pop A) + (Pop A- Assumed user of mode A)

If M_B is the percentage of population using the mode B or mode share then,

Assumed user of mode B= M_B ** Potential user of mode B*

4.5. Operationalization of the modelling framework

The modelling framework presented in figure 11 was operationalized in Community Viz, scenario 360 environment. Though Community Viz is not specialized in dealing with complex transportation planning task, but its advantage lies in supporting custom models through its open modelling framework. The building blocks provided by this tool can be used to develop model according to user's preference and need. Thus, this functionality was used to develop semi automatic model and demonstrated the application of PSS for generating scenarios and evaluating the potential of chosen LCT plans towards LCD under those scenarios. The LCT plans that were identified would be discussed in section 5.3. Figure 13 shows the part of network analysis model that was developed in model builder

GIS environment in Community Viz was used for accessibility analysis. The contour measure of location based accessibility measure was operationalized with network analyst function in GIS. The current transport system as well as new transport system was represented with distinct set of network data. The model builder was used as a platform where these prepared network data when used as an input would result into number of people that fell inside the given cut off time and the distance travelled by each mode. As shown in figure 13, the number of people that are provided with access to schools & colleges are the potential users of the mode and hence the population serviced and distance travelled by each mode were the input in ASIF framework as activity in pkm.

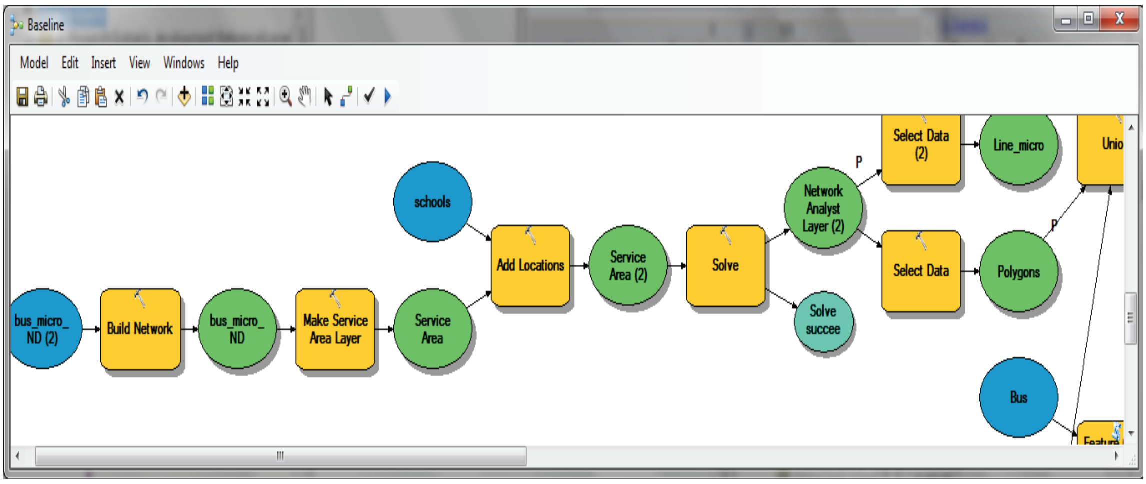


Figure 13 Applying contour measure of accessibility for each mode in model builder

The Activity-Structure-Intensity-Fuel (ASIF) framework was operationalized for this study in the open modelling platform of Scenario 360 in Community Viz. The general method of ASIF framework was followed in the calculation of emissions. For each type of mode (bus, minibus, tempo, private, trolley) user interface was created which allows the user to change the slider bar in order to change the assumptions made for the mode share, average occupancy, fuel intensity, emission factor, which together form ASIF framework. Figure 15 shows the user interface of bus as one of the public modes in the base year and figure 14 shows the user interface for trolley bus system for one of the LCT plans.

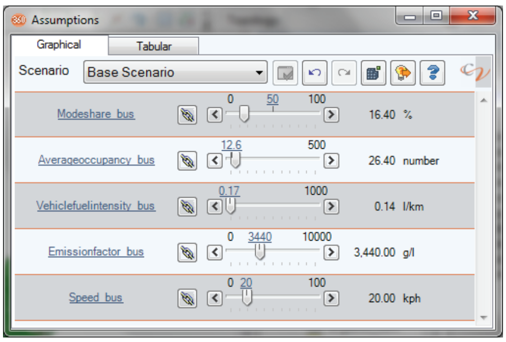


Figure 15 User interface for different variables for bus

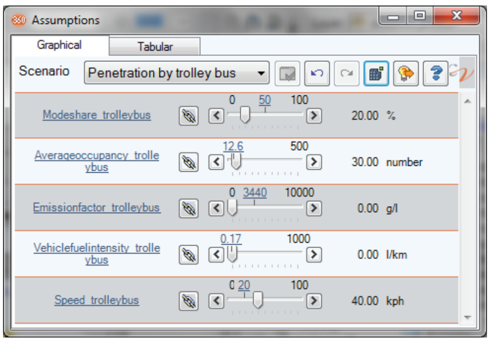


Figure 14 User interface for different variables for trolley bus

Thus with the user interface for each type of mode, one can change the different variables for the ASIF framework that would result in change in output which are the indicators. Figure 16.shows the indicator of accessibility as number of people within the service area of schools & colleges in the given cut off time with each mode in one of the chosen LCT plans. Figure 17 shows total emission from each type of mode (public transport and two wheelers) and figure 18 shows carbon intensity for each type of mode during that service provision.

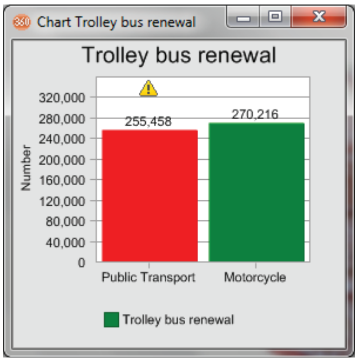


Figure 17 Indicator of accessibility

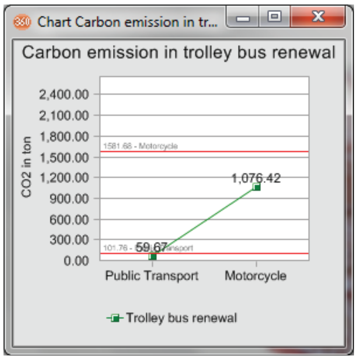


Figure 18 Indicator of emission

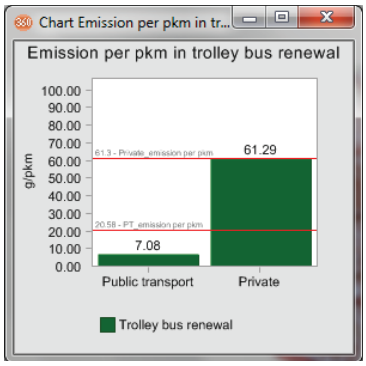


Figure 16 Indicator of carbon intensity

In addition to ASIF framework, user interface was developed to allow change in the driver of scenarios which is the population growth in this case that would be discussed in chapter 6. Thus, assuming the different values of drivers of scenarios and using the platform of model builder, the number of people served within the given cut off time for each LCT plans would be computed that would lead to change in the attribute of the serviced population. This change could be visualized instantly in the indicator of accessibility as shown in figure 16. Since this is one of the inputs in ASIF framework, this change along with other variables of the model would lead to change in the indicators of emissions which are shown in figure 17 and 18. Further, alerts were also developed to show the effectiveness of the plans against the baseline. The red colour in figure 16 shows the decrease in accessibility against the baseline for public transport in 2020 with the trolley bus renewal plans.

4.6. Conclusion

Spatial data and non-spatial data were collected during fieldwork. Through interviews a better understanding on the current situation of the city, the concept of LCD and LCT for the city along with some visions were obtained. The pre-processing of vector data was done to render usable topology for road and route network, to geo reference the population data per ward and extract potential populations for schools and colleges according to age. The integrated network dataset was prepared for base year as well as for the chosen LCT plans.

The modelling framework was formulated based on the concept of integration of accessibility analysis with the ASIF framework that distinguishes the external drivers and policy options of scenarios and other variables in the model. The model builder and Scenario 360 of Community Viz were used as the platform for operationalizing the conceptual model and to demonstrate the application of PSS for evaluating potential of LCT plans towards LCD under different scenarios.

5. INTERVIEW RESULTS , DOCUMENT ANALYSIS AND LCT PLANS FOR KMC

This chapter presents descriptive results from the interviews with relevant people on three main themes as described below followed by brief description on Kathmandu Sustainable Urban Transport Project (KSUT). From the analysis of interviews and documents on KSUT project, the third section describes the rationale on the identified Low Carbon Transport plans for the city.

5.1. Descriptive results of interviews

The interviews were mainly focussed around the following three themes:

- Understanding the current situation and problems of transportation in the city
- Understanding the concept of Low Carbon Development (LCD) for the city
- Understanding the concept of Low Carbon Transport (LCT) plans in Low Carbon Development (LCD) for the city

5.1.1. Understanding the current situation and problems of transportation in the city

Urban growth and urbanization are usually associated with environmental problems. Though both developed and developing countries are facing the problems of environmental degradation, as compared to developed countries which have financial and technological capability to cope with such environmental problems, developing countries are in worse condition with limited capability to cope with such problems. Following are the factors that have been advocated during interviews with relevant people; which are addressing negatively on one or more dimensions of sustainable transportation and hence causing transportation in KMC unsustainable:

- **Population growth, increase in income per capita and increase in motorization**

With urbanization, the city is facing an increasing population trend. Besides the natural growth in population, migration is also one of the major causes of substantial increase in the population. Along with the increase in population, vehicles numbers are also increasing.

The remittances from people living abroad have been attributed as one of the major factors for significant increase in GDP at the national level. On one hand increase in GDP has caused rise in income per capita and on the other hand this rise in income per capita has made more people capable of owning private vehicles especially two wheelers. Following this trend, it has been advocated that the vehicle growth has exceeded the carrying capacity of existing road infrastructure.

Thus rapid urbanization with increasing travel demand, limited road capacity, more people shifting towards private mode outnumbering the carrying capacity of the infrastructure; are all contributing to the problems of traffic congestion, delays and increasing travel time per trip, decrease in road safety in the city. Further, motorization of the city has always been coupled with use of poorly maintained vehicles and adulterated fuel quality which are causing excessive.

- **Public transport as bad stigma for the city**

The public transport of the city has become despicable as it holds the stigma of unreliable, inefficiency and uncomfortable. Currently, after the demise of the government owned mass transportation system such as "trolley bus system" and "sajha yatayat", the public transport system are owned and operated by more than 150 individual public transport entrepreneurs. This has resulted in the use of large number of small occupancy public vehicles; most of which are even more than 20 years older and which do not qualify as public transport. Furthermore, there is syndicate system and monopoly of few public transport entrepreneurs which discourage the fair competition. Using few numbers of vehicles in their monopolized route, they are gaining more profit. Moreover, with large number of operators and their vehicles waiting in queue for their operation turn, during the operation, drivers/operators are always tempted in maximising fare revenue. Thus, instead of service oriented, these transport entrepreneurs are more focused on gaining large profits with few of their vehicles in operation.

Consequently, unscheduled and unreliable public transport, overloading with large number of passengers and uncomfortable environment inside the vehicles, haphazard loading and unloading of passengers, issues of road safety and haphazard fare collection are prominent problems embedded in the public transport system of the city. Thus, public transport has remained as vehicles for captive users who do not have other alternatives apart from using the public vehicles whereas those who are capable are shifting on private mode especially two wheelers which are easy to use and affordable.

The mismatch between the type of road and the vehicles to be used has been advocated as another reason of traffic congestion in addition to increasing number of private vehicles. Both slow moving lower occupancy public vehicles such as tempos and higher occupancy high speed public vehicles are using the same route which has lowered the speed of high speed vehicles. Further, the placement of bus terminals and the present route planning of public vehicles originating and ending in the core city areas is another problem adding to the congestion. Moreover, lack of demarcation of lane along with poor traffic management, absence of strict laws and orders on vehicle fitness and poor driving behaviour have been highlighted as other reasons of ad hoc transport system in the city.

- **Inequitable access to transport modes**

Inequitable sharing of transportation is another factor for unsustainable transport in the city. The current transport development is focussing on mobility of vehicles rather than ease of people to reach destinations. Hence, without proper pedestrian walking environment, non motorized transport is being neglected. Besides, the motorized transport is not easily accessible to physically impaired people, women and senior citizens and the public transport usually stops after 7 hour in the evening creating difficulty to commuters. Further, as advocated, one study on the transportation cost shows that lower income groups are spending one third to half of their income on transportation.

- **Lack of institutional coordination**

Any kind of planning task requires the coordination from ministerial to departmental levels for its effective implementation. Even though different departments have the capacities, resources; without proper coordination between different departments, ministries and without good governance, effective implementation of plans and policies are at stake for the city.

5.1.2. Understanding the concept of Low Carbon Development (LCD) for the city

The GHG share of Nepal in total global emission is only 0.025 percent which is an insignificant amount. So, the immediate need of the country is adaptation rather than mitigation of GHG and as such mitigation concerns are tended to be seen as economic burden. However, mitigation efforts through Low Carbon

Development strategy in themselves do not constitute economic burden and the nation as a whole can be benefitted with such efforts. But pursuing Low Carbon Development pathway should be aligned with national priorities and capacities.

In the context of KMC, it has been advocated that though the initiation of making Low Carbon Development strategy is in initial stage, there has been an initial identification of different sectors where potential benefits of GHG emission reduction plans can be obtained. Among different sectors, energy sector has emerged as one of the most important sectors that are contributing largely in GHG emission. Though there is benchmark on reduction on energy use, there is no benchmark of emission reduction target from transport sector alone.

Current transport sector of the city is dependent on fossil fuel energy which is totally imported from foreign countries. The economy of the country is fully dependent on imported fuel which has not only burdened country's economy but also contributed in negative externalities on environment caused by energy intensive vehicles. Therefore, with this argument, the most important pathway of LCD for the city in transport sector is through reduction in its dependency on imported fossil fuel.

Only discouraging the use of fossil fuel is not sufficient. Instead, it should be followed by replacement with more efficient alternatives. The country has potentials on hydropower plant for generating electricity with zero emission which has been advocated as most sustainable energy source for the city in transportation sector. Besides, use of energy mix such as 'jatropha' in the diesel is addressed as another way of increasing energy efficiency with reduction in imported fuel consumption. However, there should be an integrated approach among all the levels of government to make these energy sources sustainable.

Secondly, encouraging mass transit system and making the public transport reliable, time and cost efficient and thus reducing the dependency on private mode can help in energy saving and thus fuel consumption. More people could be transported with less number of vehicles which reduces the emission per capita. Further, reducing travel time and cost by efficient public transport and providing access to basic services, education and opportunities to all the groups in the society bringing social equity can boost economic growth of the city which ultimately leads to Low Carbon Development pathway.

Two schools of thoughts have been advocated on the proposition of mass transit system. Based on the current population of the city and the travel demand, mass transit system such as monorail and light rail using electricity as source of energy are ought to be feasible for solving the current problems of the city as well as providing job opportunities to people. But there is a need of large initial investment as well as life time investment on maintenance of the system. So with no strong policies of the government and the tendency of private sector to invest only on short term benefits, sustainability and therefore economic benefits from such system is on verge. Thus, with this argument, second school of thoughts of managing the current infrastructure system have been widely agreed upon. For instance, renewing trolley bus system with articulated system and priority lane, proper route planning and improved traffic management with some junction improvement and hence increasing speed, result in economic benefits with less investment in terms of increasing accessibility, reduction in emission and negative externalities of environmental pollution and health impacts.

5.1.3. Understanding the concept of Low Carbon Transport plans for the city

According to literatures, three strategies, avoid-shift-improve have been identified; based on which different plans and policies are termed as Low Carbon Transport plans. Since, the implication of such strategies depends on the condition and capacity of the city, translation of such strategies is likely to differ from countries to countries or even cities to cities. Thus in the case of KMC, perceiving the current situation of the city and the development of transport sector, 'shift' and 'improve' have been addressed as most feasible strategies to relieve associated transport problem of the city.

In present context, most of the daily trips of the people of KMC are limited to jobs and education. Due to mixed land use, people can get the basic needs at shorter distance and hence has reduced the travel distance of most of the trips. But still the city is facing the problem of unsustainable transport. One of the reasons that have been advocated is the absence of integrated land use and transport planning that is causing high mobility. The development of high rise buildings is being grounded but without proper integration of land use and transports attracting more population in the city, burdening the transport infrastructure. So, the urgent need of the city as advocated is decentralization of resources and development of satellite town with the concept of "living and working together" accompanied by integrated land use and transport planning.

With this situation on hand, as advocated, strategies and polices of the city should be directed more on how people travel instead on how many trips people undertake. Moreover, transport plans on expansion and widening of road without proper management for foreseeable future of personal mobility is likely to create increase in emission with increasing vehicles and congestion. With this respect, there is general consensus on the plans that enhances the service quality of public transport or non-motorized mode. Some of the policies and plans as advocated are boot, bike and bus policies, delineation of primary and secondary routes where primary routes are dedicated to higher occupancy mass transit and secondary routes are assigned with vehicles of lower occupancy such as electric tempos, rationalization of pudblic transport system, improving walking environment and hence pedestrianization of historic areas, cording pricing for private vehicles in restricted areas, improving the current ring road as expressways. These result into gaining speed with more scheduled public bus system which encourages shift from private mode, ultimately leading to less number of vehicles, less traffic congestion and hence less emission.

However, there is a need of holistic approach. Besides, shift to environment friendly mode, there is a need on improvement on technology and energy efficiency of vehicles. Though there are policies on vehicle fitness test, EURO standard and scrapping of old vehicles, energy mix but there is a need of their effective implementation. Moreover, low cost alternative clean energy such as electricity, needs to be promoted for which policies on taxation of such vehicles should be reduced to make that energy source more affordable and sustainable.

5.2. Kathmandu Sustainable Urban Transport Project (KSUT)

Kathmandu Sustainable Urban Transport Project (KSUT) is the most comprehensive, integrated and one of the largest projects in South Asia aimed at improving the quality of urban life in Kathmandu Valley. Under the Technical Assistance (TA) of Asian Development Bank which is part of Sustainable Transport Initiatives (STI) of ADB.

STI was launched in 2006 in order to strengthen ADB's technical assistance in transport sector to provide energy efficient, inclusive and sustainable transport in developing countries. Realizing the challenges in the face of economic growth, rapid motorization, population aging and urbanization that are putting strain in the transport sector of developing countries of Asia and Pacific; ADB envisaged STI to address the need of different supports for developing countries. Within this realization according to Duncan (2010), STI includes four main aspects in the definition of sustainable transport system; accessible, safe, environment-friendly and affordable and within this definition mainstreaming the transport sector in avoid-shift-improve strategy is the prime concern.

Among five pilot cities for undertaking sustainable urban transport interventions by STI, Kathmandu is also one of them. In the process of identifying framework for sustainable urban transport, this study presents the recommendations, strategy and vision on sustainable urban transport for Kathmandu. For the short term, the measures identified are; improving public transport, implementing traffic management plan for the central area of the city, improving non-motorized mode in historic area of the city and improving air quality within the city.

Though the report presents comprehensive study on these measures with some recommendations, however detail study on these measures are still to be undertaken for which the Ministry of Physical Planning and Works, the coordinator of this project, is in the process of hiring competent consultancies.

5.3. Low Carbon Transport (LCT) plans for KMC

As discussed in chapter 1 and 2, Low Carbon Transport plans are those addressing three main strategies, avoid-shift-improve. There is also general consensus that strategies, plans or responses that have been successful in one context may not unfold in the same way in another context. In addition, Dhakal (2006) has advocated the 'rebound effect' of single policy measure during which the positive impact of a policy measure alone is often neutralised by its negative impact. So, depending on local circumstances and priorities of cities, interventions should combine elements from ASI in order to bring optimal impact. Dalkmann (2007) has further identified effective policy instruments for each strategy in the process of categorising available instruments into five groups namely planning, regulatory, economic, information and technological. So to realise substantial reduction in CO2 even within these three strategies, it can be argued that effectiveness of package of policy instruments will be greater as compared to single instrument.

In the commencement of second objective of this research, interviews and secondary data were analyzed for collecting policies/ plans and strategies that address one or more strategies of LCT which are presented below. These plans and policies are either undergoing currently or have been foreseen in future.

5.3.1. Improving public transport system and encouraging shift

Shifting transport demand to low-carbon modes especially public transport has been agreed upon by many authors as one of the successful strategies aimed at reducing GHG emission in most of the developing cities since more people could be transported with less emission per passenger kilometre. So there is need of strong 'push and pull' policies that discourage the use of private modes on one hand and at the same time attracts them towards low carbon modes (David, 2008).

Among five types of policy instruments mentioned above, all the instruments are argued to be effective in bringing shift to non-motorized mode (walking and cycling) and/or public motorized transport (Dalkmann & Brannigan, 2007). It can further be justified that in the midst of challenges of public transport as bad stigma, the package of instruments is effective in improving the patronage of public transport instead of implementing those policy instruments in isolation.

From the information gathered from interviews and KSUT report, improvement of public transport has been identified as most efficient short term measure for KMC. Some initial plans for enhancing public transport system of the city address one or more of above mentioned policy instruments and hence are included in this study.

Delineating primary, secondary routes according to vehicle type: The reorganization of public transport routes addressing planning instrument has been anticipated to improve the efficiency of public transport system by optimizing transport capacity according to the demands. This delineation of public routes as primary and secondary routes, which in current situation are being used by both high speed and slow moving vehicles, is expected to overcome the problem of mismatch between vehicle type and road, gain in speed and reduction in congestion. The primary routes are assigned to large buses, approximately 12 metres in length with estimated capacity of 100 passengers including standing. The secondary routes are assigned to 9-10 metres long minibuses with capacity of 60 including standing passengers. Even though transfers between primary routes and secondary and tertiary routes pose disadvantage to the user but such inconvenience could be minimized by providing user-friendly terminals and scheduled public transport. Moreover, fare system should be rationalised by establishing different multi mode ticket system and the project has highlighted on the need of technology instrument in the form of smart card technology for implementing sophisticated and complex fare structure for users' benefits.

Dedicated bus lanes with integrated system: The successful cases of BRT could be taken as examples where the performance of public transport system could further be enhanced by planning dedicated bus lanes or assigning some routes as bus only lanes along with integrated system of fare, clean vehicle environment and terminals, scheduled bus system.

Restriction of private modes to central part of the city: As for 'push and pull' policies, in addition to increasing patronage of public transport, this regulatory instrument helps in managing transport demand of central part of the city on one hand and encourage people to shift from private modes to public transport.

Incentives and tax reduction policies for public transport: As an economic instrument, provision of incentives for public transport users strengthens patronage of public transport whereas tax reduction policies of government on import of public vehicles attract private investors and boost the likeability of public private partnership in development of sustainable Low Carbon Transport.

5.3.2. Renewal of trolley bus system

Even with the potential of hydropower plant for electricity generation, the government owned trolley bus system got shut down completely in 2004. Though no clear reasons have been forwarded, but according to views of experts, political circumstances, poor organisation as well as weak patronage of the system were the reasons of demise of the system. Further reasons for inability to attract passengers were assumed as low speed of the vehicles with limited and inconvenient routes.

The project plan proposes renewal of trolley bus system in some of the existing routes as well as expanding it into new routes with improved technology and performance of the system. Hence addressing shift strategy, planning instrument plays a significant role in identifying potential routes whereas with improved strategies the efficiency of newly proposed vehicles could be improved. Further, economic instrument for promoting low emission vehicles are becoming more effective in combination with regulatory instruments.

5.4. Conclusion

The reasons behind the unsustainable transport system are to a large extent similar in most of the developing cities which are; increasing income and motorization, bad public transport image, poor driving behaviour, lack of strong institutional laws and rules and inequitable sharing of transport modes. So, it has become essential to implement sustainable Low Carbon Transport plans and move ahead in Low Carbon Development. However, with the notion of *'common but differentiated responsibility'* in climate change arena; depending on local context, priorities and capability; cities should recognize sustainable Low Carbon Transport plans which are feasible to local context, acceptable by general people and economically viable.

For KMC, currently undergoing project supported by ADB has recommended some important measures, policies and plans to deal with this problem. Based on ASI strategy for Low Carbon Transport along with local circumstances, package of instruments for improving public transport patronage (shift) and renewal of trolley bus system (shift and improve) have been chosen for evaluating their contribution to low carbon and development in terms of their accessibility impact.

Accessibility being function of integrated land use and transport components, decisions only on transport or land use component might not improve accessibility. Similarly, though theoretically the above chosen plans and policy package address LCT strategy, but due to rebound effect, spatial component of such plans and various other factors such as mode share, fuel economy, increasing travel demand; their effects may become negligible.

Hence the upcoming chapters describe different scenarios that study the impact of those plans followed by their analysis regarding quantification of carbon and accessibility impact by using planning support system.

6. SCENARIO DEVELOPMENT

As discussed in chapter 2, there are many definitions and typologies form around scenarios and there are different approaches to scenario planning. Following the formal approach proposed by Mahmoud (2009) and adopting the definition of scenario proposed by Engelen (2000), this chapter describes the explorative scenarios for selected Low Carbon Transport plans for KMC in which the impacts of those plans are tested under the effects of external forces that are imposed to the system. These forces are usually not under control and hence are the driving forces of scenarios whereas the plans/policies are controllable variable of scenarios. The following sections describe qualitative and quantitative description of drivers of scenarios, policies in base year and identified LCT plans.

6.1. Drivers of scenarios

The drivers of scenarios are the external variables of the system which are usually not under control and on which the policy makers have little or no influence. From the interviews and documents, main driving forces were identified which are grouped into two and discussed as below.

6.1.1. Urbanization and population growth

Urbanization has become a dynamic and ongoing process worldwide in recent years and it is most dominant in developing countries. As such, Nepal is also facing rapid urbanization with most of the population residing in urban areas which are metropolitan and sub-metropolitan areas. In the 1990s, according to Thapa & Murayama (2010) the rate of urbanization in Nepal was 6.6% per annum. But as stated by Dhakal (2006) most of this growth could be argued to have taken place in Kathmandu since it is the capital city, main political and administrative centre and economically viable urban areas.

Along with urbanization, the city is facing an increasing population. The statistics has shown that between 1991 and 2001, population of urban area of the city has increased with 7.6% per annum. It is much higher than national average of 2.24%. Besides natural growth, migration from rural to urban areas is assumed to be one of the major factors for this rapid growth.

However, compared to census 2001, the average annual growth of population in the country in a decade has decreased from 2.24 percent to 1.4 percent in 2011 (CBS, 2011). This decrease is attributed to large number of absent population who are abroad for seeking jobs and study. Though there is substantial decrease in population growth rate in a decade, the statistics show that growth rate of 4.56 percent in Kathmandu district is still highest among 75 districts.

6.1.2. Increase in income, motorization and technology improvement

The census shows that Kathmandu has the highest number of population living abroad which has been major contributing factor for significant increase in GDP at the national level from 0.12 percent in 2001/02 to 3.48 percent in 2010/11. This increase in income has made people capable owning private vehicles. Thus, the vehicle number of the valley is increasing at the rate of 15 percent as shown in graph 1 in chapter 3.

Even though there has been an increase in motorization, public vehicles still form minimum share in total vehicles whereas two wheelers form the greatest share. According to Dhakal (2006), in 2004 though public transport met 57% of travel demand, they constituted 1.4% of vehicle composition whereas two wheelers met only 25% of travel demand and constituted 71% of vehicles. The recent study by Bajracharya (2010) shows modal share of public transport for work and study purpose to be 52.8% whereas it is 40.7% for two wheelers.

The changing lifestyle with increase in income, easy credit terms, affordability and their increasing popularity among young generation have contributed in rising trend in number of two wheelers. Additionally the image of public transport of the city as unreliable, unscheduled with overloading and uncomfortable environment has made people to shift to other alternatives which are two wheelers. The day to day innovations and improvement in technology, increasing income of people has made them capable of affording technologically efficient transport mode causing positive impact on fuel efficiency.

6.2. Policies and plans

These are the variables which are under control of policy makers and can be influenced in real world. The following sections describe the storyline of existing policies and situation in base year, selected LCT plans/policies as well as their influence on different parameters of conceptual model in section 4.3.

6.2.1. Existing policies in the base year and the baseline in 2020

Some policies regarding vehicle fitness and fuel efficiency are present in the current situation or the base year. Dhakal (2006) has highlighted on some policies, their effectiveness and challenges associated with them; which are still assumed to prevail in the base year. For controlling emission, green stickers are provided to vehicles operating inside ring road and spot checking of emissions is done by traffic police under DoTM. After 2002 due to the government policy, registration of two strokes two wheelers were banned and the work out on enforcement of scrapping of vehicles of greater than 20 years were started in 2004 which is still being pressurized by transport entrepreneurs. The introduction of emission standards for new vehicles equivalent to EURO-I (Nepal Vehicle Mass Emission Standard, 2056) was effective since 2000 and since then it has not been updated even though the neighbouring country, India from where the country import vehicles as well as fuels, has gone to EURO-IV. However, new transport policy has advanced need of upgrading emission standard to EURO-III so as to prevent the degradation of efficiency of vehicles due to import of lower efficient vehicles and poor quality fuel. But the country still lacks stringent emission standards for in-use vehicles.

Though, there has been some improvement due to the above policies, the city is facing emission management challenges. Many challenges have been listed out by Dhakal (2006); increasing number of two wheelers, improper maintenance of public vehicles, overloading, poor road and transport infrastructure, weak enforcement of emission test with low non-compliance fee and corruption, tampering of carburettors and injection pump, poor quality fuel are some of the major causes of inefficiency of vehicles. Moreover, during interaction programme between transport entrepreneurs (NADA) and government held on 2010, transport entrepreneurs had argued on scrapping of old vehicles, upgrading of EURO standard, increasing engine size as not the ultimate solution. The proper establishment of vehicle fitness test centres and proper maintenance of vehicles, good fuel quality and above all enhancing public transport usage have been advocated as the long term solution.

The situation is still worsened by the absence of land use plan due to which current urbanization is taking place in a non planned way, which is putting pressure on transport infrastructure resulting in exceedance of carrying capacity. Though mixed land use and compact city can reduce travel distance theoretically but improper planning and management has affected transportation of the city as in the case study area.

For the baseline scenario in 2020, considering GDP growth of 5%, it is estimated that growth in traffic will be 8.75% per annum from 2010-2015 for public transport, car and motorcycles and 8.5, 7.5 and 5.0% per annum respectively from 2016-2020 (MoPPW & ADB, 2010). This shows that in 2020 the composition of private vehicles is likely to be changed and the largest share of two wheelers presently would be overtaken by cars/jeeps in 2020.

Even though two wheelers would be less as compared to public transport in 2020, assuming that their popularity would still continue to remain among youths and without any initiation in enhancing public transport patronage, strong enforcement of laws and orders and strong polices on 'push and pull'; current share of 52.8% by public transport and 40.7 % for two wheelers will continue in the future. The present mode share among public transport; small occupancy vehicles (micro bus and tempo) with 47% and 13% respectively and high occupancy vehicles (minibuses, buses) with 31% was also assumed to be same for the baseline scenario.

The fuel efficiency estimated by Dhakal (2006) for 2004 and MoPPW & ADB (2010) for 2010 has shown little variation. These variations can be justified with many factors such as vehicle technology, road condition, timely maintenance and inspection and policies such as phasing out old vehicles, implementation of higher EURO-standard in India. Since vehicle technology is improving worldwide and with rising income people would be more capable of affording efficient vehicles along with enforcement of some of the policies on fuel efficiency, improvement of 20% was assumed in fuel efficiency. This improvement was also assumed according to the target of India for 2020 since large number of vehicles and fuel are imported from there.

6.2.2. Low Carbon Transport (LCT) plans

The description of the chosen LCT plans was presented in section 5.3. This section describes the interpretation of those plans in term of some of the variables of conceptual model in figure 11.

6.2.3. Increased public transport patronage

Various plans and policies directed to 'push and pull' and complementing each other with same objective of enhancing public transport patronage was considered in this policy. With route reorganization, the existing problem of low average speed and congestion, mismatch between vehicle type and road is anticipated to overcome. Thus, higher occupancy large buses will be assigned to primary routes, minibuses to secondary. Moreover, providing dedicated lanes on primary routes, performance of large buses in terms of punctuality, reliability and average speed would be greatly enhanced.

With such improvement, average waiting time is expected to be 3 min in each stop (MoPPW & ADB, 2010). In contrast to average speed of 20 kph in current situation for all types of vehicles, with project implementation the average speed of vehicles is expected to be 25 kph as a conservative estimate in KSUT report whereas with dedicated bus lanes, proper traffic management, speed of large buses in primary routes is assumed to increase to 40 kph (Dhakal, 2003). In order to make public transport more attractive, by managing demand and supply, average occupancy of vehicles is assumed to decrease by 15% to create comfortable environment inside the vehicle. Hence, with these assumptions, the mode share for public transport in 2020 is estimated to be increased by 20% following KSUT report. This increase will be compensated by simultaneous decrease in mode share of private modes which are two wheelers in this study. Due to delineation of route, there will be need of interchange of vehicles from primary to secondary and tertiary. However, such interchanges will be made convenient by providing user friendly terminals, scheduled arrival and departure of vehicle as well as convenient interchange spots

The fuel efficiency and emission factors are influenced by many factors with on road average speed of vehicle, type of vehicle, road condition as well as policies. For this scenario improvement on fuel efficiency is assumed as 20% as those in the baseline scenario. Thus, quantitative value of above discussed variables and assumptions applied in model for this scenario is summarized in annexe.

6.2.4. Renewal of trolley bus system

In 1972, trolley bus services were established in Kathmandu as the government operated services in an interurban route between Kathmandu and Bhaktapur. Later it was limited between central of KMC and ring road and the service was totally ceased in 2008. One of the reasons that have been advocated is poor organization of the system.

Under the scenario of renewal of this system, few primary routes of previous plan have been identified as potential routes for trolley bus by KSUT plans. Thus, in these routes, trolley bus system will be in operation with dedicated lanes. The plan further addresses import of new trolley bus which is technologically more efficient than the older ones resulting in average speed of 40 kph as those of larger diesel buses.

Since trolley bus is operated with electricity, it is regarded as clean vehicles and the emission of the system is calculated based on the grid emission factor. In the case when there is no emission during generation of electricity, it is regarded as zero emission vehicles. Also, the country has potential of hydropower plant. Thus, with coordination of Nepal Electricity Authority, the trolley bus system will be operated with electricity from hydropower making this system sustainable. There will be an involvement of private sector for operating the system. With strong regulatory instrument as well as economic instrument of incentives and taxes, this system will be able to attract passengers.

6.2.5. Penetration of trolley bus system along with PT improvement plans

This scenario considers penetration of trolley bus system along with PT improvement plans. Based on number of trolley buses, it is estimated that it will be able to meet 20% of travel demand in 2020. Thus, 20% of modal split of large buses on primary routes will be shared by trolley bus. The remaining assumptions on average occupancy, fuel efficiency, emission factors will be as those of PT improvement plans.

6.3. Definition of scenarios

To investigate the effect of the chosen LCT plans and policies on accessibility of people to opportunities and related carbon emissions during that service, different scenarios were constructed under various assumptions with respect to the driving forces As discussed earlier, there are many driving forces which could shape future differently and the chosen LCT plans could show their impact differently. But developing scenarios for all possible drivers and in all possible directions would be difficult to accomplish and to communicate (Westhoek et al., 2006). Since the definition of accessibility in this research was operationalized as how many more people would be served by the new plans or the new system, uncertainties on future growth of population would yield different result. Thus, with the combination of low and high population growth rate and selected policies and plans, following scenarios were constructed.

The time horizon considered for all the constructed scenarios was 2020 according to ADB's transport strategy.

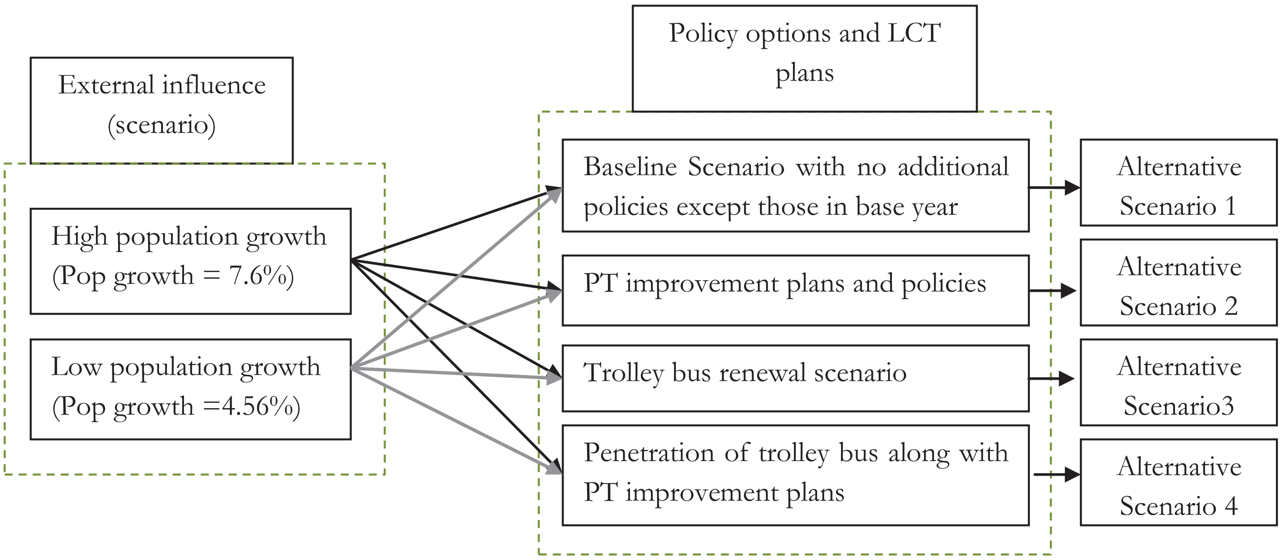


Figure 19 Combination of drivers of scenarios and LCT plans

For the analysis of service accessibility across all the scenarios, current location of 151 higher secondary schools and colleges were considered to be same in 2020. As discussed in section 2.3, accessibility to schools and colleges is one of the enabler for broadening the capabilities of young people. Moreover, access to education widens the horizon and provides freedoms for young generation so that they can seek socio-economic opportunities and ultimately contribute in the sustainable development of the city. The scenarios consider no intervention in land use planning and current mixed land use with dispersed facilities would remain unchanged in 2020. By improving capacity of existing facilities same number of facilities would be sufficient for increased population.

7. RESULTS AND DISCUSSIONS

This chapter presents the quantitative results of each scenario that were developed in earlier chapter, in the form of maps and charts. The results are then followed by a discussion on those scenarios, their potential towards Low Carbon Development and the modelling framework in the PSS.

7.1. Results on scenarios

7.1.1. Low population growth in 2020

The first scenario considers a low population growth of 4.56% in each ward of the city based on current census of 2011. The table in annexe summarizes the assumptions of key drivers of scenarios and other variables in the model.

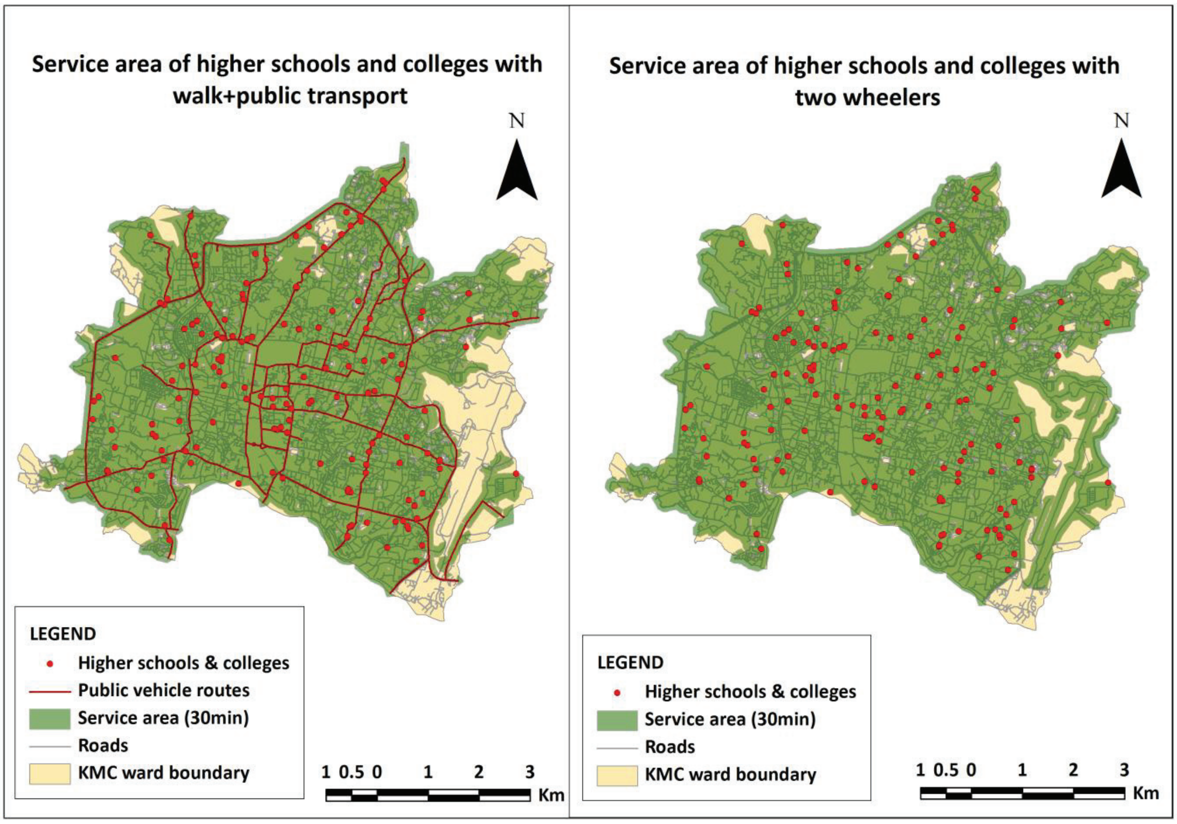


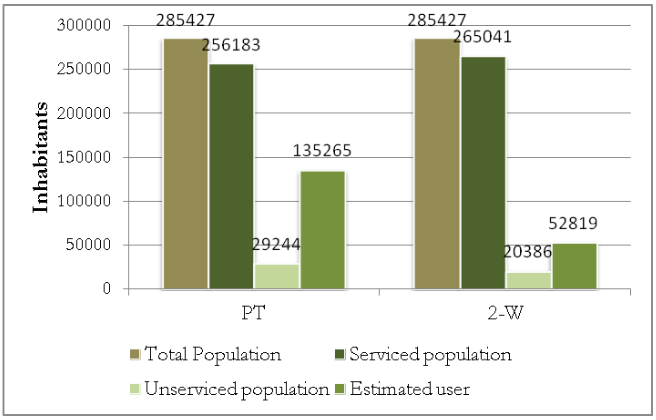
Figure 20 Map showing service area by public transport + walk and two wheelers within 30 min from facilities (higher schools & colleges) for baseline scenario in 2020

7.1.1.1. Alternative scenario 1(Baseline scenario)

Figure 20 shows the service area accessibility of higher schools & colleges (facilities) for KMC within 30 minutes of travel time by using two different modes; public transport (PT) with walk combination (left side) and private transport which is two wheeler in this case (right side). With 151 facilities distributed in the city and overlaps between routes over the different types of public transport (minibus, microbus, gas tempo and electric tempo); providing mode choices to population; most of the areas of the city are accessible within 30 minutes of travel time by public transport (without congestion). In this case improvement on the accessibility by two wheeler can be seen minimal and mostly on the south eastern part and periphery of the city.

Graph 2 shows the total population, inhabitants that fell inside 30 min of travel time from the facilities and estimated users for each mode in 2020

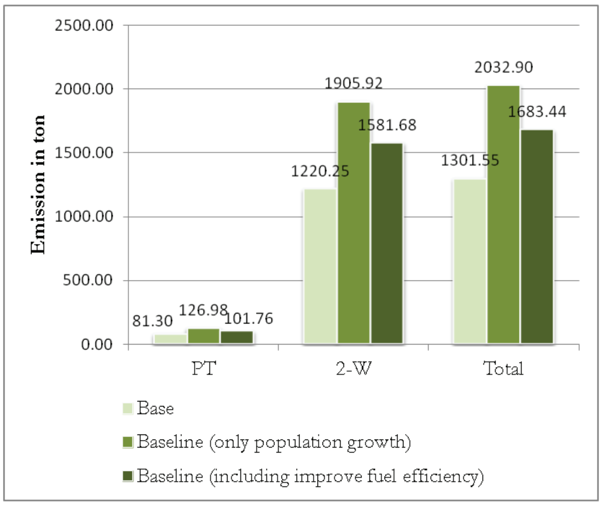
It can be seen that out of the total population, the majority of people could reach at least one of the facilities within 30 minutes using PT as mode of transport whereas 2W could improve the accessibility of additional 6800 people.



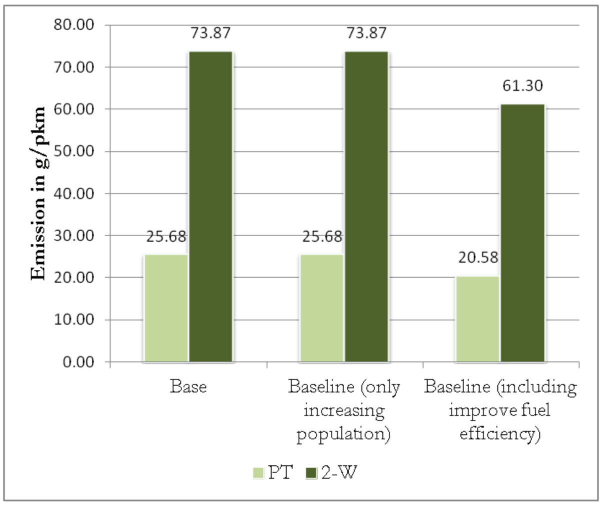
Graph 2 Total population, population served by PT & 2W and estimated user of each mode in 2020

The potential users of PT as explained in section 4.4 were those people who can reach the destinations within the assumed travel time by using PT whereas estimated users were derived according to assumed value of the mode share of 52.8% for public transport. For the case of 2W potential users considered were those additional people who should use 2W to reach the destinations along with those people who did not use PT even though they were provided opportunities by PT. Finally, the estimated users of 2W were derived by assuming the value of mode share of 40.7% out of the potential users of 2W. With the higher number of people being served by public transport, the estimated users of PT have come 2.5 times higher than that of 2W.

The baseline scenario considers projection of current situation for the future. In the face of rapid vehicle technology advancement and increasing income level of people along with the strong enforcement of some of the policies of the base year regarding vehicle technology and fuel efficiency, the baseline scenario for 2020 assumed 20% improvement on fuel efficiency. The vehicle occupancy rate and emission factors for the baseline scenario were considered same as in the base year which is given in annex.



Graph 4 Emissions in ton for the base year and the baseline with and without fuel efficiency in 2020



Graph 3 Emission in g/pkm for the base year and the baseline with and without fuel efficiency in 2020

Graph 3 shows the total emissions while graph 5 shows the emission in g/pkm in the base year and the baseline scenario for 2020 for both modes (PT & 2W), with and without considering technology improvement. It can be seen that even with this improvement in vehicle technology, emissions in the baseline scenario for modes, PT and 2W, would still be higher compared to the base year. But this vehicle technology improvement and hence the fuel efficiency, would be able to decrease the emissions in each passenger km for both modes.

7.1.1.2. Alternative scenario 2(PT improvement scenario)

Figure 21 below shows the service area of higher schools and colleges in KMC within 30 minutes of travel time in 2020 after implementation of LCT plans for improving public transport patronage.

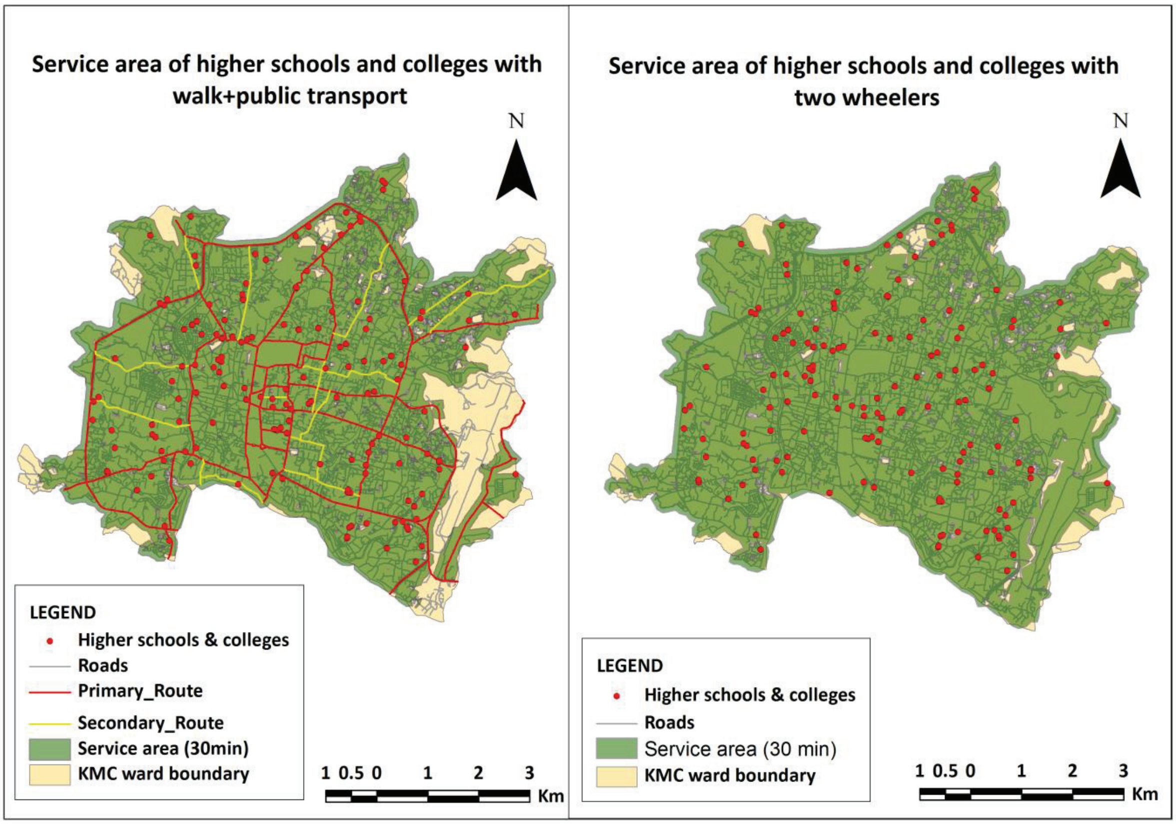


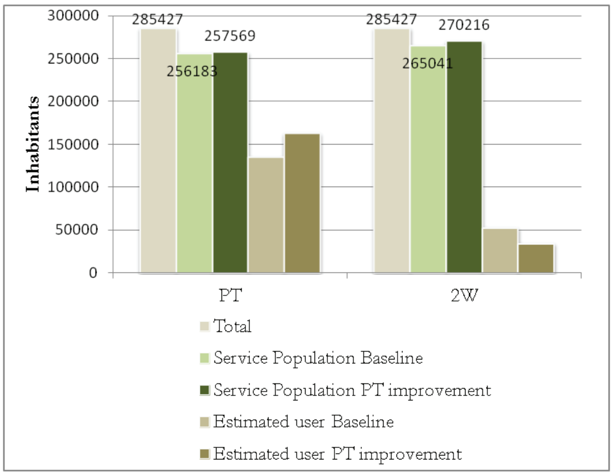
Figure 21 Map showing service area by public transport + walk and two wheelers within 30 min of travel time from facilities (higher schools & colleges) for improved public transport in 2020

The result showed that as compared to the baseline scenario in 2020, the implementation of this LCT plan would not hamper the accessibility of people to schools and colleges. Instead some of the areas in periphery of the city would be benefitted with this plan. On the other hand with the rebound effect of less congestion, it was estimated that the average speed of two wheelers would also be improved and was assumed to be 25 kph as those of the public vehicle in secondary routes. Hence this would result in an increase in the accessibility of south eastern part of the city by 2W.

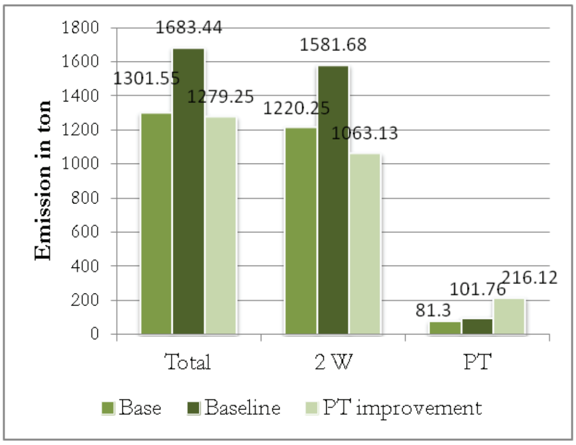
The following graph 5 shows the comparison of improved public transport patronage with baseline scenario for the number of potential population that fall inside the contour of 30 min travel time and the estimated users of two modes, PT and 2W

In addition to 256,183 people served in the baseline by old system, PT improvement plans would be able to provide access to about 1300 more people whereas with the use of 2W about 5100 more people would be able to reach the destinations in addition to 265,041.

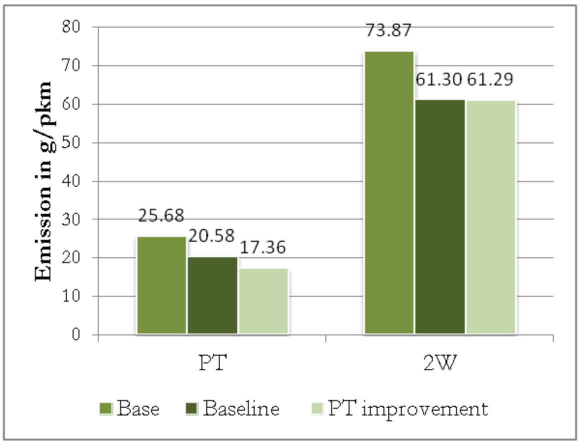
Due to a lack of the information on possible modal shift of people to the improved transport system, assumption on the future mode share was taken from KSUT report. Under the assumption of 20% increase in mode share of PT against the baseline which comes with the reduction by same percent from 2W, there would be an increase in estimated users of PT and decrease in 2W as shown in graph 5.



Graph 5 Comparison of population within 30 min of travel time with PT improvement plan against baseline and estimated user for each mode



Graph 6 Comparison of emission in ton in total and for each mode for PT improvement plans against the base year and the baseline in 2020



Graph 7 Comparison of emission in g/pkm for each mode for PT improvement against base year and baseline in 2020

Graph 6 and graph 7 show comparisons of emissions and emission per pkm for PT improvement plans against the base year and the baseline in 2020 for each mode under low population growth.

With PT improvement plan, assumption was made that there would be increase in average speed of vehicles, 40 kph in primary routes and 25 kph in secondary routes. No further improvement on fuel efficiency and emission factors was assumed and hence the values considered were the same as that of the baseline with improved fuel efficiency. It resulted in an increase in the emissions from public transport against the base year as well as against baseline as shown in graph 6, but the decrease in emissions in total as well as for 2W against both the base year and the baseline. The result on carbon intensity as shown in graph 7 shows the decrease in emission per pkm against both the base year and the baseline in 2020 for each mode.

7.1.1.3. Alternative scenario 3(Renewal of trolley bus system)

Figure 22 below shows the service area of higher schools and colleges in KMC within 30 minutes of travel time in 2020 after trolley bus renewal in some of the chosen primary routes.

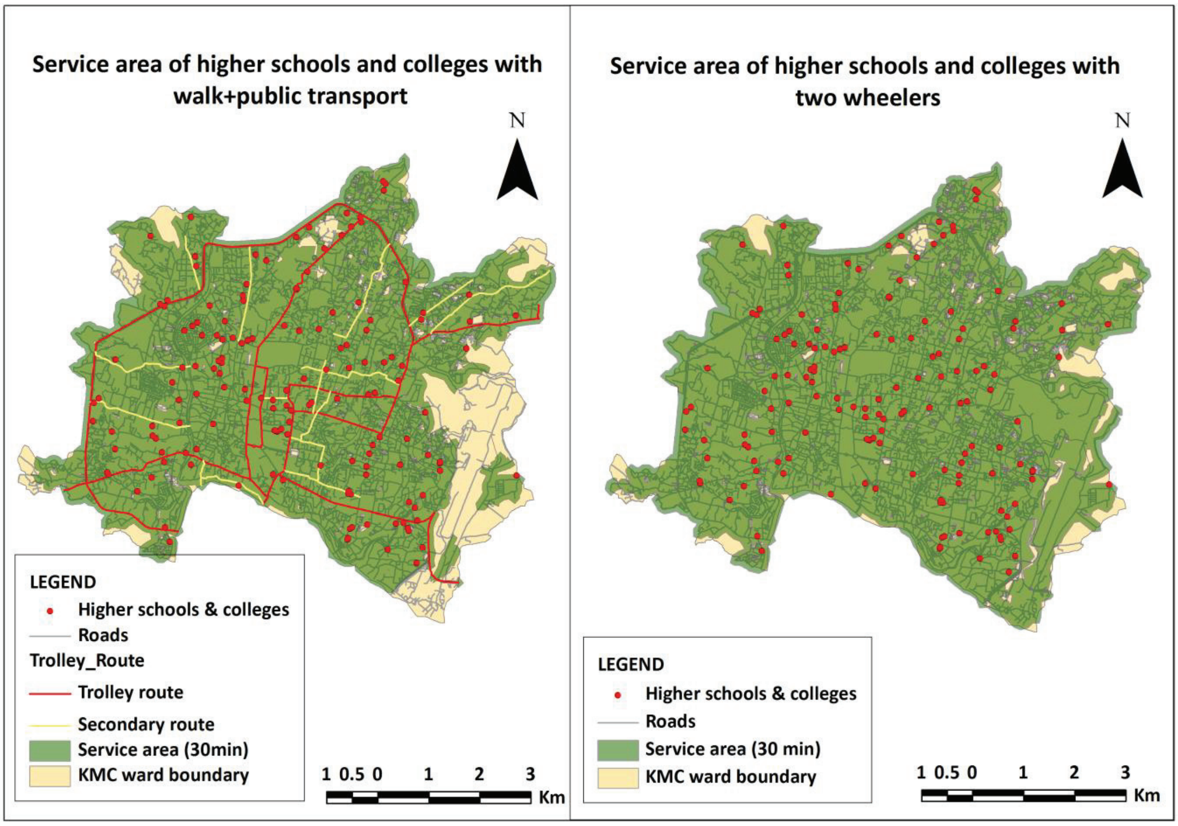
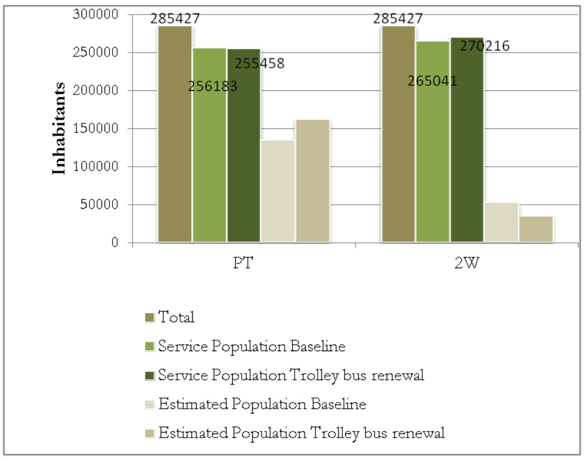


Figure 22 Map showing service area by public transport + walk and two wheelers within 30 min of travel time from facilities (higher schools & colleges) for trolley bus renewal plans in 2020

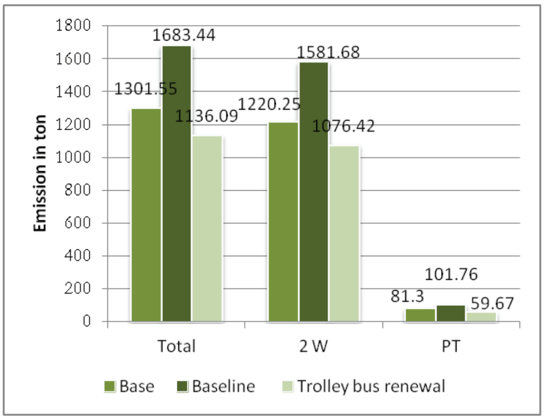
In the replacement of large buses on primary routes, this scenario considered the renewal of trolley buses. Some of the primary routes were chosen for operating trolley bus which would have similar performance in terms of speed as that of large bus. This scenario also assumed the need of interchange between primary and secondary routes with average waiting time of 3 min. In terms of speed, average speed of 40 kph was assumed on primary route and 25 kph for secondary. The result of this scenario shows some decrease in service area mostly in the south eastern part of the city for PT whereas for the two wheelers with consideration of increase in speed against the baseline, there would be some increase in service.



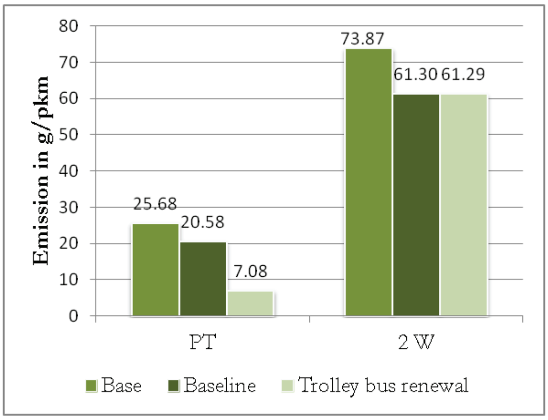
Graph 8 Comparison of inhabitants within 30min of travel time for trolley bus renewal against the baseline in 2020

Graph 8 shows the comparison of the number of inhabitants that fall inside the above service area of higher schools & colleges against the baseline and the estimated user for modes, PT & 2W. It can be seen that out of 256,183 people served by old system, about 700 people who were able to reach to at least one of the facilities within 30 min of travel time in the baseline with old transport system would not be able to reach the facilities using the new system. But with the assumption on increase in speed of 2W, 5000 more people would have access in addition to 265,041. Under the assumption of increase in ridership of new system by 20%, the result of estimated users show s an increase for PT whereas a decrease for 2W

Graph 9 shows the comparison of total emission and emission for each mode against the base year and the baseline whereas graph 10 shows the comparison of carbon intensity for each mode against the base and the baseline.



Graph 10 Comparison of emission in ton in total and for each mode for trolley bus renewal against the base year and the baseline in 2020



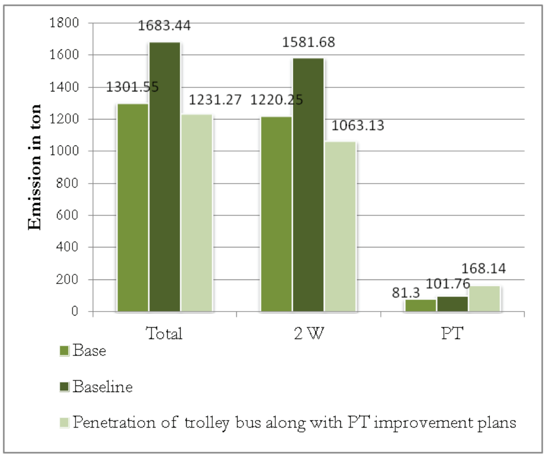
Graph 9 Comparison of emission in ton in total and for each mode for trolley bus renewal against the base year and the baseline in 202 Comparison of emission in g/pkm for each mode for PT

The replacement of large buses operating on diesel by trolley bus which was assumed to be zero emission vehicles resulted in decrease in total emission against both the base year and the baseline under low population growth. Considering an increase in ridership of PT by 20% and subsequent decrease for 2W and assuming same values for other components of ASIF framework such as fuel efficiency and emission factors of minibuses in secondary routes and 2W; this scenario show a decrease in total emission and emission per pkm for each mode against both the base and the baseline in 2020 as shown in graph 9 and 10 respectively.

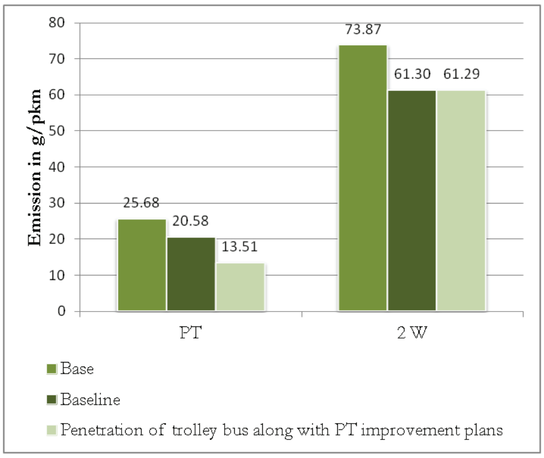
7.1.1.4. Alternative scenario 4(Penetration of trolley bus system along with PT improvement plans)

This scenario considers combination of alternative scenario 2 and alternative scenario 3. Along with PT improvement plans, penetration of trolley bus in vehicle fleet of large buses on primary routes was considered in this scenario. The performance of trolley bus in terms of speed, average occupancy was considered to be the same as that of large bus. But with lesser number of vehicles in operation, according to conservative assumption of KSUT, it was estimated that trolley bus would meet 20% demand of that of the large bus on primary routes in future. In this situation, it was assumed that 48.36% of potential user of PT would use large bus whereas 20% would use trolley bus making the whole share of PT in 2020 to be 68.36%.

Since, this scenario considered penetration of trolley bus in vehicle fleet of large buses, service area coverage of facilities would be the same as shown in figure 21. Hence the number of people that would be provided with access to reach at least one of the facilities within 30min of travel time along with the estimated users of each type of mode would also be the same as shown in graph 5. Graph 11 and 12 show the comparison of total emissions and carbon intensity respectively against the base and the baseline for both modes when there would be penetration of trolley bus system along with PT improvement plans



Graph 11 Comparison of emission in ton in total and for each mode for PT improvement against the base year and the baseline in 2020



Graph 12 Comparison of emission in g/pkm for each mode for trolley bus renewal against base year and baseline in 2020

Addressing improve strategy, this penetration would lead to decrease in total emissions. However, meeting 20% ridership by trolley bus which was assumed as zero emission vehicles, emission from PT would still be higher as compared to the base and the baseline whereas emission from 2W would be less as a result of a decrease in share as shown in graph 11. On the other hand, there would be reduction in emission per pkm for both modes as shown in graph 12.

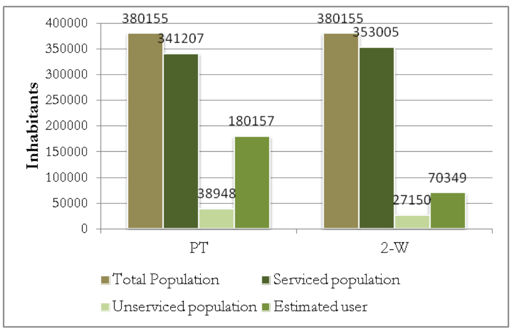
7.1.2. High population growth in 2020

This scenario considers high population growth of 7.9% for each ward according to the growth rate of 1991-2001.The same assumptions on land use and transport components as those in the alternative scenarios of low population growth scenario, resulted in the same catchment area of each facility. So the influence of population growth rate was expected to have on number of people that are provided with access to facilities and the related emissions during that service. Moreover, each alternative scenario under this high growth scenario assume the same assumptions on modal share in future, average occupancy, fuel efficiency and emission factors, as those of alternative scenarios under low growth. The following sections summarize the result on impact of chosen LCT plans under this scenario

7.1.2.1. Number of people serviced in alternative scenarios during high population growth

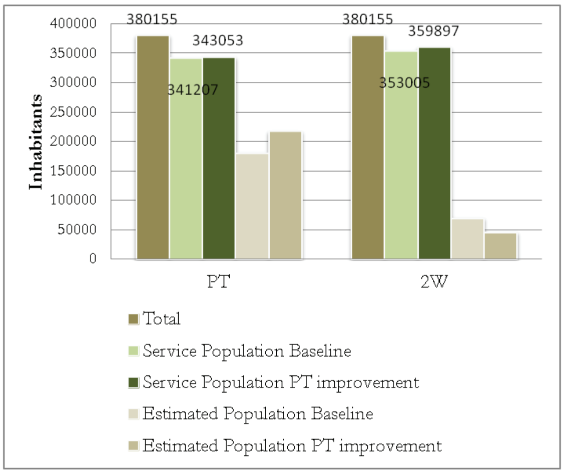
Graph 13 shows the inhabitants that fall within 30 min of travel time in the baseline in 2020 and estimated users of mode.

Graph 14 and 15 shows the comparison of population served by PT improvement plans and trolley bus renewal plans against the baseline in 2020 under high population growth.

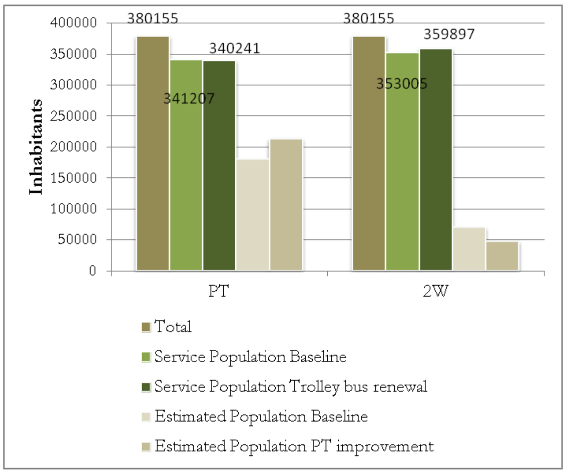


Graph 13 Total population, population served by PT & 2W and estimated user of each mode within 30min travel time in the baseline in 2020

In addition to 341,207 people served in the baseline, PT improvement plans would provide access to about 1800 more under high population growth scenario whereas 900 people would not be able to reach the facilities with trolley bus renewal plans. In all the cases, accessibility provided by 2W would be higher as compared to public transport.



Graph 14 Comparison of population within 30 min of travel time with PT improvement plan against the baseline and the estimated users for each mode in 2020

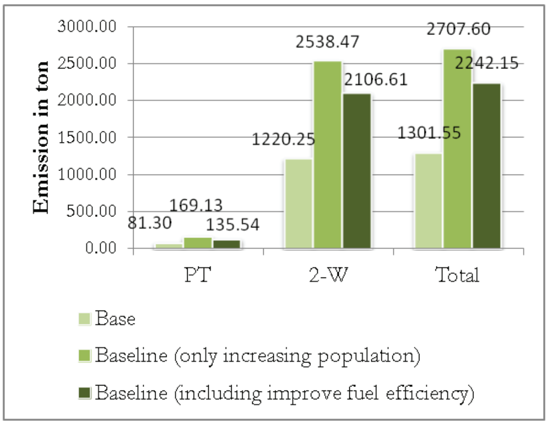


Graph 15 Comparison of population within 30 min of travel time with trolley bus renewal plan against the baseline and the estimated user for each mode in 2020

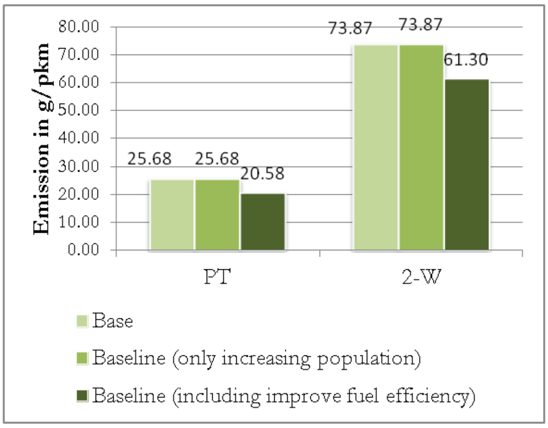
7.1.2.2. Emission in tons CO2 and emission in CO2 per passenger km for each mode in each alternative scenarios during high population growth

The following results show CO2 emission in ton and in g/pkm for alternative scenarios; baseline, PT improvement plans, trolley bus renewal plans and penetration of trolley bus system along with PT improvement plans; under high population growth.

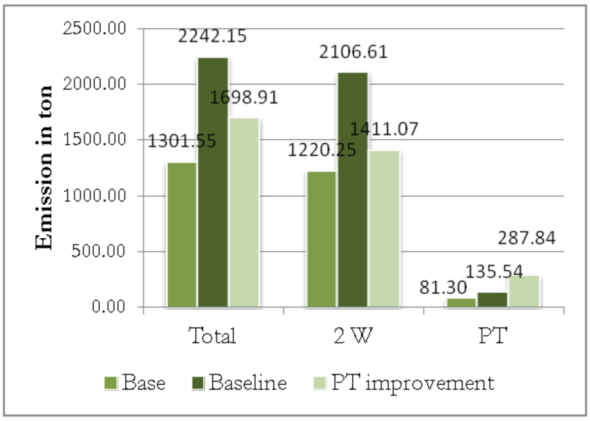
Graph 16 and 17 show the comparison on total emissions, emission for each mode in ton and in g/pkm respectively against base line with and without fuel efficiency for 2020. Graph 18 and 19, 20 and 21, 22 and 23 show the comparison on total emissions, emission for each mode in ton and in g/pkm respectively for PT improvement plans, trolley bus renewal, penetration of trolley bus along with PT renewal; against the base year and the base line for 2020



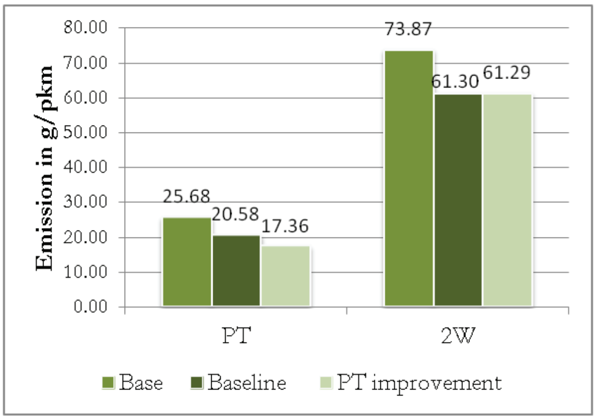
Graph 16 Comparison of emission in ton in total and for each mode for the baseline in 2020 against the base year



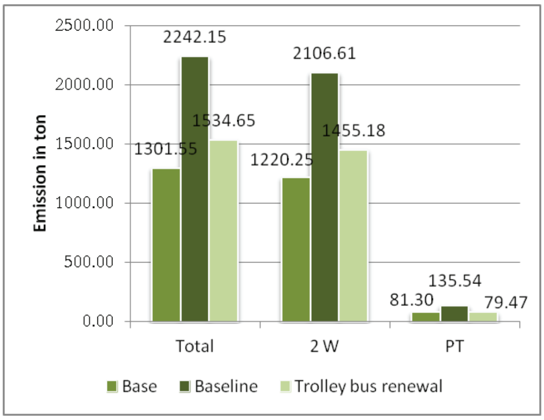
Graph 17 Comparison of emission in g/pkm for each mode for the baseline in 2020 against the base



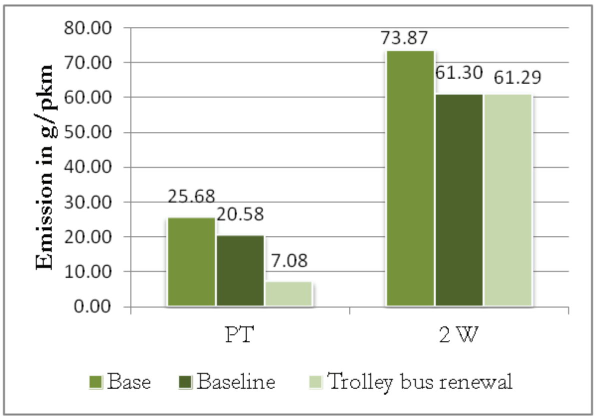
Graph 19 Comparison of emission in ton in total and for each mode for PT improvement against the base year and the baseline in 2020



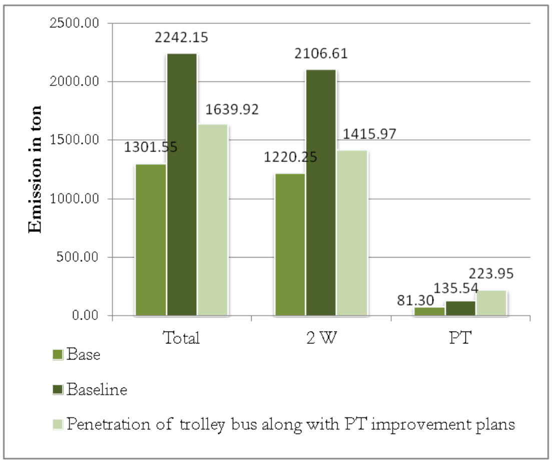
Graph 18 Comparison of emission in g/pkm for each mode for PT improvemnt against the base year and the baseline in 2020



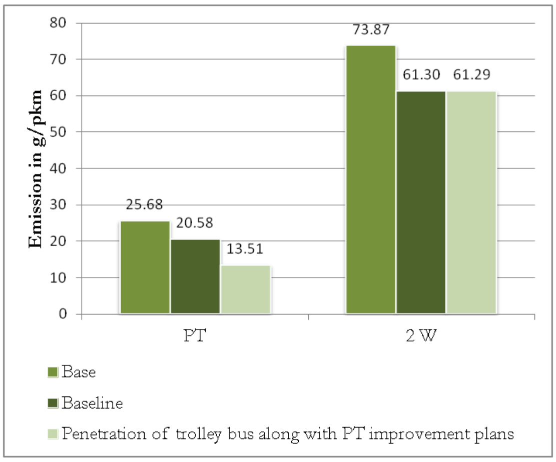
Graph 21 Comparison of emission in ton in total and for each mode for trolley bus renewal against the base year and the baseline in 2020



Graph 20 Comparison of emission in g/pkm for each mode for trolley bus renewal against the base year and the baseline in 2020



Graph 23 Comparison of emission in ton in total and for each mode for penetration of trolley bus along with PT improvement against the base year and the baseline in 2020



Graph 22 Comparison of emission in g/pkm for each mode for penetration of trolley bus along with PT improvement against the base year and the baseline in 2020

Under the same assumptions of mode share, average occupancy, emission factors and fuel efficiency as those used in low population growth scenario, the result in total emission under high population growth show increase for all the LCT plans against the base year whereas against the baseline scenario for 2020, they show decrease in emission. In the case of carbon intensity, the result show decrease for PT with all the chosen LCT plans.

7.2. Discussions

This section discusses on different scenarios and alternative scenarios, assumptions made on the scenarios and their effects on the result, the results on sensitivity analysis of some of the parameters of the model and finally the potential of those chosen plans in Low Carbon Development of KMC, which is the last sub objective of this research.

7.2.1. Data and approach in Community Viz

Accessibility to jobs and employment has been considered in several researches as an indicator for assessing and valuing the benefits of proposed land use and transport plans/ policies in economic development. But there is a lack of information on jobs distribution in KMC. Nevertheless, with wider horizon of development concept forming around Amartya Sen's capability approach as discussed in section 2.3 and arguing on physical accessibility to education is also one of the enablers for developing capability of young people to participate in economic development of the country in future, accessibility to schools and colleges can be argued as an important proxy for assessing the impact of LCT plans on the development of the city. Moreover, most of the daily trips of people in KMC constitute of work and education trips.

Among different level of education (primary, secondary and higher level), schools & colleges offering secondary and higher level education were chosen. It was assumed that students of these age groups are rational decision makers who can make choices on selection of schools & colleges and can commute independently. Further, these are the groups who are being attracted to two wheelers as their mode of transport.

The lack of data on origin and destination of student, their choice of mode and desirable time on travel for education has limited the choice of measure of accessibility to contour measure. In spite of this limitation, the contour measure could still be justified for this study due to its easy interpretability, operationalization, communicability and plainness. However, the soundness of this measure as argued by Bertolini et al. (2005) depends on the chosen cut off time. The modal share of the new system in future is another uncertainty that would affect the result. Thus, it is worthwhile to perform sensitivity analysis of these parameters, which would be presented in section7.2.4.

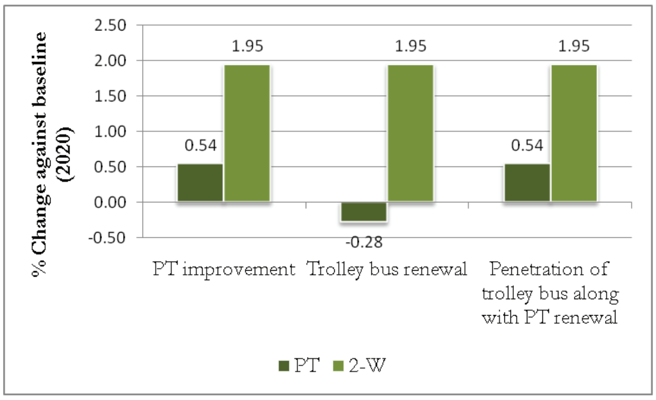
7.2.2. Accessibility impact of LCT plans

The results on accessibility to these schools & colleges in the baseline scenarios under both high and low population growth show that within 30 min of travel time, most of the areas of the city would be accessible from at least one of the facilities (higher schools & colleges), by using either of the mode; public or private. It can be attributed to 151 numbers of facilities dispersed around the city. In addition to higher number of facilities, this result could be argued on various other assumptions made in the accessibility analysis model.

Horak & Sedenkova (2005) have emphasized on adequacy of network model for better representation of accessibility in reality. Thus, all transport flow lines and their characteristics such as one way, two ways, should be included in the prepared network. Besides this, setting up impedance in each segments of road network has been addressed as another challenge that has significant influence on analysis results ((Horak & Sedenkova, 2005; O'Sullivan et al., 2000). According to O'Sullivan et al. (2000) the assumption that vehicle travel at a constant speed and consideration of average speed along whole network might possibly overestimate the speeds in city centre whereas underestimates in other areas of the city. The assumption on waiting time for public vehicle to arrive at stops is another point of simplification in accessibility model. Further congestion is another factor that constraint mobility and hence accessibility.

The network model prepared for this analysis had considered two ways traffic with constant average speed for every road segment and no congestion factor was applied. Due to irregularity in frequency of public vehicles in the city, the average waiting time of 10 minutes was assumed for the baseline whereas based on KSUT report, 3 min was assumed for the new system. Thus, with these assumptions and in the absence of calibration and validation of model for the case study area, there is high probability of deviation of accessibility result from reality. Despite these limitations, since the analysis was done in relative term comparing each scenario with baseline scenario, it could be argued that the results are still valid.

Graph 24 shows the percentage change in number of people served by each chosen plans against the baseline. Under both high and low population growth scenario, service area of facilities with each chosen LCT plans resulted in same catchment area due to the assumptions of same average speed and cut off time. However, .the number of people served during high population growth scenario is high as expected. But the percentage change in population within 30 min of travel time for each chosen plans against the respective baselines of high and low growth, shows the same result as shown in graph 24. This is attributed to uniform growth in density and population for each ward.

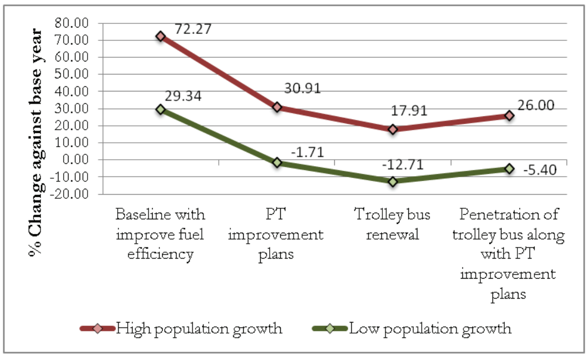


Graph 24 Percentage change against baseline (2020) for number of people served by chosen LCT plans for each mode.

Under both scenarios, PT improvement plans and penetration of trolley bus system along with PT improvement plans would result in 0.5% increase in accessibility against the baseline scenario of 2020 whereas there would be a decrease in accessibility by nearly 0.3 % with the implementation of only trolley bus renewal plans which would be due to absence of few primary routes. The assumption that after some congestion relief, the average speed of 2W would also increase; result in increase in accessibility by nearly 2%.

7.2.3. Emission under each alternative scenarios

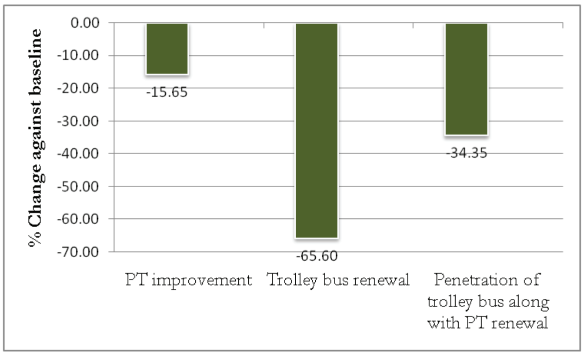
Graph 25 shows the percentage change of the total CO_2 emissions against the base year under both high and low population growth scenarios; for each alternative scenarios; baseline with improve in fuel efficiency, PT improvement plans, trolley bus renewal and PT improvement plans along with trolley bus renewal.



Graph 25 Percentage change in total emission against the base year for chosen LCT plans under high and low population growth in 2020

The baseline scenario only with improvement in fuel efficiency by 20% is clearly not desirable during both high and low population growth scenarios. Under high population growth scenario, there would be an increase in total emission with all the chosen plans against the base year whereas those plans would lead into lower emission as compared to the base year during low population growth. Thus, it has shown that the outcome of emission results heavily dependent upon the assumptions made on modal shift from private to public transport by 20%, improvement in fuel efficiency by 20%.

Even though there would be increase in accessibility by the chosen plans in during high growth, the assumptions on shift would not be suffice to reduce the emission whereas, the same assumptions during low growth scenario would lead to decrease in emissions.

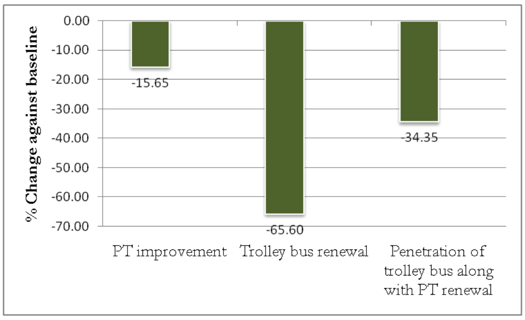


Graph 26 Percentage change of emission against baseline during implementation of chosen LCT plans in 2020

Graph 26 shows the percentage change in emissions against the baseline in 2020 for both high and low population growth scenarios. It shows that with the PT improvement plans, emissions from the new system would increase by 112% against the baseline whereas it would increase by about 65% when there would be penetration of trolley bus system in vehicle fleet along with these plans. The trolley bus renewal plans has shown decrease in emission by 41% for public transport. With all the three plans, the graph shows decrease in emission from 2W by about 33% and in total highest reduction gain could be seen in trolley bus renewal (33%), followed by combined package i.e. penetration of trolley bus along with PT improvement plans (27%) and PT improvement plans (24%).

More accessibility means more people would be able to take part in activity which increases travel demand. In addition to it, with PT improvement plans, it was assumed that the modal share of public transport would increase by 20% from the baseline which increases the users of PT. Further, in contrast to the baseline scenario where people would have choices on different types of public modes and where modal split would determine travel demand of each type of mode; due to delineation of primary and secondary routes in PT improvement plans, it had been assumed that people would need to interchange between these routes. This would lead to increase in total travel demand in pkm for public transport resulting in increased VKT to reach to destinations. This increase would further be resulted due to construction of some new routes, both primary and secondary where large buses in primary and minibuses in secondary using diesel as fuel would be in operation. But with the same assumptions of public transport activity, mode share, average occupancy, fuel efficiency, emission factors as that in PT improvement plans, penetration of trolley bus system on primary routes and meeting 20% of ridership of large buses, would cause only 65% higher emission against the baseline since trolley bus was considered as zero emission vehicle. On the other hand the reduction in emissions from public transport in the case of trolley bus renewal would be caused by decrease in accessibility of people by the new system as well as meeting travel demand by zero emission vehicles. Since increase in modal share for public transport was assumed to be compensated by subsequent decrease in modal share of 2W, there would be reduction in emission from 2W.

Graph 27 shows the percentage change in carbon intensity (g/pkm) against the baseline. It is noticeable that the variation in carbon intensity could be seen only for public transport which has been brought about due to the share of pkm by energy efficient trolley bus. But, under the assumptions of same average occupancy, fuel efficiency and emission factors for 2W in all the plans, the result show no change in carbon intensity. Further, it can be seen that the greatest reduction in carbon intensity would be with trolley bus renewal plans which would be at the expense of lower accessibility. As compared to PT improvement plans, penetration of trolley bus along with PT improvement plans would halve the carbon intensity for public transport.



Graph 27 Percentage change of carbon intensity against baseline during implementation of chosen LCT plans in 2020

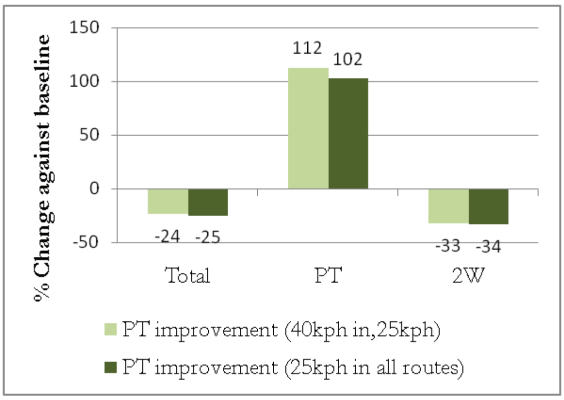
7.2.4. **Sensitivity analysis**

The following sections discuss the sensitiveness of the result with respect to speed, mode share and cut off travel time for some of the chosen plans under low population growth scenario.

7.2.4.1. Change in speed

Travel time was considered as impedance in network, so the average speed of vehicles considered in the network was one of the critical parameters. Moreover, it had been assumed that one of the effects of implementation of the LCT plans would be on improvement in average speed of vehicles which would result in change in the accessibility of people. Since, primary routes form large part of public vehicle routes, sensitivity analysis with the change in speed was done considering lower speed for these routes. Graph 28 and 29 shows the percent change in number of people served and related emissions under different assumptions of speed.

Graph 29 Percentage change in number of people served in 2020 against baseline with consideration of different speed for PT improvement plans

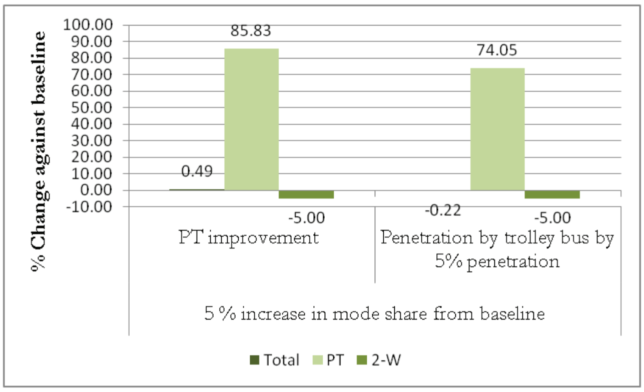


Graph 28 Percentage change in emission 2020 against baseline with consideration of different speed for PT improvement plans

It can be seen that change in the average speed has influence on potential population. However, within this limit of change in speed, the LCT plans would still result in higher accessibility as compared to the baseline. In the case of total emissions under both assumptions, there would still be reduction gain even though there would be change in amount of reduction.

7.2.4.2. Change in mode share

There are many factors that influence the choice of mode by individuals such as cost, travel time, security, convenience, comfort. It was found that within sample population, for work and study trips, people in Kathmandu give preference to reliability and punctuality indicating preference on travel time, secondly comfort and least preference to the fare (Bajracharya, 2010). Hence it could be argued that if the new system would be able to increase its patronage in terms of reliability, comfort, convenience at lower or the same cost as of the old system then there would be some modal shift. Even then the degree of modal shift remains uncertain. Hence the sensitivity analysis was performed to see the performance of those plans under varying mode share.



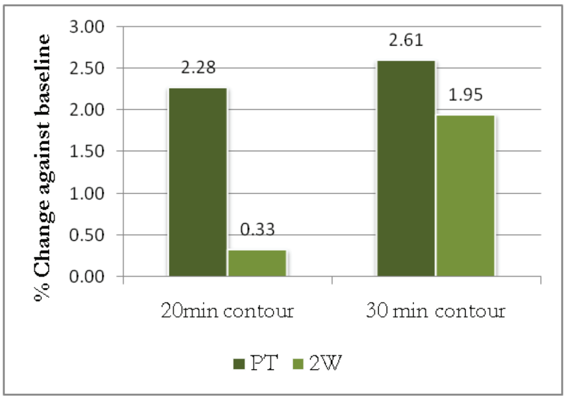
Graph 30 Percentage change in emission in total and for each mode against baseline with 5% increase in mode share for two of the chosen plans

Graph 30 shows the emission reduction gain in total and for each mode. It can be seen that with 5% increase in the mode share of public transport due to subsequent shift from the 2W, it would lead to emission reduction gain of about 0.2% against the baseline for the combined package of penetration of trolley bus along with PT improvement plans; even when there is only 5% share in ridership by trolley bus. But in the case of PT improvement plans, only, 5% shift from private would not be able to lead to emission reduction gains since public transport would contribute to the emissions along with 2W.

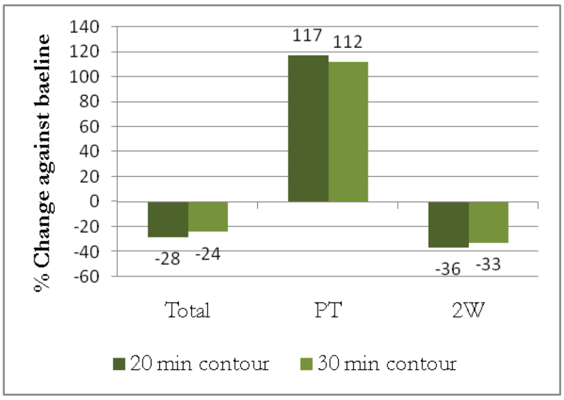
7.2.4.3. Change in contour time to 20 min

Graph 31 shows the percentage change in number of people served by each mode for 20 and 30 min travel time. Graph 32 shows the emission in total and for each mode during consideration of 20 and 30 min travel time.

It can be seen that consideration of different travel times would not change the performance of chosen plans. However, 20 min travel time have large effect on number of people served by 2W compared to PT as shown in graph 31. But under the assumptions of same mode share, average occupancy and fuel efficiency, there would be reduction gain in both cases, but more gain during 20 min contour resulted due to less number of people served reducing transport activity in each mode



Graph 31 Percentage change against baseline for number of people served by each mode under different travel time in 2020



Graph 32 Percentage change against baseline emission in total and for each mode under different travel time in 2020

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7.2.5. Towards Low Carbon Development

As discussed in chapter 1 and 2, the notion of Low Carbon Development addresses enhancement of development by minimizing carbon emission. Without any target to meet, Tilburg (2011) define 'low carbon' as minimizing emissions from baseline when there is no additional policy interventions. The chosen LCT plans for KMC address shift and improve strategies which basically deal with meeting maximum share of travel demand with low carbon modes such as public transport or meeting those demand with energy efficient modes. In this research defining accessibility as one of the performance indicators for sustainable development, it had been argued that to realise Low Carbon Development for the city along with minimization of carbon emission, LCT plans should provide easy access to reach to the facilities. But increase in accessibility means providing more opportunities to people to participate which increase the travel demand. Under such circumstances, choice of low carbon modes by individuals or shift to energy efficient modes becomes important to realize LCD.

The results on LCT plans show increase in accessibility with emission reduction gains of 24% and 27% respectively for PT improvement plans and penetration of trolley bus system along with PT improvement plans against baseline for 2020. On the other hand trolley bus renewal plans show emission reduction gain of 42% but at the expense of lower accessibility. The sensitivity analysis has shown that only 5% shift from private to public transport lead to emission reduction gain when there is penetration of trolley bus system as zero emission vehicle and sharing only 5% of ridership of large buses. With this regard, penetration of trolley bus system along with PT improvement plans has shown potential towards LCD.

However, it can be argued that only making low carbon modes like public transport appealing and user friendly through spatial organization and route reorganization would not be suffice for minimizing emission and other negative externalities, but there must be behavioural change and shift from private modes which is one of the essence of Low Carbon Transport for total emission reduction gains. There are many arguments formed around the effectiveness of package of policies such as shift along with improving vehicle technology, efficient public transport with economic instruments (Dhakal, 2006; Dulal et al., 2011; Jun, 2011; Ramanathan & Parikh, 1999). Thus, this argument can be seen viable for the case of KMC as well. The potential of plans on route reorganization of public vehicles and improving their patronage in emission reduction would only be realized if there would be substantial shift from private mode as shown from the results of sensitivity analysis. Further, incorporating improve strategy along with shift, it can be seen that penetration of trolley bus system and meeting only 5% of ridership of large diesel buses would lead to increase in emission reduction gain under the circumstances that it is zero emission vehicle.

7.2.6. Conclusion

The lack of data on the demand side; origin and destination of students of KMC, their choice of mode, value given by them to destination has limited the choice of measure of accessibility to contour measure. Moreover, with the lack of origin and destination of people, the model has assigned all the potential population to the total distance travelled by the mode resulting into overestimation in quantity of CO2. However, analysis was done in relative terms comparing each alternative to the base or the baseline, it can be argued that the results on performance of LCT plans would still be reasonable. Another limitation was the assumptions made on mode choice of people and percentage shift from private to public transport due to improve in public transport patronage. However it has shown a significant variation in results on the impacts of chosen LCT plans on emission under high and low population growth.

Given these limitations, based on the result of sensitivity analysis in section 7.2.4, it can still be concluded that the chosen LCT plan which is a combination of PT improvement plan along with the penetration of trolley bus system, has a great potential towards LCD in the transport sector for KMC.

8. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the findings and achievements made for each objective of the research after which recommendations highlight on the issues that need to be taken into consideration for future research in this direction.

8.1. Conclusions

The main objective of this research was to evaluate Low Carbon Transport plans and their potential contribution in Low Carbon Development of Kathmandu Metropolitan City (KMC) in the transport sector by developing accessibility based planning support system. This research has been able to fulfil its main objective with the following three deliverables

- Development of the concept of accessibility on LCD and LCT
- Development of a GIS-based platform for evaluating LCT plans for their potential towards LCD
- Demonstration of the application of the GIS-based platform for the case of KMC

Thus, with the above deliverables of this research the following specific conclusion was drawn for each sub objectives.

To define concept of Low Carbon Development and Low Carbon Transport in general and specific for KMC

1. **How are Low Carbon Development (LCD) and Low Carbon Transport (LCT) being defined?**

Low Carbon Development is ensuring economic development of the country or city while minimizing emissions. There are many sectors where LCD can be pursued depending on nation's local context, capacities and priorities. Transport is that sector where there is global concern on the urgent need of action by ensuring LCD pathway. With the realization of the need of a paradigm shift to deal with the unsustainable transport, avoid-shift-improve strategies have been advocated as the potential strategies and hence those responses addressing one or combination of these strategies are characterized as Low Carbon Transport.

2. **How are LCD and LCT being translated for the case of KMC?**

Though development of LCD is at an initial stage, there has been an identification of sectors where LCD can be pursued. One of the sectors is energy which has been largely causing GHG emission. .Since the current transport of the city is dependent on fossil fuel energy which is imported into the country, it is burdening country's economy on one hand and on the other hand use of fossil fuel is causing negative impact on environment and the health of people causing loss of productivity. In the absence of proper land use plans, shift and improve strategies have been addressed as strategies of LCT for KMC to deal with this problem.

To identify Low Carbon Transport plans for KMC

1. **How to identify current Low Carbon Transport plans for KMC?**

Since, national priorities, capacities and context are important to identify potential Low Carbon Transport plans and policies for the city, interviews were carried out along with document analysis of

KSUT report. Based on avoid-shift-improve strategies, some Low Carbon Transport plans for KMC were identified.

2. **What are the physical interpretations of the identified plans in terms of their influence in land use and transport component (spatial location, speed, emission)?**

   The chosen LCT plans address shift and improve strategies which deal with meeting maximum share of travel demand with low carbon modes such as public transport or meeting those demands with energy efficient modes. The physical interpretation of plans in terms of speed, fuel efficiency, emission factors were collected from several secondary sources.

To develop urban accessibility scenarios of identified Low Carbon Transport plans with planning support system

1. **What are the factors to be considered in qualitative description of scenario**?
   The scenario must have a storyline on external drivers, polices and must be logical and plausible with certain time horizon. The description of scenarios distinguishes drivers of scenarios with existing as well as new policy levers and plans. For the drivers, high and low population growth was considered with the time horizon of 2020. The existing policy of fuel efficiency was considered for the baseline scenario whereas public transport improvement plans, trolley bus renewal plans and the combination of these plans i.e. penetration of trolley bus system along with PT improvement plans were tested under these two growth scenarios.

2. **What modelling approach can be applied for developing alternative scenarios of Low Carbon Transport plans?**
   The modelling approach that was adopted for developing alternative scenarios of Low Carbon Transport plans in terms of accessibility and emission was the integration of accessibility analysis model with ASIF framework. The output of accessibility analysis as potential user of mode and distance travelled by the mode to reach the facilities, were used as input as activity in ASIF framework in terms of passenger km. Along with mode share, average occupancy, fuel efficiency and emission factor, emissions from each mode was calculated

3. **Which activity based accessibility measure can be used for analyzing accessibility of identified Low Carbon Transport plans?**
   The chosen activity based accessibility measure was contour measure for this research due to following reasons. Firstly, with the purpose of demonstrating the application of PSS for evaluating accessibility scenarios on Low Carbon Transport plan, this measure was easy to operationalize, interpret and communicate. Secondly, in the absence of information on origin and destination of people, value given by individuals to transport and land use, the undemanding data need of this measure was found to be appropriate.

4. **What is the result of quantitative assessment of constructed scenarios regarding urban accessibility and emissions?**
   Under different population growth scenarios, the chosen LCT plans showed a decrease in emissions against the base year under low population growth scenario. But with greater increase in transport activity during high population growth scenario, same assumptions on the mode share of PT, average occupancy, fuel efficiency and emission factors; would not be sufficient enough to decrease the emissions as compared to the base year. While compared to their respective baseline scenario, all the chosen LCT plans had shown similar performance under both high and low

growth scenarios. PT improvement plans and penetration of these plans with trolley bus system had shown improvement in accessibility with reduction in total emission whereas trolley bus renewal plans showed reduction but with lower accessibility.

To assess potential contribution of the constructed scenarios to Low Carbon Development for KMC

1. **What is the result of qualitative analysis of the constructed scenarios for their potential in Low Carbon Development of KMC?**

   From the sensitivity analysis, even a 5% shift from private to public transport with combined package i.e. penetration of trolley bus along with PT improvement plans; led to a decrease in total emissions. In this regard, penetration of trolley bus system along with PT improvement plans has potential towards LCD. It was shown that shift is necessary to realize the benefits of LCT plans. To encourage shift package of policies that address 'push and pull' effects such as incentives to PT, congestion pricing and high fuel pricing to private user, restriction to some areas with private vehicle should also be incorporated. .

   The choice of mode by individual depends on many factors such as cost, comfort and reliability. These transport plans consider integration of mode in primary and secondary routes which is not always comfortable and might even lead to increase in travel time and cost unless the system should be integrated in every aspects such as no extra cost for change of mode, coordination between vehicles in primary and secondary routes, comfortable waiting environment during interchange. Thus, the combined plans have shown potential towards LCD for KMC. However, it has shown that behaviour of people and their choice of mode greatly influence the performance of those plans.

8.2. Recommendations

This research was able to relate urban accessibility with Low Carbon Transport by developing a PSS for the case of KMC. However, as discussed earlier the approach had been limited with unavailability of transport demand data. With these limitations, following recommendations are presented that would help in future research development.

- The data on demand side such as origin and destination of people, mode choice of people and hence the modal split, value given by people to land use and transport components will help to operationalize other measure of accessibility to overcome theoretical shortcomings of contour measure that had been used for this study. This will further help to acquire actual distance travelled which will be necessary to improve ASIF framework in terms of emissions.

- The methodology followed in this research is sensitive to reliable data sources. The unavailable data was dealt either by assumptions or acquiring data from secondary sources some of which were not updated especially for emission factors, fuel efficiency. Thus, these have direct implication on quantity of emissions.

- There are many factors that influence the mode choice of people such as their socio-economic characteristics, cost, travel time, reliability and comfort, convenience. To have a better representation of modal split for current transport system and after the implementation of chosen plans, there is a need of survey. Stated preference survey design which was used by Bajracharya (2008) for BRTS scenario, can be used for understanding future mode share with the new system.

- As land use and transport are integrated, the spatial distribution of people according to socio-economic group, activities and land use have impact on travel demand and hence accessibility of people and related emissions. For this research, the current land use and activity has been used for all the future scenarios. The only variation was on transport component offered by chosen LCT plans and difference in modal split which was also considered same under high and low population growth scenarios. The growth rate was also considered uniform in each ward which has led to high level of aggregation. But in reality the land use is itself affected by travel pattern, transportation system and different parts of the city experience different growth rate resulting into different travel pattern. These will have impact on accessibility of people and hence the emission. This entails the need of refinement of the platform to incorporate these changes.

- The case study area has been limited to KMC and supply driven modelling approach was adopted. To upgrade the platform with demand side data, there will be a need to scale up the case study area where most of the daily trips of people are intercity between three cities, Kathmandu, Bhaktapur and Patan.

Thus with the above recommendations further studies is emphasized in this directions.

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ANNEXE

A. Questionnaires for semi-structured interview

Name of the interviewee:
Organization:
Post:

Understanding the current situation and problems of transportation in the city

- What are the key factors that are causing transport system of KMC unsustainable?
- What are the key priorities for urban transport?
- What policies, plans and actions have been/ planning to be made in future focussing on this problem of city?

Understanding concept of Low Carbon Development (LCD) for the city

- Low Carbon Development (i.e reducing carbon emission without hampering development of the city/nation) has been realized as an important pathway to be followed by both developing and developed countries. What policies, strategies (existing/planned) for the city address this issue of LCD?
- What are the advantages that could be derived for the city by pursuing LCD pathway?
- When can it be called that the KMC city has achieved low carbon? Is there any baseline, reference or target to be achieved in transport sector? Is there any indicator for measuring it in the context of KMC?
- What actions have been taken to reduce emission in transport sector while focussing on development of city?
- How important is accessibility of people to various opportunities from development point of view?
- What are the relevant indicators of development for the city? (transport sector)

Understanding concept of Low Carbon Transport (LCT) in Low Carbon Development (LCD) for the city

- How can transport sector be more climate-friendly for the city?
- In your opinion how relevant is the following strategies of Low Carbon Transport for the city and why?
    1. **AVOID-** reducing the need to travel
    2. **SHIFT-** encourage people to shift to environmental friendly transport mode/ prevent people to shift to private vehicle
    3. **IMPROVE-** improve the efficiency of the individual transport mode
- What are the actions or plans being made under these strategies?
- What are the key barriers for implementing these strategies?
- How can these be overcome?

B. List of Interviewees

- **Government sector**
  - Anil Gurung, (MoLTM)
  - Kamal Raj Pandey, Ministry of Physical Planning and Works(MoPPW)
  - Dr. Madhu Sudan Acharya, Department of Roads (DoR)
  - Archana Shrestha, Kathmandu Metropolitan City office (KMC)
  - Neeraj Sharma, Kathmandu Sustainable Urban Transport Office (KSUT)
  - Ravi Shah
  - Batu Krishna Uprety, Ministry of Environment (MoE)
- **Academics**
  - Prof. Dr. Chandra Shrestha, Nepal Transportation Development and Research Center (NTDRC)
  - Ashim Bajracharya, Institute of Engineering (IOE)
- **Private Consultant**
  - Dr. Sunil Babu Shrestha (Clean Development Consultant)

C. Assumptions and quantitative interpretations of alternative plans

Alternative scenario1 (Baseline Scenario)

S. No.	Transport Component		Source
1.	Modal split		Source: KSUT report, Bajracharya (2010)
	Public transport	52.8%	
	Minibus	16.37%	
	Microbus	30.1%	
	Gas tempo	4.28%	
	Electric tempo	5.58%	
	Two wheeler	40.7%	
2.	Average speed (PT)	20 kph	Source: KSUT report
	Average speed (2W)	20 kph	
3.	Fuel efficiency		Source: KSUT report
	Public transport		
	Minibus	0.17 l/km, 0.14 l/km(improve)	
	Microbus	0.13 l/km, 0.104 l/km(improve)	
	Gas tempo	0.005 cyl/km	
	Electric tempo	0	
	Two wheeler	0.024 l/km, 0.02 l/km (improve)	
4	Emission factor		Source: Dhakal (2006)
	Public transport		
	Minibus	3440 g/l	
	Microbus	2530 g/l	
	Gas tempo	1620 g/l	
	Electric tempo	0	
	Two wheeler	3984.8 g/l	
5	Average occupancy		Source: KSUT report
	Public transport		
	Minibus	26.4	
	Microbus	12.3	
	Gas tempo	7.6	
	Electric tempo	7.6	
	Two wheeler	1.3	

Alternative scenario 2 (PT improvement plans)

S. No.	Transport Component		Source
1.	Modal split		Source: KSUT report, Bajracharya (2010)
	Public transport	63.36%	
	Large bus	63.36%	
	Minibus	63.36%	
	Two wheeler	32.6%	
2.	Average speed (PT)	40 kph in primary, 25 kph in secondary routes	Source: KSUT report
	Average speed (2W)	25 kph	
3.	Fuel efficiency		Source: KSUT report
	Public transport		
	Large bus	0.14 l/km	
	Minibus	0.14 l/km	
	Two wheeler	0.02 l/km	
4	Emission factor		Source: Dhakal (2006)
	Public transport		
	Large bus	3440 g/l	
	Minibus	3440 g/l	
	Two wheeler	3984.8 g/l	
5	Average occupancy		Source: KSUT report
	Public transport		
	Large bus	30	
	Minibus	22.4	
	Two wheeler	1.3	

Alternative scenario 3 (Trolley bus renewal)

S. No.	Transport Component		Source
1.	Modal split		Source: KSUT report, Bajracharya (2010)
	Public transport	63.36%	
	Trolley bus	63.36%	
	Minibus	63.36%	
	Two wheeler	32.6%	
2.	Average speed (PT)	40 kph in primary, 25 kph in secondary routes	Source: KSUT report
	Average speed (2W)	25 kph	
3.	Fuel efficiency		Source: KSUT report
	Public transport		
	Trolley bus	0	
	Minibus	0.14 l/km	
	Two wheeler	0.02 l/km	
4	Emission factor		Source: Dhakal (2006)
	Public transport		
	Trolley bus	0	
	Minibus	3440 g/l	
	Two wheeler	3984.8 g/l	
5	Average occupancy		Source: KSUT report
	Public transport		
	Trolley bus	30	
	Minibus	22.4	
	Two wheeler	1.3	

Alternative scenario 4 (Trolley bus renewal)

S. No.	Transport Component		Source
1.	Modal split		Source: KSUT report, Bajracharya (2010)
	Public transport	63.36%	
	Large bus	43.36%	
	Trolley bus	20%	
	Minibus	63.36%	
	Two wheeler	32.6%	
2.	Average speed (PT)	40 kph in primary, 25 kph in secondary routes	Source: KSUT report
	Average speed (2W)	25 kph	
3.	Fuel efficiency		Source: KSUT report
	Public transport		
	Large bus	0.14 l/km	
	Trolley bus	0	
	Minibus	0.14 l/km	
	Two wheeler	0.024 l/km, 0.02 l/km	
4	Emission factor		Source: Dhakal (2006)
	Public transport		
	Large bus	3440 g/l	
	Trolley bus	0	
	Minibus	3440 g/l	
	Two wheeler	3984.8 g/l	
5	Average occupancy		Source: KSUT report
	Public transport		
	Large bus	30	
	Trolley bus	30	
	Minibus	22.4	
	Two wheeler	1.3	