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CLIMATRANS

Sustainable Transport Measures for Liveable Bengaluru

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Note: This is a sub report. The full report containing all the case cities Bengaluru, New Delhi and Mumbai will be released soon.

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ABSTRACT

India is one of the fastest urbanizing countries in the world and the urban centres share a major part in improving nation's economy. Growing economies have led to employment opportunities which in turn lead to a lot of migration to the cities. Rapidly growing economies coupled with urbanization pose a great threat to the resilience, sustainability and liveability of the cities. Increasing urban population and motorization in most of the Asian countries are bound to raise road congestion and environmental pollution making cities difficult to live. Recently, liveability has received more importance due to the degrading condition in the quality of life in metropolitan cities. Mobility is a major concern in many Indian cities, due to inadequate transport infrastructure, increased usage of private vehicles, traffic congestion, pollution and lack of integration between land use and transport planning thus, undermining the cities' efforts to meet global standards of living. Recently, the Government of India has also formulated 79 indicators in 15 categories in order to measure the liveability standards of 116 Indian cities focusing on four main aspects such as institutional, social, economic and physical that affects the quality of life.

This report is an outcome of last 4 years of research work under an Indo-Norway project CLIMATRANS to develop and evaluate sustainable transport measures that improves the liveability of Indian cities including, Bengaluru, Delhi, and Mumbai. The current report presents only the case study of Bengaluru Metropolitan Region (BMR) which includes Bengaluru urban district, Bengaluru rural district and Ramnagara covering an area of about 8005 sq.km. BMR is one of the rapidly urbanizing metropolitan area with 584% increase in the city's built up area in the past four decades. The increased population in urban areas eventually led to increased vehicle usage in the limited city's infrastructure causing traffic congestion, longer travel times and pollution, making it hard to live in the city. Also, due to concretization of land, encroachment of water bodies, improper maintenance of drainage facilities has resulted in higher runoff on the roads getting the city transportation sector to a halt and thereby reducing the resiliency of the transportation system in the city. This report details about the quantitative evaluation of sustainable transport mitigation and adaptation measures aimed to improve the liveability of Bengaluru in terms of; reduced traffic congestion (VKT), reduced exhaust emissions (PM, CO, NO_X, HC etc.), reduced greenhouse gas emissions (CO_2), reduced carbon emission intensity w.r.t. GDP growth, increased consumer surplus of sustainable modes, and also improved resiliency of transportation system. The same was done by comparing the Business as Usual scenario and various sustainable transport scenarios, for the base year and the future years 2030 and 2050. It is expected that the findings of this report will provide more scientific and evidence based decision support for framing right kind of sustainable transport planning and policy measures to make Bengaluru more liveable. Also, the basic principles and developed methodology from this study can be applied to other Indian cities as well to develop similar measures aimed at improving their liveability.

EXECUTIVE SUMMARY

Rapidly growing economies and subsequent increase in private vehicle usage pose a threat to the sustainable development of most of the developing cities worldwide. Increasing urban population and motorization in most of the Asian countries are bound to raise road congestion and environmental pollution. Sustainable transport measures are seen as a tool to reduce the vulnerability to the potential negative impacts of urbanization. Transportation being a critical sector contributes to the smooth functioning of societies and fosters economic growth of a nation. Bengaluru is a good example of rapid urbanization, which is evident from the fact that the city added about two million people in just the last decade. In the history of Bengaluru, the highest growth in population of 106% is recorded in the last two decades. Although Bengaluru's rapid economic growth has substantially improved the local quality of life, yet challenging issues of urbanization, motorization, congestion & pollution looms over the development of the city. Bengaluru's infrastructure and urban planning has not kept pace with its rapidly increasing population and the growing number of vehicles on the road. This study has been carried out to address the issue by quantitative evaluation of sustainable transport mitigation and adaptation measures aimed to improve the liveability of Bengaluru in terms of; reduced traffic congestion (VKT), reduced exhaust emissions (PM, CO, NO_X, HC etc.), reduced greenhouse gas emissions (CO_2), reduced carbon emission intensity with respect to GDP growth, increased consumer surplus of sustainable modes, and also improved resiliency of transportation system. The main objectives of the study are:

1) Developing mitigation strategies for transportation sector which are aimed at reducing the GHG emissions, local pollutants and traffic congestion from a baseline condition. These mitigation strategies will be developed for two scenarios which are Business as usual scenario and sustainable transport Scenario for the base year and the future years 2030 and 2050.
2) Identification of the transportation infrastructure that is vulnerable to climate change and assess the impacts of climate change on the transportation infrastructure.
3) Developing adaptation strategies for the base year and the horizon years 2030 & 2050 to evaluate the vulnerability, scope & extent, severity of each flood event caused by climate change to transportation sector.
4) Improving the overall liveability of Bengaluru.

The demographics & mobility of the BMR region for the base year 2008 is studied and forecasted for the years 2030 & 2050 as a part of Business as Usual scenario (BAU). The mitigation and adaptation strategies are developed to estimate and evaluate the effects of each policy on the BAU scenario for the years 2030 & 2050. Bengaluru is the most urbanized district with 90.94% of its population residing in urban areas. Traffic problems are diverse and complex ranging from low speeds, long travel times and the peak hour travel speed in the city is less than 17 km/hr *(CTTS report, 2010)*. Personalized modes of

transport have grown at a tremendous rate and two wheelers along with the cars almost comprise 90% of the total registered vehicular population in the city. The population living in urban slums in Karnataka has risen from 1.402 million (2001) to 3.291 million (2011) in a decade.

Business as Usual scenario - Mitigation

Mitigation*:* Mitigation is defined as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2001a). **Mitigation** can mean using new technologies and renewable energies, making older equipment more energy efficient, changing management practices or consumer behaviour.

The total population of the BMR region as per the census in 2001 is 8.5 million and in 2011 is 10.8 million. The source for this data was taken from Comprehensive Traffic and Transportation Studies (CTTS) report and has been projected to 2030 and 2050. It is estimated that the population would reach 18 million by 2030 and 33 million by 2050. The study estimated that the average trip length for the base year for BMR is 14 km and 11 km for private and public transport respectively and has increased for the years 2030 and 2050 as shown in the table below.

Table I: Comparison of average trip lengths

Average Trip Length (km)		
Year	**Private Transport**	**Public Transport**
Base Year	14.1	11.4
2030	17.41	16.36
2050	18.17	18.22

With majority of the population opting for public transport as their mode of travel, it has a mode share of 49.7 % with the least being car (2.3%). Mode share of two wheelers is 28.9%, 3 wheelers (Auto) 3.7% and NMT share is about 15.4%. The future projections of mode share for the years 2030 and 2050 are shown in Figure below.

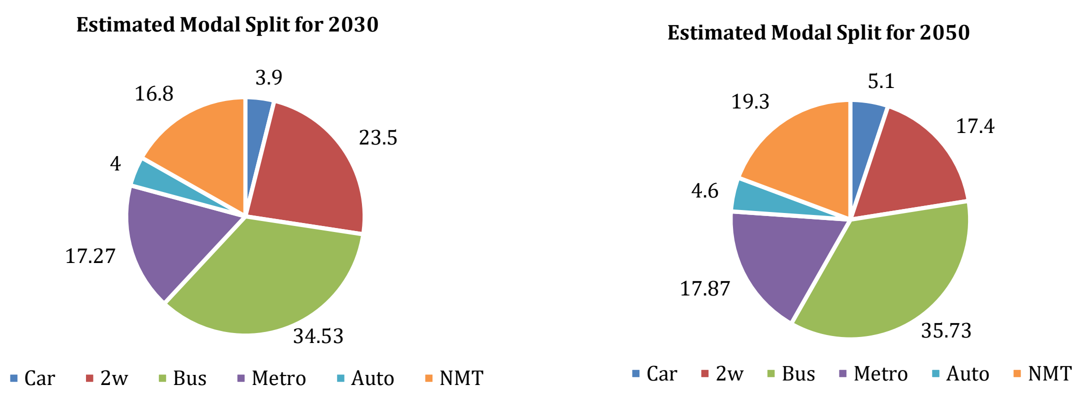


Figure I: Estimated mode share for the years 2030 and 2050

The ratio of Bangalore Metropolitan Transport Corporation (BMTC) to BMRCL mode share is taken out from the report and applied to the model to estimate the modal share of BMRCL for 2030 and 2050. The total Vehicle Kilometres Travelled (VKT) by the vehicles in the BMR region is about 31 million for the base year and is estimated to increase about 48 million and 72 million for the years 2030 and 2050 respectively which is about 60% growth rate of VKT in 2050 from base year.

The vehicular emissions are dependent on Vehicle Kilometres Travelled. For this study 5 pollutants namely CO, HC, NOx, CO_2, PM are considered. Emissions estimated for the modes considered for the study are stated in the table below.

Table II: Total Emissions in Base Year, 2030 and 2050 (BAU Scenario)

Pollutant	Emissions in Tonnes/ year (% change w.r.t Base Year)		
	Base Year	2030	2050
CO	15743	18179 (15%)	23567 (50%)
HC	7315	2930 (-60%)	3841 (-47%)
NOx	6985	28864 (313%)	22962 (229%)
CO2	695617	16782759 (2313%)	17662478 (2439%)
PM	973	2009 (106%)	1519 (56%)

Mitigation Policy Scenarios

Based on the IPCC definition, inputs from multiple stakeholder meetings and Delphi survey with various government officials of Bengaluru, 4 policy bundles are formulated. The main objective of these mitigation policy bundles is to attain an optimum balance of push and pull strategy by developing policies that encourage public transportation and also other sustainable modes. This helps in reducing the vehicle kilometres travelled which leads to reduction in emissions and traffic congestion as compared to Business as usual scenario thereby improving the quality of life of people in Bengaluru city.

Table III: Policy bundles for mitigation

Policies under *bundle 1*
Increasing network coverage of Public Transit
Cycling and walking infrastructure
Additional tax on purchasing vehicles
Policies under *bundle 2*
Additional tax on purchasing vehicles
Strict Vehicles inspection/Improvement in standards for vehicle emission
Increase in fuel cost
Policies under *bundle 3*
Increasing network coverage of Public Transit
Defining car restricted roads
Congestion Pricing
Park and Ride
Cycling and Walking infrastructure
Encouraging car-pooling and High Occupancy Lanes
High density mix building use along main transport corridors
Policies under *bundle 4*
All policies in bundle 3 + All buses and cars running on electricity

Each bundle mentioned above is a mixture of various policy instruments. Bundle 1 is a mixture of **Planning & Regulatory** Instruments. Bundle 2 is a mixture of **Economic &**

Regulatory Instruments, bundle 3 is a mixture of **Planning, Regulatory & Economic** Instruments and bundle 4 is a blend of **planning, regulatory, economic and technology** instruments. The bundle 4 includes the assumption of electrification of all cars and buses for horizon years. In addition, four different scenarios are assumed based on the different projections of the energy mix in the target years as follows:

i. **Scenario 1:** New Policies Scenario (IEA, 2015) - Non-renewable sources & Electricity (74% - 26%)

ii. **Scenario 2:** Electricity from non-renewable Sources (100 %)

iii. **Scenario 3:** Half electricity from renewable and another half from non-renewable sources (50 % - 50 %)

iv. **Scenario 4:** Electricity from Renewable Sources (100 %)

Bundles are carefully evaluated and tested at various locations in BMR. It is observed that Bundle 3 (also Bundle 4) which is a comprehensive mixture of 7 policies gives the best results with respect to VKT reduction, Improved Public Transport Share and reduction in emissions. The substantial reduction in emissions is observed with the implementation of bundle 4 - scenario 4 where the electricity is assumed to be generated only from renewable sources. The comparison of BAU 2030 with the 3 policy bundles is shown the figures below.

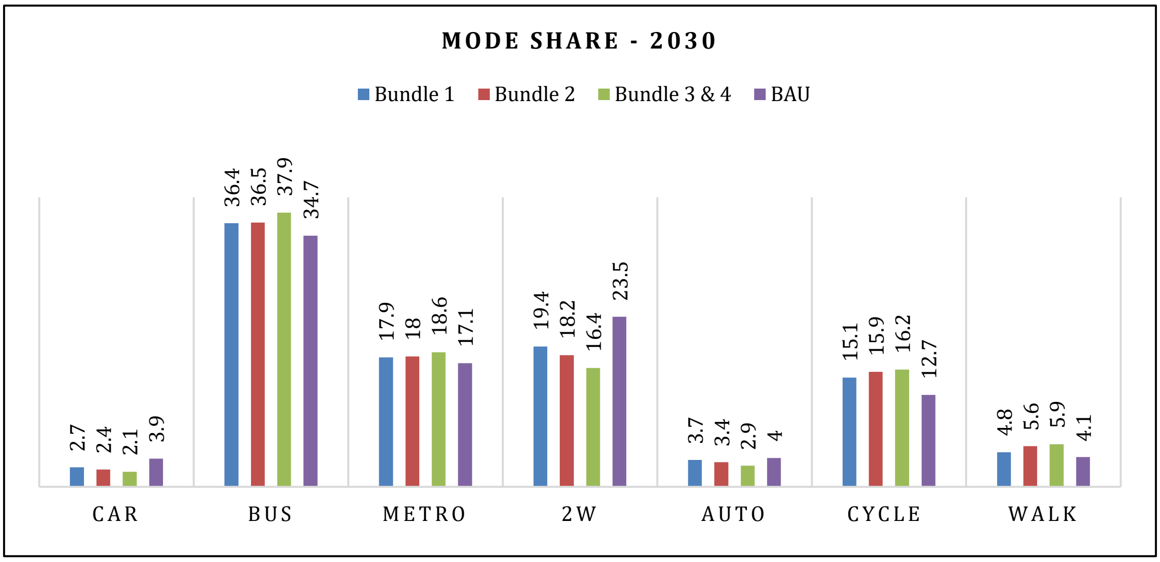


Figure II: Mode share comparison between BAU and Policy Bundles for the year 2030

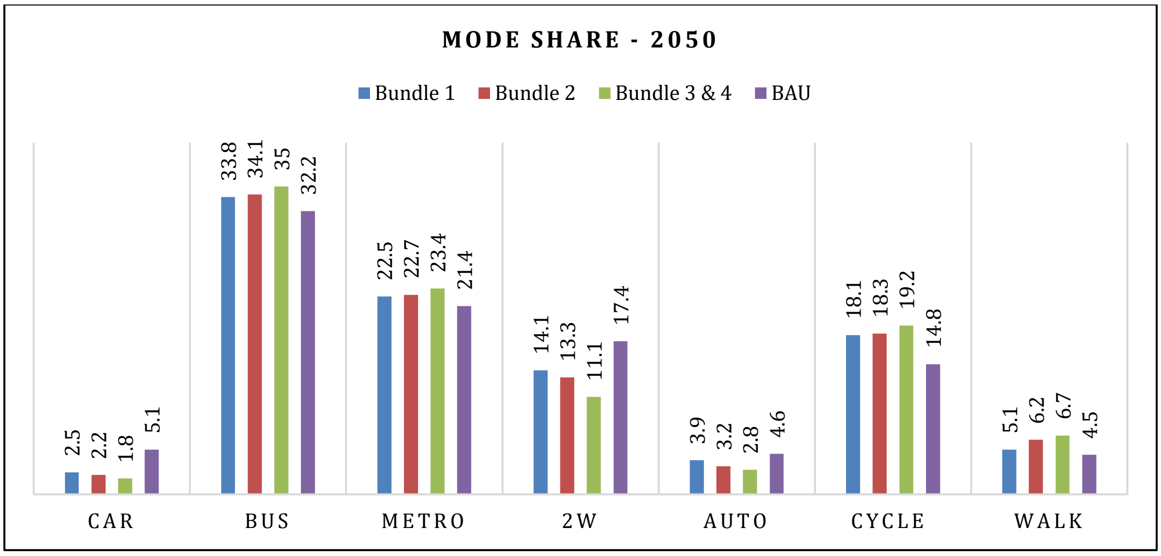


Figure III: Mode share comparison between BAU and Policy Bundles for the year 2050

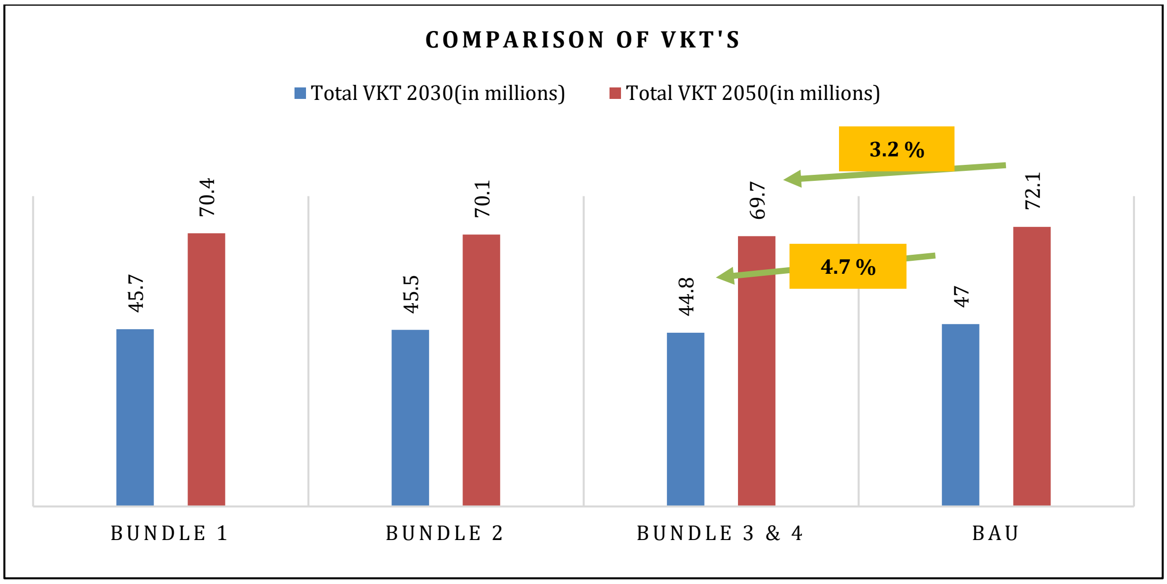
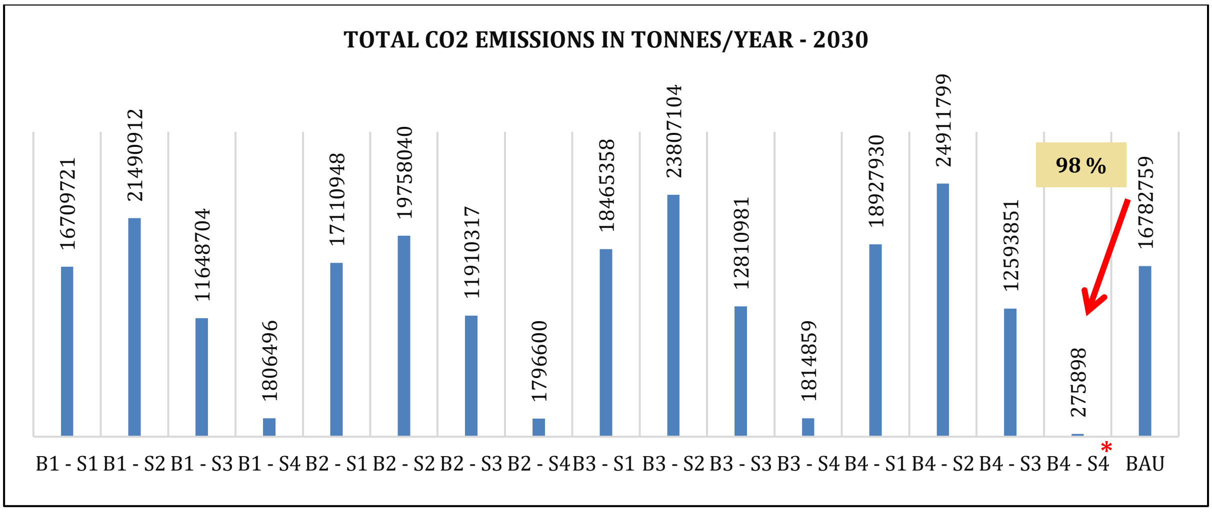


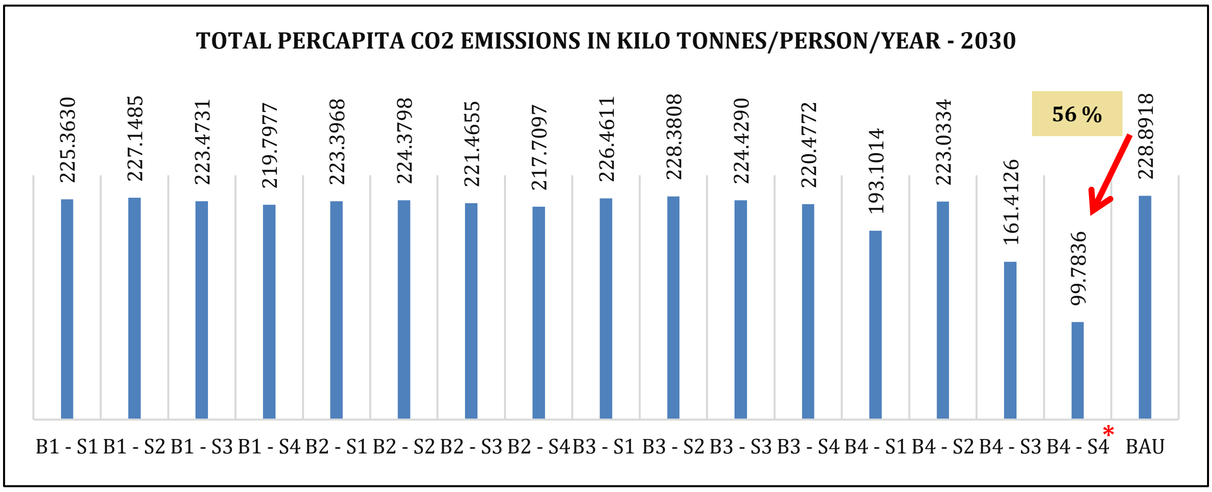
Figure IV: VKT comparison for BAU and Policy Bundles for 2030 & 2050

It is clearly seen from the figures that the private transport mode share will reduce and public transport and NMT mode share will increase across all the policy bundles, with bundle 3 (also bundle 4) producing the best results. Due to increase in mode share of public transport with high occupancy levels, the total vehicle kilometers travelled reduces substantially when compared with BAU for 2030. Since emissions are a function of vehicle kilometers travelled, it is seen that the emissions reduce across all bundles with the bundle 4 - scenario 4 giving best results. **In bundle 4 - scenario 4 it is observed that the CO_2 emissions were found to reduce by almost 98% for 2030 and 2050 when compared with 2030 and 2050 BAU scenarios respectively**. The emissions comparison for the pollutant CO_2 for bundles 1-4 with BAU scenario of 2030 and 2050 is shown in Figures below.



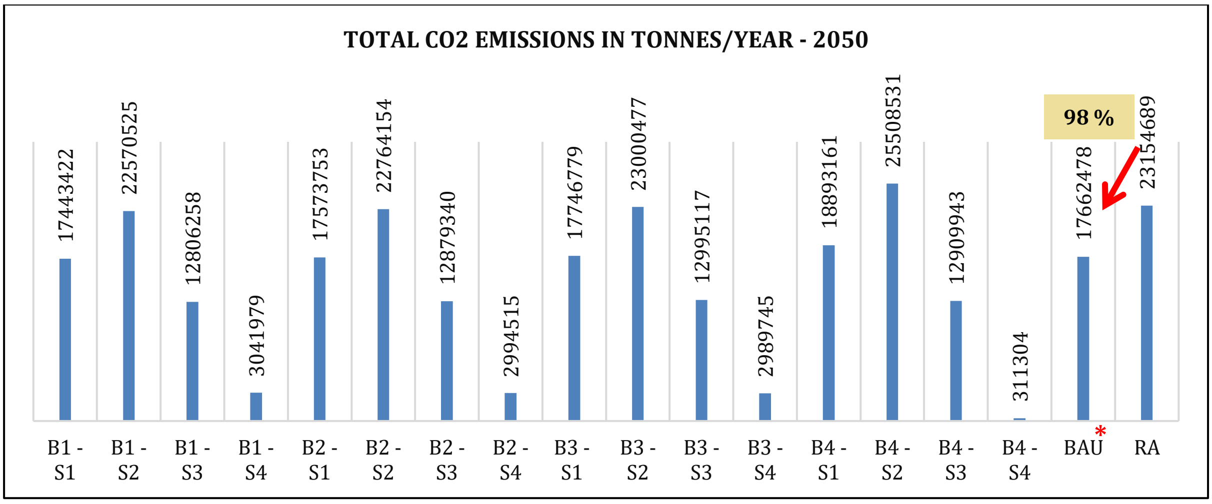
*98% reduction in total CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **89%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **98%** reduction in total CO_2 emissions can be achieved with respect to BAU scenario

Figure V: Total CO_2 emissions in tonnes/year for 2030



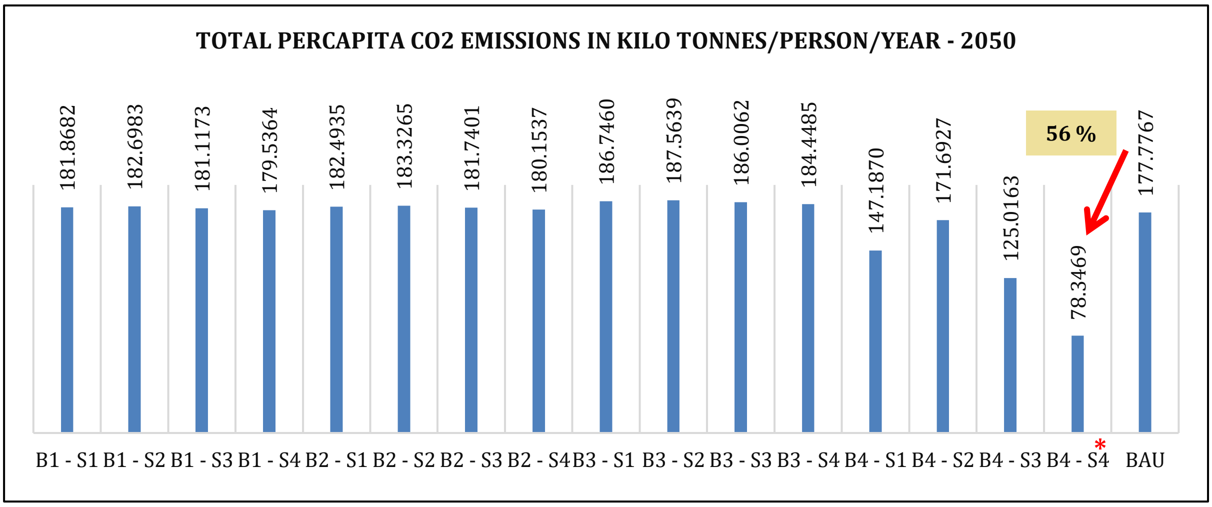
*56% reduction in total percapita CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **3%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **56%** reduction in total percapita CO_2 emissions can be achieved with respect to BAU scenario

Figure VI: Total Percapita CO_2Emissions in kilo tonnes/person/Year for 2030



* 98% reduction in total CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **82%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **98%** reduction in total CO_2 emissions can be achieved with respect to BAU scenario

Figure VII: Total CO_2 emissions in tonnes/year for 2050



* 56% reduction in total percapita CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, **56%** reduction in total percapita CO_2 emissions can be achieved with respect to BAU scenario

Figure VIII: Total PercapitaCO_2 Emissions in kilo tonnes/year for 2050

It can be seen that in Bundle 3 - Scenario 4 total CO_2 emissions are higher compared to Bundle 1 and bundle 2. This is because of high mode shift towards public transport. Since buses have high emissions factors the total CO_2 seems to be on the higher side. But from the figure VIII it is clearly observed that the bundle 3 - Scenario 4 gives less per-capita emissions compared to bundle 1 and bundle 2 since bus transport is shared by more number of people. However, in bundle 4 - scenario 4 with electrification of buses and generating electricity only from renewable sources demonstrates substantial reduction in emissions. As per the Intended Nationally Determined Contributions (INDC), India targets to reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005

Level. Since, the share of transportation is not mentioned the same intended percentage has been assumed for transport sector.

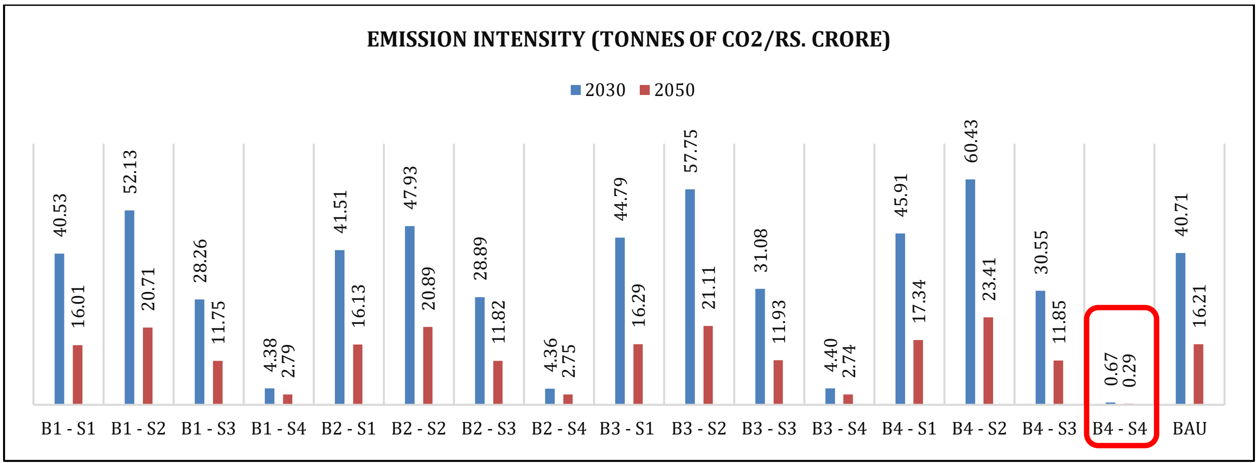
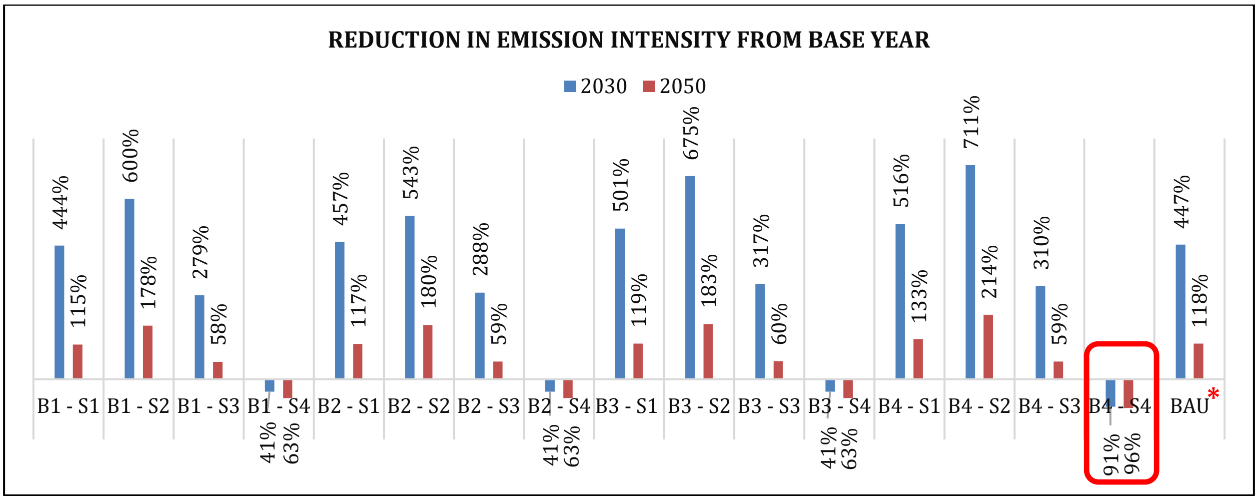


Figure IX: Emissions Intensity comparison between BAU and Policy Bundles for 2030 and 2050



* The carbon emissions intensity is increasing at the greater rate in BAU 2030 and 2050 scenario because Metro is not available in Bengaluru during base year and it is the only electricity based transportation with high emission factor values. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in BAU scenario, **39%** reduction in total CO2 emission intensity can be achieved in BAU 2030 with respect to base year and **60%** reduction in total CO2 emission intensity can be achieved in BAU 2050 with respect to base year.

Figure X: Percentage reduction in Emission Intensity of BAU 2030, 2050 and Bundles from Base year (2008)

The carbon emissions intensity is increasing at the greater rate in BAU 2030 scenario because Metro is not available in Bengaluru during base year and it is the only electricity based transportation with high emission factor values. The share of generation of electricity from renewable and non-renewable sources plays a significant role in emission intensity. The study clearly states that the emission reduction reaches the INDC targets even for the BAU scenarios of 2030 and 2050 with the extreme scenario case of assuming that the electricity will be purely generated from renewable sources. If the bundle 4-scenario 4 is implemented the percapita emission intensity will reduce by 97% for the year 2030 and 99% for 2050, highlighting that electrification of vehicles is the best solution. Also, consumer surplus costs associated with bundles 1, 2 & 3 have been estimated and it was found that from bundle 3 consumers who use Public transportation gain about Rs. 0.71 million for the year 2030 and Rs. 1.1 million for 2050 while the 2 wheeler users are at the major loss with Rs. 360 million for 2030 and Rs. 1220 million for 2050.

BAU Scenario for Adaptation

Bangalore Metropolitan Region flood map is prepared based on the heavy rainfall occurred on November 3rd 2015 (total rainfall - 266mm, duration - 4 hrs 10 mins, return period - 100 yrs) and it is overlaid over the BMR road network to extract the flood levels. For the BAU network each road link is divided into multiple small links depending on the level of flood in that particular link. The percentage share of flood depth on road network of BMR is shown in the below figure. Links which carry a flood depth above 0.5 m are considered to be not motorable in the BAU model. Roads that are heavily flooded and the zones that do not have redundant roads for the trip to happen are considered to have no trips from those zones. BAU modelling is done for the base year i.e., 2008 and for the future years 2030, 2050 for both private and public transport networks. Since this is not a frequent event and not a usual scenario the mode shift is kept the same even though trip lengths change.

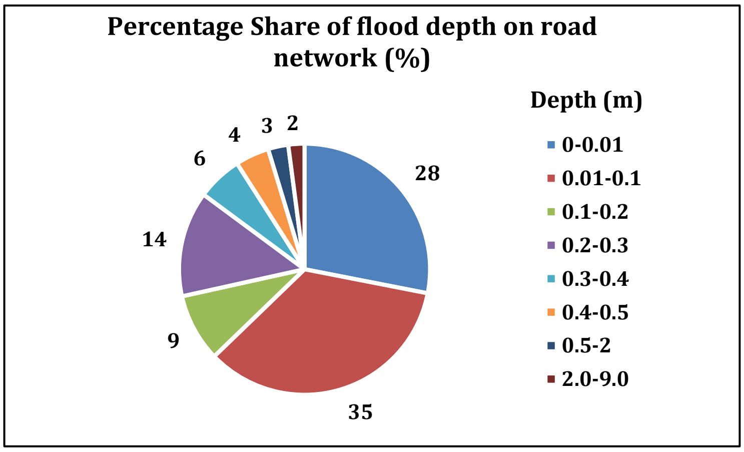


Figure XI: Percentage share of flood depth on BMR road network for the base year

Due to the flooding of roads, people who commute in their usual shortest paths change their course which leads to longer paths and longer travel time.

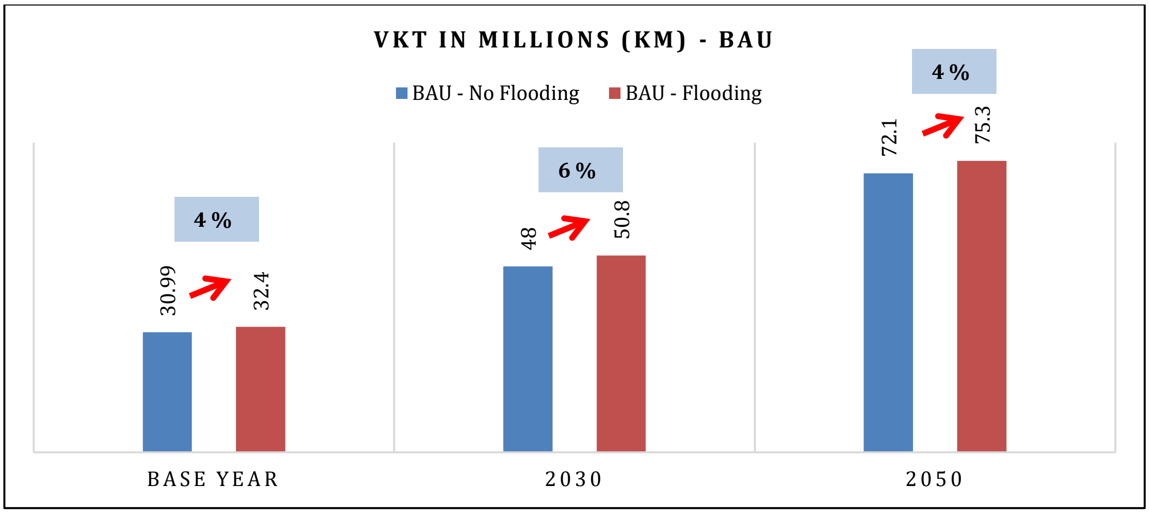


Figure XII: Comparison of VKT for flooding and No flooding scenarios for base year, 2030& 2050

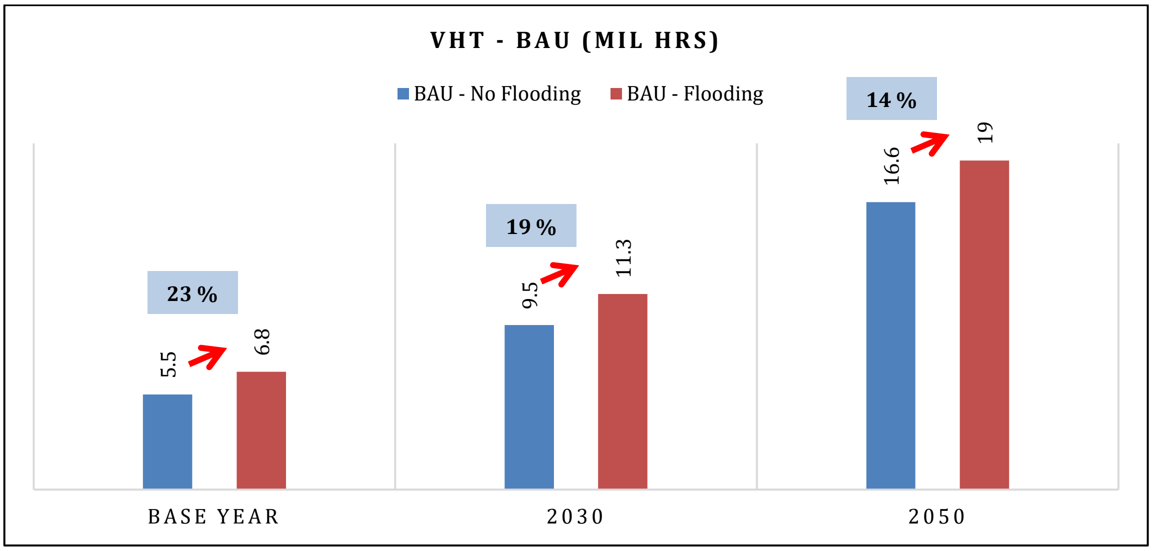


Figure XIII: Comparison of VHT for flooding and No flooding scenarios for base year, 2030& 2050

It is observed that the average private transport trip lengths increase from 14.1 km in BAU base year (no flood scenario) to 21.7 km in 2050 for a flood scenario. For public transport the average trip lengths increase from 11.4 km in BAU base year no flooding scenario to 20.4 km in 2050 flooding scenario. Also, the average daily vehicle speed reduces from 27kmph in base year no flooding to 13kmph during flooding in 2050.

Adaptation Policy Scenarios

As discussed in the first section adaptive measures are seen as a tool to reduce the vulnerability to the potential negative impacts of climate change and strengthen the inherent capacity of a system to undertake defensive as well as protective actions that help to avoid loss and facilitate recovery from any impact by increasing the resilience of the entire system.

The main objective of the adaptation strategies is to create a transportation system that is resilient to urban flooding. **Urban floods** are the main focus for the adaptation part of the project and so most of the policies have been formulated keeping urban flooding in mind. Climate change is inevitable; however, adaptive strategies will help in strengthening the road network system and act as resilient measures against urban floods.

Bundles are formulated in such a way that there is resilience in the infrastructure and also a reduction in runoff on the road network.

Table IV: Policy Bundles in Adaptation

Policies under *bundle 1*
Replacement of impermeable road surface with permeable material in vulnerable areas
Slum relocation and rehabilitation
Providing proper drainage facilities at vulnerable areas
Construction of redundant infrastructure
Policies under *bundle 2*
Rerouting people during flooding
Restricting development in low lying or vulnerable areas
Slum relocation and rehabilitation
Policies under *bundle 3*
Replacement of impermeable surfaces with permeable material in vulnerable areas
Providing proper drainage facilities at vulnerable areas
Rerouting people during flooding

Bundle 1 consists of land use and infrastructure related policies, Bundle 2 consists of land use and Information related policies (Traffic management) and Bundle 3 is a mixture of Infrastructure and information (Traffic Management) related policies.

These policies were evaluated by feeding the necessary variable into the transport model. It is observed that the Vehicle kilometres travelled reduces from 50.8 million km to 48.6 million km for the year 2030 flooding scenario. For the year 2050 the VKT's reduced from 75.3 mil km to 73.1 mil km (3% reduction). The comparison of VKT's for various scenarios for the years 2030 and 2050 and it is seen that the maximum reduction in VKT comes from bundle 1.

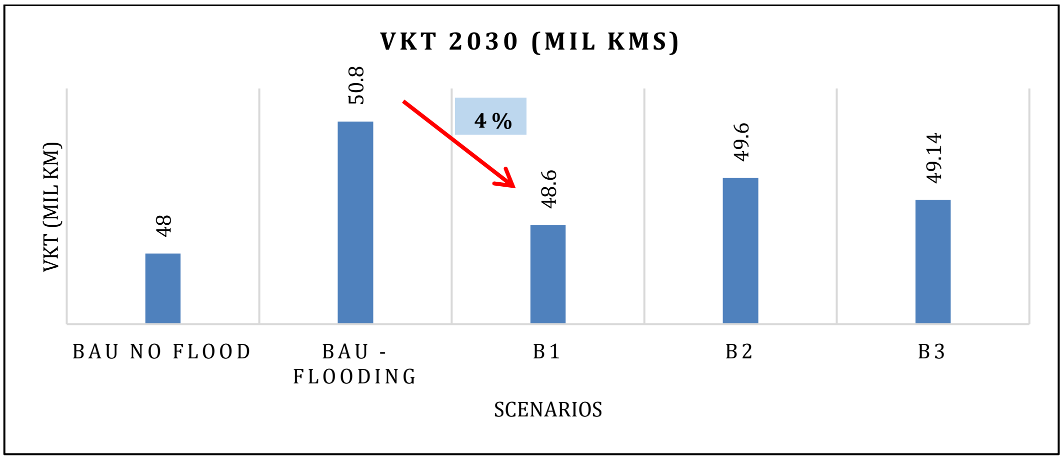


Figure XIV: Comparison of VKT for BAU and Adaptation Bundles for 2030

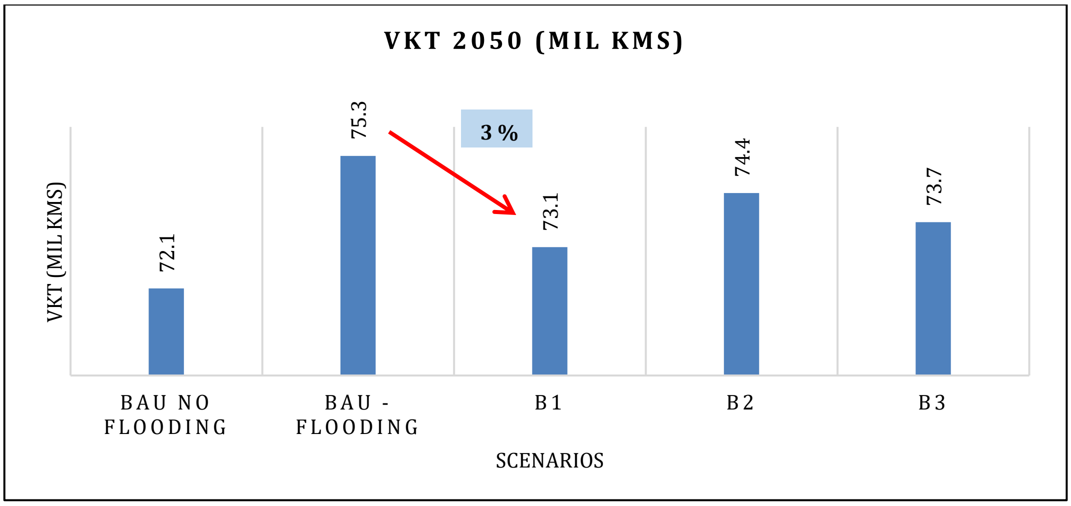


Figure XV: Comparison of VKT for BAU and Adaptation Bundles for 2050

It is observed that the daily average travel speed increases from 16.8 kmph to 21.3 kmph in bundle 1 for the year 2030 and from 13.2 kmph to 19.1 kmph in bundle 1 for the year 2050 which is 45% increase in travel speeds with respect to BAU. The trip lengths were found to reduce by 10% - 13% between bundle 1 and BAU scenario. By implementing these bundles there will be a reduction in travel times with the best bundle being bundle 1. Vehicle hours travelled reduces from 11.32 million hours in to 10.25 million hours in bundle 1 for 2030. Zones that do not have access to other zones due to heavy flooding on the road network are assumed to have cancelled trips. It is seen that there are 1.6 million trips are cancelled in BAU scenario for the flood scenario whereas no trips are cancelled upon the implementation of Bundle 1.

This report contains the mitigation and adaptation measures that are quantitatively evaluated thereby improving the liveability of Bengaluru in terms of; reduced traffic congestion (VKT), reduced exhaust emissions (PM, CO, NO_X, HC), reduced greenhouse gas emissions (CO_2), reduced carbon emission intensity, increased consumer surplus of sustainable modes and also improved resiliency of transportation system. The significant reduction in emissions is observed with the implementation of bundle 4-scenario 4 which includes the electrification of all buses and cars. Thus, it is concluded and recommended that the implementation of bundle 4 along with scenario 4 will result in considerable reduction in emissions from transport sector. Although CO_2 emission factor values are zero in scenario 4 it is suggested that shifting towards mass transportation systems like Bus & Metro not only reduces the emissions but also reduces the congestion on the roads by a great amount. A proper amalgamation of **planning, regulatory, economic and technology** instruments incorporating the complete clean energy can help in improving the sustainability of transportation systems thereby enhancing liveability of the city. The study also clearly states that with a proper management of land use and infrastructure policies we can nullify the trips that get cancelled due to flooding and people can still make trips in such extreme events.

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1 INTRODUCTION

1.1 GENERAL BACKGROUND

Rapidly growing economies and subsequent increase in private vehicle usage pose a great threat to the sustainable development of most of the developing cities worldwide. Increasing urban population and motorization in most of the Asian countries are bound to raise road congestion and environmental pollution making cities difficult to live. There are many sectors that are contributing to the environmental pollution and transportation sector is one of the major contributors.

Bengaluru, for decades has been known for its pleasant weather which attracted people from length and breadth of the country. The development of IT industry has changed the face of Bengaluru from what it was once used to be and attracted many people to settle in Bengaluru. However, the unplanned and uncontrolled urbanization has resulted in a rapid increase in urban area and reduction in vegetation and water bodies. There has been a 584% increase in the city‘s built up area in the past four decades. Bengaluru is called as garden city because of its vast land area covered under vegetation. Due to increased urbanization it reduced from 68% in 1973 to 23% in 2012. Bengaluru also has a huge network of water bodies which reduced from 3% in 1973 to less than 1% in 2012. This unprecedented growth in urbanization and income levels has resulted in the growth of the private vehicles that are plying on Bengaluru roads. This has led to chaotic traffic conditions choking the limited infrastructure that is available for vehicle movement. Transportation sector is one the major contributors of Greenhouse gases which are known to warm the earth. Bengaluru has a pleasant weather ranging from an average of 14 ^{o}c in January to 33 ^{o}c in April which has hit a maximum of 39.2 ^{o}c in 2016. Apart from the above mentioned issues congestion is also a major issue in Bengaluru leading longer travel times, exposing to pollution for longer times causing health problems; polluted lakes like Bellandur are to be noted.

Mercer a global consulting firm developed a Quality of Living Index for 2017 in which Bengaluru is ranked 146 globally and in terms of infrastructure Bengaluru ranks at 177 and lowest among the surveyed Indian cities. The Union Ministry of Housing and Urban affairs (MoHUA) on January 19th 2018 decided to assess the livability index of 116 Indian cities. Liveability index is tool that aims to measure quality of life in 99 smart cities, capital cities and those with a population of over one million. India does not have a liveability index so far and this will be the first of its kind. This index will be assessed on the basis of four main pillars which are governance, social, physical and economic.

The current study addresses the indicators that were mentioned in the liveability index for Indian cities report. This report considers emissions from transport sector and urban floods which are affecting transportation sector as the core issues. This report is an attempt to make Bangalore Metropolitan Region more liveable by implementing certain policies that mitigate the emissions from transportation sector and policies that helps the transportation sector to be adaptable to the sudden urban flooding. Although the focus is on reducing emissions from transport sector, implementation of these policies will result in reduction of congestion in Bengaluru making it safer for travel and for a healthy living.

India communicated its Intended Nationally Determined Contribution (INDC) in response to Paris COP-21 agreement for the period 2021 to 2030 to reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level. However, INDC does not mention the percentage share of emissions reduction for transport sector because of which the same targets have been considered for transport sector also.

The main objectives of the study are:

1) Developing mitigation strategies for transportation sector which are aimed at reducing the GHG emissions, local pollutants and traffic congestion from a baseline condition. These mitigation strategies will be developed for two scenarios which are Business as usual scenario and sustainable transport Scenario for the base year and the future years 2030 and 2050.
2) Identification of the transportation infrastructure that is vulnerable to climate change and assess the impacts of climate change on the transportation infrastructure.
3) Developing adaptation strategies for the base year and the horizon years 2030 & 2050 to evaluate the vulnerability, scope & extent, severity of each flood event caused by climate change to transportation sector.
4) Improving the overall liveability of Bengaluru.

In this research, the demographics & mobility pattern of the Bangalore Metropolitan Region (BMR) has been studied for the base year 2008 and then forecasted for the horizon years 2030 & 2050 as a part of Business As Usual scenario (BAU). The mitigation and adaptation strategies are developed to estimate and evaluate the effects of each policy on the BAU scenario for the years 2030 & 2050.

1.2 BENGALURU CITY

Karnataka, the south western state of India is the 7th most urbanized State in the country. Bengaluru, the Capital city of Karnataka is the fifth largest metropolitan city in India in terms of population. Popularly known as the 'Silicon Valley 'of India due to the IT Industry boom that shaped the economy of the city in the 1990's, the city has grown from a 'Pensioner's Paradise' to the R&D Hub of the Country. With economic growth, Bengaluru's labour force, research capacity, pleasant climate made it an attractive base for the emerging high-tech and business process outsourcing industries. Apart from national and international software companies, other major industries such as automobile manufacturing and aviation have also had a larger role in shaping the economy. The Karnataka state map with administrative divisions is shown in Figure 1.

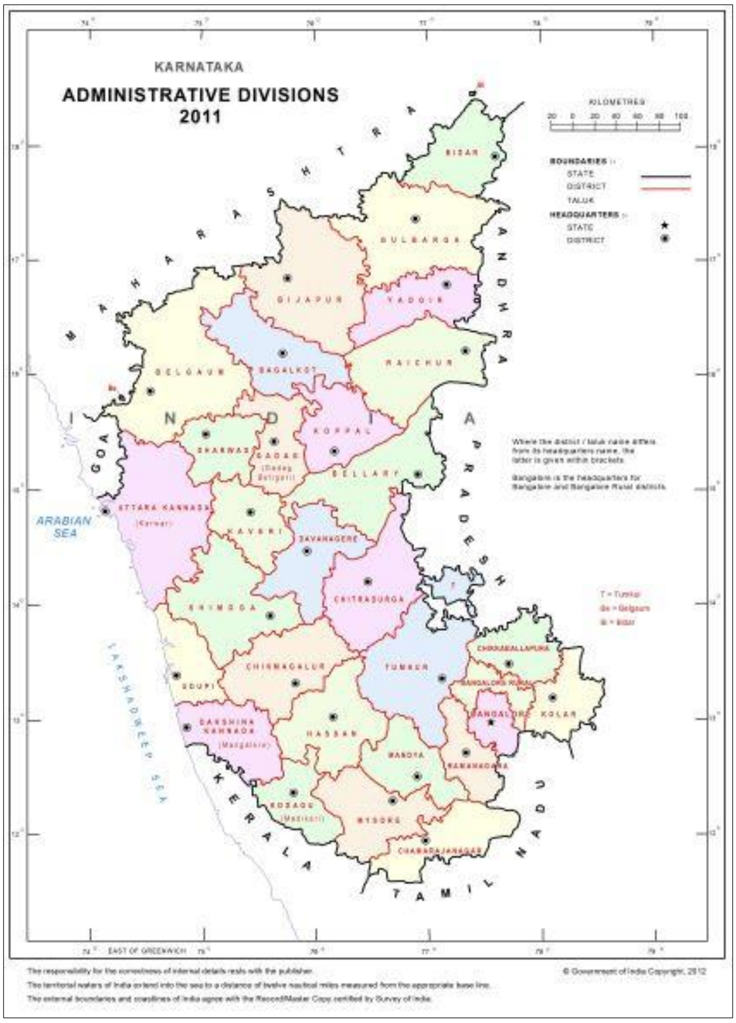


Figure 1: Karnataka State Map

1.3 TOPOGRAPHY

Bengaluru is located in the South East of Karnataka. It is located in the heart of the Mysore Plateau at an average elevation of 920M (3,018 feet) above mean sea level. It is positioned at 12.97° N 77.56° E. Bengaluru District borders with Kolar District in the North-East, Tumkur District in the North-West, Mandya District in the South-West, Chamarajanagar District in the South and the neighbouring state of Tamil Nadu in the South-East. Bengaluru has a number of fresh water lakes and water tanks, some of the largest lakes and water tanks are Hebbal Lake, Ulsoor Lake, Madivala Tank and Sankey Tank. The map showing the topography of Bengaluru urban district is presented in Figure 2.

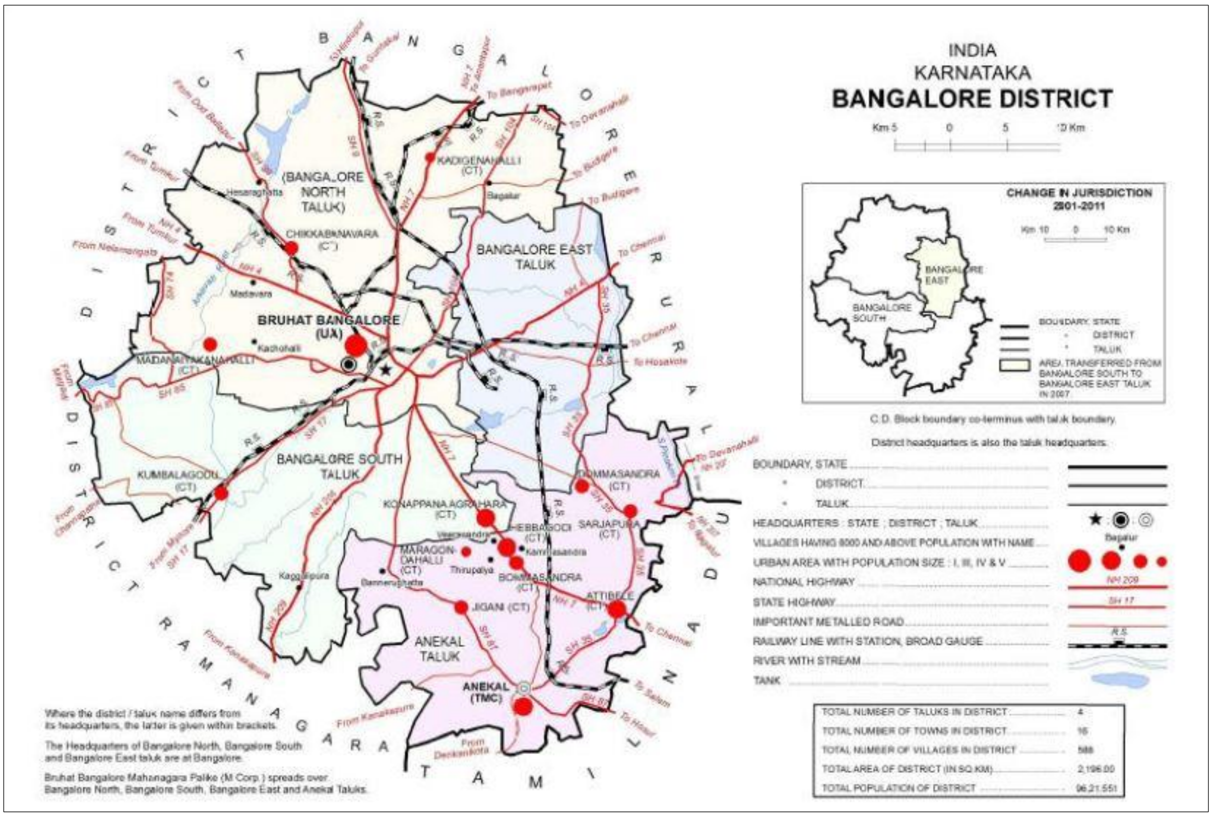


Figure 2: Topography Map of Bengaluru Urban

(Source: Census 2011)

1.4 DEMOGRAPHY

Bengaluru is a good example of rapid urbanization, which is evident from the fact that the city added about two million people in just last decade. Bengaluru recorded the highest growth of 106% in the last two decades. Although Bengaluru's rapid economic growth has substantially improved the local quality of life, yet challenging issues of urbanization, motorization, congestion & pollution looms over the development of the city. Bengaluru's infrastructure and urban planning has not kept pace with its rapidly increasing population and the growing number of vehicles on the road. The population of Bengaluru had increased from 8.5 million in 2001 to 10.8 million in 2011.Bengaluru is the most urbanized district with 90.94% of its population residing in urban areas.

Bangalore Metropolitan Region consists of three districts namely, Bengaluru Urban District, Bengaluru Rural District and Ramanagaram District (Ramanagaram is a newly created district carved out from Bengaluru Rural district that includes Ramanagaram, Chennapatna, Magadi and Kanakapura taluks). The figure 3 shows the blow up of the three districts.

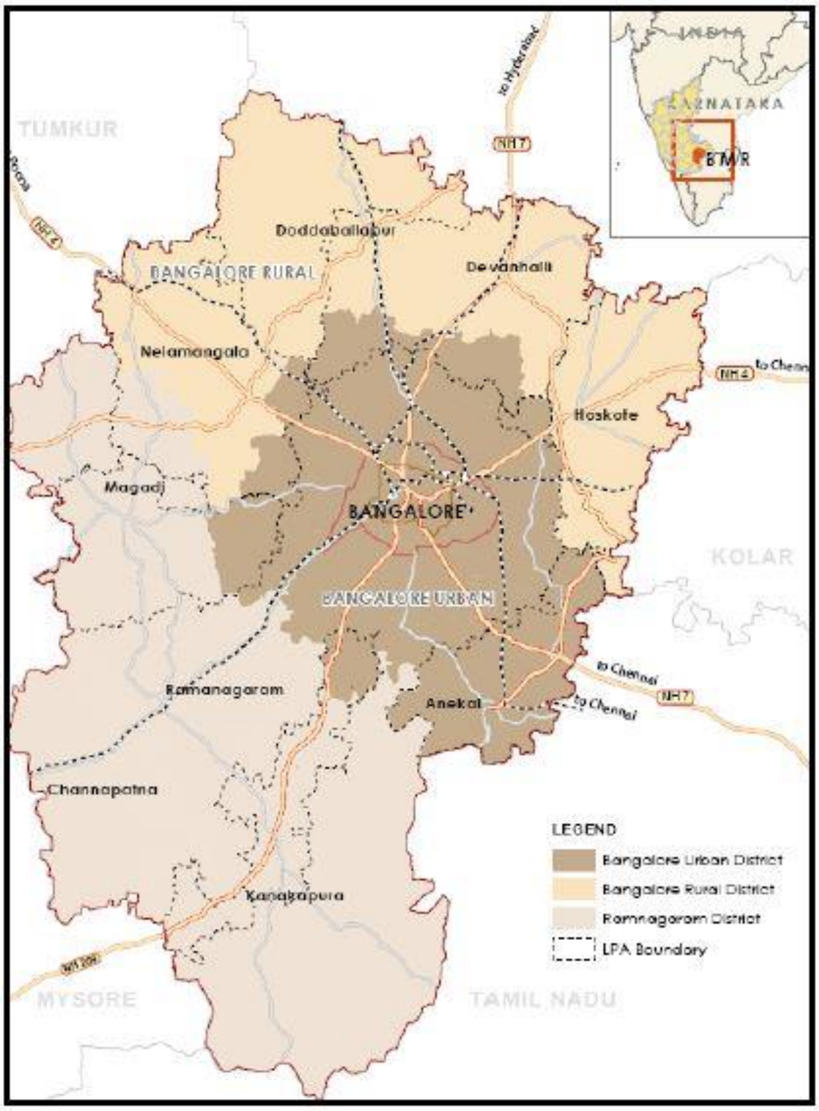


Figure 3: Blow up of Bangalore Metropolitan Region

(Source: BMR revised structure plan 2031)

1.5 MOBILITY

The transportation system in Bengaluru is far behind than what is needed to suffice the increasing urbanization. Traffic problems are diverse and complex ranging from lower speeds, longer travel times (the peak hour travel speed in the city is 17 km/hr) poor road safety, inadequate infrastructure and environmental pollution. Personalized modes of transport have been growing at a tremendous rate; two wheelers along with cars almost comprise 90% of the total registered vehicular population in the city. Over 0.58 million new vehicles were registered between 2015 and 2016 taking the total number to over 6.6 million in the BMR. The relative inadequacy of public transport in suburban areas, where it has not developed in pace with urban expansion, further adds to the gap in spatial mobility and makes it harder to meet the most basic needs of urban and suburban residents.

2 BACKGROUND

2.1 POPULATION

The population growth rate of the BMR during the decade 2001 and 2011 is observed to be 28.5 percent, whereas the Bengaluru Urban district recorded 47.18 percent population growth rate during 2001-2011. The declining trend in decadal growth rate is observed since 1961 onwards. The decadal growth rate of the Bengaluru Urban district has been increased by 12.1 percent compared to the previous growth rate between 1991 and 2001. Table 1 and Figure 4 show the population increase from 2001 to 2011 for the Bangalore Metropolitan Region.

Table 1: Population Density of BMR

Year	2001	2011
BMR Population	8418638	10818655
Area (sq.km)	8005	8005
Density	1052	1351

(Source: CTTS, 2010)

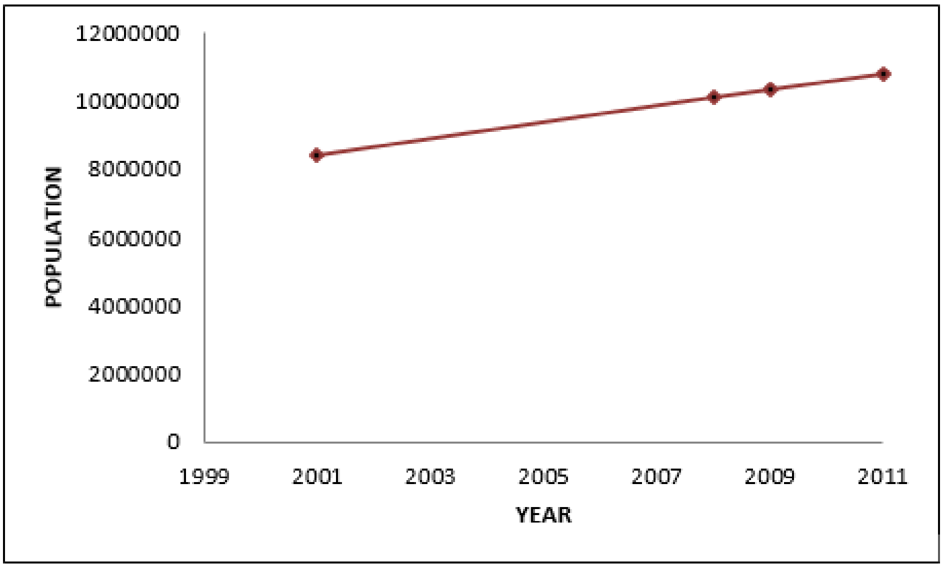


Figure 4: Population growth of BMR from 2001 to 2011

(Source: CTTS, 2010)

The decadal growth rate in urban areas is greater than the growth rate registered in rural areas that is 51.91% and 12.16% respectively. The state is expected to reach an urban population proportion of 50% in the next fifteen years (2026). The population living in urban slums in Karnataka has risen from 1.4 million (2001) to 3.3 million (2011) in a decade. This is a rise from 7.8% of the total urban population of the State being slumdwellers according to the 2001 Census to 13.9% now. Bengaluru district has 21.5% of the total slum population (Census 2011).

2.2 AREA

In January 2007, the Karnataka Government issued a notification to merge 100 wards of the erstwhile Bengaluru Mahanagara Palike with seven City Municipal Councils (CMC), one Town Municipal Council (TMC) and 111 villages around the city to form a single administrative area, Bruhat Bengaluru Mahanagara Palike (BBMP). Bangalore Metropolitan Region is 8005 sq.km in area. The figure 5 shows the area under jurisdiction of Bangalore Metropolitan Region Development Authority.

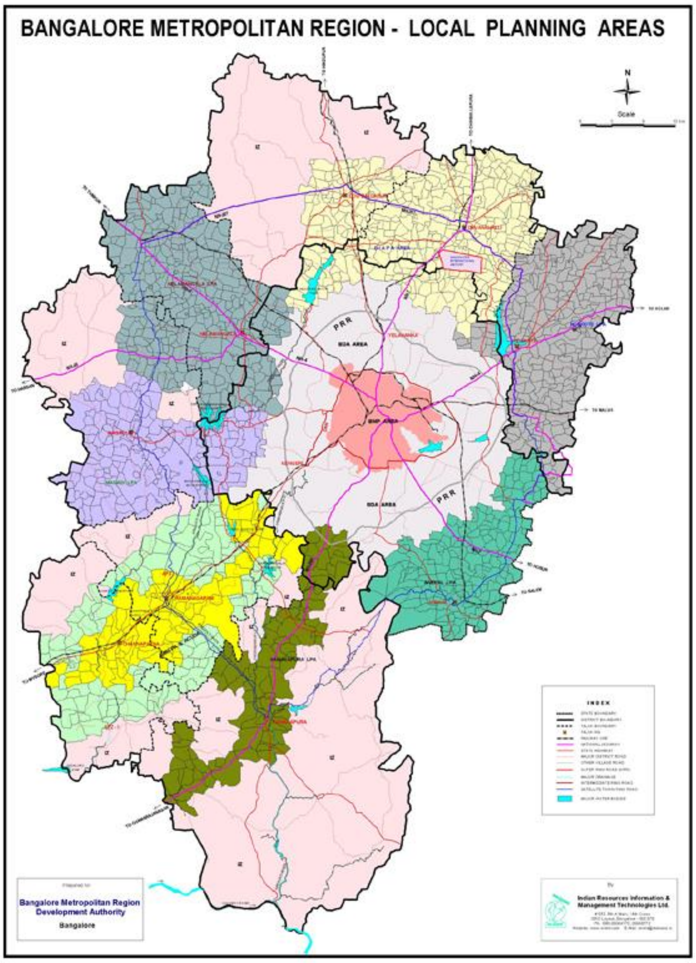


Figure 5: Area under jurisdiction of BMRDA

(Source: CTTS, 2010)

Bengaluru city has been sprawling due to rapid urbanization. The following figure 6 illustrates the expansion in the built up area till the year 2010.

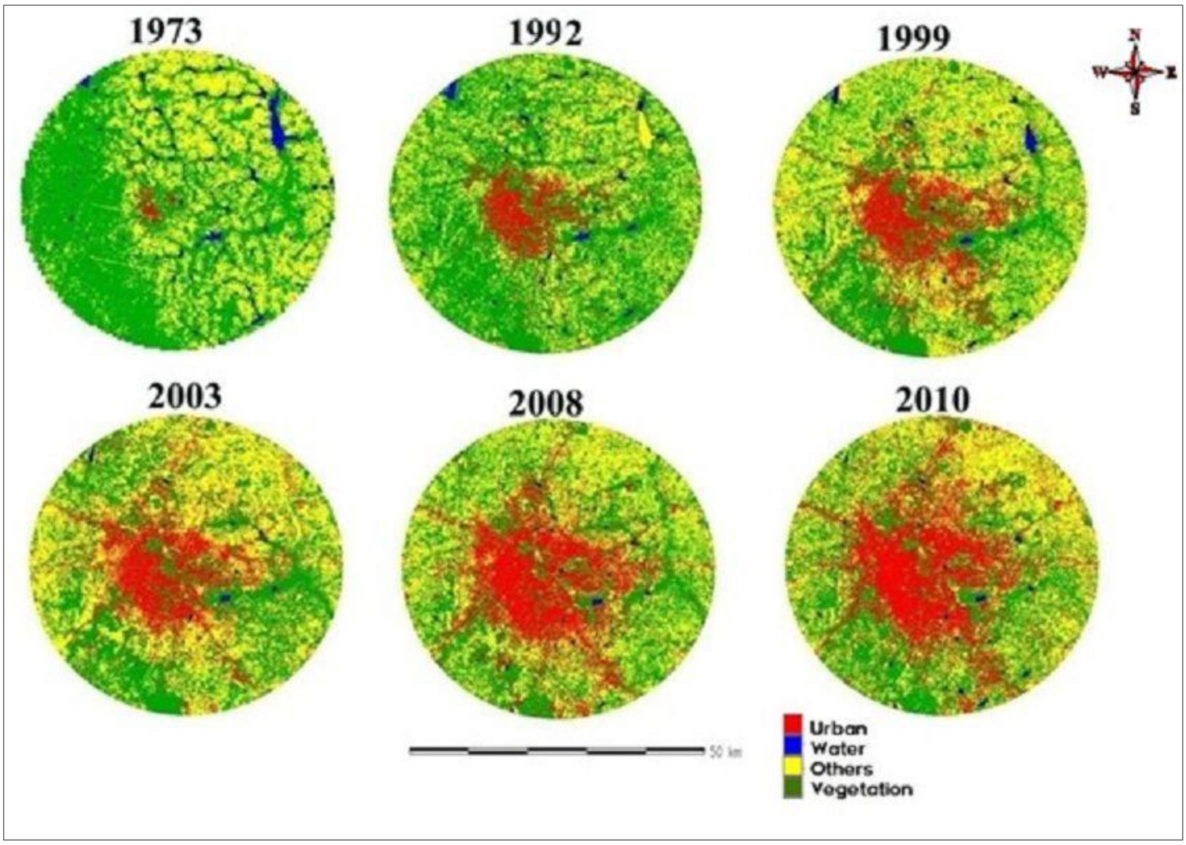


Figure 6: Classified Land Use of Bangalore (1973-2010)

(Source: Peri-Urban To Urban Landscape Patterns Elucidation through Spatial Metrics T. V. Ramachandra CES, IISc)

2.3 ECONOMY

Bengaluru is not only a home to major IT companies of the country but also to premier scientific centres like Indian Institute of Science (IISc), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian Space Research Organization (ISRO), National Aerospace Laboratories (NAL), Defence Research and Development Organization(DRDO) amongst others. An important feature of the economic activities of Bengaluru is the huge concentration of Small and Medium Enterprises (SMEs) in diversified sectors across the city. Bengaluru has more than 20 industrial estates/areas comprising large, medium and small enterprises.

Public Sector Undertakings and the textile industry initially drove Bengaluru's economy, but the focus in the last decade has shifted to high-technology service industries. Bengaluru Urban District stood first in the total District Income as well as per capita district income for the year 2011-12. Bengaluru Urban District itself contributes about 33.8% to GSDP at Current Prices.

Bengaluru has the second highest literacy rate (83%) for an Indian metropolis, after Mumbai. The city's workforce structure is predominantly non-agrarian, with only 6% of

Bengaluru's workforce being engaged in agriculture-related activities. The Gross District Domestic Product (GDDP) for BMR is given in table 2.

Table 2: GDDP growth for BMR

Year	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
GDDP in Rs. (at current prices)	11,741,176	12,911,681	14,612,933	17,306,057	19,277,397	29,433,784

(Source: State and district domestic product of Karnataka 2014-15, Directorate of economics and statistics, Bengaluru)

2.4 CONNECTIVITY

Bengaluru is served by Kempegowda International Airport located at Devanahalli, about 40 kilometres (25 miles) from the city centre. It was formerly called Bangalore International Airport. The Kempegowda International airport is the third busiest airport in India after Delhi and Mumbai in terms of passenger traffic and the number of air traffic movements (ATMs). Taxis and air conditioned Volvo buses operated by BMTC connect the airport with the city.

Bengaluru is well connected by rail to most cities in Karnataka, as well as with other major cities in India. Bengaluru is a divisional headquarters of the South Western Railway zone of the Indian Railways. There are four major railway stations in the city: Bengaluru City junction, Bengaluru Cantonment Railway station, Yeshwanthpur station and Krishnarajpuram railway station.

Bengaluru’s buses are operated by the Bangalore Metropolitan Transport Corporation (BMTC) which is seen as one of the most successful bus operations in India. BMTC runs air-conditioned luxury buses on major routes, and also operates shuttle services from various parts of the city to Kempegowda International Airport. The Karnataka State Road Transport Corporation operates buses connecting Bengaluru with other parts of Karnataka as well as other neighbouring states.

2.5 LANDUSE

Bengaluru City had developed spatially in a concentric manner. Bengaluru has grown radially from 1973 to 2010 indicating that the urbanization is intensifying from the central core and has reached the periphery of the Greater Bengaluru. Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010. The spatial distribution of existing land use (2015) and the proposed land use for 2031 is presented in figure 7 and 8 respectively.

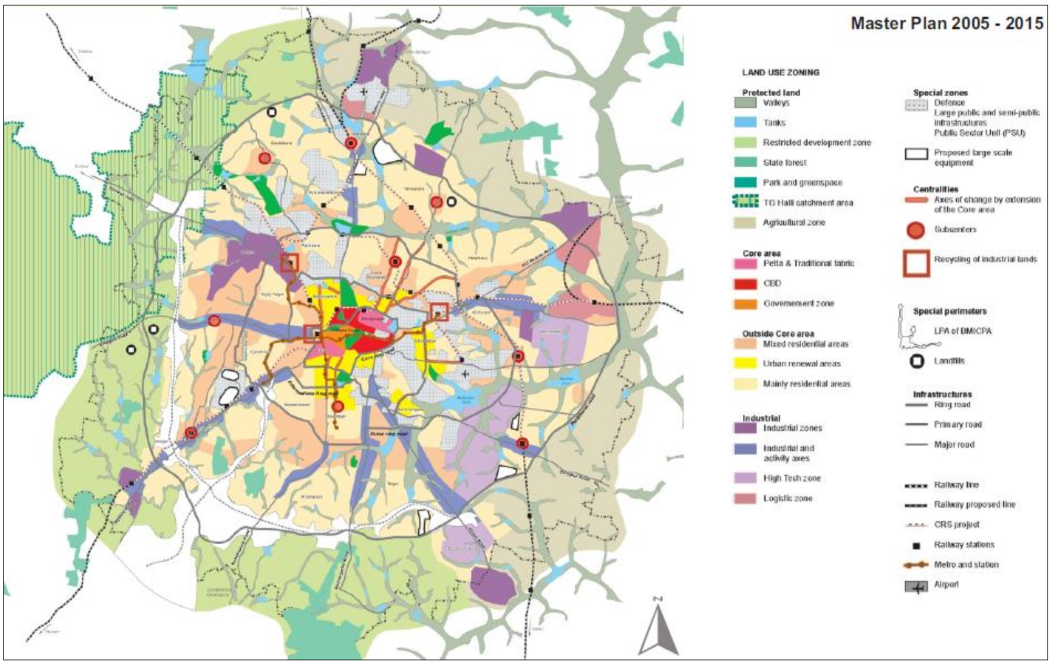


Figure 7: Spatial Distribution of Existing Land Use (2015)

(Source: Draft Master Plan 2015, BDA)

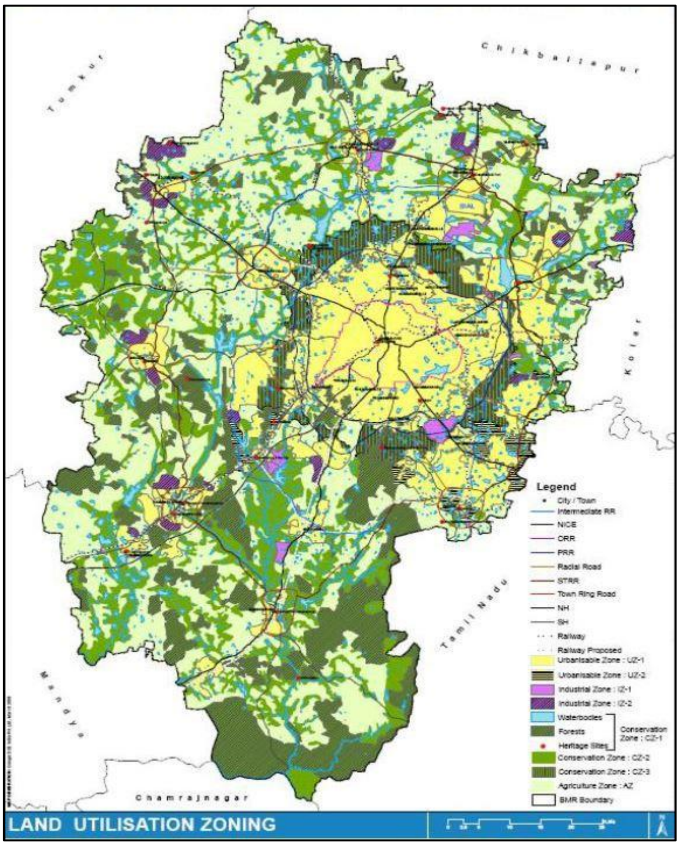


Figure 8: Proposed Land Use for 2031

(Source: BMR revised structure plan 2031)

2.6 ROAD NETWORK SYSTEM

Bengaluru Metropolitan Region (BMR) has approximately 6000 km of road length for an area of 8005 sq. km. The BMR is intercepted by 2 National Expressways and 3 National Highways and 12 State Highways connecting major towns and cities within BMR and beyond. The radial road network in the BMR converges into the core and contains centre-periphery traffic as well as the transit traffic which chokes the city centre.

2.7 REGISTERED VEHICLES AND TRENDS IN MOTORISATION

Present vehicle population in BMR is 6.6 million with a major share of two-wheelers (69%) followed by passenger cars (19%) (*Source: RTO*). Between 1990 and 2016, the number of vehicles registered in Bengaluru has increased from 0.63 million to 6.6 million. Within the region, Bengaluru Urban has the majority of vehicular population of 96% compared to Bengaluru Rural with 3.7% and Ramanagaram with 0.3%. The year wise vehicular growth between the years 2001-02 and 2015-16 is shown in figure 9. Urban transport in Bengaluru is essentially road based, since the national rail lines were neither designed nor operated with regard to urban and regional traffic (infrequent stations, no pass-through lines, low service frequency).

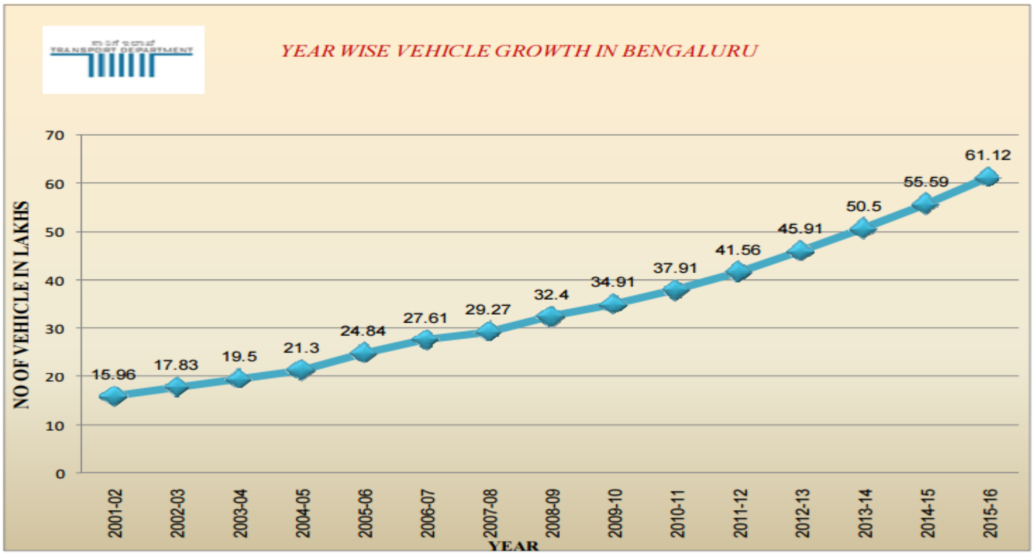


Figure 9: Year-wise Vehicle Growth in Bengaluru

(Source: Annual report 2015-16 RTO)

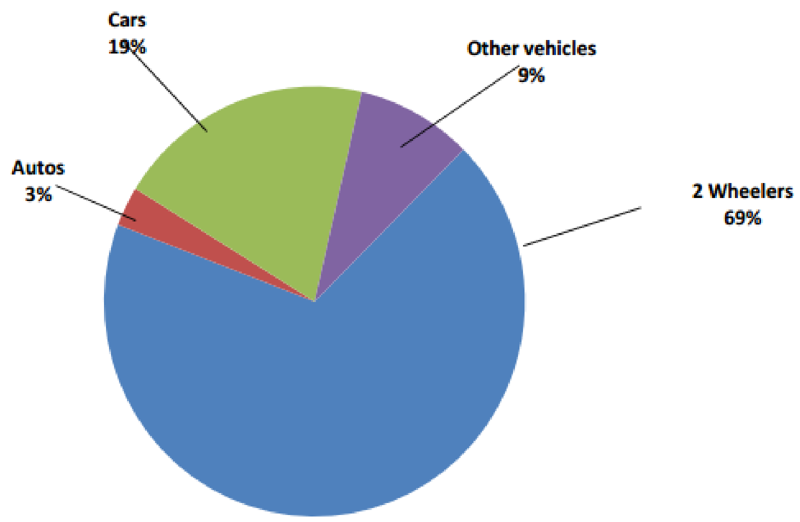


Figure 10: Vehicular Composition in Bengaluru as on 31st March 2016 (%)

(Source: Annual report 2015-16 RTO)

2.8 URBAN BUS TRANSPORT SYSTEM

Conventional public transport services are provided by Bangalore Metropolitan Transport Corporation (BMTC) with 6635vehicles and daily trips of 71374 (BMTC 2018). The specification of the urban bus network run by BMTC is given in table 3. BMTC currently provides point-to-point services throughout the city. This routing practice usually results in low frequency of service and low service levels characterized by large waiting time, number waiting and total travel time.

Table 3: Specification of the Urban Bus Network

Fleet Strength	6635
No. of Schedules	6141
Service kms (in Million)	1.155
No. of trips	71374
Revenue(in Million)	47.8
Depots	44
Bus stations	53
Staff strength	34214

(Source: BMTC website, March 24, 2018)

2.9 BENGALURU METRO RAIL SYSTEM

'Namma Metro' (literally 'our metro') or the Bengaluru Metro is the rapid mass transit system for the city. A 7-kilometre (4 mi) stretch from Bayappanahalli to MG Road was opened to public on 20 October 2011, while another 10 kilometres (6 miles) stretch from Malleswaram to Peenya was opened on 1 March 2014.

Phase 1 consisted of two corridors:

1. East-West Corridor from Baiyappanahalli Terminal to Mysore Road Terminal - 18.10 km.
2. North-South Corridor from Hesaraghatta cross Station to Puttenahalli cross - 24.20 km.

Out of a total of 42.30 km system about 8.80 km is underground section and balance about 33.50 km is elevated with 40 stations of which 7 stations are underground, 2 at grade and 31 are elevated. The final section of Phase 1 of the metro construction was completed and opened to public in June 2017. The details of the existing metro lines are given in table 4. Construction of 72.1 km of Phase 2 of the Bengaluru Metro system began in November 2015. Phase 2 includes a total length of 72.095 km (13.79 km underground) and 61 Stations with 12 Underground Stations. The map showing the alignment of Phase 1 & 2 metro lines is presented in figure 11.

Table 4: Details of two existing Metro Lines

Line	Stations	Total Length (in KM)	Terminals		Frequency	Vehicle kilometers travelled	Ridership/ day(avg.)
Purple Line	16	18.10	Baiyappanahalli	Mysore Road	91	14,986	1647.1
Green Line	24	24.20	Puttenahalli	Nagasandra	99	13,066	2250.6

(Source: BMRCL website)

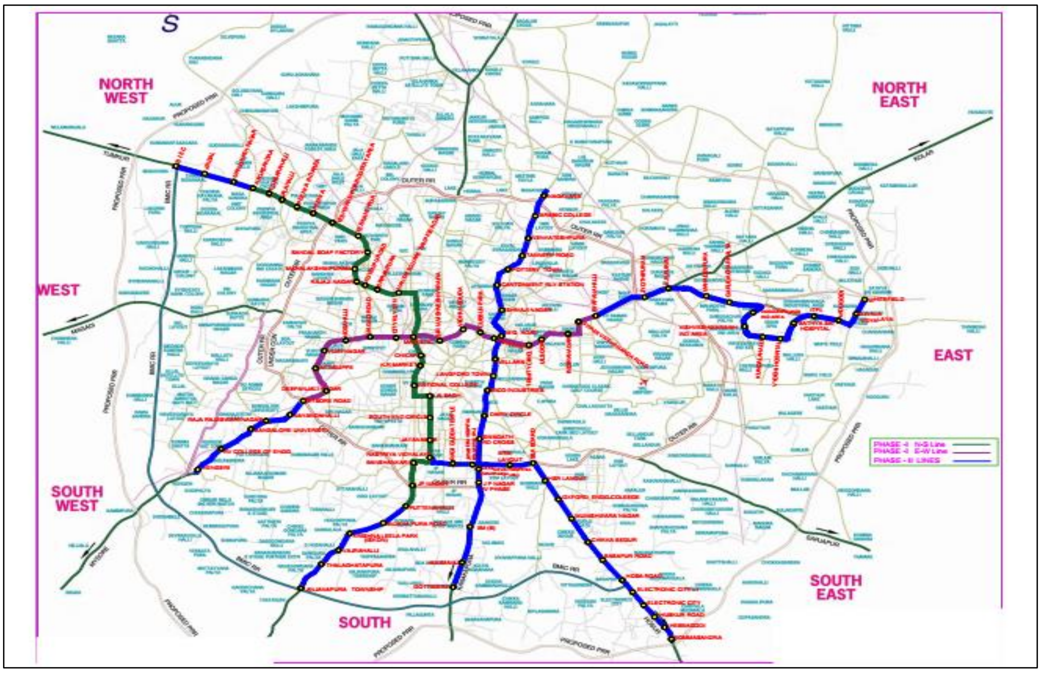


Figure 11: Bengaluru Metro Rail Alignment – Phase I & II

(Source: BMRCL website)

2.10 TRAVEL DEMAND

2.10.1 Trip Generation and Average Trip Length

A study estimated a total of 128.38 lakh trips generated in BMR in the year 2009. The average trip length was 10.1 km. The total number of vehicles in BMR in 2009 was estimated to be 33 lakhs.

Table 5: Trip Production in 2009

Year	**2009**
Motorised Trips (in lakhs)	128.38
Avg. Trip Length for motorised vehicles (in kms)	10.1
Total Vehicle Population (in lakhs)	33

(Source: CTTS, 2010)

2.10.2 Per capita Trip Rate (PCTR)

In the BMR region, the per capita trip rate for motorised vehicles was estimated to be 1.28 km in 2009.

3 BASE YEAR TRAVEL DEMAND MODEL

Four-Step travel demand modelling is the traditional procedure utilized for transportation forecasts. The flow chart depicting the standard four-stage travel demand modelling is illustrated in the figure 12.

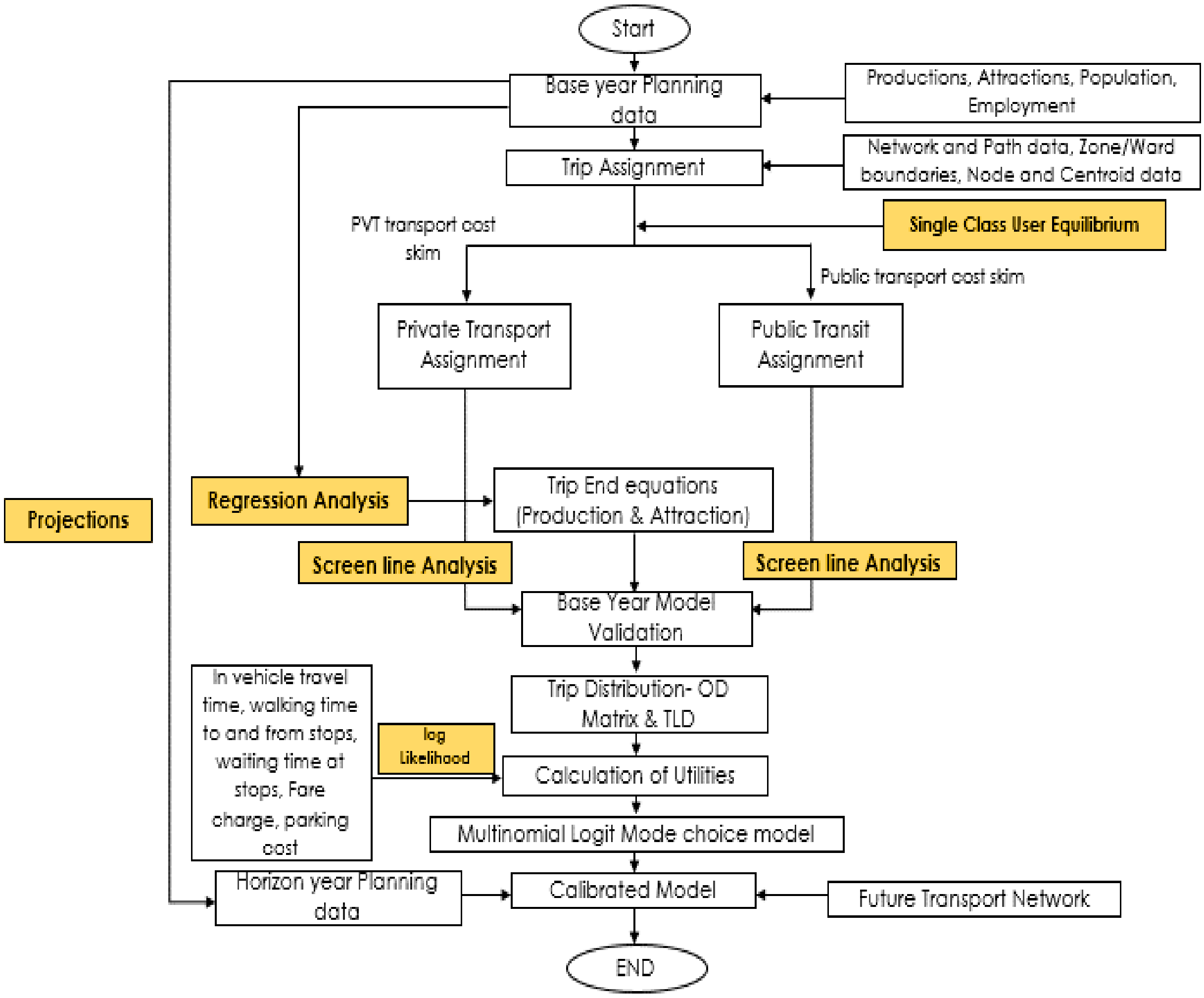


Figure 12: 4-Stage Travel Demand Modelling Flow Chart

3.1 TRAVEL DEMAND MODELLING RESULTS

3.1.1 Trip Generation

Trip generation is the first stage of the demand models. It aims at predicting the total number of trips generated and attracted to each zone of the study area. It consists of two types as follows:

1. *Trip Production*: All the trip which are home based or have a non-home based origin are Trip Productions. Various independent variables like household income, vehicle ownership, household structure and family size influence trip productions.

2. *Trip Attraction*: Trip Attraction is the non-home based trip and is the destination of a non-home based trip. It is influenced by factors such as land use, employment, accessibility etc.

The population and employment variables for the base year 2008 have been considered to generate the trip end equations for productions and attractions respectively using a linear regression model. These trip end equations are used to forecast the future year productions and attraction using the future year's population and employment and are developed separately for private and public transport. The generated trip end equation for private and public transport is displayed in table 6.

Table 6: Trip End equations for Private and Public Transport

Mode	P-A	Trip End Equations	R^2
Private	*Production*	0.56 x POP + 1344.34	0.46
	Attraction	0.76 x EMP + 6877.28	0.4
Public	*Production*	0.42 x POP + 4080	0.43
	Attraction	0.76 x EMP + 6231	0.4

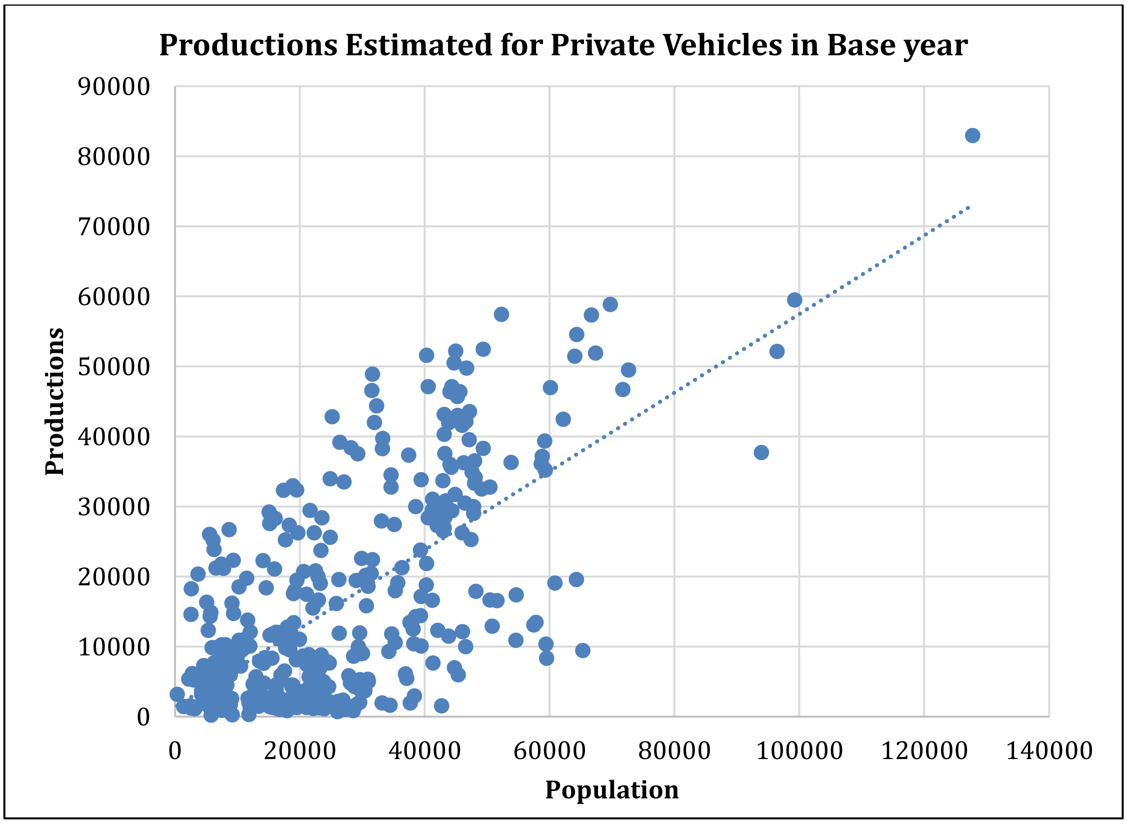


Figure 13: Estimated productions for Private Vehicles in Base Year

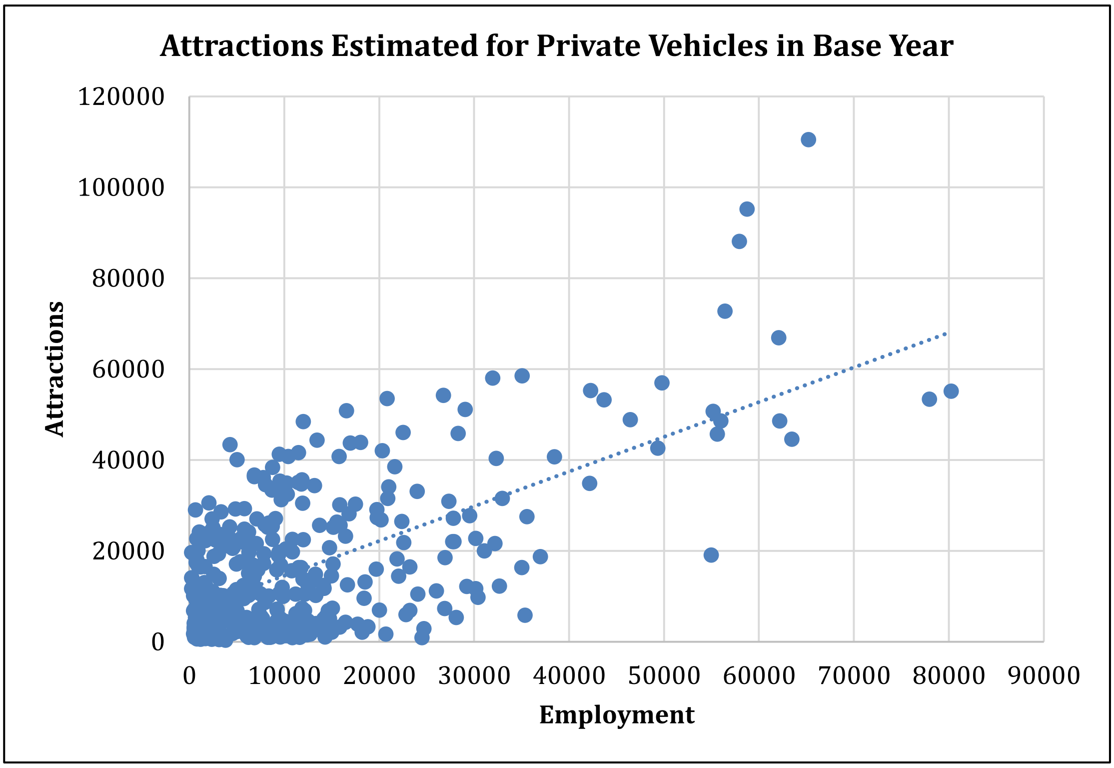


Figure 14: Estimated Attractions for Private Vehicles in Base Year

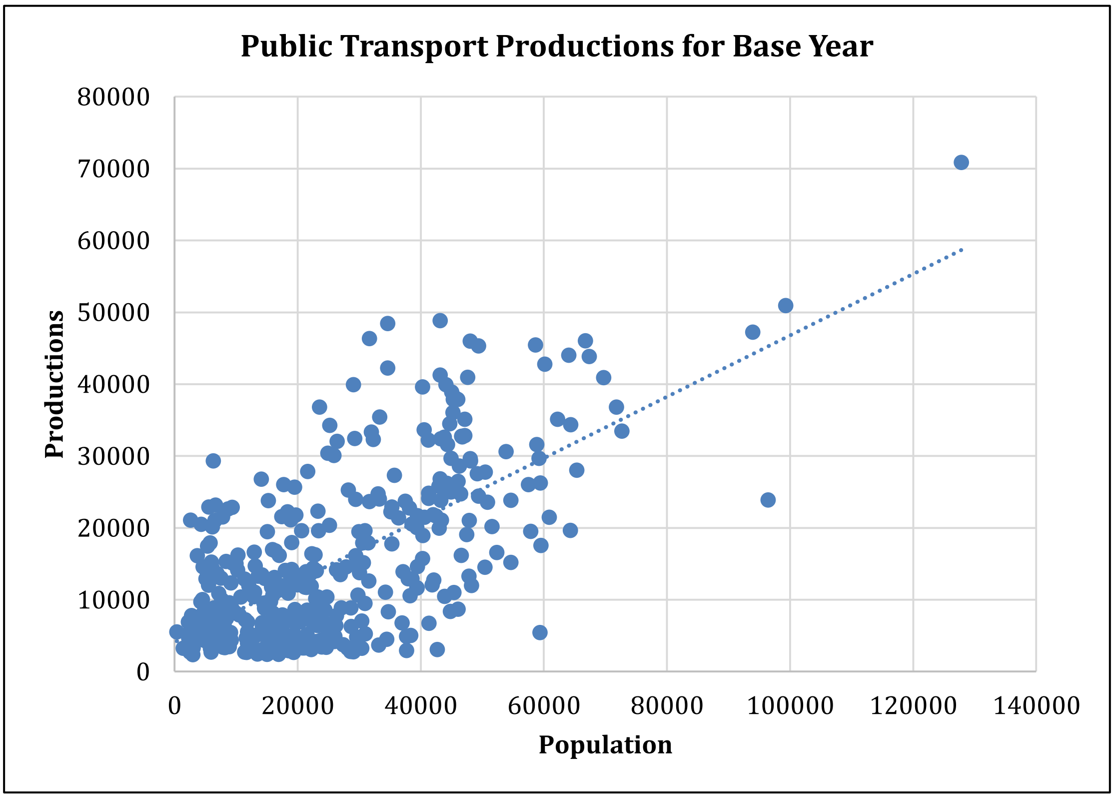


Figure 15: Estimated productions for Public Vehicles in Base Year

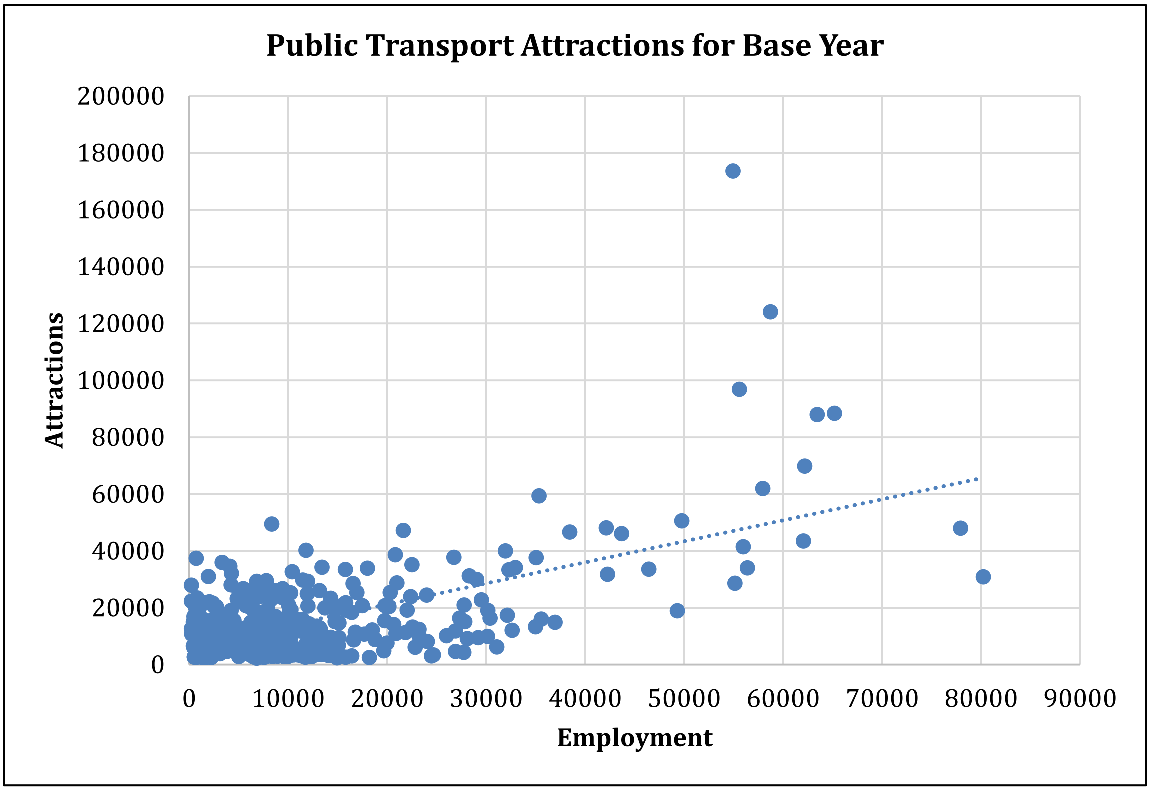


Figure 16: Estimated attractions for Public Vehicles in Base Year

The per capita trip rates for the whole BMR region for private and public transport are shown below in Table 7.

Table 7: Estimated Per Capita Trip Rates (PCTR) for Private and Public Transport

Mode	Estimated PCTR
Private Vehicles (including NMT)	0.61
Public Transport	0.58

The equations shown in table 6 act as a basis for estimating the future year's trip productions and attractions for public and private transport by replacing the Population (POP) and Employment (EMP) variable with the required year's population and employment. In order to use these equations for the predictions they should be validated and that is carried out in trip assignment section.

3.1.1.1 *Trip generation model validation*

The total trip productions and attractions were calculated using the equations mentioned in table 6. In order to validate these trip end equations, the estimated productions are then compared with the observed productions. The correlation coefficient of trip productions for estimated and observed private vehicles and public transport are 0.79 and 0.75 respectively which signifies a positive correlation. Similarly, correlation coefficient was estimated for trip attractions of private and public transport which are

0.69 and 0.63 respectively. The base year OD matrix is validated by assigning the flows on to the road network separately for private and public transport. Screen line analysis has been performed at different locations and it was found that the errors are within permissible limits. The model will be termed as validated once the traffic loadings on the network are matching the 44 selected check points (screen lines locations) on the road network. The selected screen lines and screen line locations for the validation is demonstrated in the figure 17 and the model validation results are given in table 8.

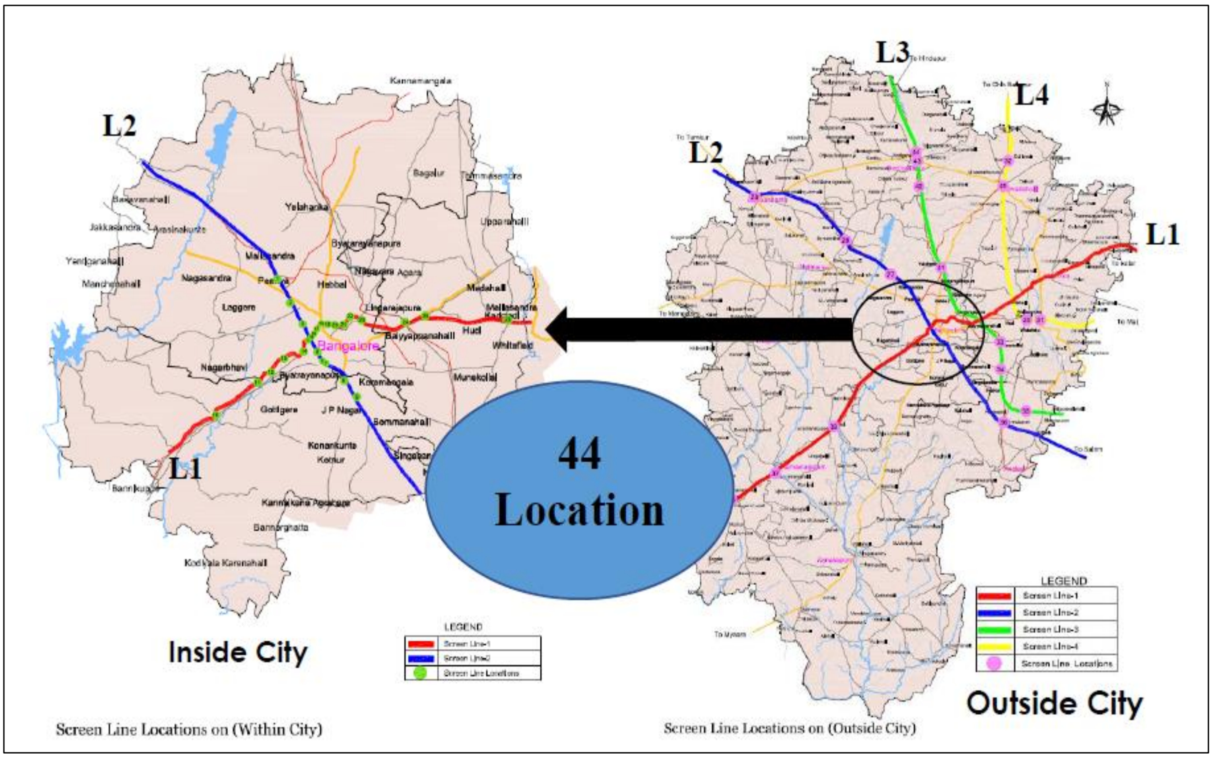


Figure 17: Screen Lines and Screen line locations

Table 8: Model validation Results

Screen line No	Calculated ADT	Observed ADT	Percentage Error Final
	Inside City		
L 2	519192.9462	485982	6.8
L 1	269042.0065	319672	15.8
	Outside City		
L 1	24907	21724	14.7
L 2	47714.44178	45778	4.2
L 3	100569.0657	97899	2.7
L 4	30995.64527	34118	9.1

3.1.2 Trip Distribution

Trip Distribution is the second step Travel Demand Modelling. Its purpose is to analyse and synthesis trip linkages between traffic zones concerned with the estimation of target year trip volume. A doubly constrained gravity model has been used to distribute the trips between origin and destination. Trips distributed between 384 zones is given by the following equation,

$$T_{ij} = A_i O_i B_j D_j f(c_{ij}) \ldots \text{Eq. 1}$$

$B_j = 1/\Sigma_i A_i O_i f(c_{ij})$

$A_i = 1/\Sigma_j B_j D_j f(c_{ij})$

Where, A_i and B_j are the Balancing factors

O_i and D_j are Origin and Destination respectively

$f(c_{ij})$ is the Generalized cost function or deterrence function

Shortest Path matrix has been created with travel length as a parameter for Private and public transport between 384 zones. This shortest path matrix of size 384 x 384 is used as an impedance matrix to calculate friction factor matrix. Friction factor matrix which is obtained from the generalized cost functions is created using Gamma function and calibrating the parameters. The calibration process includes comparison of observed and estimated mean trip lengths as well as shape of the trip length frequency distribution curves. The gamma deterrence function is given by the following equation

$$f(c_{ij}) = K\, c_{ij}^{-\alpha} \times e^{-\beta\, (c_{ij})} \ldots \text{Eq. 2}$$

Where, c_{ij}= Shortest Path Matrix (Distance)

$f(c_{ij})$ = Friction factor matrix (generalized cost function)

The calibrated parameters for the gamma function are shown below in Table 9.

Table 9: Calibrated Deterrence function parameters

Mode	Calibrated Parameters		
	K	**Alpha**	**Beta**
Private	196.2829	0.7192	0.0389
Public	104.9148	0.8954	0.0108

Using the above parameter values the friction factor matrix is calculated and the origin and destination are calculated using equation 1. The trip distribution is done for the peak hour traffic data and also for 16hr data. The results shown here represents peak hour data for the purpose of validation since the past data is available for peak hour data.

After obtaining the O-D matrix, the trip length distribution is estimated for both private and public transport. The trip length distribution graphs are shown in figure 18 and 19 for private and public transport respectively.

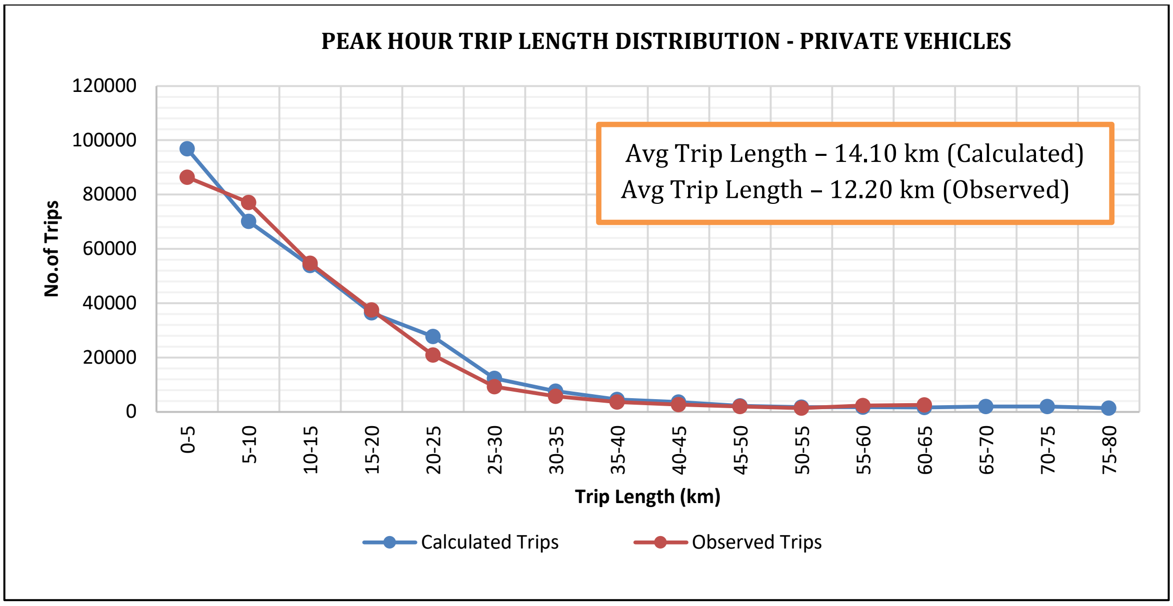


Figure 18: Graphical representation of peak hour TLD – Private Vehicles

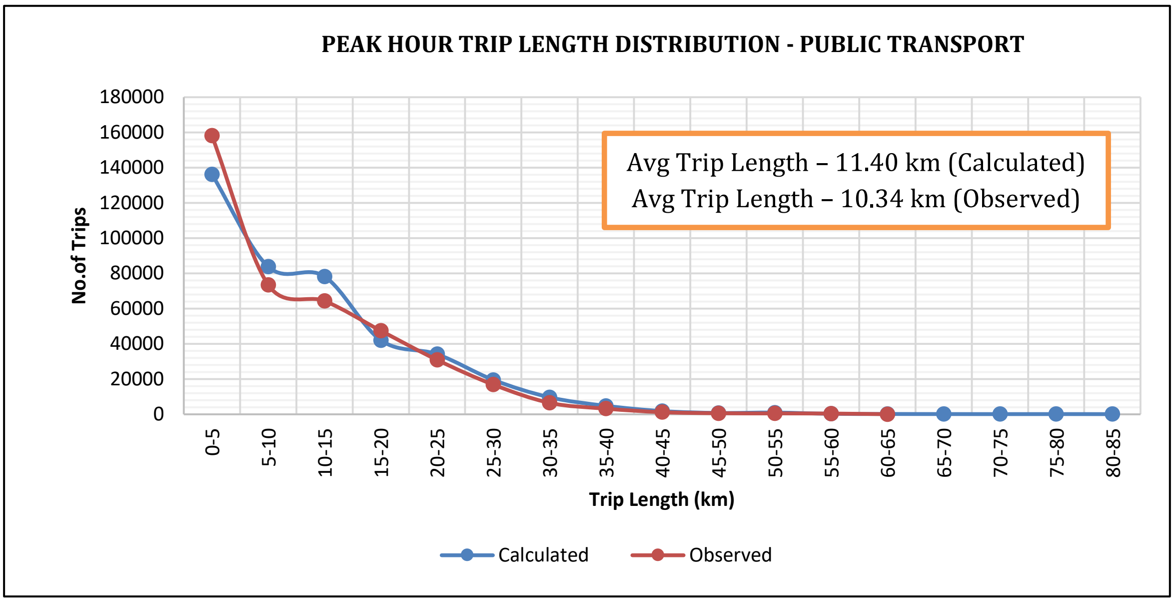


Figure 19: Graphical representation of peak hour TLD – Public Transport

3.1.3 Modal Split

The third stage in travel demand modelling is modal split. The trip matrix or O-D matrix obtained from the trip distribution is sliced into number of matrices representing each mode. The variables that are considered for mode choice analysis include the travel times, travel costs of various modes, age and sex.

This section of the modelling is about the proportion of the people choosing particular mode for the transportation. Multinomial Logit model is used for mode choice analysis. Six modes chosen for the analysis are as follows:

1) Car
2) Public Transit
3) Two Wheeler
4) Auto Rickshaw
5) Cycling
6) Walking

In multinomial logit model the proportion of choosing a particular mode over the other modes is given by the formula

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j \in C_n} e^{V_{nj}}} \quad \text{...Eq3}$$

$$V_{ni} = \beta_1 * X_{1ni} + \beta_2 * X_{2ni} + \ldots + \beta_k * X_{kni} + \text{ASC}$$

Where, P_{ni} = probability that individual 'n' chooses an alternative 'i'

V_{ni} = Systematic component of utility associated with alternative 'i'

"β' are the parameters to be estimated (using log-likelihood method)

"X_i" are the exogenous variables included in the model

ASC = Alternate Specific Constant

The parameters 'β' were estimated by applying log likelihood method using Biogeme. The estimated parameters are shown in Table 10.

Table 10: Estimated Parameters

Variable	Parameter value (P-value)	Variable	Parameter value (P-value)
ASC(Public Transit)	2.8100 (0.00)	Household income (walk)	-0.0943 (0.00)
ASC (Two wheeler)	3.9400 (0.00)	Number of vehicles by earners(car and two-wheeler)	0.3740 (0.08)
ASC (Auto)	0.3070 (0.47)	Age(public transit)	-0. 0376 (0.00)
ASC (cycle)	6.9900 (0.00)	Age(walk)	-0.0816 (0.00)
ASC (Walk)	7.5500 (0.00)	Age(cycle)	-0.0275 (0.00)
In vehicle travel time (MV)	-0.0064 (0.00)	Gender (public transit)	-0.5170 (0.00)
In vehicle Travel time (cycle)	-0.0781 (0.00)	Gender (walk)	-0.6090 (0.00)
In vehicle Travel time (walk)	-0.0943 (0.00)	Gender (cycle)	-0.5360 (0.00)
Travel cost (Generic)	-0.0079 (-0.00)	Purpose school(Car)	2.3100 (0.00)
Out of vehicle travel time (Public Transit)	-0.0635 (0.00)	Purpose school (Public Transit)	1.8500 (0.00)
Household income (two wheeler)	-0.0916 (0.00)	Purpose-school (cycle)	0.8080 (0.00)
Household income (Auto)	-0.1150	Purpose-school (walk)	2.1100 (0.00)
Household income (cycle)	-0.1810		
	Null log-likelihood	-5701.859	
	Final log-likelihood	-2084.096	
	Rho-square	0.634	

The above mentioned parameters has been used to estimate the mode shares in BMR which is shown in the table 11.

Table 11: Estimated and Observed Modal Share for Base Year

Mode	Base Year	
	Estimated	Observed
Car	2.3	4.0
2w	28.9	26.0
Bus	49.7	47.0
Auto	3.7	4.5
NMT	15.4	18.5

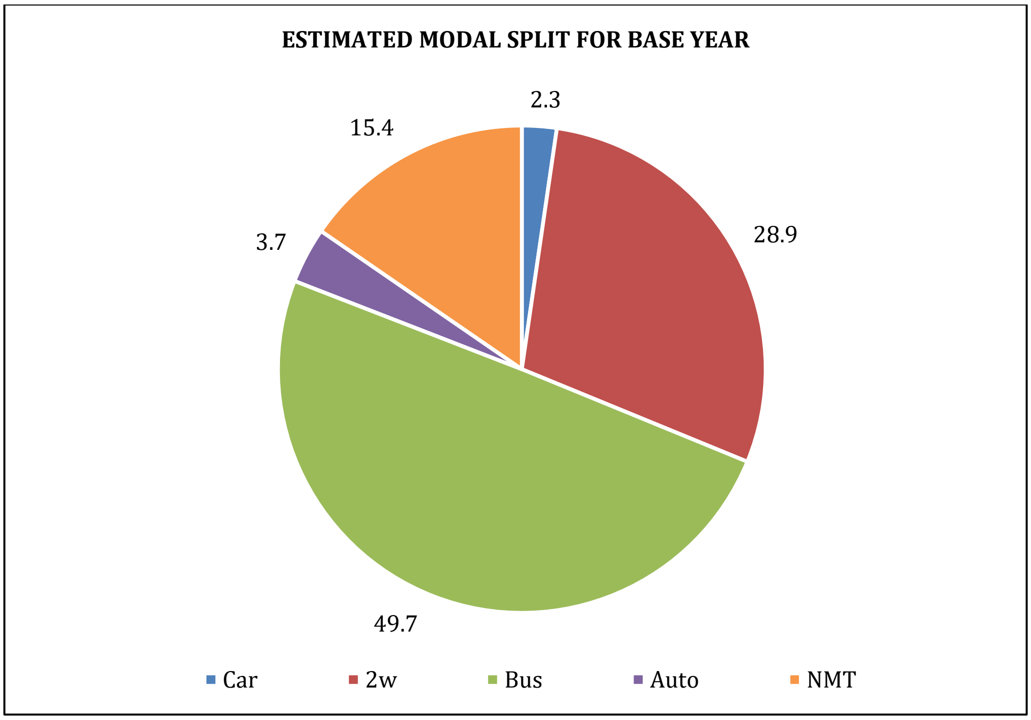


Figure 20: Modal Split estimated for Base Year

The slight difference between the estimated mode share from the model and observed mode share from the data collected is negligible. It is observed that the Public transport has the maximum share of 49.7% followed by two wheelers 28.9% and are identified as the major mode of transportation in BMR.

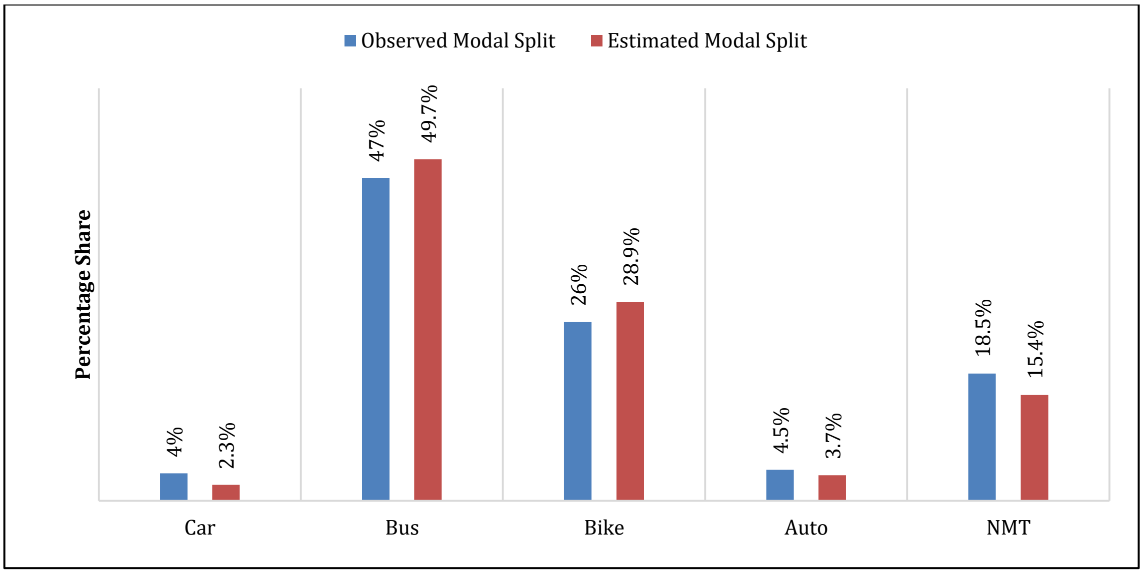


Figure 21: Comparison between the Observed and Estimated Modal Split

3.1.4 Traffic Assignment

The process of allocating a given set of trip interchanges to the specified transportation system is usually referred to as traffic assignment. The fundamental aim of the traffic assignment process is to reproduce on the transportation system, the pattern of vehicular movements which would be observed when the travel demand represented by the trip matrix, or matrices, to be assigned is satisfied.

The type of traffic assignment model used for this study is the User Equilibrium assignment. A shortest distance matrix has been developed between 384 zone centroids for public and private transport. This shortest path matrix (384 x 384) is used as the cost skim for public and private transport (i.e.) the trips are assigned to routes depending on the shortest distance and not shortest time.

3.1.4.1 *Assigned Traffic Volume*

The traffic assignment has been carried out in the following sequence:

- Private Vehicles Trips
- Buses

After assigning all modes on to the network, the assigned traffic streams have been compared with the Daily traffic volumes at screen line locations. The daily traffic assignment in Passenger Car Units (PCU) is shown in the figures 22 and 23.

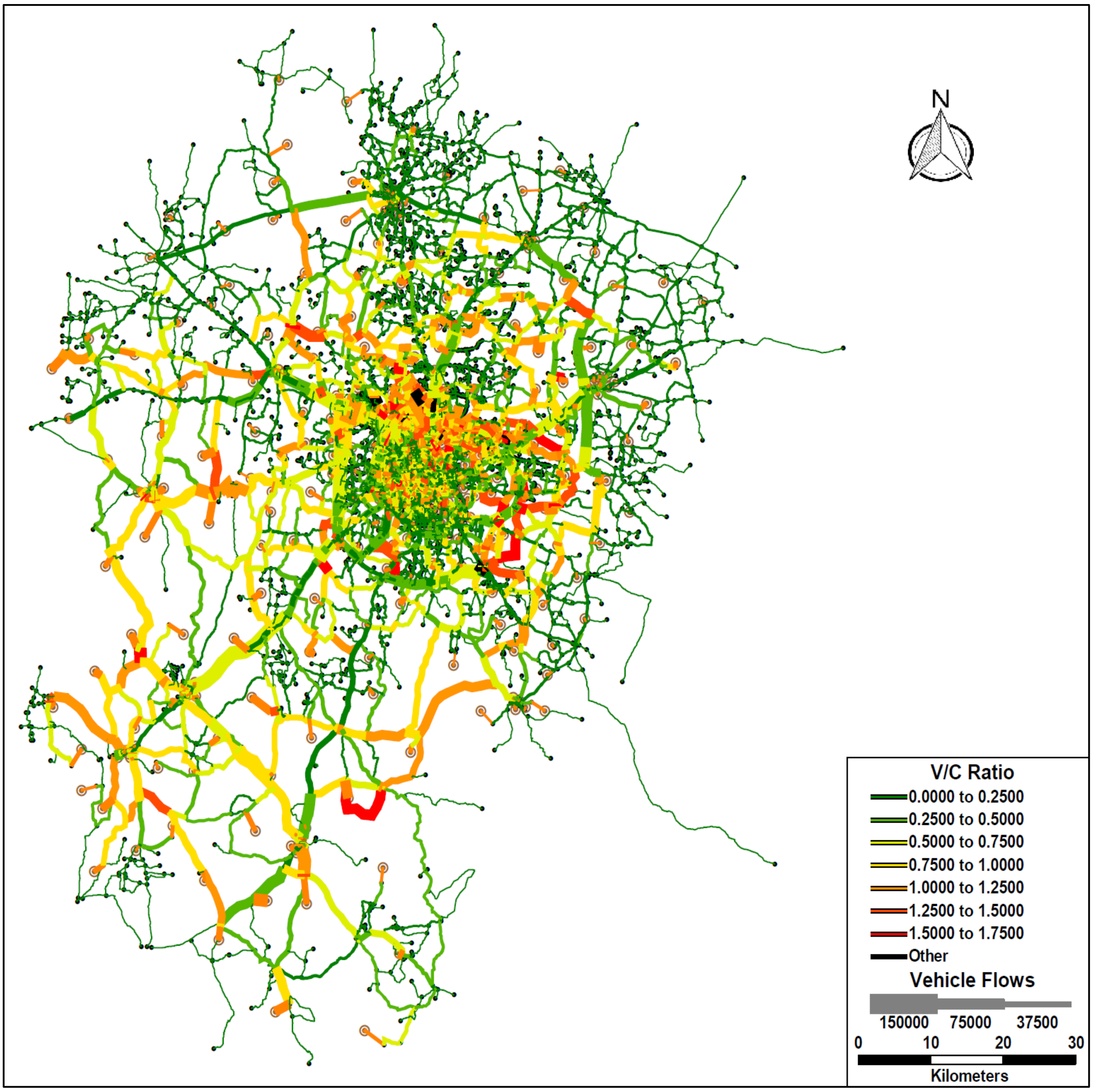


Figure 22: Trip Assignment of Private vehicles for Base Year

Initially, the assignment for the private transport is done on the private transport network. Public transport follows only specific routes out of the same road network on which the private transport has been assigned. For this purpose, the public transport road network is selected out of the whole road network and during assignment of public transport preload of private vehicles is given on to the links. The figure 23 displays the Public transport assignment which is preloaded by private vehicles. The process is carried out for the horizon years 2030 and 2050.

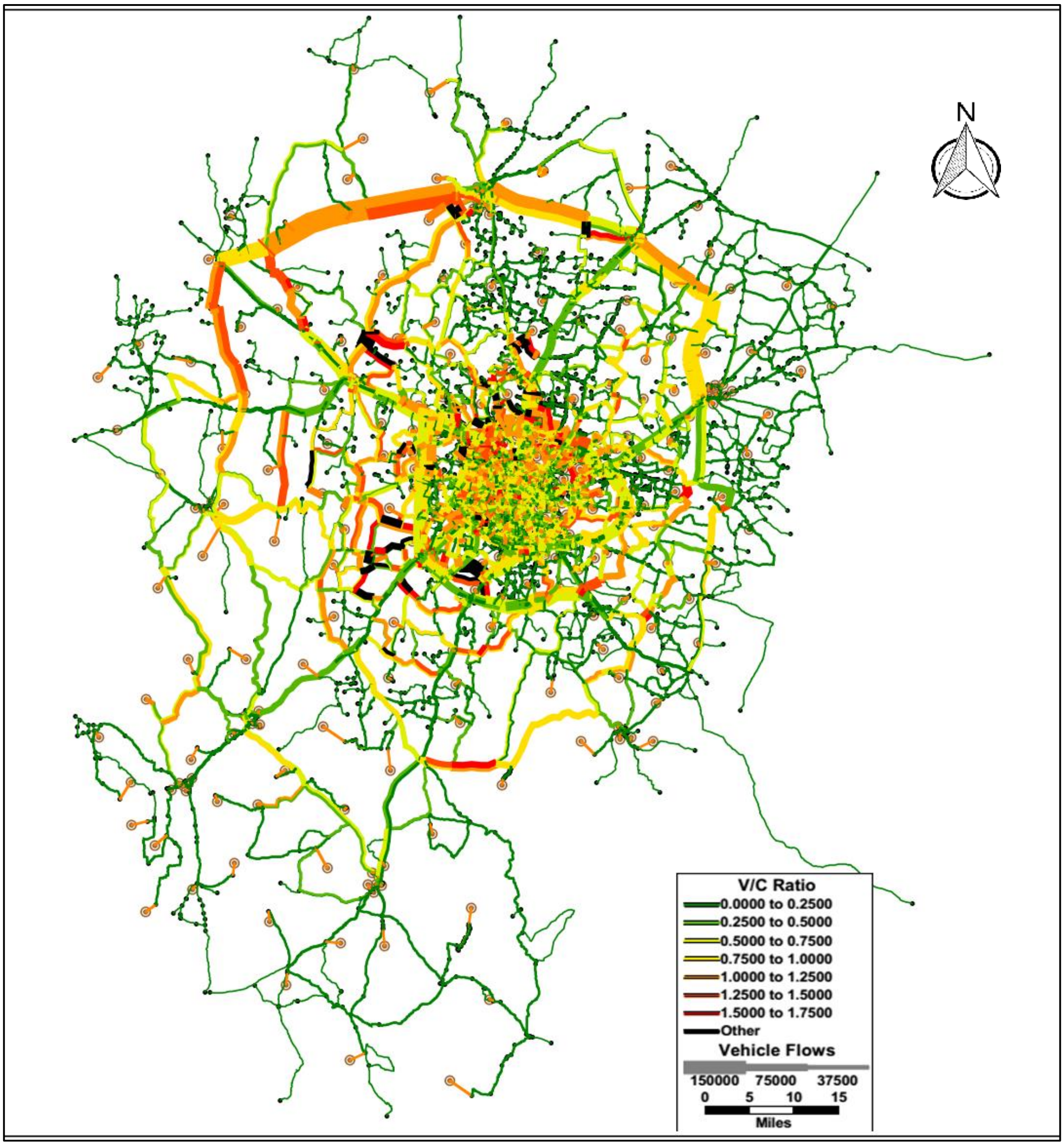


Figure 23: Trip Assignment of Public Vehicles for Base Year

4 TRAVEL DEMAND FORECAST FOR 2030 AND 2050 (BAU SCENARIO)

The base year model is used to forecast the travel demand for 2030 and 2050. The additions in the Transport Network in the future years like the Metro Rail Network and few Road Network Projects are also considered in estimating the travel demand for future years. After developing the Final Transport Network for future years, the calibrated model will be used to forecast the trips for 2030 and 2050.

4.1 PROPOSED ADDITIONS ON THE ROAD NETWORK

4.1.1 Upcoming Road Network Project in BMR

The undergoing projects like the construction of Flyover along Outer Ring Road at Doddanekundi Junction and construction of Hennur flyover have been added to the future road network.

4.2 PROPOSED ADDITIONS ON THE METRO NETWORK

Phase 1 of the metro construction includes purple line and green line; the final section of the metro line was completed during June 2017. Two metro lines are already in operation whereas the construction of 72.1 km Phase 2 of the Bangalore Metro system began in November 2015. The first section of phase 2 is expected to open in 2019 and the last section in 2024. The map showing phase 1 and phase 2 metro lines is displayed in figure 24.

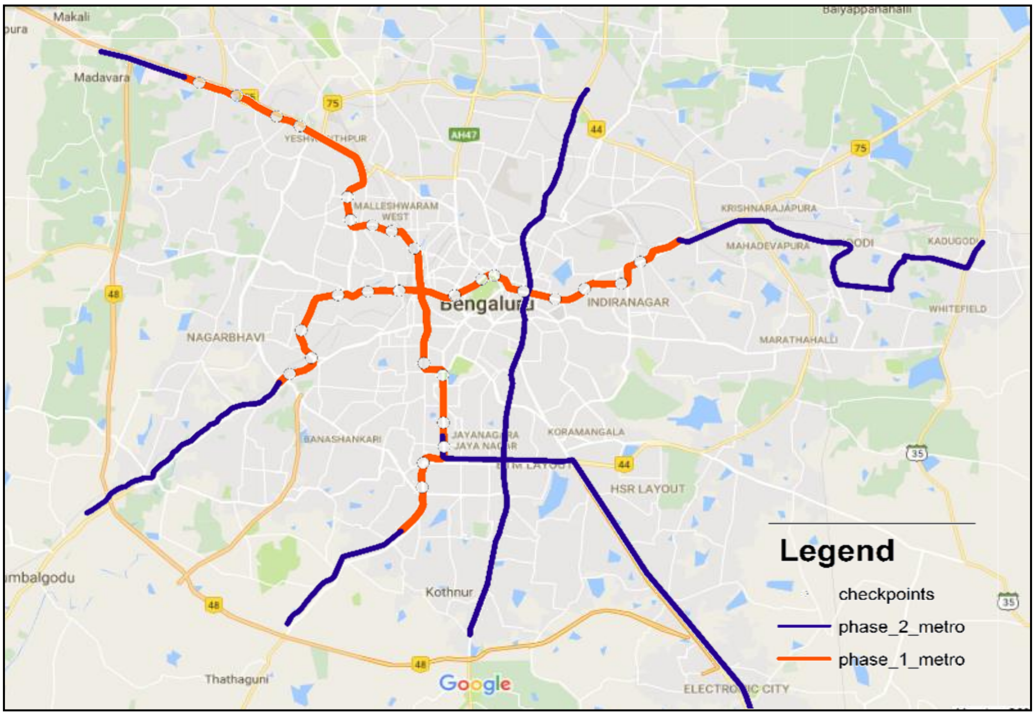


Figure 24: Metro Lines Phase 1 and 2

4.3 FORECASTING VARIABLES FOR 2030 AND 2050

4.3.1 Population Forecasts

To forecast the population for future years, a linear trend was adopted to estimate the population for 2020, 2030, 2040 and 2050. The population was linearly forecasted for all 384 Traffic Analysis Zones to finally attain the forecasted population for 2030 and 2050. The source of this data is the CTTS Report, 2010. The following table 12 and figure 25 shows the forecasted population for the horizon years and it is observed that the population is likely to increase from 10.8 million in 2011 to 33.1 million in 2050.

Table 12: Population Forecast for future years

Years	Population (in Millions)	GR (%)
2011	10818655	
2016	12836515	**18.65**
2020	13926912	**8.49**
2030	18045955	**29.58**
2040	24107365	**33.59**
2050	33111526	**37.35**

(Source: CTTS Report, 2010)

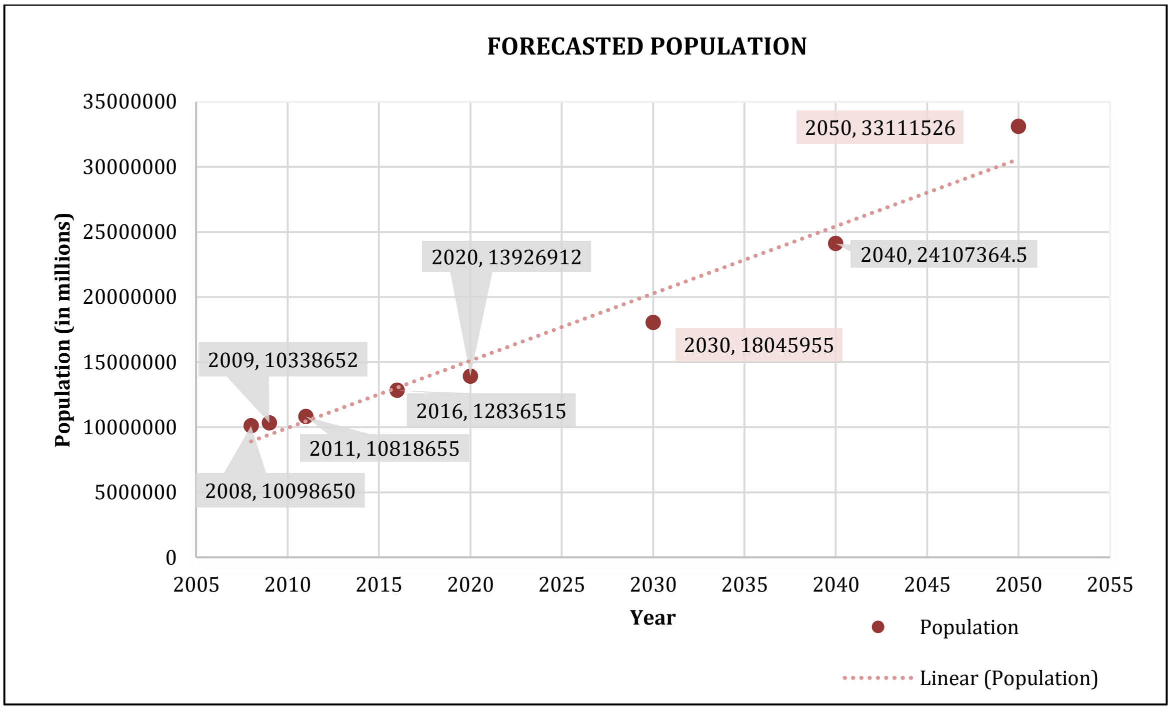


Figure 25: Linear Trend Population Forecast

(Source: CTTS Report, 2010)

4.3.2 Employment Forecast

The data about number of people employed till the year 2030 has been obtained from the CTTS Report, 2010. The method used to forecast the employment is similar to the one used for forecasting population. Following the linear trend, the number of people employed in 2050 was estimated and is also presented in figure 26. The following table 13 shows the forecasted employment along with the work force participation rate for each year.

Table 13: Forecasted Employment and Work Force Participation Rate

Year	Employment	WFPR
2008	4638261	45.93%
2011	4753148	43.93%
2016	4883377	38.04%
2020	5956602	42.77%
2030	7268248	40.28%
2040	8968435	37.20%
2050	11198227	33.82%

(Source: CTTS Report, 2010)

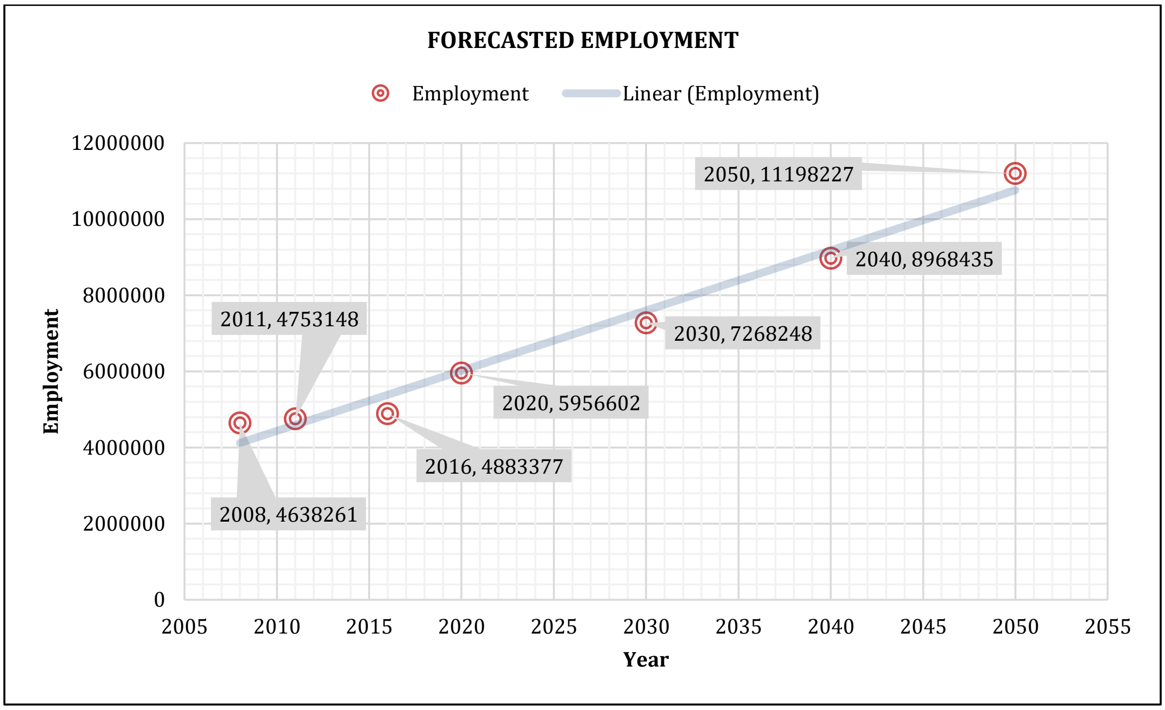


Figure 26: Forecasted Workers

(Source: CTTS Report, 2010)

4.4 TRAVEL DEMAND FORECAST

4.4.1 Trip Generation

The trip end equations developed for the base year have been used to forecast the productions and attractions for the horizon years 2030 and 2050 by using the forecasted population and employment respectively. The productions and attractions estimated are shown in the table below:

Table 14: Forecasted Productions for Private and Public Transport

Mode	Year	Trip End Equations	Productions
Private	**2030**	0.56 x POP + 1344.34	10621961
	2050		19058681
Public	**2030**	0.42 x POP + 4080	9146021
	2050		15473561

Table 15: Forecasted Attractions for Private and Public Transport

Mode	Year	Trip End Equations	Attractions
Private	**2030**	0.76 x EMP + 6877.28	10621961
	2050		19058681
Public	**2030**	0.76 x EMP + 6231	9146021
	2050		15473561

Considering the total trip and the total population for 2030 and 2050, the Per Capita Trip Rate has been estimated and is shown in the table 16. Thepercapita trip rate for 2030 and 2050 have been estimated as 1.08 and 1.02 respectively.

Table 16: Per Capita Rate Estimation for 2030 and 2050

Year	Population	Total Trip	PCTR
2030	18045955	Private	0.58
		Public	0.5
2050	33111526	Private	0.56
		Public	0.46

4.4.2 Trip Distribution

The peak hour trip length distribution for private and public transport for the base year and the future years is presented in the figure 27 and 28 respectively. The average trip length for private transport for the forecasted year is 17.41 km (2030) and 18.17 km (2050) whereas in case of public transport the forecasted average trip length is observed as 16.36 km (2030) and 18.22 km (2050). It has also been observed that as trip length increases, number of trips decreases.

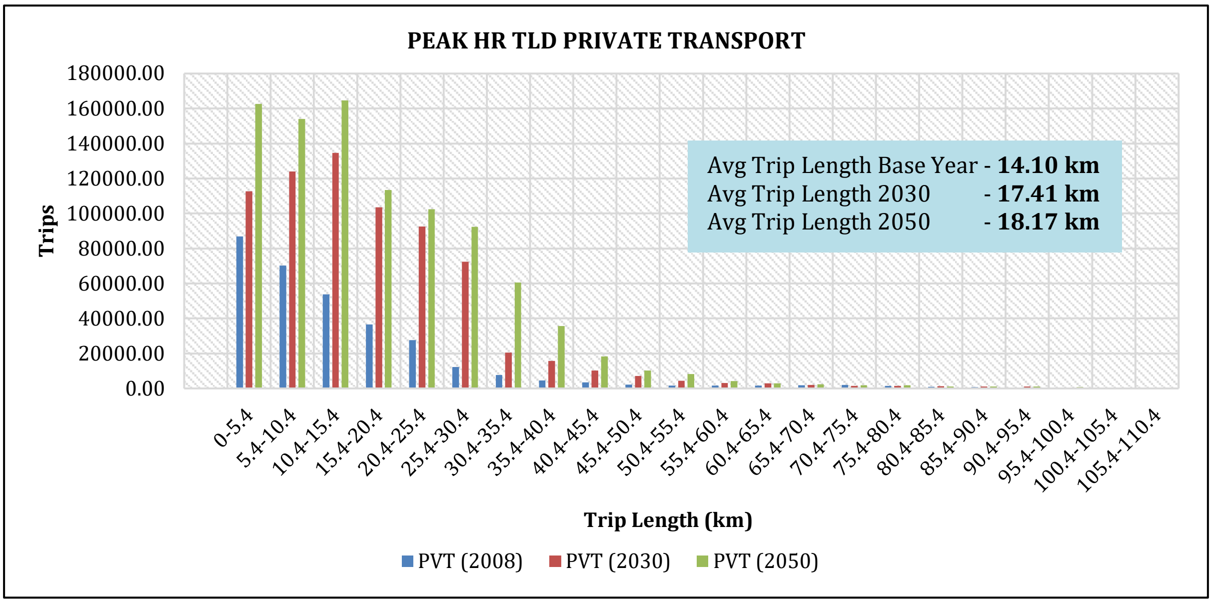


Figure 27: Estimated Trip Length Distribution for Private Vehicles for Base Year, 2030 and 2050

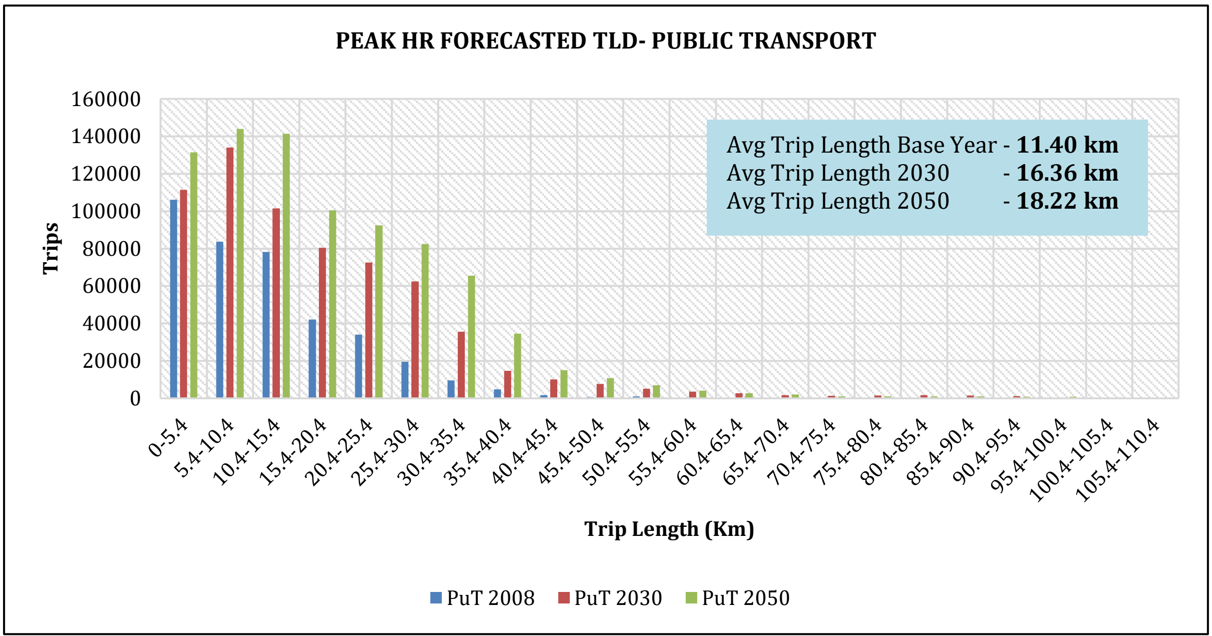


Figure 28: Estimated Trip Length Distribution for Public Vehicles for Base Year, 2030 and 2050

4.4.3 Modal Split

The base year calibrated parameters were used to estimate the modal split of the future years. The modal share estimation for base year and future years is given in table 18. The results show an increase in the NMT from 15.4 percent in base year to 16.8 percent in 2030 and to 19.3 percent in 2050. There is a considerable decrease in the modal share of two-wheelers from 28.9 percent in base year to 23.5 percent and 17.4 percent in 2030 and 2050 respectively.

The estimation of Metro Rail's modal share has been done based on certain assumptions adopted from a report by CSTEP (Centre for Study of Science, Technology and Policy) in May 2015. This is because the revealed survey data used for this study was collected in the year 2008 when Metro Rail was not functional in Bengaluru. Therefore, the data source does not include Metro as one of the modes of travel. However, in one of the reports by CSTEP the metro ridership and modal share has been projected for the years 2021 and 2031 based on which the following assumptions have been made for estimating the metro share for the current study and also the same has been given in table 17.

1. The total public transport mode shares by BMTC and BMRC (34.5 percent) in 2031 will be assumed for 2050 as well.
2. The modal share of BMTC buses and Metro Rail for 2031 will be used to split the projected modal share of Public transport for 2030 and 2050 according to the ratio of BMTC to BMRCL in the report.

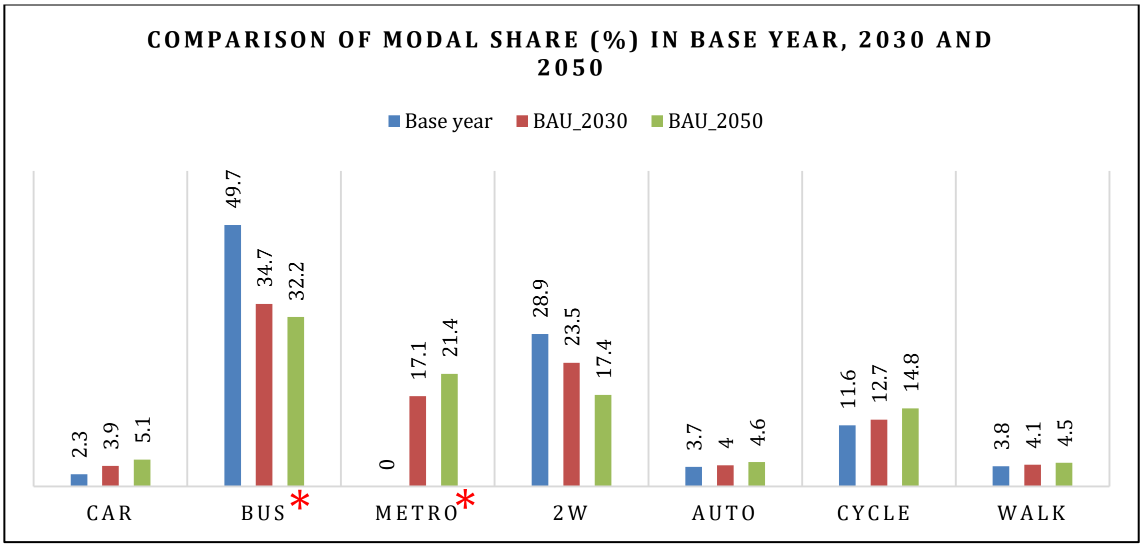
Table 17: Modal Share for Metro

Year	BMTC		BMRCL		Total PT Coverage (BMTC + BMRCL)	
	Passenger Trips per day	Modal Share	Projected passenger trip per day	Modal Share*	Projected passenger trip per day	Modal Share
2020	56 lakhs	25 %	22 lakhs	9.5 %	89 lakhs	34.5 %
2030	56 lakhs	23 %	28 lakhs	11.5 %	101 lakhs	34.5 %

**Calculations based on actual BMRCL DPR projections, GoI/GoK population projections*

Table 18: Modal Share Estimation for Base Year and Future Years

Mode	Estimated Mode Share in Percentage (%)		
	Base Year	2030	2050
Car	2.3	3.9	5.1
Bus	49.7	34.7	32.2
Metro	na	17.1	21.4
2w	28.9	23.5	17.4
Auto	3.7	4	4.6
Cycle	11.6	12.7	14.8
walk	3.8	4.1	4.5



*(*The mode share of public transport has increased from 49.7% in base year to 51.8% and 53.6% in future years 2030 & 2050 for Business as Usual scenario)*

Figure 29: Comparison of the projected Modal Share for the base year and future years

From the figure 29, it is observed that with the Metro Rail functioning in the city, the modal share of BMTC buses is found to be decreasing with a parallel increase in the modal share of Metro.

4.4.4 Trip Assignment

The following figures from figure 30 to figure 33 show the assignment of trips forecasted for 2030 and 2050 on to an updated road network with proposed roads.

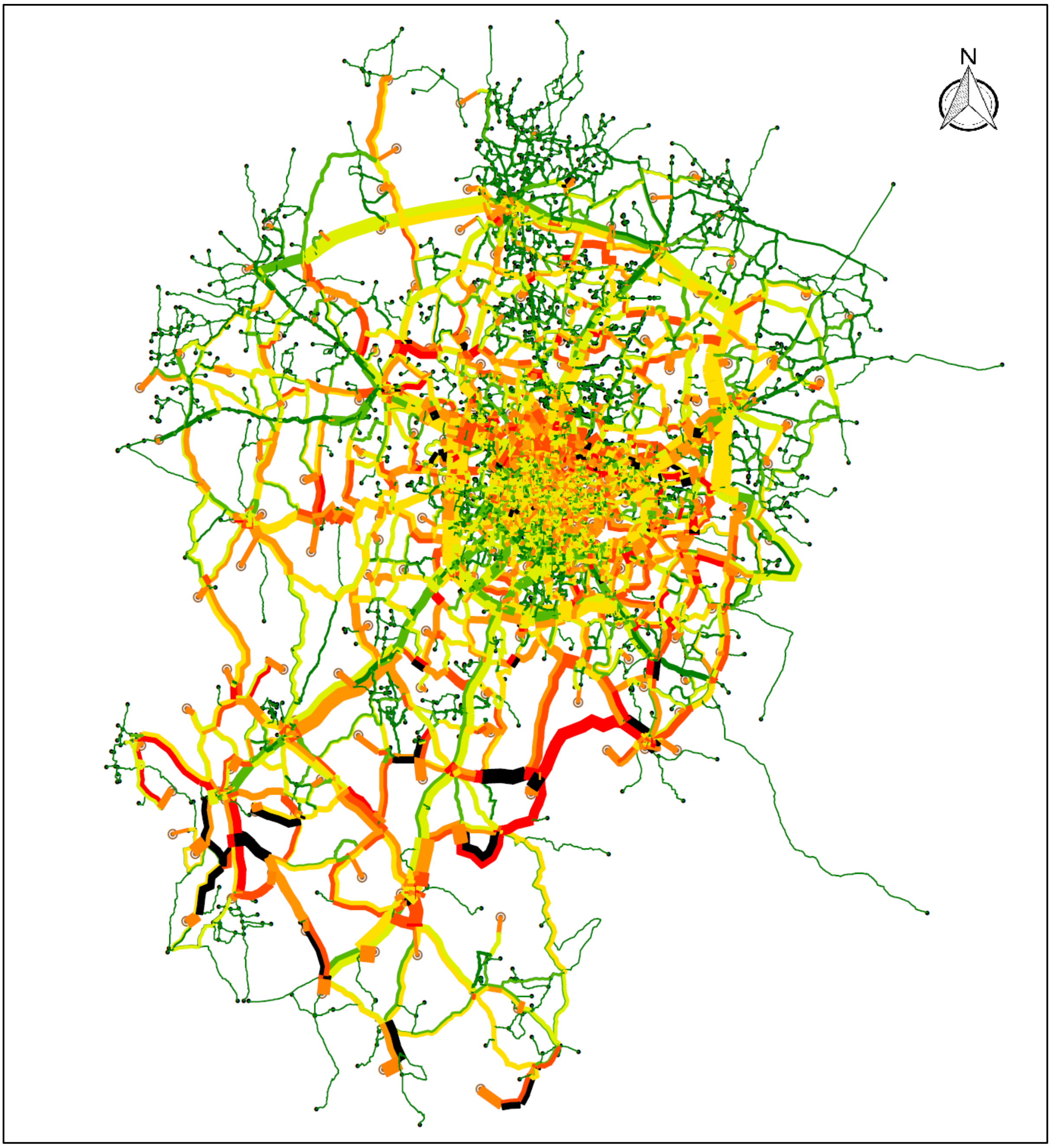


Figure 30: Trip Assignment of Private Vehicles for 2030

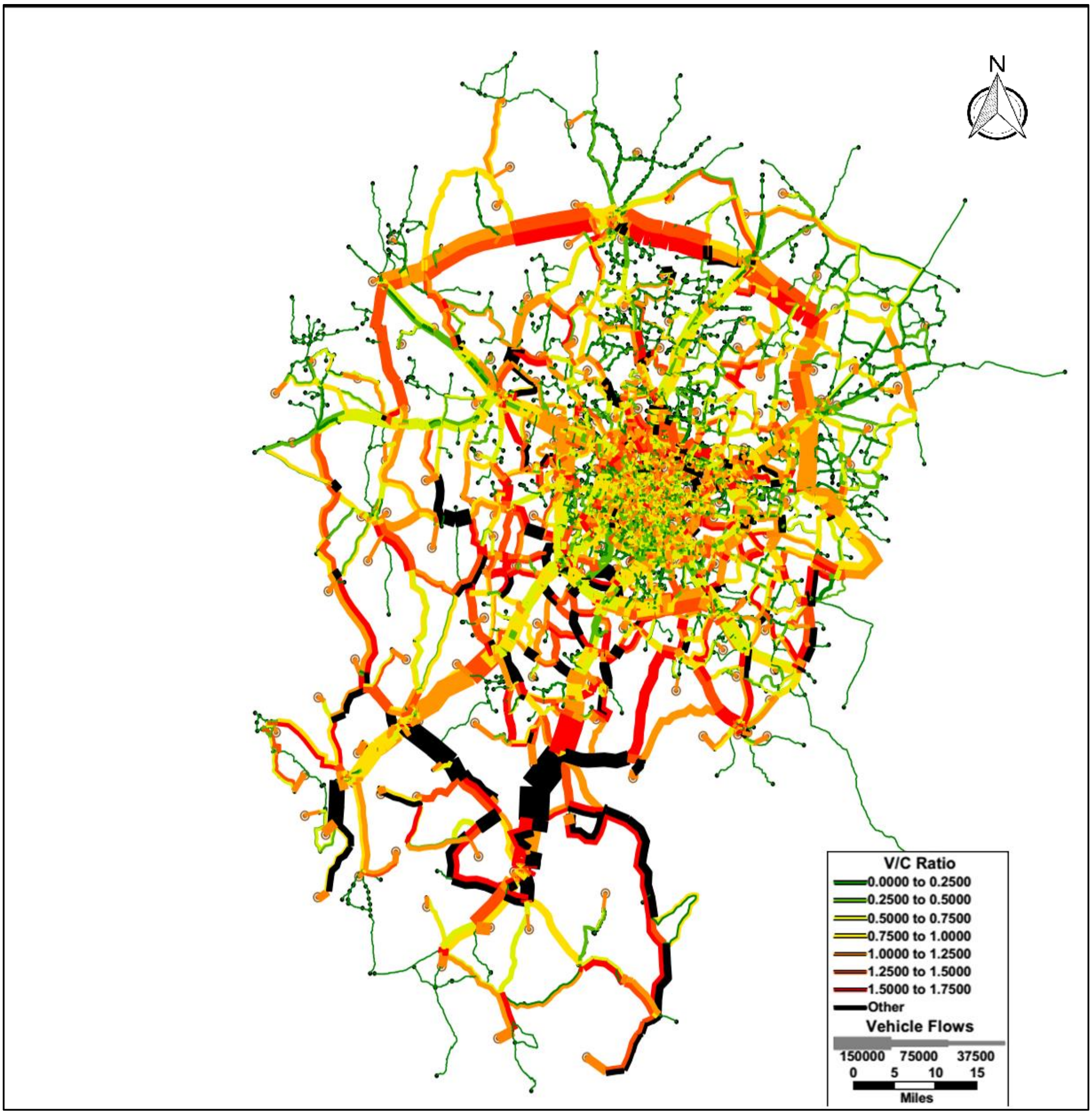


Figure 31: Trip Assignment of Public Vehicles for 2030

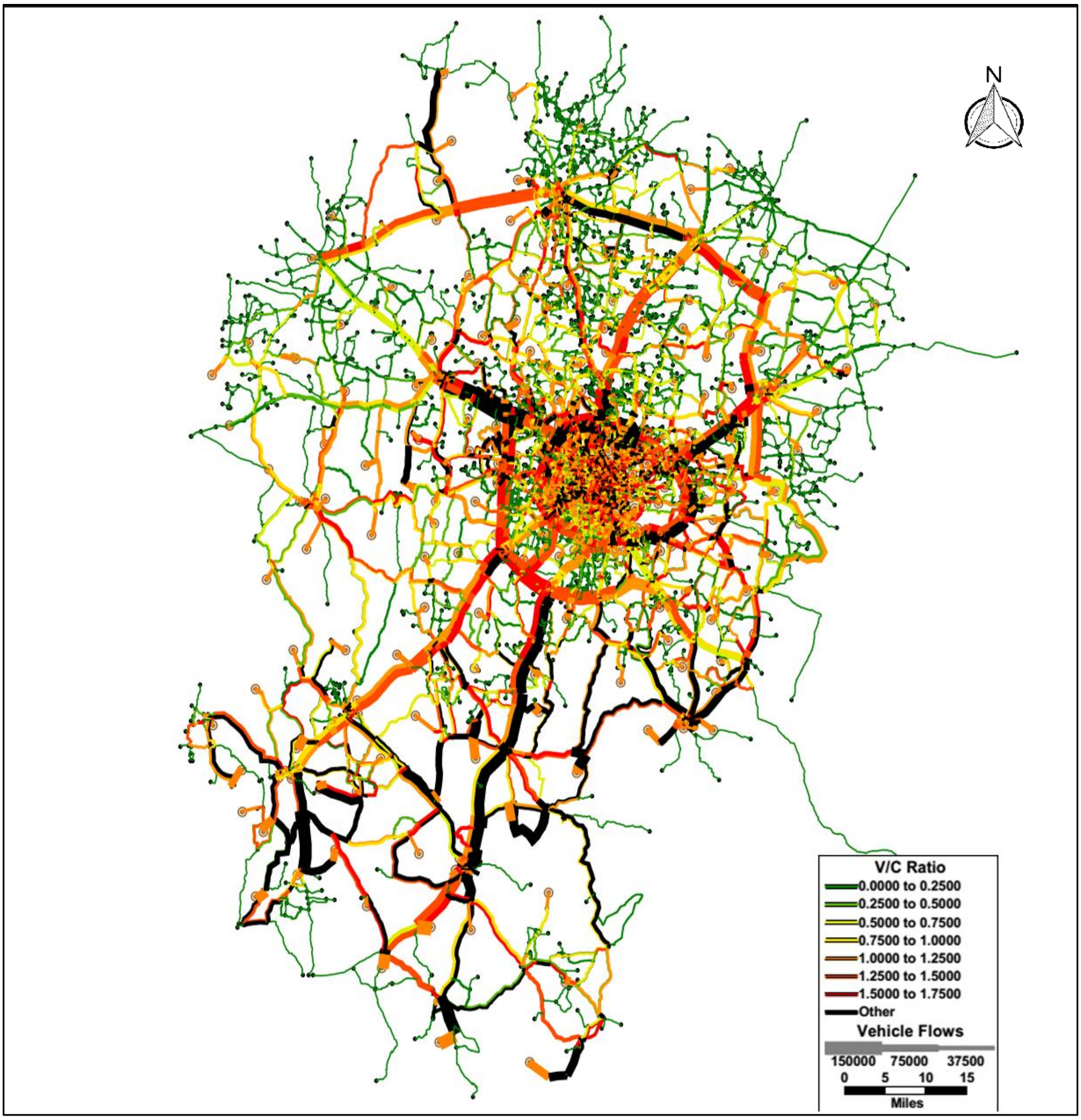


Figure 32: Trip Assignment of Private Vehicles in 2050

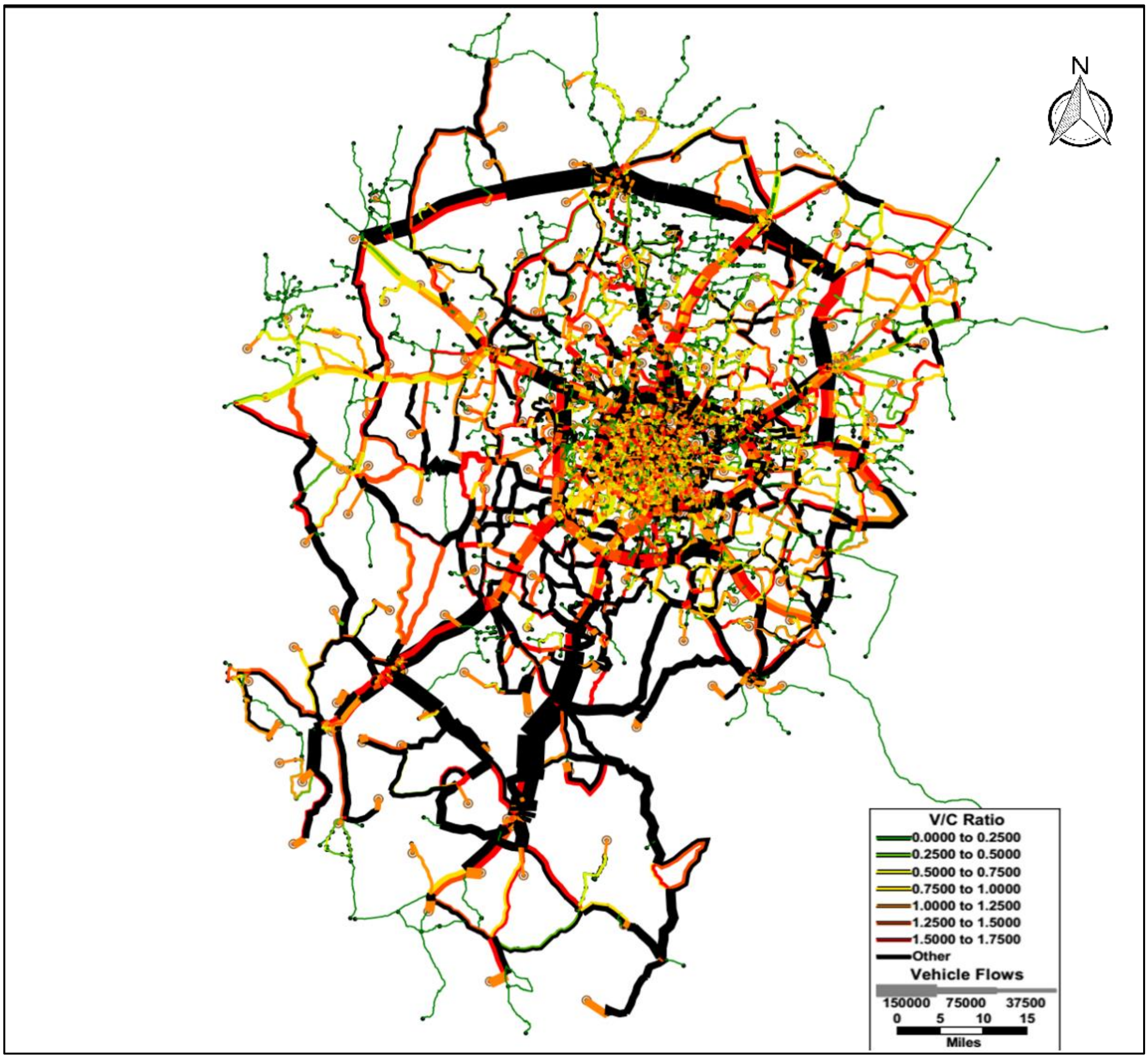


Figure 33: Trip Assignment of Public Vehicles in 2050

It can be seen from the figures 30 to figure 33 that with business as usual scenario the volumes of vehicles on the roads are way over the capacity. The black lines in the figures shows the V/C ratios above 1.75.

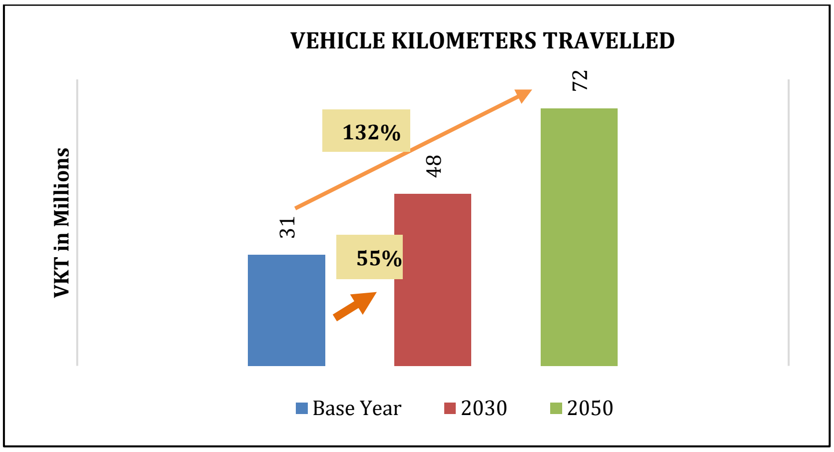


Figure 34: Total Vehicular Kilometres Travelled in Base Year, 2030 and 2050

The total vehicular kilometres travelled for the base year and future years with updated road network has been estimated and given in the figure 34. It is observed from the figure that there is 55% increase in the VKT in 2030 and more than 100% increase in the VKT in 2050 with respect to base year in Business as Usual Scenario.

4.5 ESTIMATION OF EMISSION LEVELS

The emission factors for automobiles are estimated for different scenarios for electricity generation as well as for different ranges of electric vehicle mileage (kWh/km) (Munish et. al., 2018). For BS-VI vehicles, emissions standards are assumed as emission factors. The vintage of the vehicles and the technology have been used to estimate the average emission factors for each vehicle type. An extensive study has been conducted by one of the project partners Dr. Munish K. Chandel, Centre for Environmental Science and Engineering, Indian Institute of Bombay, for estimating the emission factors for both conventional vehicles and electric vehicles based on various scenarios. The table 19 displays the emission factors for conventional vehicles.

Table 19: Emission Factors for Conventional Vehicles (gm/km)

Emission Factors for Conventional Car/Taxi					
	gm/km				
	CO	**HC**	**NOx**	**CO2**	**PM**
2005	2.444	0.267	0.344	133.576	0.0276
2021	0.604	0.139	0.178	144.126	0.004
2031	0.528	0.133	0.13	144.29	0.004
2050	0.528	0.133	0.020	147.116	0.0038
Emission Factors for Conventional Two-Wheelers					
	gm/km				
	CO	HC	NOx	CO2	PM
2005	1.153	0.790	0.112	31.065	0.022917
2021	0.628	0.416	0.122	36.332	0.022882
2031	0.933	0.201	0.057	42.709	0.011
2050	0.994	0.099	0.06	43.61	0.004
Emission Factors for Conventional Three-Wheelers					
	gm/km				
	CO	HC	NOx	CO2	PM
2005	4.468	1.889	0.558	77.170	0.203
2021	1.55	0.65	0.385	85.51	0.025
2031	0.487	0.316	0.147	81.74	0.017
2050	0.302	0.206	0.084	67.53	0.011
Emission Factors for Conventional Buses					
	gm/km				
	CO	HC	NOx	CO2	PM
2005	7.997	1.601	11.955	789.182	1.38
2021	3.0262	0.2711	4.6413	611.479	0.0851
2031	2.8774	0.2023	1.3189	611.151	0.0225
2050	2.8774	0.1913	0.774	611.151	0.0178

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

In India, the electricity is produced from following sources:

- Non-renewable sources (Coal, Heavy Fuel Oil, Natural Gas, and Nuclear)
- Renewable Sources (Hydropower, Bioenergy, Solar, Waste, and Wind).

Renewable share of electricity in future years is assumed to increase (IEA, 2015). Solar, wind and hydro power are considered as low-carbon energy sources and have great deal in achieving reduction in other pollutants as well. Biofuels is also a renewable source but at certain point the other resources might have to be compromised. However, in India biofuels will occupy only modest 3% overall share in the road transport fuel mix in 2040(IEA, 2015). In the current study, emissions for the electricity (g/kWh) are calculated based upon different energy mix scenarios. Due to different projections of the energy mix in the horizon years 2031 and 2050, four different scenarios are assumed:

- **Scenario 1:** New Policies Scenario (IEA, 2015)
- **Scenario 2:** Electricity from non-renewable Sources (100%)
- **Scenario 3:** Half electricity from renewable and another half from non-renewable sources (50%-50%)
- **Scenario 4:** Electricity from Renewable Sources (100%)

In Scenario 1, the electricity grid mix for future, horizon years, is taken from IEA (2015) that is 74% and 26% of electricity will be generated from Non-renewable sources and renewable Sources respectively. Further, the share of bioenergy in renewable sources is assumed to vary from 2.9% to 11.5% in scenarios 1 to 4 respectively. The share of bio energy is zero in scenario 2 and 6% in scenario 3. The calculated electricity emission factors for all the scenarios with different categories of electricity consumption of electric vehicles are given in table 20 to table 23 respectively. In this study, cars and buses are assumed to be electrified in future years and metro already runs on electricity thus, the emission factors of these 3 modes are only presented in the tables below.

Table 20: E- Vehicle Emission Factor Value: Average City conditions (Scenario 1)

Vehicle	Year	gm/km				
		CO	HC	NOx	CO2	PM
Car / Taxi	Base Year	0.058	0.00001	0.390	129.555	0.064
	2031	0.047	0.00001	0.180	101.95	0.013
	2050	0.042	0.00001	0.117	88.18	0.009
Bus	Base Year	0.508	0.0001	3.442	1144.03	0.568
	2031	0.414	0.0001	1.592	900.23	0.113
	2050	0.366	0.0001	1.036	778.63	0.076
Metro/Mono Rail	Base Year	7.950	0.0015	53.837	17892.66	8.883
	2031	6.479	0.0012	24.905	14079.57	1.767
	2050	5.732	0.0011	16.203	12177.78	1.187

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

Table 21: E- Vehicle Emission Factor Value: Average City conditions (Scenario 2)

Vehicle	Year	gm/km				
		CO	HC	NOx	CO2	PM
Car / Taxi	Base Year	0.058	0.00001	0.390	129.555	0.064
	2031	0.059	0.00001	0.225	134.65	0.016
	2050	0.054	0.00001	0.149	119.57	0.011
Bus	Base Year	0.508	0.0001	3.442	1144.03	0.568
	2031	0.523	0.0001	1.987	1189.04	0.142
	2050	0.473	0.0001	1.313	1055.83	0.097
Metro/Mono Rail	Base Year	7.950	0.0015	53.837	17892.66	8.883
	2031	8.186	0.0016	31.080	18596.52	2.217
	2050	7.397	0.0014	20.538	16513.23	1.516

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

Table 22: E- Vehicle Emission Factor Value: Average City conditions (Scenario 3)

Vehicle	Year	gm/km				
		CO	HC	NOx	CO2	PM
Car / Taxi	Base Year	0.058	0.00001	0.390	129.555	0.064
	2031	0.034	0.00001	0.133	67.33	0.009
	2050	0.031	0.00001	0.089	59.78	0.006
Bus	Base Year	0.508	0.0001	3.442	1144.03	0.568
	2031	0.299	0.0001	1.174	594.52	0.083
	2050	0.270	0.0001	0.785	527.92	0.057
Metro/Mono Rail	Base Year	7.950	0.0015	53.837	17892.66	8.883
	2031	4.672	0.0009	18.368	9298.26	1.292
	2050	4.226	0.0008	12.282	8256.62	0.889

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

Table 23: E- Vehicle Emission Factor Value: Average City conditions (Scenario 4)

Vehicle	Year	gm/km				
		CO	HC	NOx	CO2	PM
Car / Taxi	Base Year	0.058	0.00001	0.390	129.555	0.064
	2031	0.008	0.00000	0.041	0.00	0.003
	2050	0.008	0.00000	0.029	0.00	0.002
Bus	Base Year	0.508	0.0001	3.442	1144.03	0.568
	2031	0.074	0.0000	0.362	0.00	0.024
	2050	0.067	0.0000	0.257	0.00	0.017
Metro/Mono Rail	Base Year	7.950	0.0015	53.837	17892.66	8.883
	2031	1.157	0.0002	5.656	0.00	0.368
	2050	1.055	0.0002	4.027	0.00	0.263

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

The following table 24 shows the emissions calculated for the Base Year and the future Years 2030 and 2050 for Business as Usual Scenario.

Table 24: Total Emissions in Base Year, 2030 and 2050 (BAU Scenario)

Pollutant	Emissions in Tonnes/ year (% change w.r.t Base Year)		
	Base Year	**2030**	**2050**
CO	15743	18179 (15%)	23567 (50%)
HC	7315	2930 (-60%)	3841 (-47%)
NOx	6985	28864 (313%)	22962 (229%)
CO2	695617	16782759 (2313%)	17662478 (2439%)
PM	973	2009 (106%)	1519 (56%)

The total emissions of all the pollutants for car, two-wheeler, three-wheeler and buses for the base year are estimated using the derived emission factors for conventional vehicles. In a similar way, the total emissions for the horizon years are also estimated for all the modes of transport including metro share. It is because, in base year there is no metro line but the metro share should be incorporated for future years since two metro lines are already in operation and phase 2 metro lines are also likely to be opened for operation by 2020. From the table 24, it is evident that in the BAU scenario GHG and NO_x emissions due to transport sector is going to increase tremendously unless proper mitigation measures are implemented. The emission level of other local pollutants such as CO and PM is also likely to increase in base year.

4.6 SUMMARY

- The total population of the BMR region in 2001 as per the census is 8.5 million and is 10.8 million in 2011. It has been estimated that the population would reach 18 million by 2030 and 33 million by 2050.
- The study estimated that the average trip length for the year 2008 for BMR is 14 km and 11 km for private and public transport respectively and has increased for the years 2030 and 2050.
- With majority of the population opting for public transport as their mode of travel, it has a mode share of 49.7 % with the least being car (2.3%). Mode share of two wheelers is 28.9%, 3 wheelers (Auto) 3.7% and NMT share is about 15.4%.
- The total Vehicle Kilometres Travelled (VKT) by the vehicles in the BMR region is about 31 million for the year 2008 and is estimated to increase about 48 million and 72 million for the years 2030 and 2050 respectively which is about 60% growth rate of VKT in 2050 from 2008.
- The growth rate of the total VKT from 2008 to 2030 is estimated as 56% and from 2030 to 2050 as 78%.

- It is observed that for the years 2030 and 2050 under BAU scenario the vehicle volumes on the road network are way more higher compared to the capacities. The V/C ratios are over 1.75 as seen in the VDF maps of trip assignment.
- Green House Gas (GHG) emissions are dependent on Vehicle Kilometres Travelled. For this study 5 pollutants namely CO, HC, NOx, CO2, PM are considered.

5 MITIGATION POLICY BUNDLES EVALUATION FOR BANGALORE

5.1 INTRODUCTION

Mitigation is defined as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2001a). Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, changing management practices or consumer behaviour. The mitigation policy bundles are formulated to reduce GHG emissions, local pollutants and traffic congestion for the Bangalore Metropolitan Region. A total of four bundles have been formulated for mitigation and their evaluation is detailed out in this chapter.

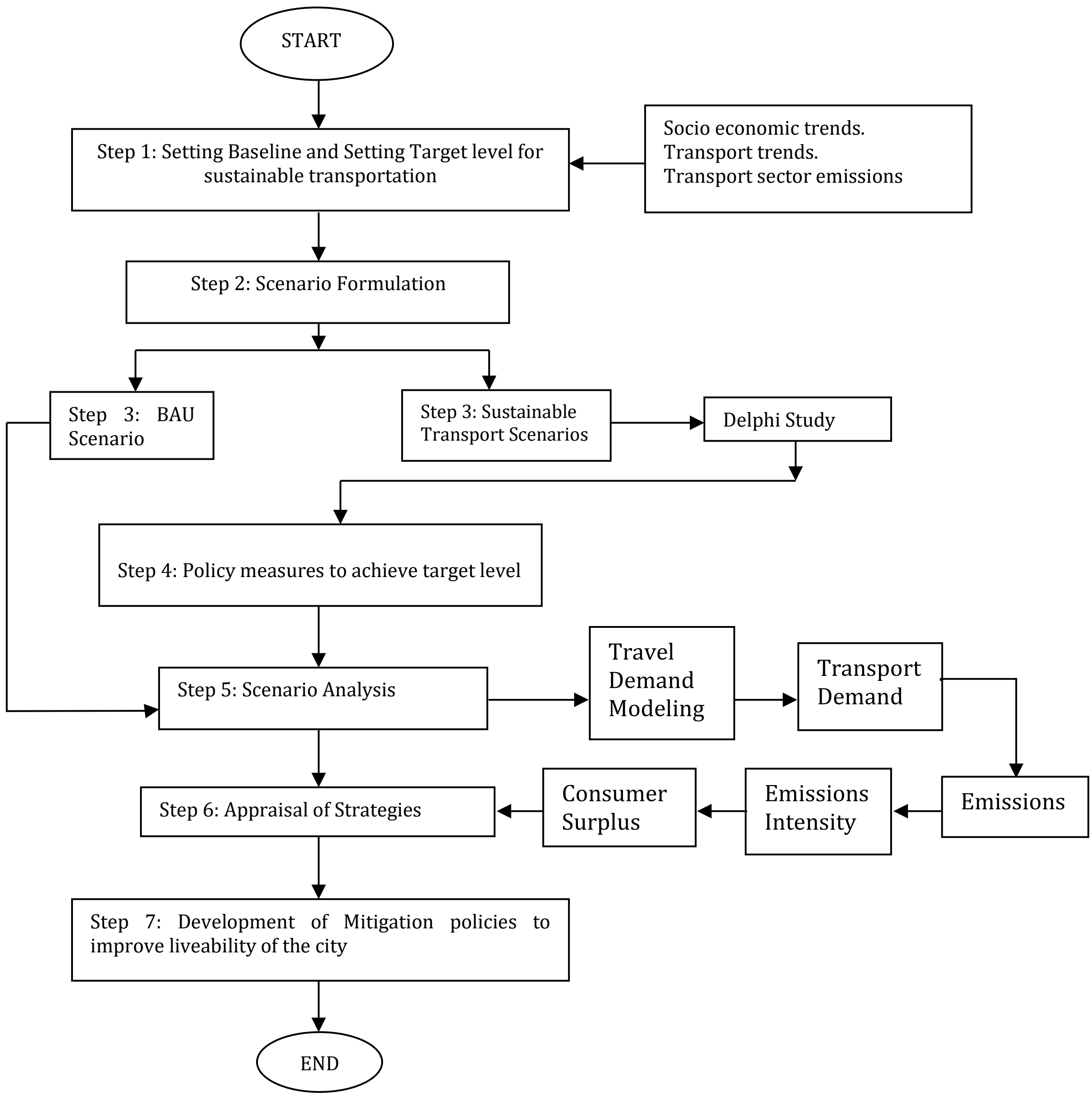


Figure 35: Flow chart depicting methodology for assessing mitigation policies

5.1.1 Delphi Study

Delphi is a technique in which a panel of experts attempts to generate ideas or find a solution for a specific problem. It is a method for the systematic collection and aggregation of informed judgments from a group of experts on specific issues. The Delphi method has proven a popular tool in various application areas for identifying and prioritizing issues for managerial decision-making. This technique is adopted in this research to identify the best policy instruments by circulating the formulated policy bundles to the stakeholders. The policies with 75 percent votes after the final scoring are chosen for further evaluation while the rest are disqualified. The flow chart depicting the methodology followed in the Delphi technique for this study is given in figure 36.

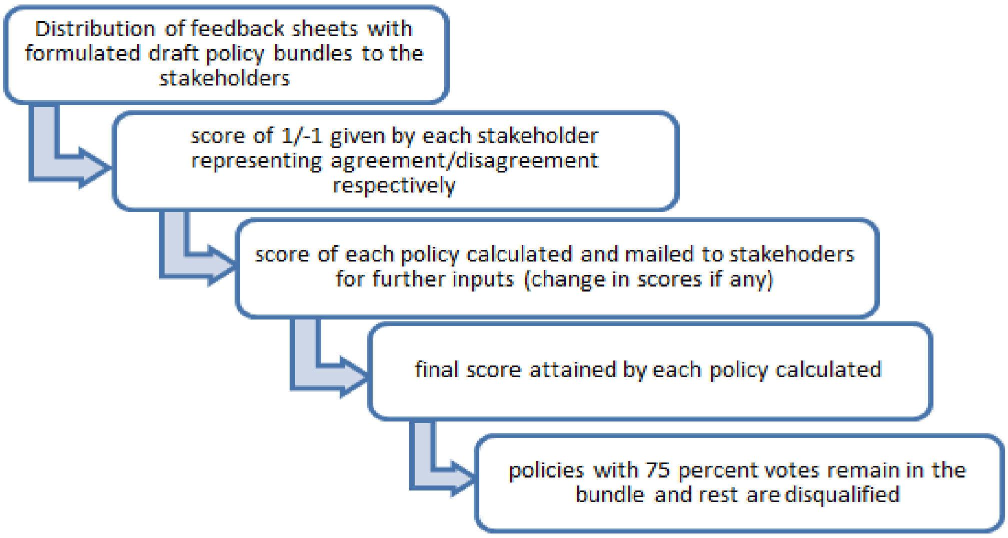


Figure 36: Methodology adopted to finalize policy bundles

5.2 BUNDLE EVALUATION

Based on the IPCC definition, inputs from multiple stakeholder meetings and Delphi survey with various government officials of Bengaluru, 4 policy bundles are formulated. The main objective of these mitigation policy bundles is to attain an optimum balance of push and pull strategy by developing policies that encourage public transportation and also other sustainable modes. This helps in reducing the vehicle kilometres travelled which leads to reduction in emissions and traffic congestion as compared to Business as usual scenario thereby improving the quality of life of people in Bengaluru city. This section consists of bundle-wise evaluation for the four bundles. Table 25 contains each bundle being evaluated.

Table 25: Policy bundles for mitigation

Policies under ***bundle 1***
Increasing network coverage of Public Transit *Cycling and walking infrastructure* *Additional tax on purchasing vehicles*
Policies under *bundle 2*
Additional tax on purchasing vehicles *Strict Vehicles inspection/Improvement in standards for vehicle emission* *Increase in fuel cost*
Policies under *bundle 3*
Increasing network coverage of Public Transit *Defining car restricted roads* *Congestion Pricing* *Park and Ride* *Cycling and Walking infrastructure* *Encouraging car-pooling and High Occupancy Lanes* *High density mix building use along main transport corridors*
Policies under *bundle 4*
All policies in bundle 3 + All buses and cars running on electricity

Each bundle mentioned above is a mixture of various policy instruments. Bundle 1 is a mixture of Planning & Regulatory Instruments. Bundle 2 is a mixture of Economic & Regulatory Instruments, bundle 3 is a mixture of Planning, Regulatory & Economic Instruments and bundle 4 is a blend of planning, regulatory, economic and technology instruments. Bundles are carefully evaluated and tested at various locations in BMR.

5.3 EVALUTION READY DESCRIPTION OF MITIGATION POLICIES

5.3.1 Increasing network coverage of Public Transit

The network coverage of public transit has an effect on the ridership. By increasing network coverage, there will be an increase in the accessibility, which in turn increases the ridership. The ridership increase might be due to new commuters or the ones who shifted from private vehicles. Thus, this policy affects the mode share of public transport. There will be quantitative changes in the following variables:

- Travel cost
- In vehicle travel time
- Out of vehicle travel time (Public Transit)

The BMR region has 7067 km of public transit road network. Using GIS software both the networks (public and private) were overlaid and links with no public transit service were identified. For 2030 and 2050, 60.1 km and 30 km of public road network were increased on these identified links after the GIS analysis. The newly added public transport links are displayed in figure 37.

1. Doddabelavangala road
2. Near Dabaspete - Hosur Highway
3. Near Chikkondanahalli road
4. Beside Bangalore – Mysore highway (SH 94)
5. Trunk road near Bangalore – Mysore highway
6. Near Magadi Road
7. Near Naganna Road

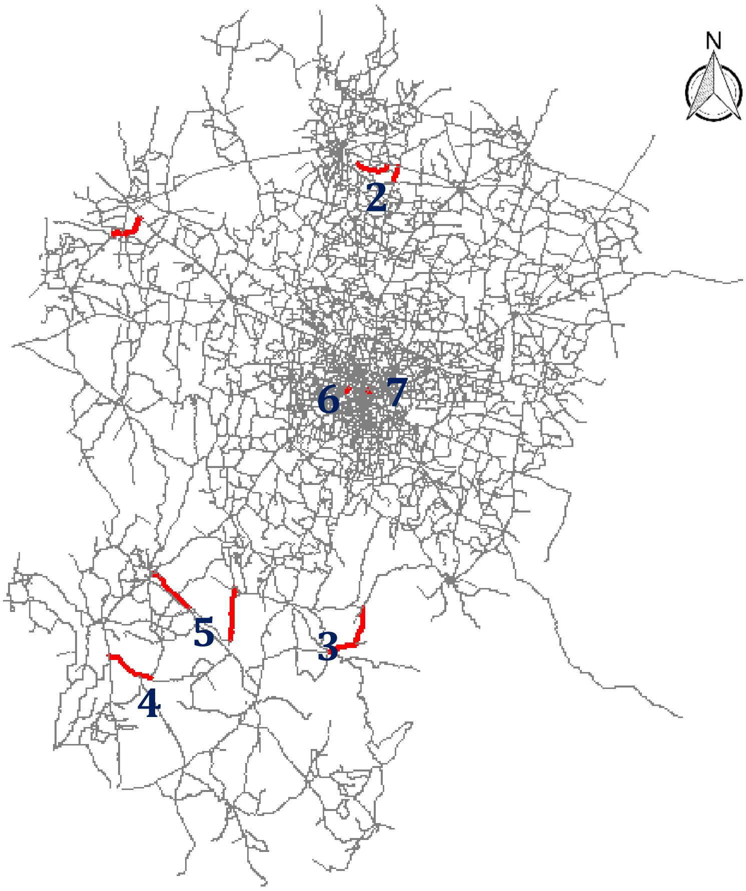


Figure 37: Newly added Public Transport links

5.3.2 Defining car restricted roads

Defining car restricted roads will help in the reduction of cars attracted to certain selected zones. With the implementation of this policy, commuters travelling via cars will have a choice to either park their vehicle outside those roads and take public transit or, use NMT. This will result in changing their modes of travel and thus it will impact the mode choice stage in the TDM. Also, this policy might have an impact on the trip assignment as commuters might choose alternative routes. The following variables are subject to change:

- Travel cost
- In vehicle travel time (MV)
- In vehicle travel time (Cycle)
- Out of vehicle travel time (Public Transit)

A total of 15 links were selected for incorporating in the model. The roads from which the links are selected is listed below,

1. Brigade road
2. SP road
3. BVK Iyengar road
4. Malleswaram 8th cross
5. Tulsi theatre road.

The selection of these links was based on two reasons, first, these links are heavily congested and second, they have a lot of pedestrian users also. The map showing the car restricted roads is given figure 38.

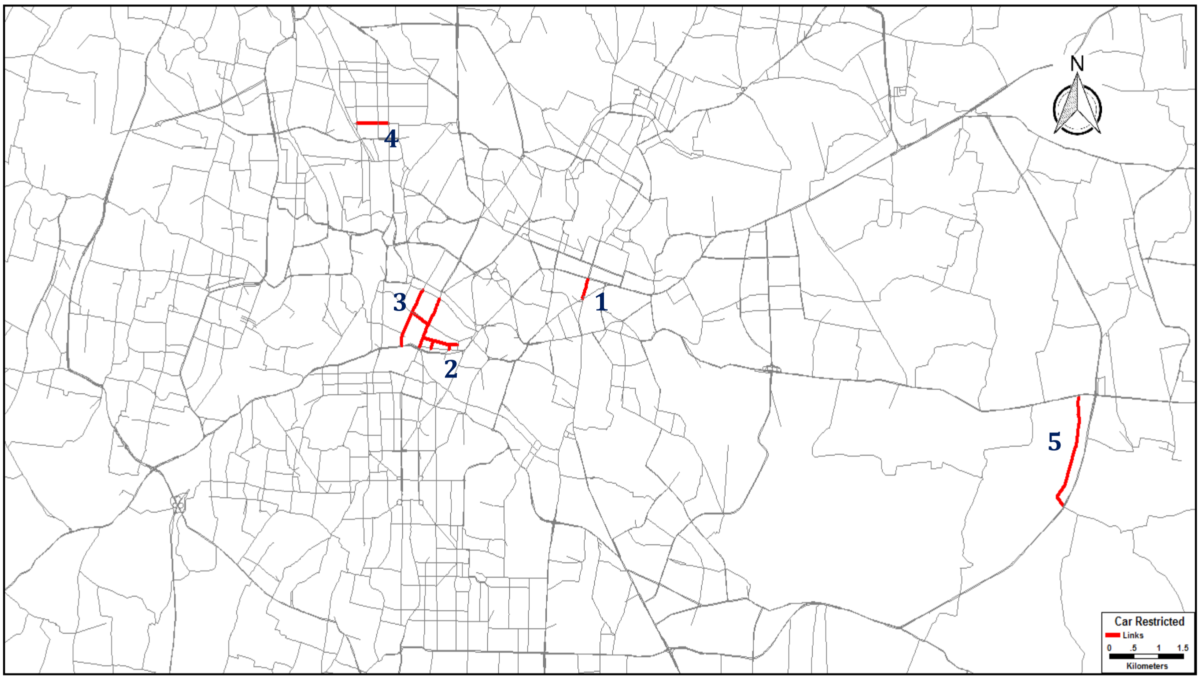


Figure 38: Car Restricted Roads

Car restricted roads are removed from the road network and car O-D matrix is modeled with non-car O-D matrix as preload. The private transport model output is private transport flows with no cars on car restricted zones. Public transportation is now modeled with private transport network flows as preloads on public transport network. Thus, successfully applying car restricted roads in the modeling

5.3.3 Increase in fuel cost

This policy will be evaluated by changing the fuel cost included in the travel cost variable in the mode choice stage of the four stage model. The fuel price data was taken from the IOCL (official) website for the years 2002 to 2017, which was used to forecast the future fuel price (petrol and diesel separately) for the years 2030 and 2050. Since the fuel price for Bengaluru city was not available, fuel price taken was the average of the fuel prices in four cities (Delhi, Chennai, Mumbai and Kolkata).

Table 26: Average cost/litre for diesel

Year	*Average cost/lit*	*Year*	*Average cost/lit*
2017	59.99	2009	33.87
2016	53.16	2008	35.69
2015	50.82	2007	32.88
2014	59.50	2006	34.88
2013	53.90	2005	31.06
2012	46.36	2004	27.23
2011	43.54	2003	22.69
2010	39.34	2002	20.44

The monthly fluctuations over a year were averaged to obtain yearly fuel price. The table 26-29 show the price considered for Diesel and Petrol respectively. Fuel costs were increased by Rs. 10/- for 2030 and 2050 with respect to BAU costs for evaluating this policy.

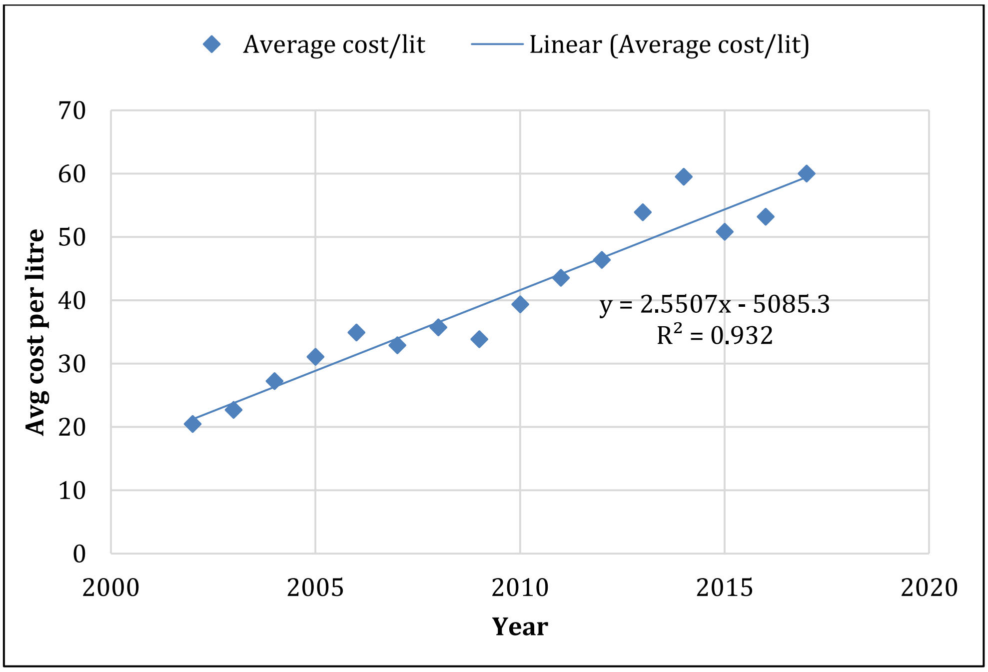


Figure 39: Average cost/lit of Diesel

Table 27: Projected cost for diesel for 2030 and 2050

Year	*Projected Cost*
2030	92.62
2050	143.63

Table 28: Average cost/litre for petrol

Year	*Avg. cost/lit*	*Year*	*Avg. cost/lit*
2017	72.00	2009	54.75
2016	64.83	2008	50.88
2015	65.67	2007	46.44
2014	74.29	2006	50.04
2013	73.18	2005	43.01
2012	73.22	2004	40.11
2011	67.24	2003	34.01
2010	45.47	2002	31.45

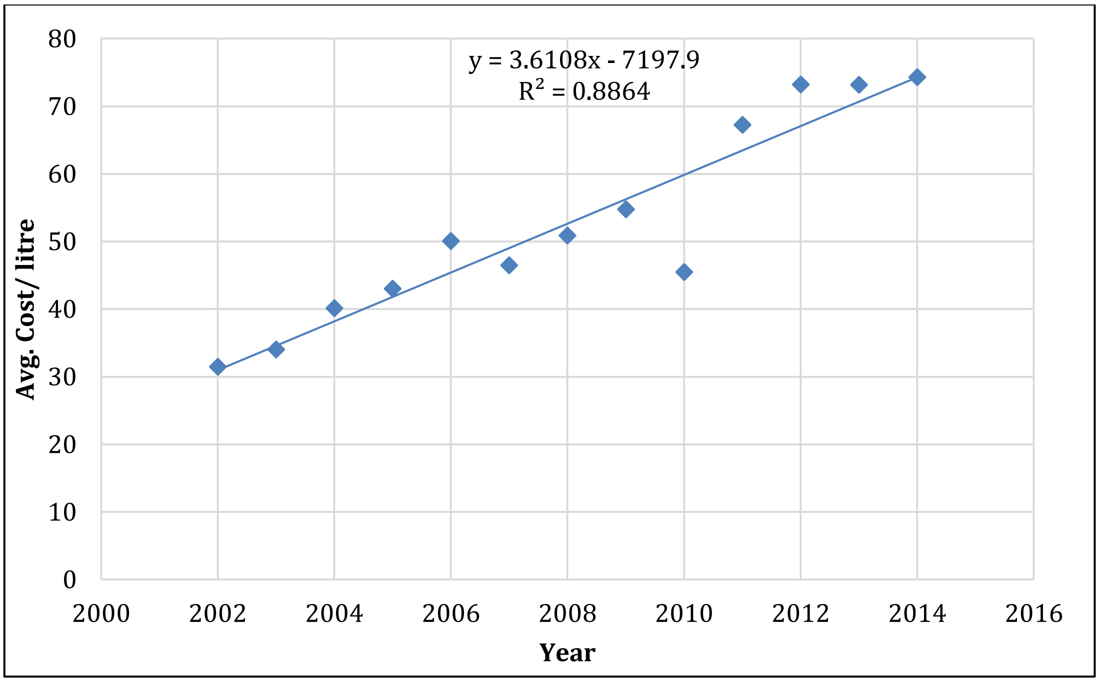


Figure 40: Average cost/lit of Petrol

Table 29: Projected cost for petrol for 2030 and 2050

Year	*Projected Cost*
2030	132.02
2050	204.24

5.3.4 Strict Vehicles inspection/ Improvement in standards for vehicle emission

The following conditions were applied in evaluating this policy:

- Vehicles older than 15 years will be removed from the OD matrix which is used for 2030.
- This is applied especially for cars and 2 wheelers.

- Vehicle registered per year information of Bengaluru is used for this purpose.
- Base year vehicles are projected to 2030 & 2050 and vehicles from 2015 are used in 2030 OD matrix for this policy and 2035 vehicles for 2050.
- Due to unavailability of data, an equal share of vehicles is removed from the OD matrix from all zones during analysis.

5.3.5 High density mix building use along main transport corridors

The aim of this policy is to decrease the trip length by introducing high density mix building use along the transport corridors. The zones with higher number of attractions and productions along the main transport corridors were identified. Then, 10 percent of the productions from the zones with high productions were shifted to the zones where a large number of trips are being attracted. This reduces not only the travel distance but also the travel time since these trips will now be intra-zonal trips.

Also, it will impact the TDM at the mode choice stage as the average trip lengths will decrease and the commuters might have more utility for other modes of travel as well. Therefore, this policy impacts the Trip Distribution, Mode share and Trip Assignment. The following variables are subject to change:

- Zone specific trip attractions and productions
- Travel cost
- In vehicle travel time
- Out of vehicle travel time (Public Transit)

Development has to be focused in areas adjacent to bus stations where public transport accessibility will be high. There is high probability of commuters using public transportation. Also, some commuters might shift from private to public transportation. Locations selected for the policy implementations are:

a) Mahatma Gandhi Road (M G Road)
b) Traffic Transit Management Centres
c) Madiwala
d) Ring roads (Inner and outer)
e) Intermediate ring road

5.3.6 Park and Ride

For evaluating this policy, the existing parking cost at Traffic and Transportation Management Centres (TTMCs) was obtained (Rs. 15 for two-wheelers and Rs. 25 for cars). This cost was added to the Travel Cost of the individuals whose originating zone matches with the zones where TTMCs are located. The objective of this policy is to increase the mode share of buses in future years to reduce vehicular emissions and improve the sustainability of transportation.

This policy has an impact on the Mode Share and Trip Assignment in the TDM and the following variables will be used to evaluate its impact:

- In-vehicle time (MV)
- Out-vehicle time (Public Transit)
- Travel cost (fuel cost, parking cost, fare for metro)

It is assumed that all the private trips originating from the same zone as TTMC are to park their vehicles in the respective centres and use the public transport. The policy is evaluated by adding the parking cost to travel cost. Thus, new mode shares are obtained and new OD matrix is formed which will be used for modelling.

Park and Ride shall be applicable to implement at the Traffic Transit Management Centres (TTMCs).

1 Shanthinagar
2 Jayanagar
3 Kengeri
4 Banashankari
5 Koramangala
6 Yeshawanthapura
7 Vijayanagar
8 Domlur
9 International Tech Park (ITPL)
10 Bannerghatta

Figure 41: Location of Traffic Transit Management Centres (TTMC's)

5.3.7 Congestion Pricing

The policy aims to reduce the number of vehicular trips being generated. In zones like CBD where people go to work and shop, congestion is the maximum. A congestion price of Rs.10.50 per km (Rahul et. al., 2013) added to the travel cost of the trip, will impact the utility of that mode for individuals which would reflect in the mode share. They might prefer using public transit to commute. This policy has an impact on the Mode Share and Trip Assignment in the TDM and the following variables will be used to evaluate its impact:

- In-vehicle travel time (MV)
- Out-vehicle travel time (public transit)
- In-vehicle travel time (walk)
- In-vehicle travel time (cycle)
- Travel cost (congestion price, fuel cost, fare)

Assumption: Congestion Pricing will be the same for all days in a week.

The identified locations where this is tested are listed below and the map showing the locations can be viewed in the figure 42.

1.Krishna Rajendra Market (K R Market)
2.Shivajinagar
3.Silk Board junction
4.Madiwala
5.Koramangala
6.M G Road
7.Whitefield
8.Malleswaram
9.Hebbal
10Yeshwantpur-Rajajinagar

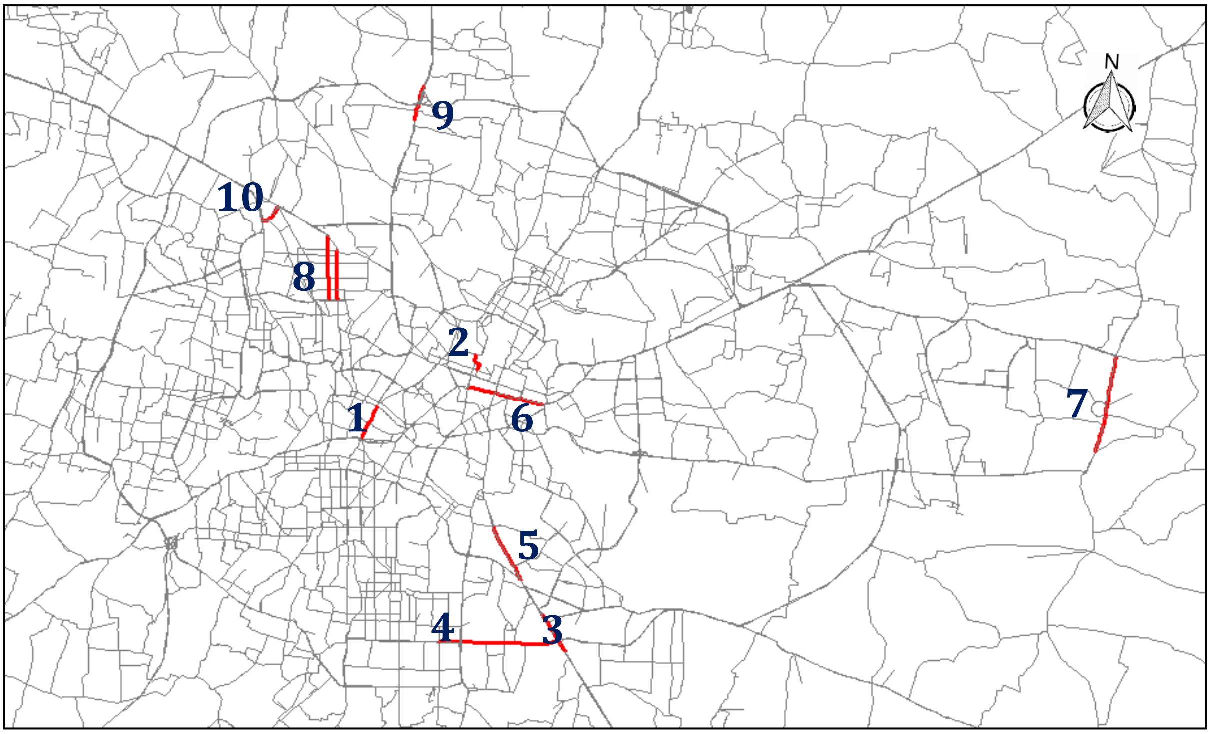


Figure 42: Road Links for Congestion Pricing

5.3.8 Cycling and Walking Infrastructure

The aim of this policy is to improve the cycling, walking infrastructure to encourage Non-Motorized transport (NMT) and to improve accessibility to public transport. The spatial analysis of the Bengaluru city shows that most of the IT industries are located around the Outer ring road. This policy is tested within Outer Ring Road limits to encourage NMT. This policy has an impact on the Mode Share in the TDM and the following variables will be used to evaluate its impact:

- In-vehicle travel time (MV)
- In-vehicle travel time (walk)
- In-vehicle travel time (cycle)
- Travel cost (congestion price, fuel cost, fare)

Assumption: With an improvement in the cycling and walking infrastructure, all the trips which are shorter than the acceptable trip length of 0.75 km and 1.66 km (Rahul et. al., 2013) for walking and cycling respectively will shift to NMT. Thus, new mode shares are calculated and new OD matrix generated which feeds to the model for analysing the impact of the policy.

5.3.9 Encouraging carpooling and High Occupancy Vehicle (HoV) Lanes

Carpooling can reduce the number of vehicles on a route with similar or same origin destinations. The policy will be tested on all sub-arterial & arterials roads and main transport corridors of Bengaluru where HoV lanes can be provided. Faster movement would be ensuring with the provision of HoV lanes.

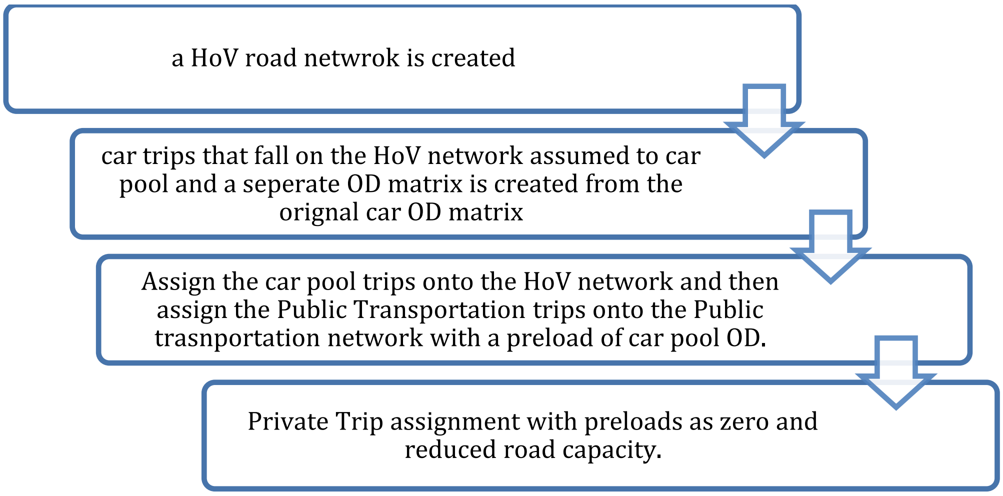


Figure 43: Process of evaluation of carpooling and HoV lanes

This policy has an impact on the Mode Share in the TDM and the following variables will be used to evaluate its impact:

- In-vehicle travel time (MV)
- Travel cost (congestion price, fuel cost, fare)

Assumption: all the individual trips having the same origin destination will carpool.

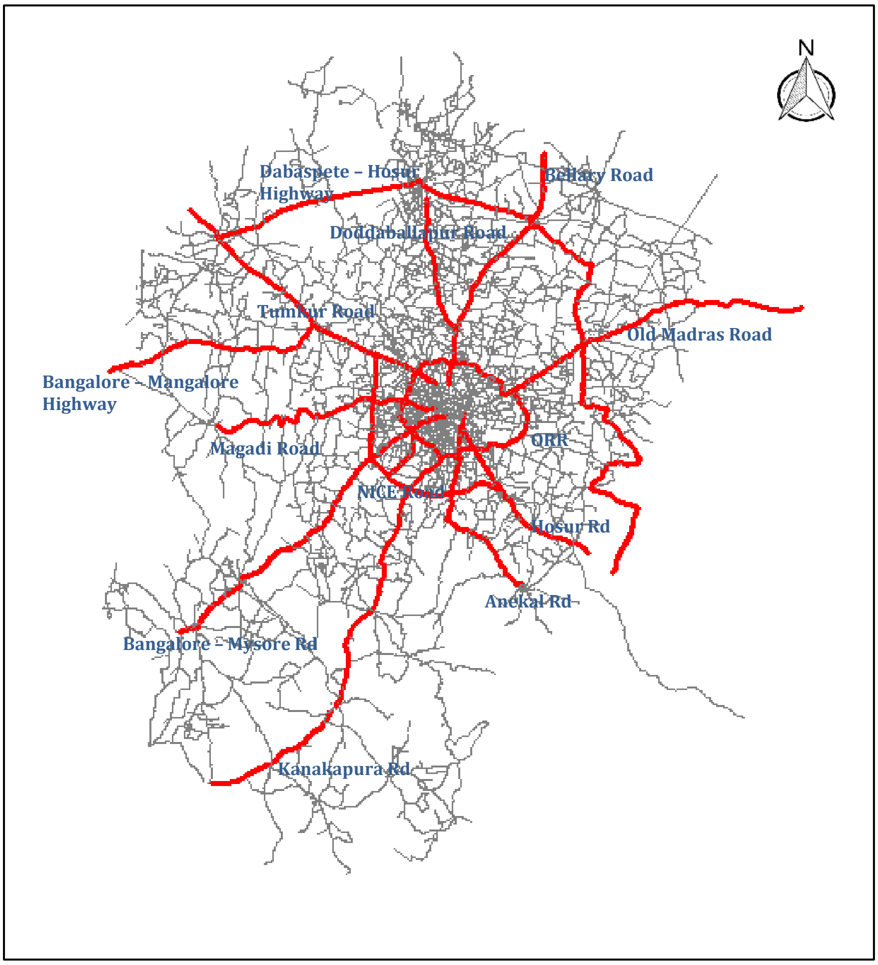


Figure 44: Roads tested for HOV lanes and Car pooling

5.3.10 Additional taxes while purchasing motorised vehicles

This policy aims to reduce the number of motorised vehicles with higher emissions by taxing them. This tax would be an addition in the Travel Cost variable in TDM model and would reflect in the mode share. Life time tax (15 yrs.) is converted to daily tax and added to travel cost variable.

The following taxes were considered for different vehicles

a. Car: additional 5 percent
b. Two-wheeler: additional 5 percent

5.3.11 Electrification of buses and cars

This policy aims to reduce the emissions by assuming that all the buses and cars will be running on electricity in future years.

5.4 MITIGATION BUNDLE 1

Bundle number 1 has three polices under it. Table 30 shows the policies under this bundle.

Table 30: Policies in bundle 1

Increasing network coverage of Public Transit
Cycling and walking infrastructure
Additional tax on purchasing vehicles

The aim of bundle 1 is to encourage public transport, non-motorized transport and to discourage the private transport by increasing the taxes for new vehicle purchase. Because of providing proper infrastructure to cycling and walking the travel times have reduced and hence the increase in mode shares of cycling and walking.

5.4.1 Mode share and VKT calculation

The mode share values obtained after evaluating policy bundle 1 for 2030 and 2050 have been mentioned in figure 45, alongside the BAU mode share values.

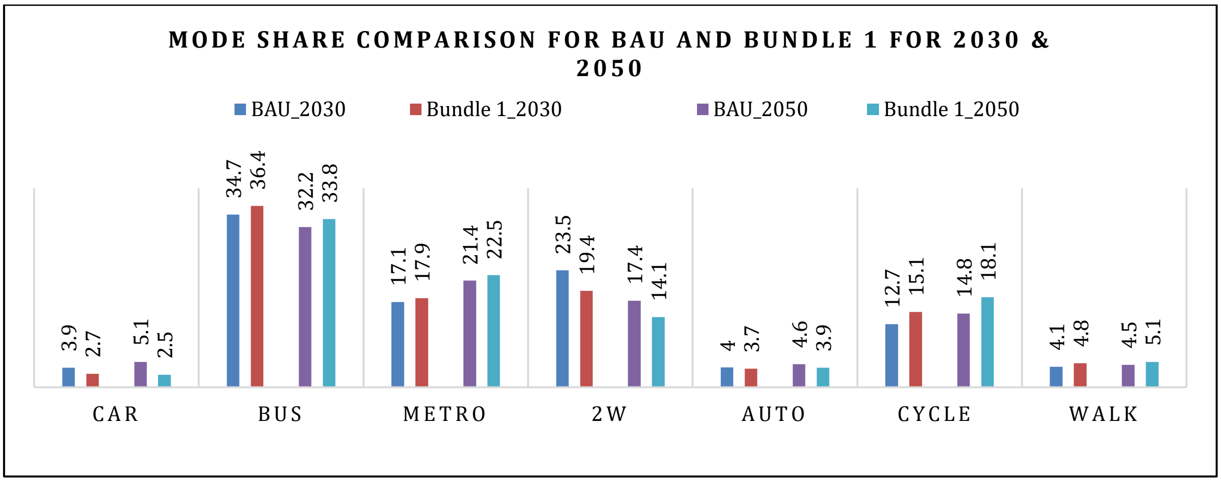


Figure 45: Mode Share values for Policy Bundle1 and BAU

The corresponding VKTs for this particular policy bundle are shown in figure 46.

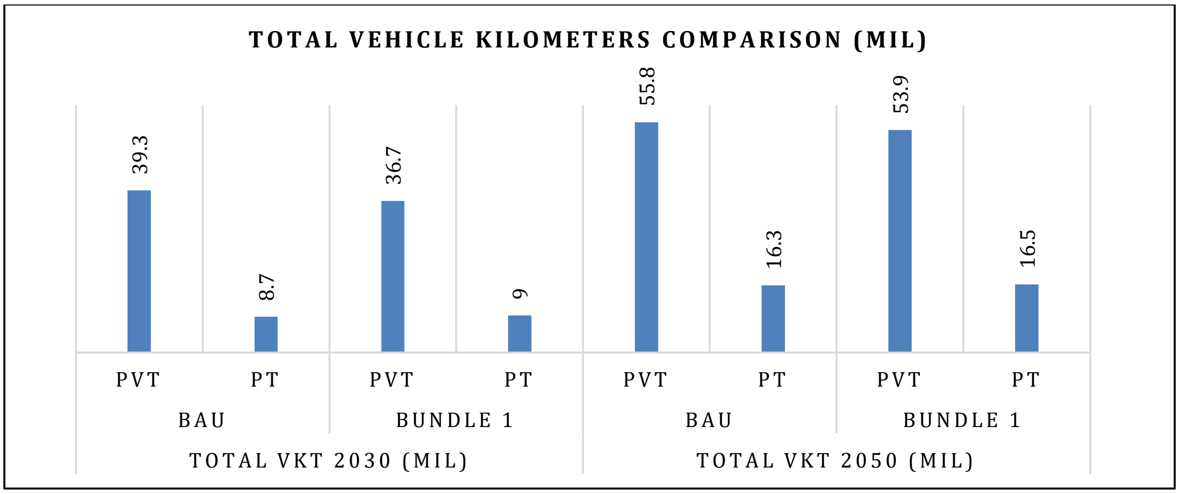


Figure 46: VKTs obtained after Policy Bundle 1 for 2030 and 2050

5.5 MITIGATION BUNDLE 2

Bundle number 2 has three polices under it. Table 31 shows the policies under this bundle.

Table 31: Policies in bundle 2

Additional tax on purchasing vehicles
Strict Vehicles inspection/Improvement in standards for vehicle emission
Increase in fuel cost

In bundle 2, apart from increasing the taxation upon purchase of new vehicles the fuel prices are also increased which go into travel cost variable of the mode share model. Also, vehicles that are older than 15 years have been removed from the travel demand modeling. This causes a shift in the mode from private to public due to reduction in travel times. Because of the strict vehicle inspection people who own two wheelers are shifted to cycling and walking and public transport because of the tax restraint.

5.5.1 Mode share and VKT calculation

The mode share values obtained after evaluating this policy for 2030 and 2050 have been mentioned in figure 47, alongside the BAU mode share values.

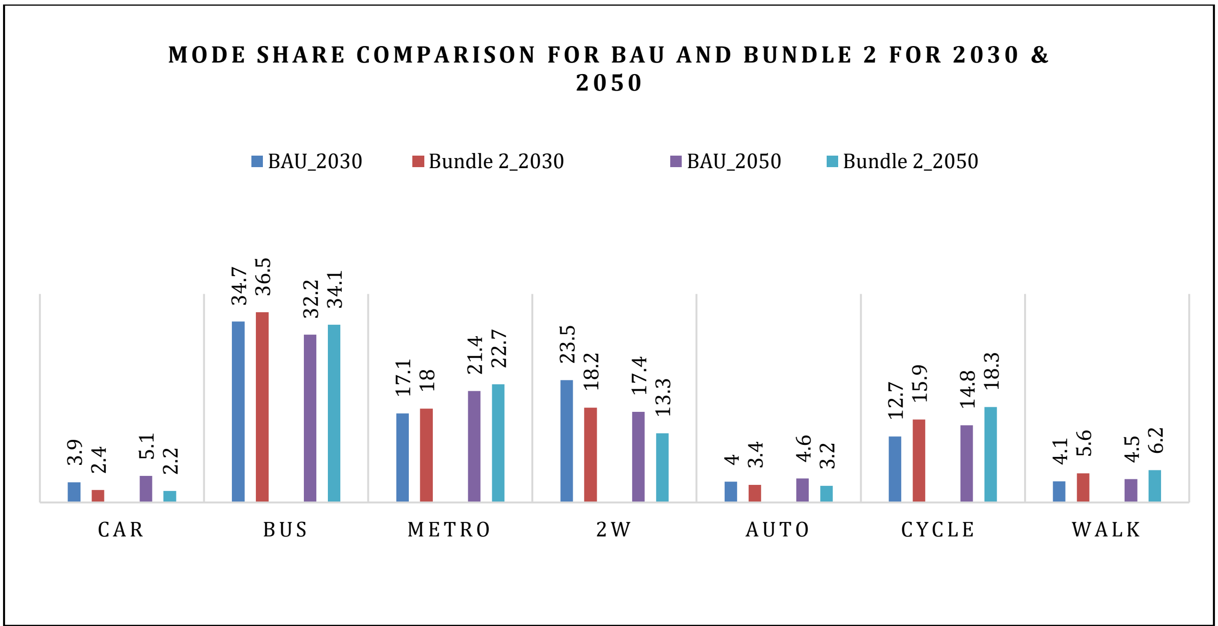


Figure 47: Mode Share values for Policy Bundle 2 and BAU

The corresponding VKTs for this particular policy bundle are shown in figure 48.

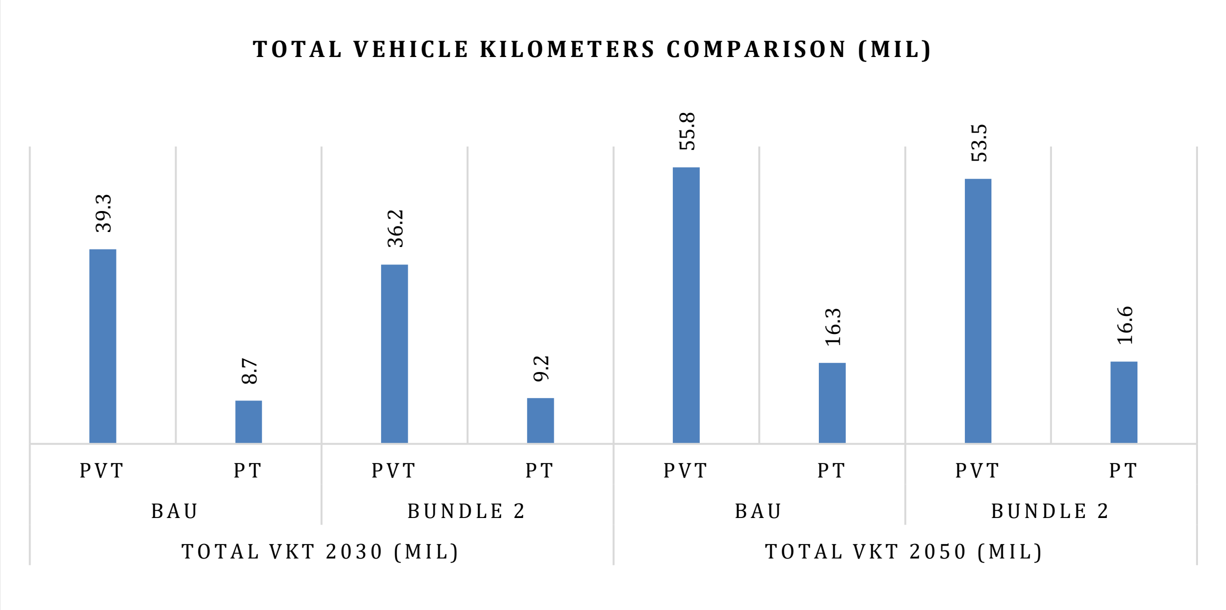


Figure 48: VKTs obtained after Policy Bundle 2 for 2030 and 2050

5.6 MITIGATION BUNDLE 3

Bundle number 3 has seven polices under it. Table 32 shows the policies under this bundle.

Table 32: Policies in bundle 3

Increasing network coverage of Public Transit
Defining car restricted zones
Congestion Pricing
Park and Ride
Cycling and Walking infrastructure
Encouraging car-pooling and High Occupancy Lanes
High density mix building use along main transport corridors

In bundle 3, we can see there is more encouragement towards public transport, better connectivity, NMT and discouraging car transport. Because of the car restricted zones policy the travel times of the car have increased. On the other hand, we have provided exclusive lanes for high occupancy vehicles and carpooling vehicles reducing their time of travel which has a positive impact on utility of buses and car pooling vehicles. Further the travel times are reduced by 'High density mix building use along main transport corridors' which aims to reduce the distance of travel and time as well. All these policies as a bundle led to mode shift towards public transport and NMT.

5.6.1 Mode share and VKT calculation

The mode share values obtained after evaluating this policy for 2030 and 2050 have been mentioned in figure 49, alongside the BAU mode share values.

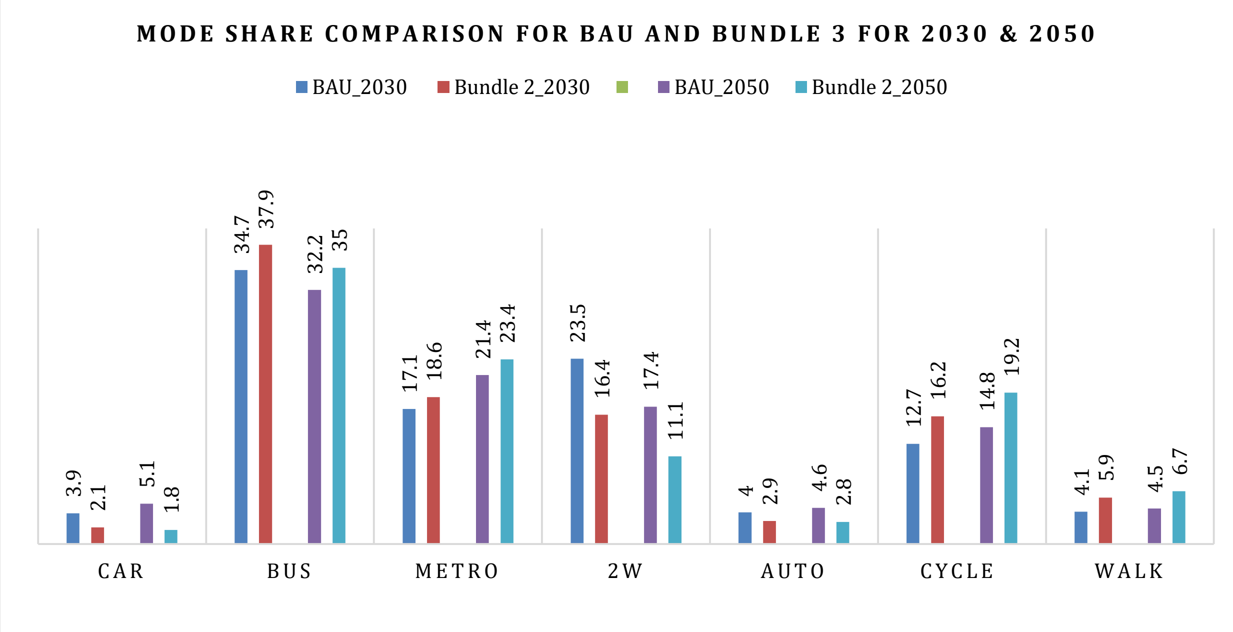


Figure 49: Mode Share values for Policy Bundle 3 and BAU

The corresponding VKTs for this particular policy bundle are shown in figure 50.

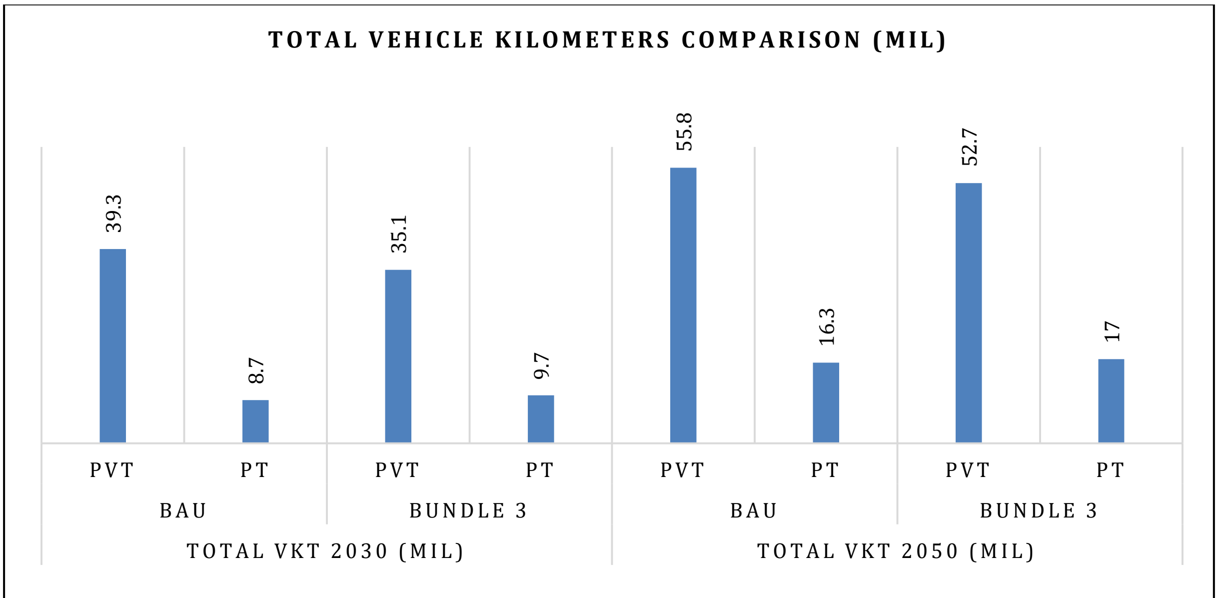


Figure 50: VKTs obtained after Policy Bundle 3 for 2030 and 2050

5.7 MITIGATION BUNDLE 4

Bundle number 4 has eight polices under it. Table 33 shows the policies under this bundle.

Table 33: Policies in bundle 4

Increasing network coverage of Public Transit
Defining car restricted zones
Congestion Pricing
Park and Ride
Cycling and Walking infrastructure
Encouraging car-pooling and High Occupancy Lanes
High density mix building use along main transport corridors
All buses and cars running on electricity

The policies in bundle 4 is same as bundle 3, additionally it has been assumed that all the buses and cars will be running on electricity for future years. Thus, the modal share values and the corresponding VKTs will remain same as evaluated in mitigation bundle 3.

5.8 COMPARISON BETWEEN BAU & POLICY BUNDLES

The comparison of mode shares and Vehicle Kilometres Travelled between Business As-usual Scenario and mitigation policy bundles for the future years 2030 and 2050 is given in figure 51 - 53.

5.8.1 Mode Share

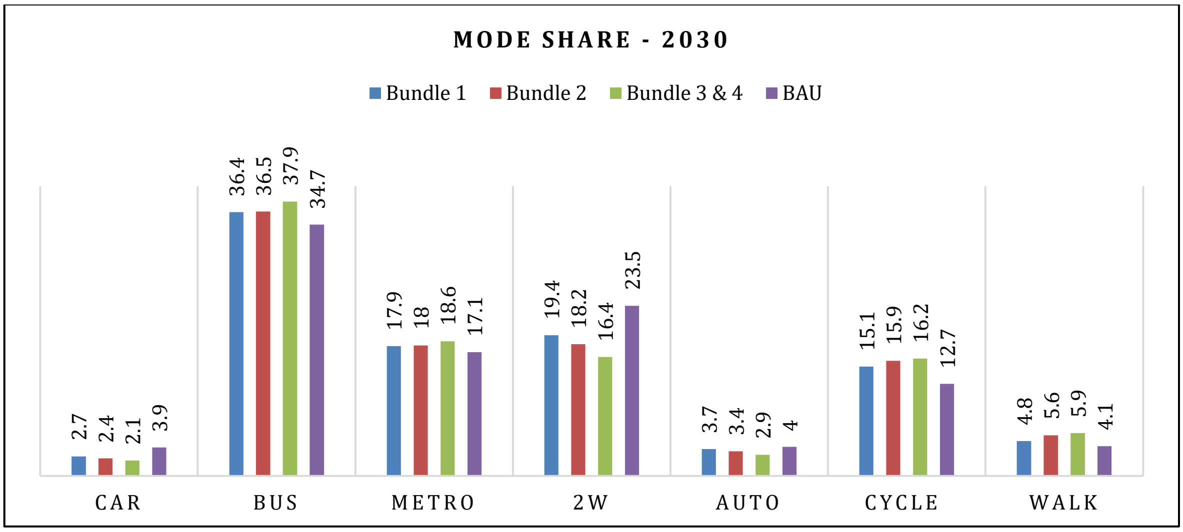


Figure 51: Comparison or mode share drawn between BAU & policy bundles for 2030

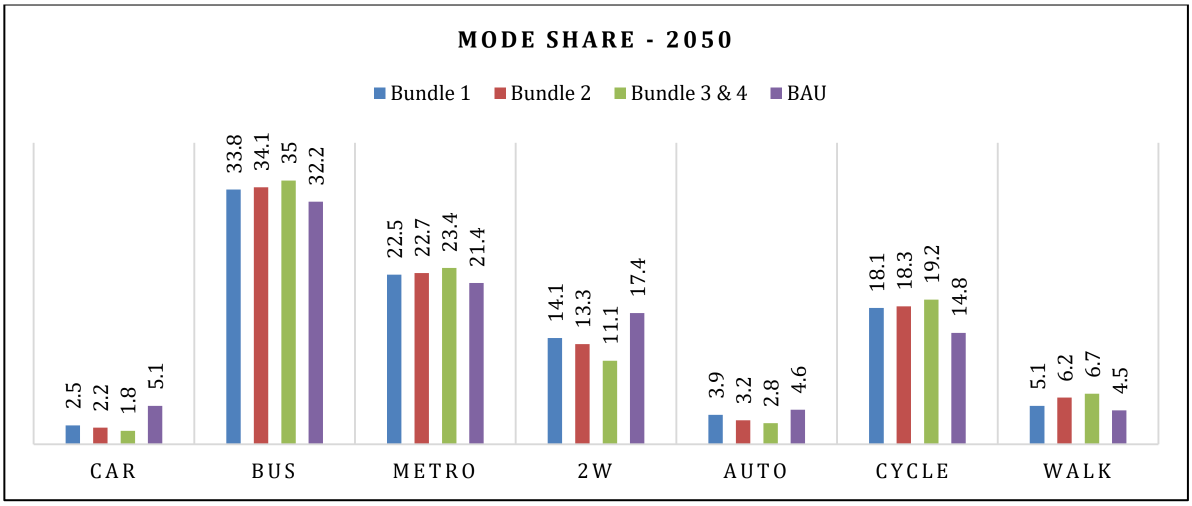


Figure 52: Comparison of mode share drawn between BAU & policy bundles for 2050

From the figures 51 and 52 it is observed that there public transport services like bus, metro have higher mode share as compared with BAU scenario for 2030 and 2050. Increase in mode share is also seen in cycling and walking whereas reduction of mode share is observed in car, two wheeler and auto. This is because of the design of the policies which were made to encourage public transportation and reduce the usage of private transport.

5.8.2 Vehicle Kilometres Travelled

The following figure 52 shows the VKTs obtained from each policy after assigning.

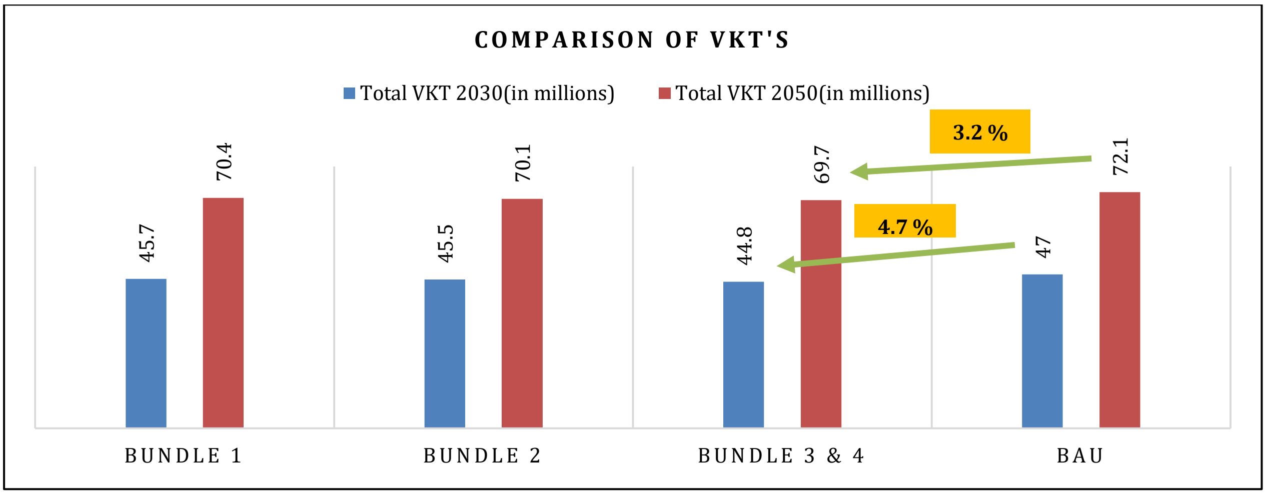


Figure 53: Comparison of VKTs obtained from different bundles for 2030 and 2050

Figure 53 explains that the vehicle kilometres travelled are less in case of Bundle 3 & 4 compared to other bundles and BAU. Although there is a high mode shift towards public transport in bundle 3&4, the high occupancy levels of these systems is the reason for less vehicle kilometres travelled.

5.9 BASE YEAR VEHICULAR EMISSIONS

This section shows the mode wise emissions for the base year of BAU scenario.

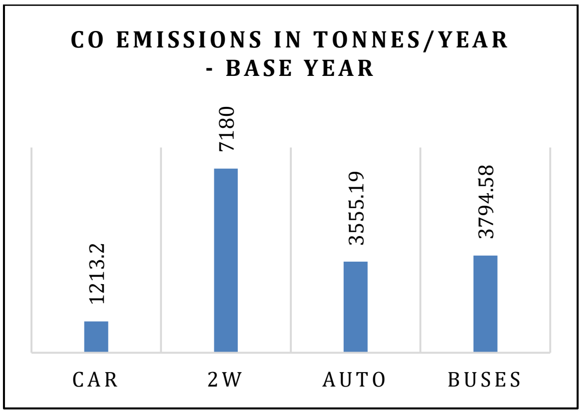


Figure 54: Modewise CO Emissions in tonnes/year for Base Year

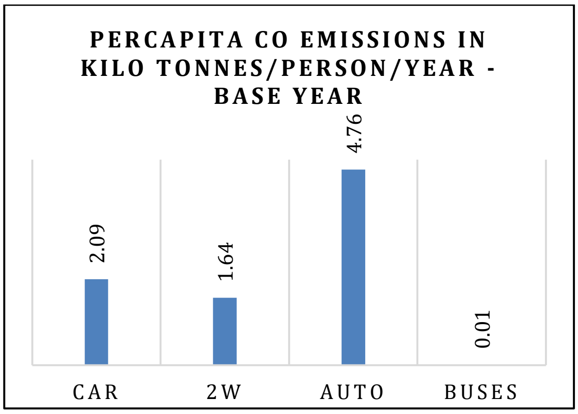


Figure 55: Mode wise Percapita CO Emissions in Kilo tonnes/person/year for Base Year

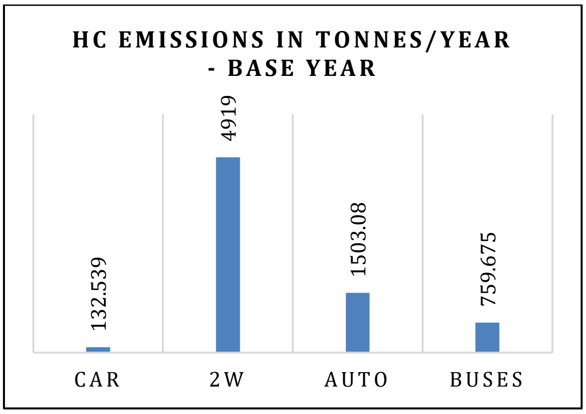


Figure 56: Modewise HC Emissions in tonnes/year for Base Year

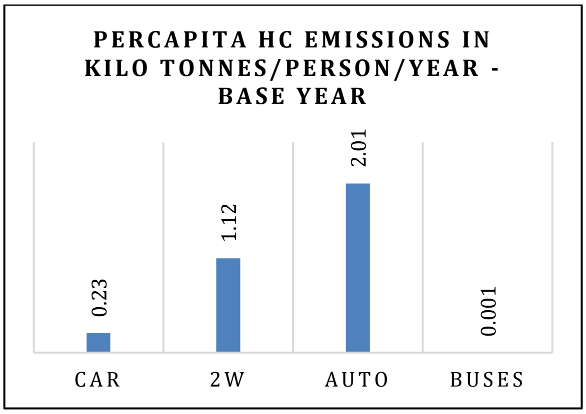


Figure 57: Mode wise Percapita HC Emissions in Kilo tonnes/Person/year for Base Year

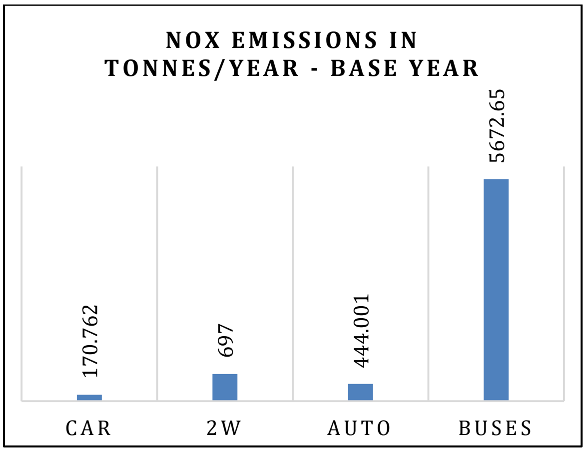


Figure 58: Modewise NOX Emissions in tonnes/year for Base Year

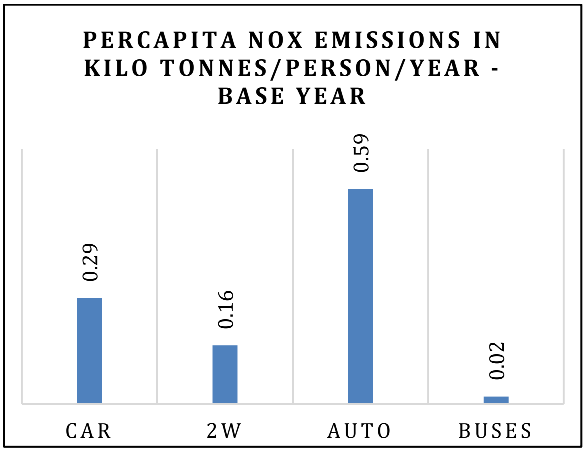


Figure 59: Mode wise Percapita NOx Emissions in Kilo tonnes/Person/year for Base Year

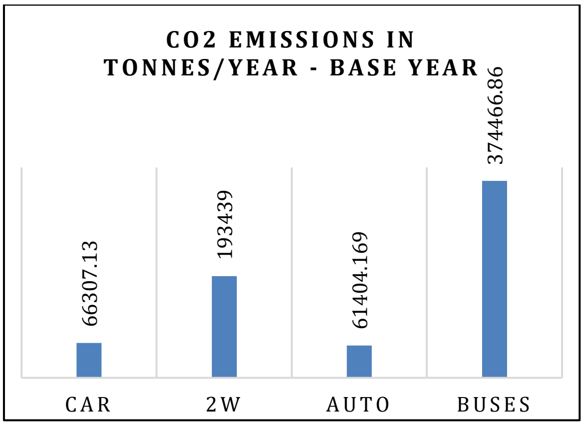


Figure 60: Modewise CO2 Emissions in tonnes/year for Base Year

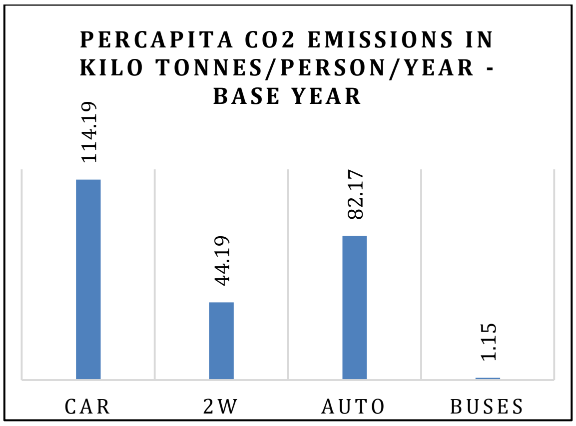


Figure 61: Mode wise Percapita CO2 Emissions in Kilo tonnes/person/year for Base Year

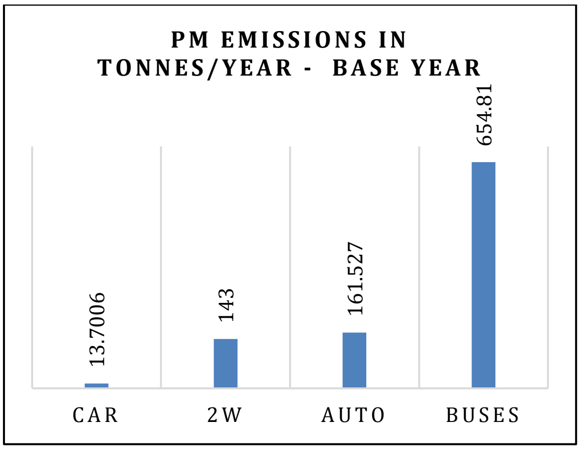


Figure 62: Modewise PM Emissions in tonnes/year for Base Year

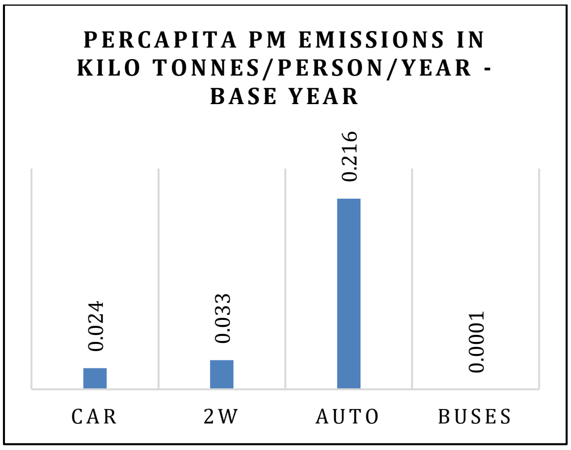


Figure 63: Mode wise Percapita PM emissions in Kilo tonnes/person/year for Base Year

From figure 60 it is seen that buses emit high amounts of CO_2 when compared with car, two wheeler and auto. Since bus has high occupancy levels, the per-capita share of CO_2 is less than other modes as seen in figure 61.

5.10 BAU &POLICY BUNDLES VEHICULAR EMISSIONS – 2030 & 2050

The comparison between the emissions for the BAU scenario with the evaluated policies for the years 2030 and 2050 are discussed and presented in the Figures 64 - 123. In the below figures B1 refers to Bundle 1, B2 refers to Bundle 2, B3 refers to Bundle 3 whereas Bundle 4 represented as B4 has four scenarios namely Scenario 1, Scenario 2, Scenario 3 and Scenario 4 which are represented as S1, S2, S3 and S4 respectively. Similarly, BAU refers to Business as usual scenario.

The bundle 4 includes the assumption of electrification of all cars and buses for horizon years. The emissions for the electricity (g/kWh) are calculated based upon different energy mix scenarios. Four different scenarios assumed based on the different projections of the energy mix in the target years are as follows:

i. **Scenario 1:** New Policies Scenario (IEA, 2015)–Non-renewable sources & Electricity (74% - 26%)

ii. **Scenario 2:** Electricity from non-renewable Sources (100 %)

iii. **Scenario 3:** Half electricity from renewable and another half from non-renewable sources (50 % - 50 %)

iv. **Scenario 4:** Electricity from Renewable Sources (100 %)

Mode wise emissions for car, two wheelers, auto and buses for all the pollutants are presented in separate figures showing the comparison between four bundles incorporating four scenarios in the Bundle 4. However, since metro is already running in electricity, the bundles have been evaluated considering four scenarios in each bundle independently for metro. Finally, the total emissions and total percapita emissions for all the pollutants such as CO, HC, NOx, CO_2 and PM have been evaluated considering all the modes and presented in the following figures respectively.

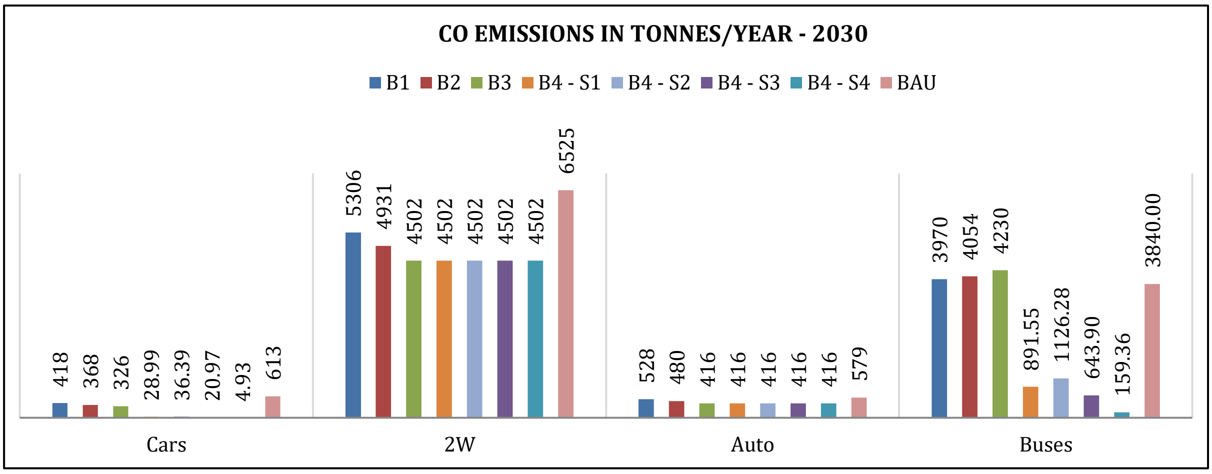


Figure 64: Mode wise CO Emissions in tonnes/year for 2030

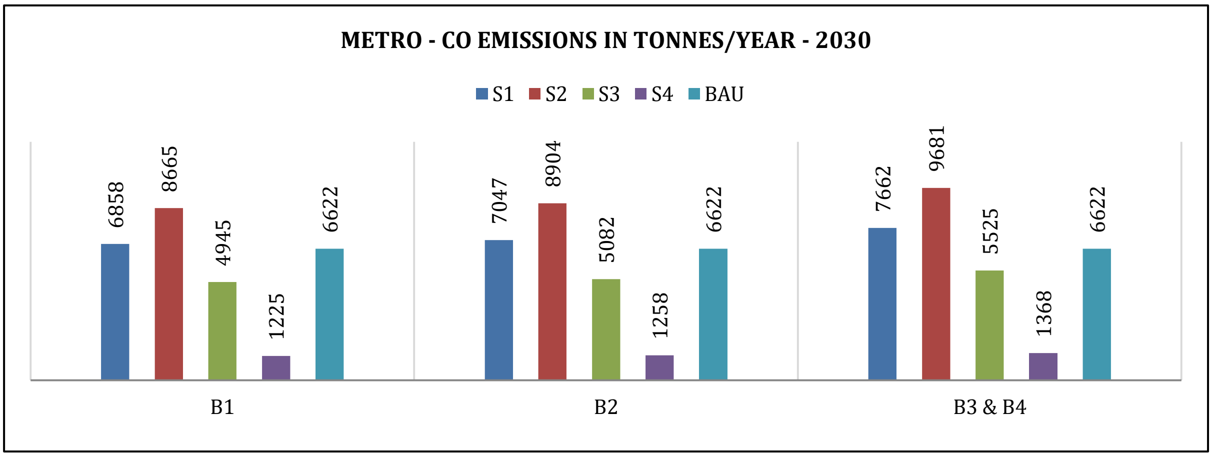
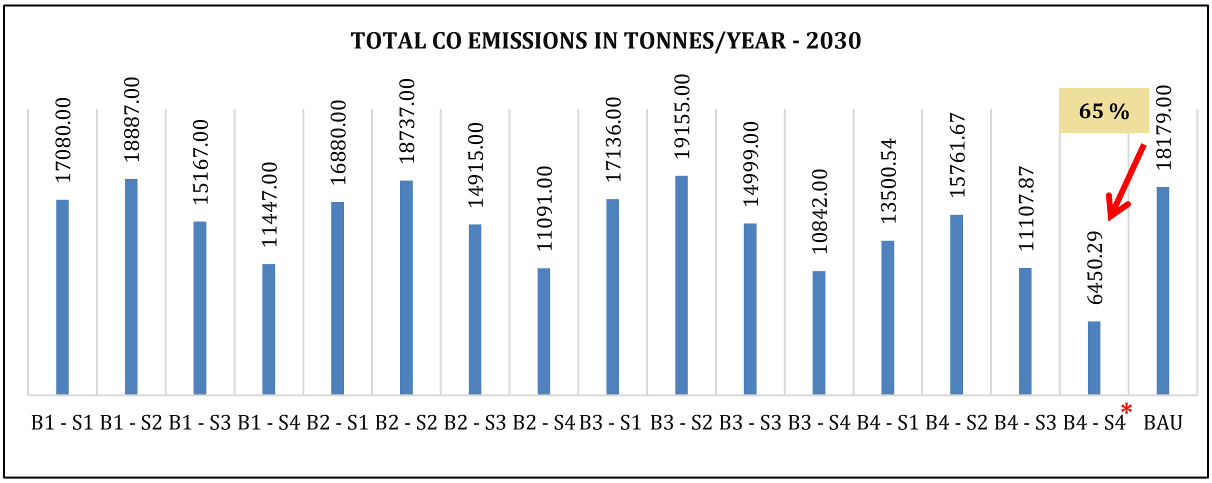


Figure 65: Metro - CO Emissions in tonnes/year for 2030



* 65% reduction in total CO emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **36%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **73%** reduction in total CO emissions can be achieved with respect to BAU scenario

Figure 66: Total CO Emissions in tonnes/year for 2030

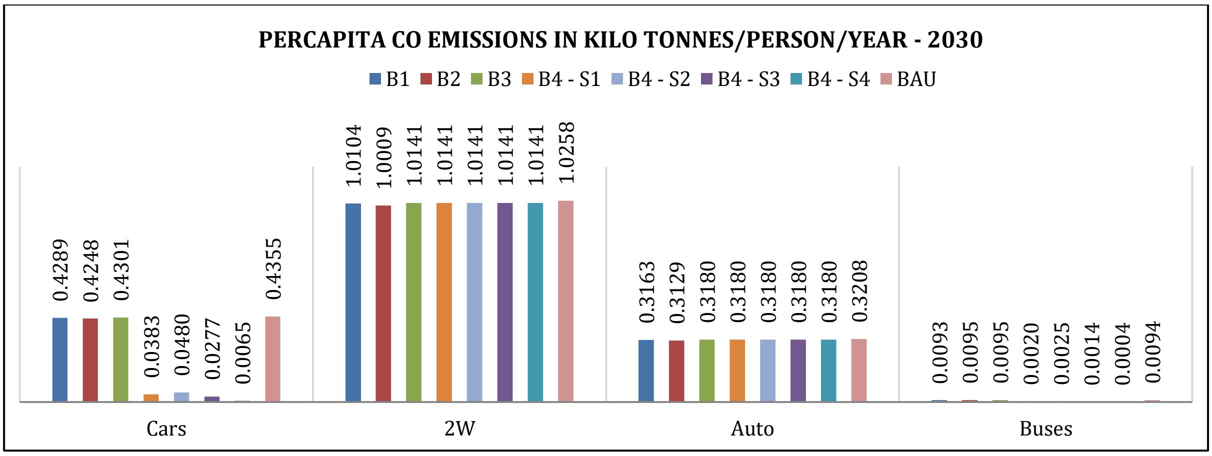


Figure 67: Mode wise Percapita CO Emissions in kilo tonnes/person/Year for 2030

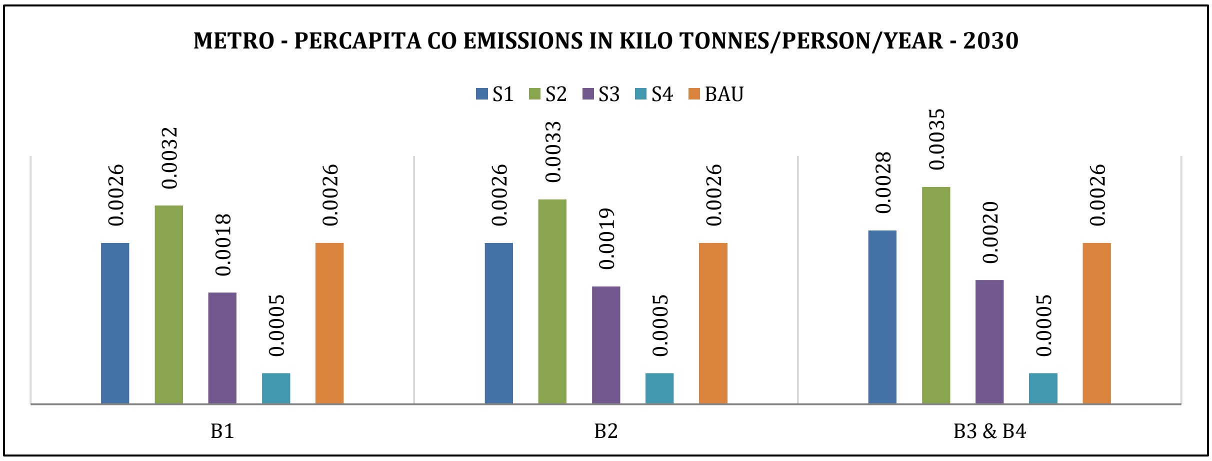
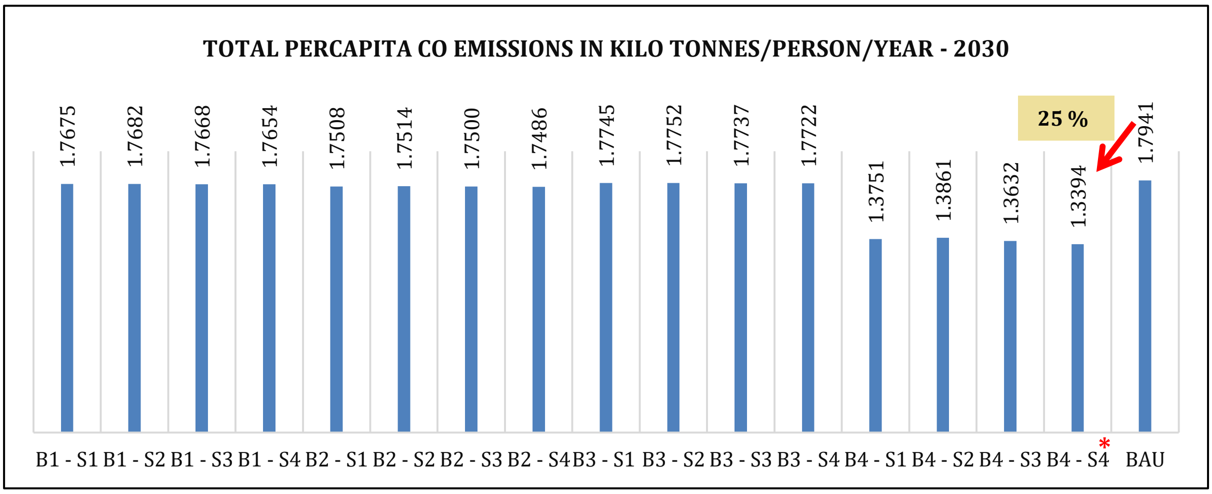


Figure 68: Metro - Percapita CO Emissions in kilo tonnes/person/Year for 2030



*25% reduction in total percapita CO emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, **26%** reduction in total percapita CO emissions can be achieved with respect to BAU scenario

Figure 69: Total CO Percapita Emissions in kilo tonnes/person/Year for 2030

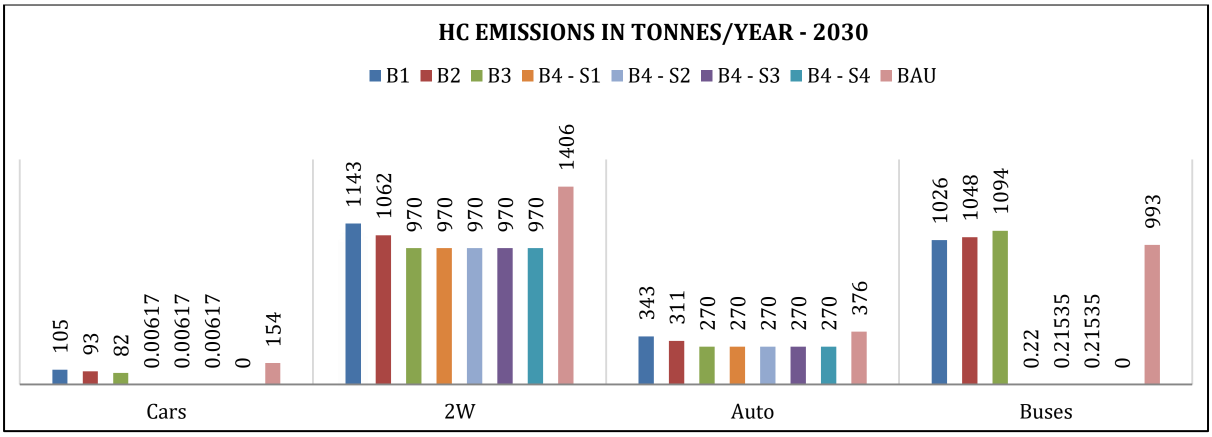


Figure 70: Mode wise HC Emissions in tonnes/year for 2030

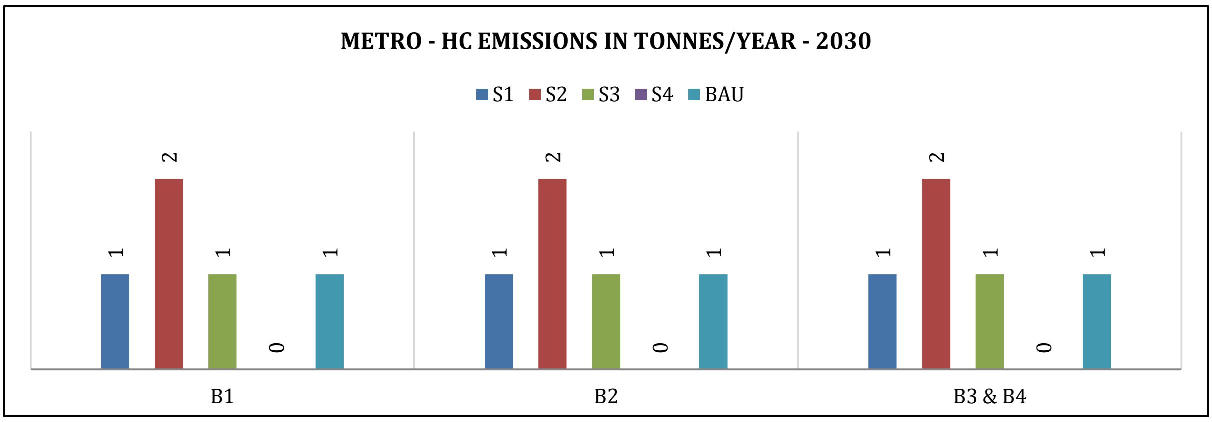
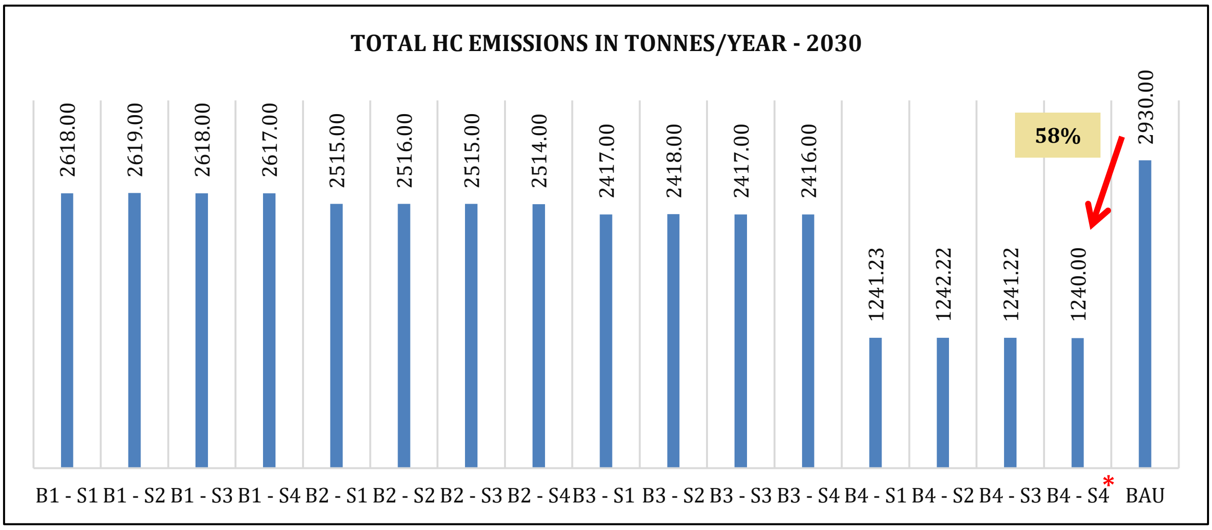


Figure 71: Metro - HC Emissions in tonnes/year for 2030



*58% reduction in total HC emissions is observed in B4-S4 w.r.t. BAU and further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, the same percentage reduction in total HC emissions is observed with respect to BAU scenario

Figure 72: Total HC emissions in tonnes/year for 2030

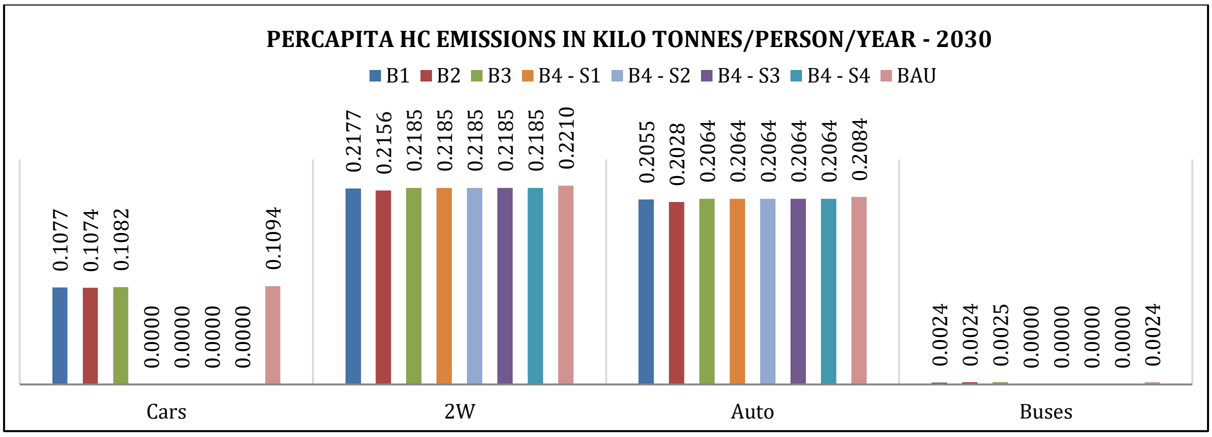


Figure 73: Mode wise percapita HC Emissions in kilo tonnes/person/year for 2030

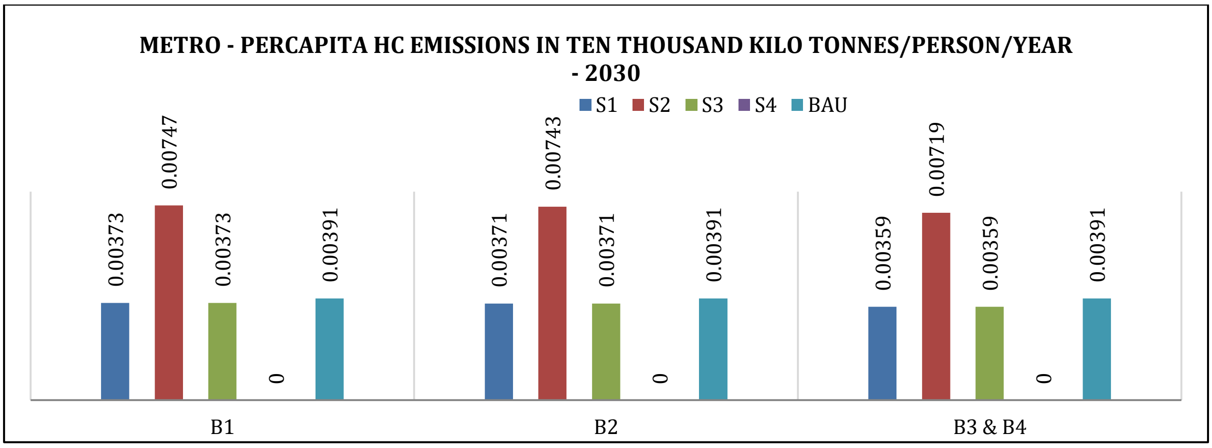
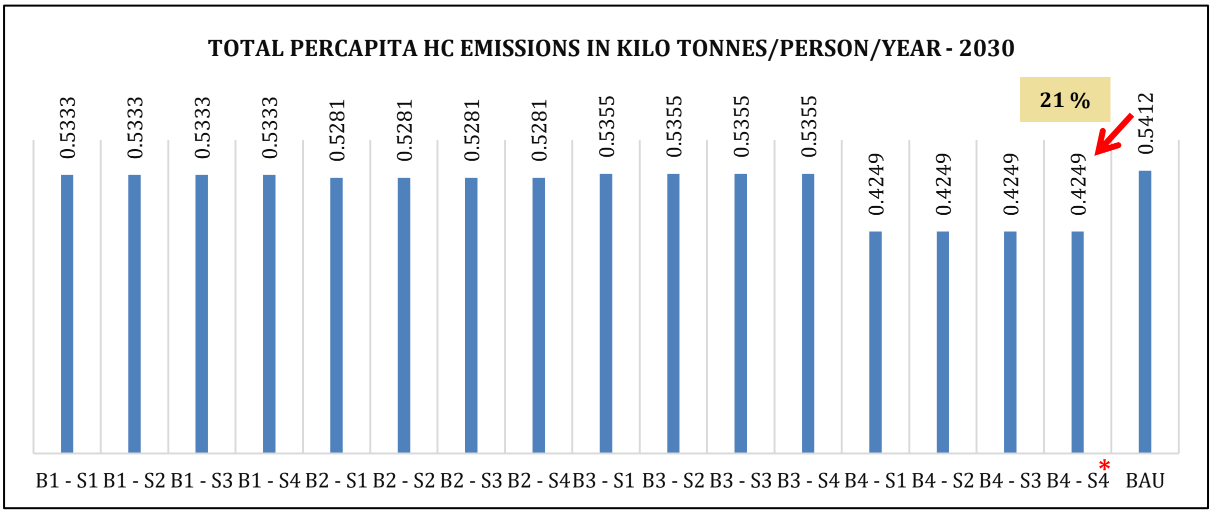


Figure 74: Metro - Percapita HC Emissions in ten thousand kilo tonnes/person/year for 2030



*21% reduction in total percapita HC emissions is observed in B4-S4 w.r.t. BAU and further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, the same percentage reduction in total percapita HC emissions is observed with respect to BAU scenario

Figure 75: Total HC percapita Emissions in kilo tonnes/person/year for 2030

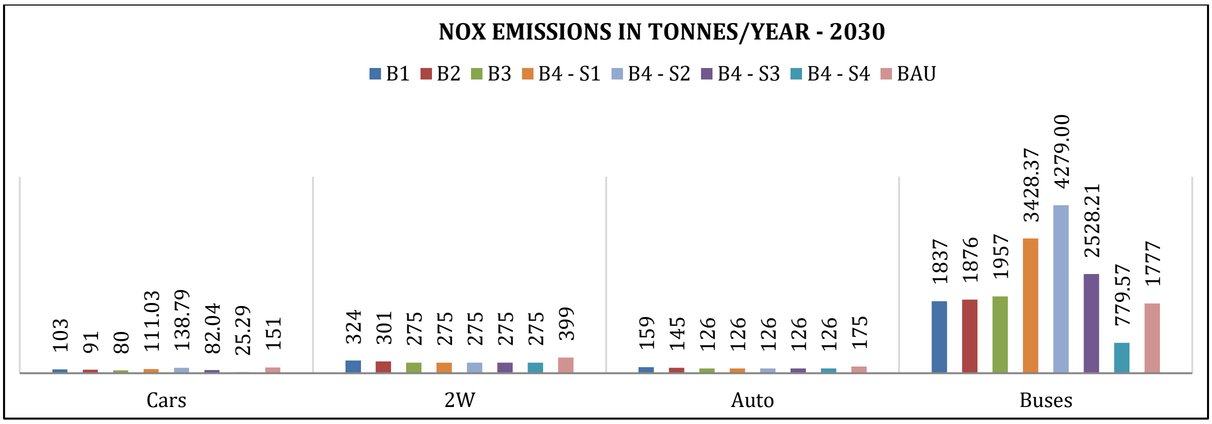


Figure 76: Mode wise NOx Emissions in tonnes/year2030

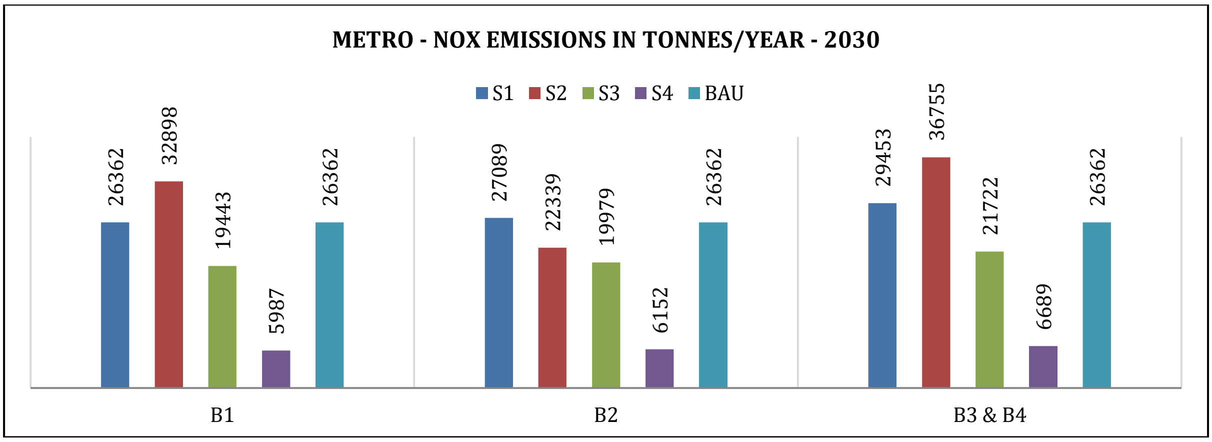
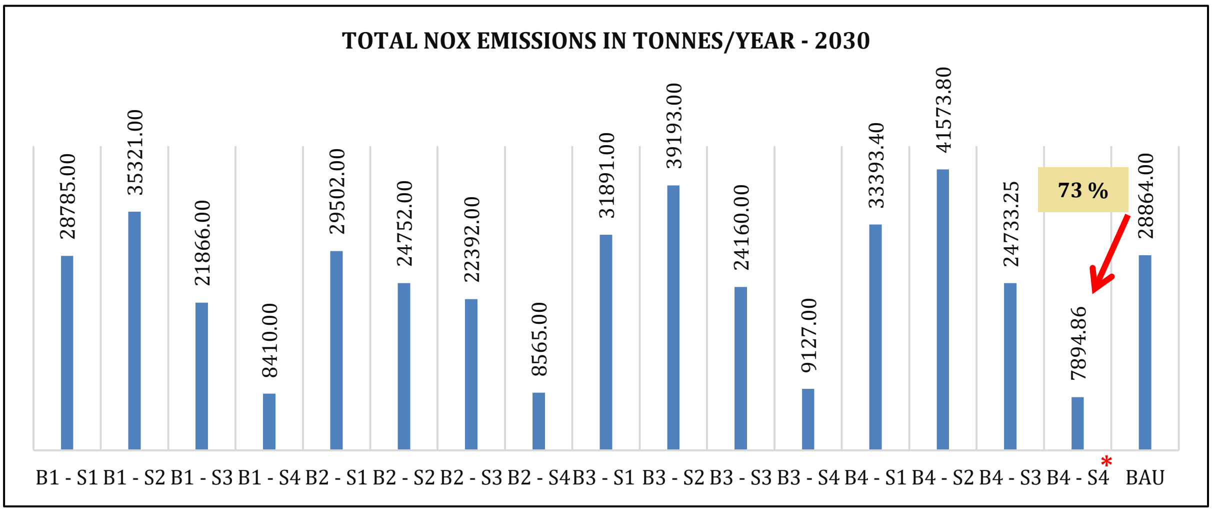


Figure 77: Metro - NOx Emissions in tonnes/year2030



*73% reduction in total NOx emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **91%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **99%** reduction in total NOx emissions can be achieved with respect to BAU scenario

Figure 78: Total NOx Emissions in tonnes/year for 2030

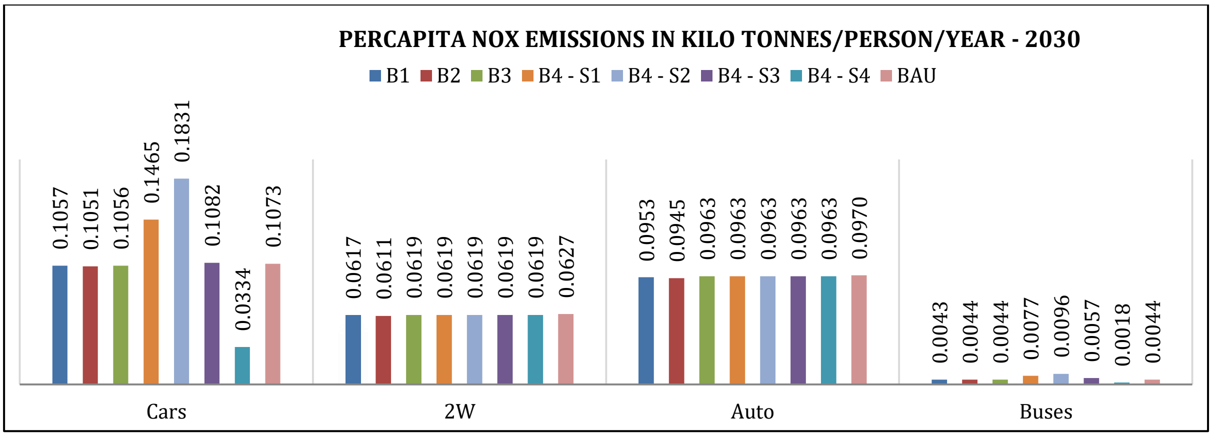


Figure 79: Mode wise Percapita NOx Emissions in kilo tonnes/person/Year for 2030

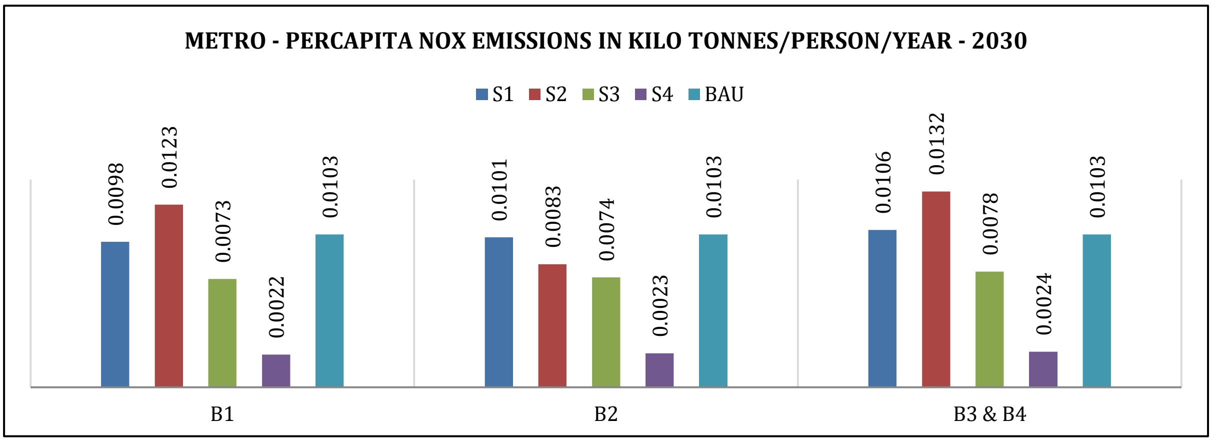
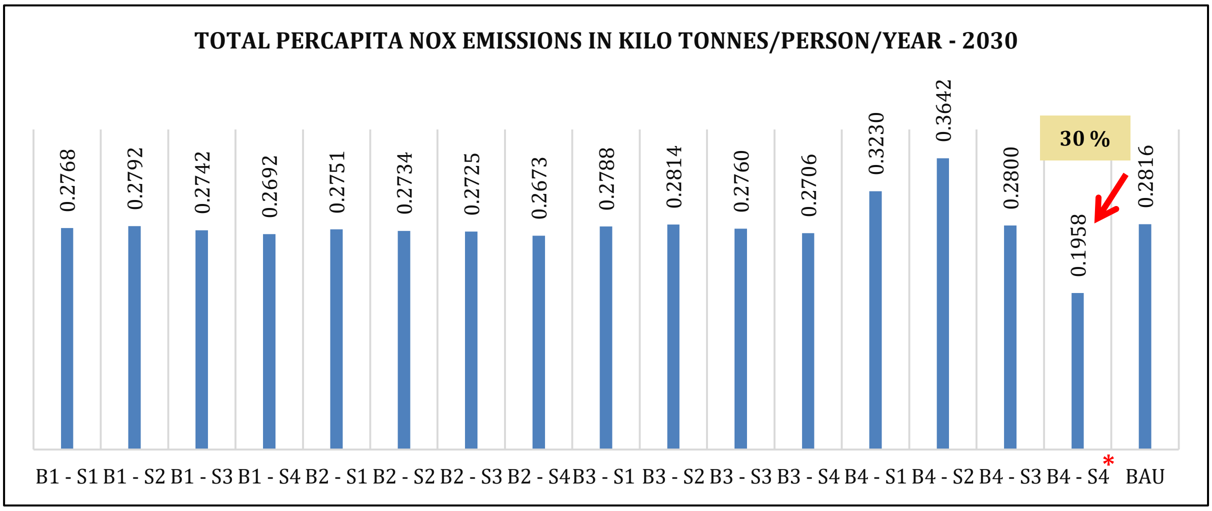


Figure 80: Metro - Percapita NOx Emissions in kilo tonnes/person/Year for 2030



*30% reduction in total percapita NOx emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **4%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **44%** reduction in total percapita HC emissions can be achieved with respect to BAU scenario

Figure 81: Total NOx Percapita Emissions in kilo tonnes/person/Year for 2030

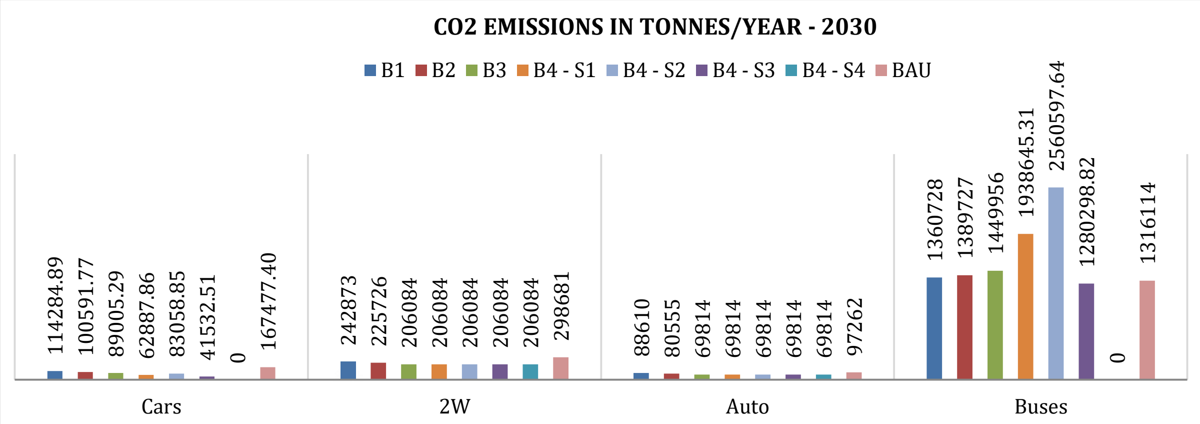


Figure 82: Mode wise CO_2 emissions in tonnes/year for 2030

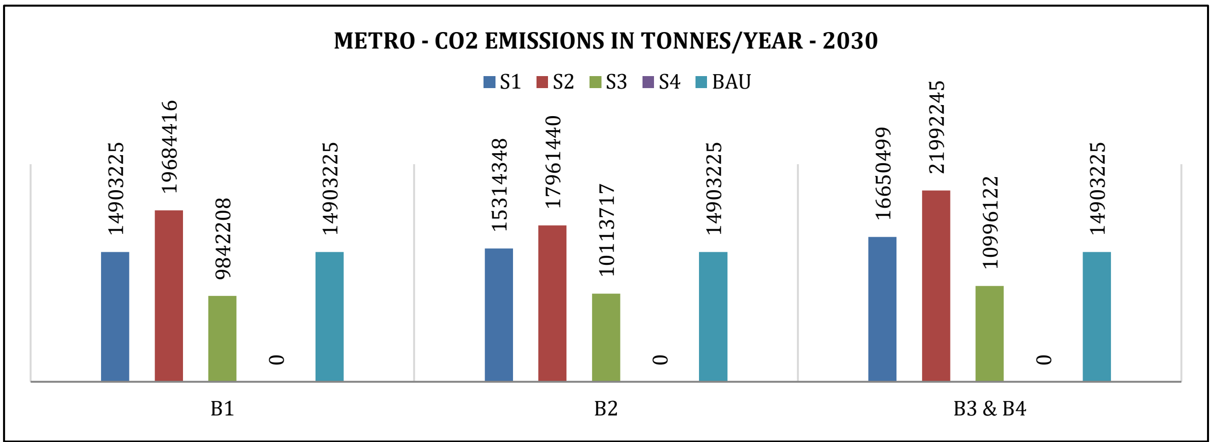
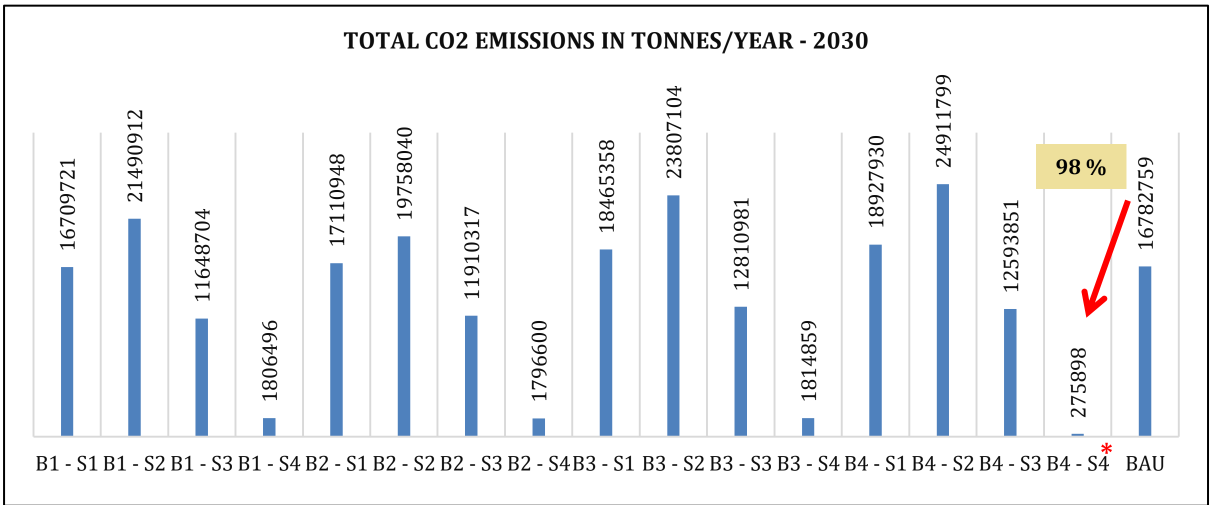


Figure 83: Metro - CO_2 emissions in tonnes/year for 2030



*98% reduction in total CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **89%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, the same reduction is observed as in scenario condition with respect to BAU scenario

Figure 84: Total CO_2 emissions in tonnes/year for 2030

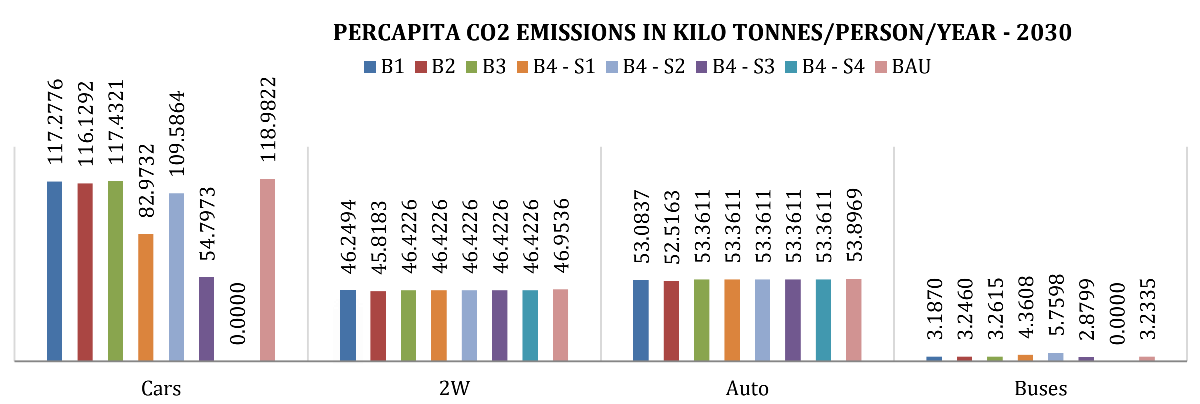


Figure 85: Mode wise Percapita CO_2 Emissions in kilo tonnes/person/Year for 2030

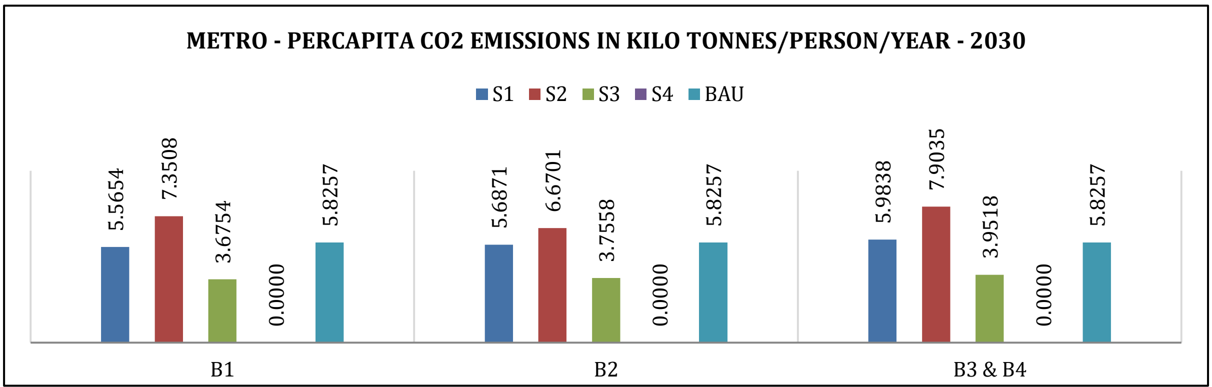
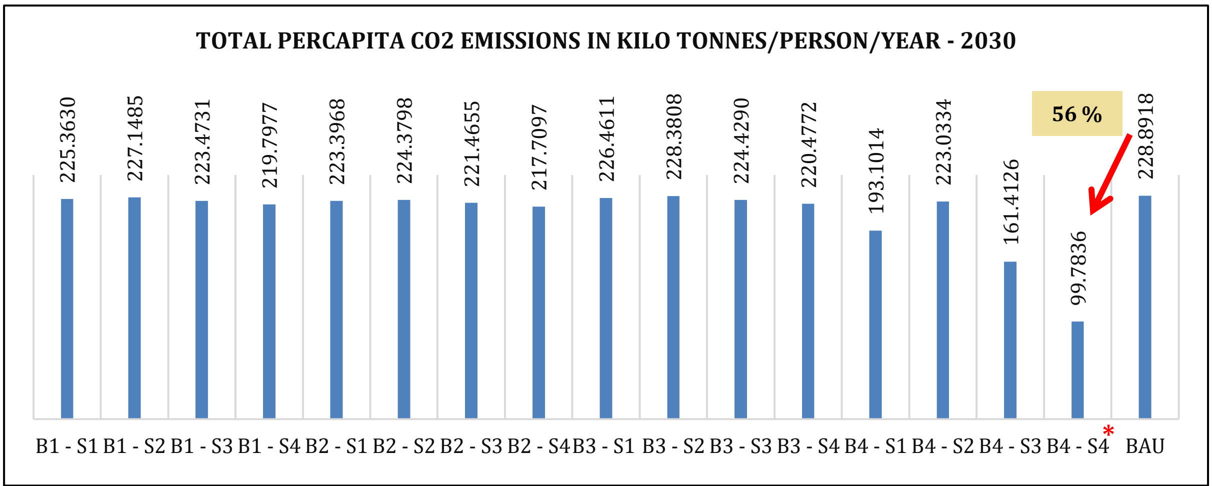


Figure 86: Metro - Percapita CO_2 Emissions in kilo tonnes/person/Year for 2030



*56% reduction in total percapita CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further, considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **3%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, the same reduction is observed as in scenario condition with respect to BAU scenario.

Figure 87: Total Percapita CO_2Emissions in kilo tonnes/person/Year for 2030

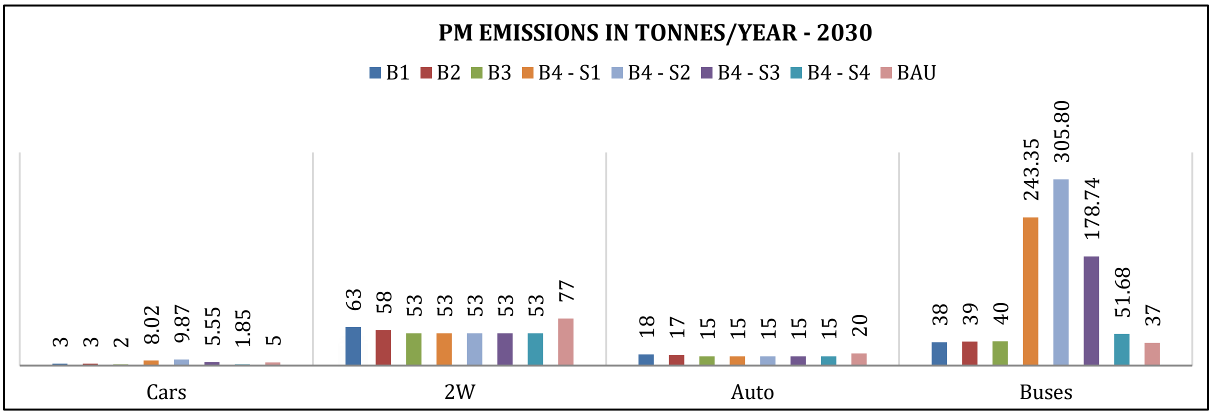


Figure 88: Mode wise PM Emissions in tonnes/year for 2030

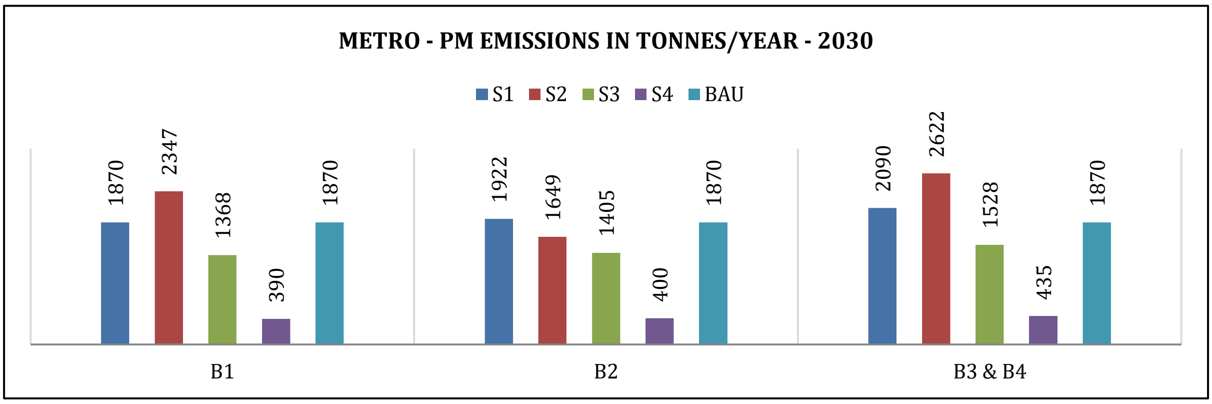
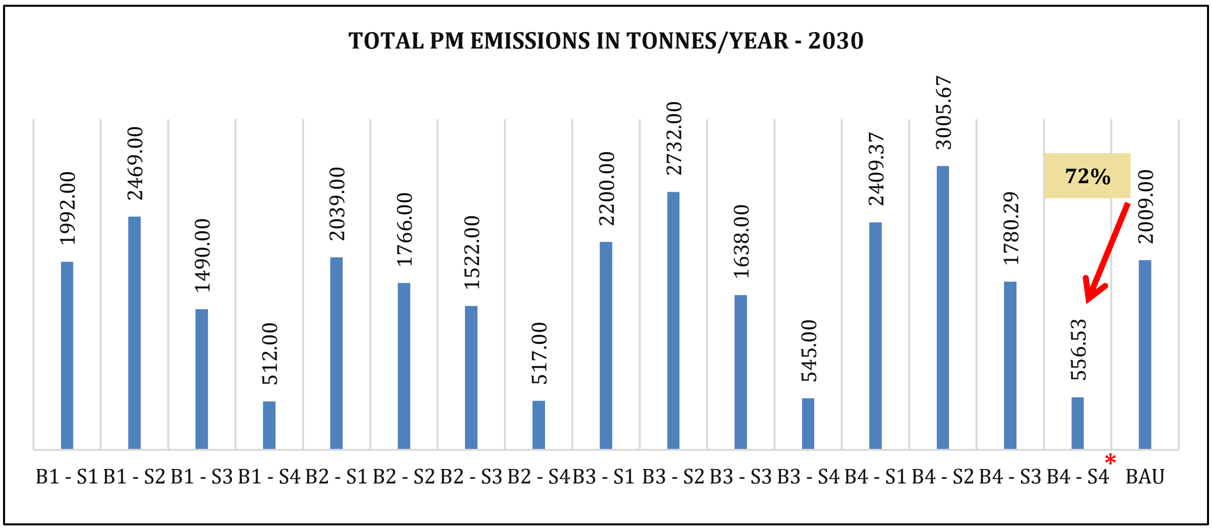


Figure 89: Metro - PM Emissions in tonnes/year for 2030



*72% reduction in total PM emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **97%** reduction in total PM emissions can be achieved with respect to BAU scenario

Figure 90: Total PM Emissions in tonnes/year for 2030

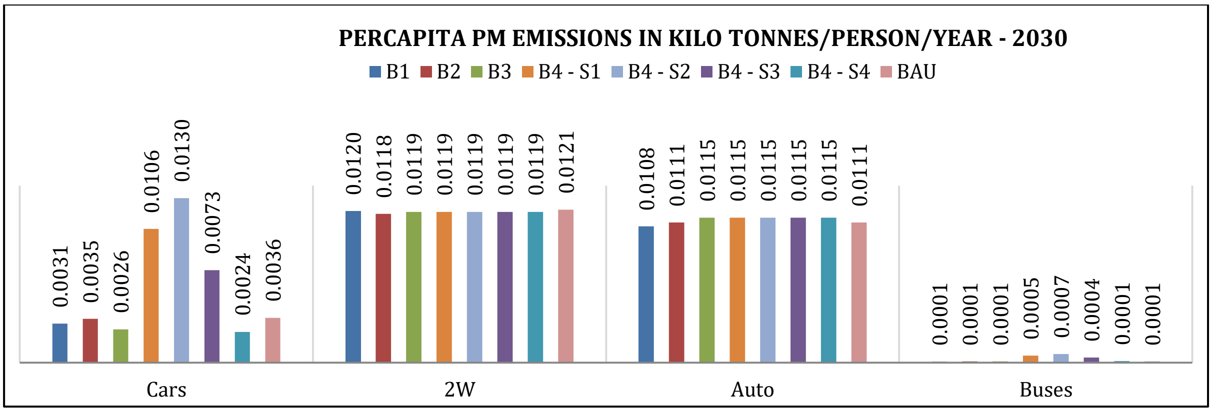


Figure 91: Mode wise Percapita PM Emissions in kilo tonnes/person/Year for 2030

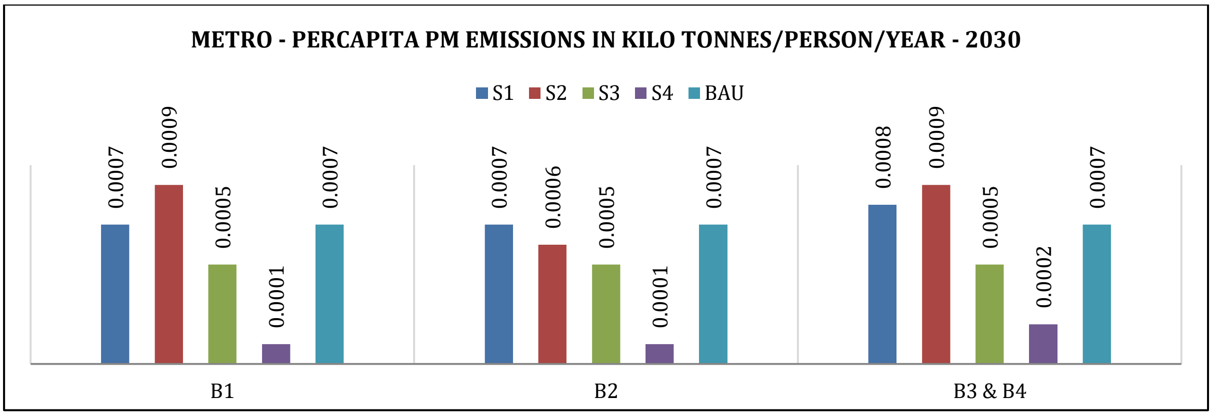
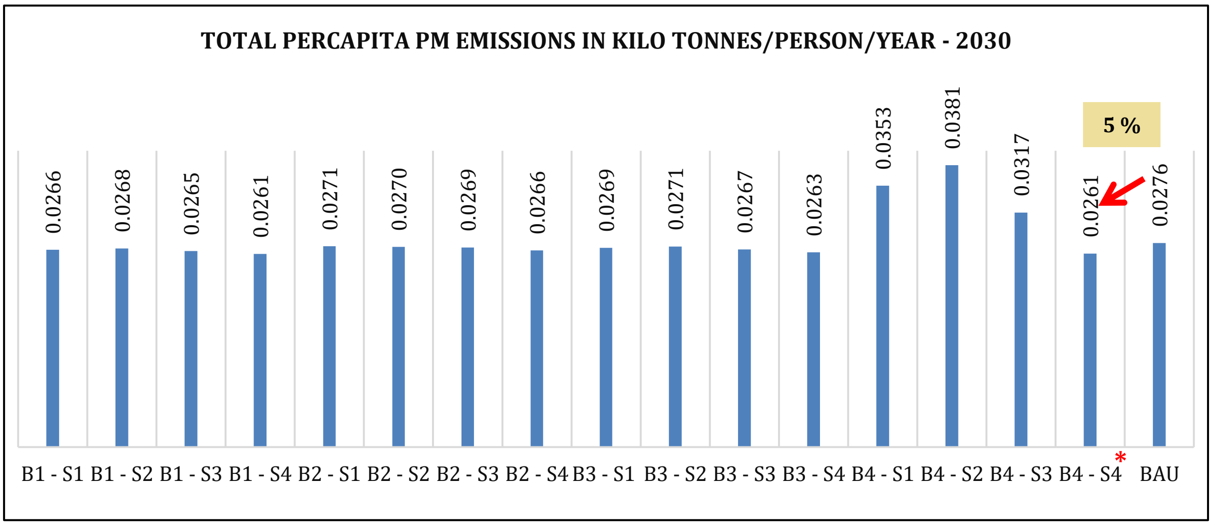


Figure 92: Metro - Percapita PM Emissions in kilo tonnes/person/Year for 2030



*5% reduction in total percapita PM emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **3%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario,**15%** reduction in total percapita PM emissions can be achieved with respect to BAU scenario

Figure 93: Total Percapita PM Emissions in kilo tonnes/person/Year for 2030

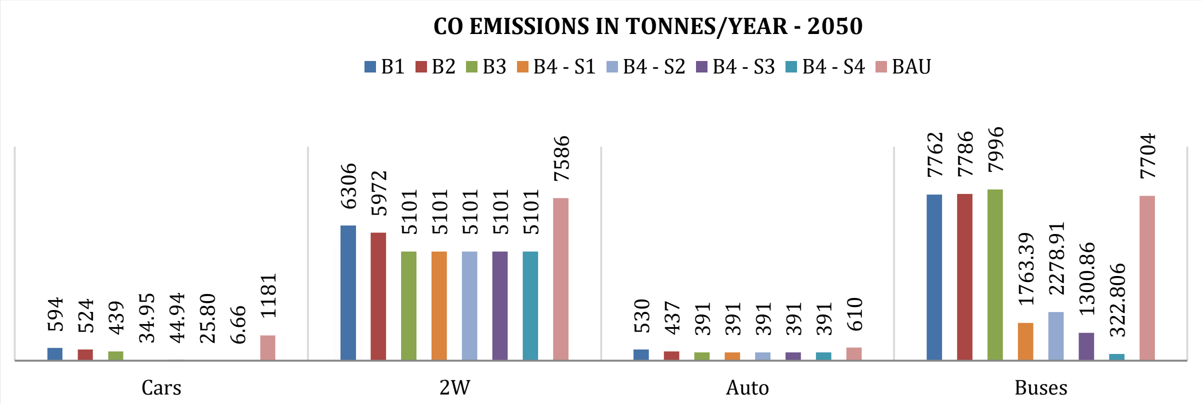


Figure 94: Mode wise CO Emissions in tonnes/year for 2050

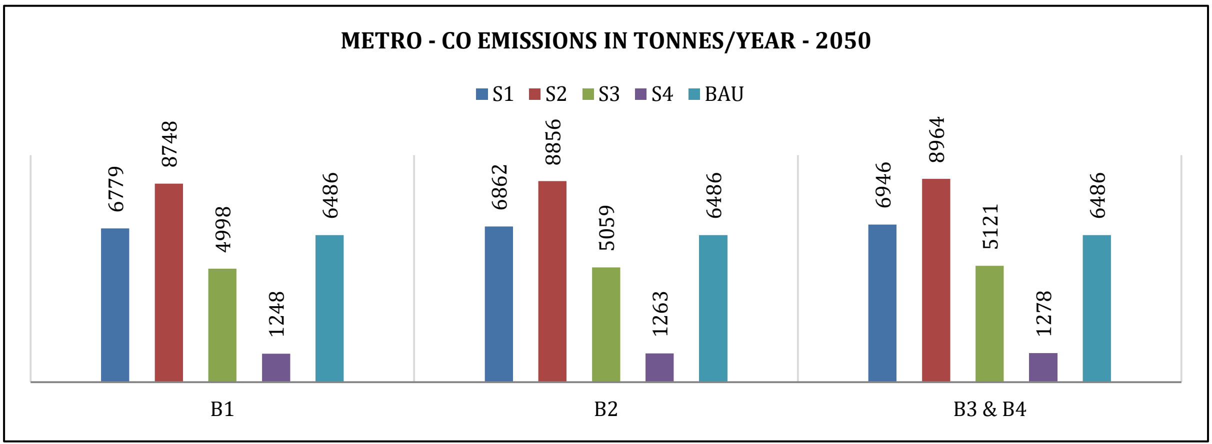
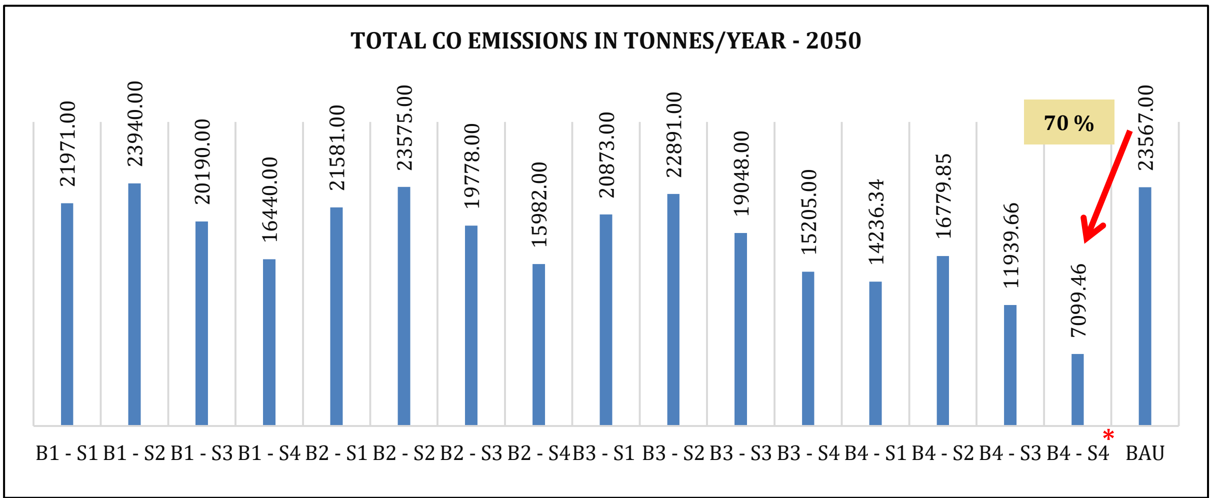


Figure 95: Metro - CO Emissions in tonnes/year for 2050



*70% reduction in total CO emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **28%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario,**77%** reduction in total CO emissions can be achieved with respect to BAU scenario

Figure 96: Total CO Emissions in tonnes/year for 2050

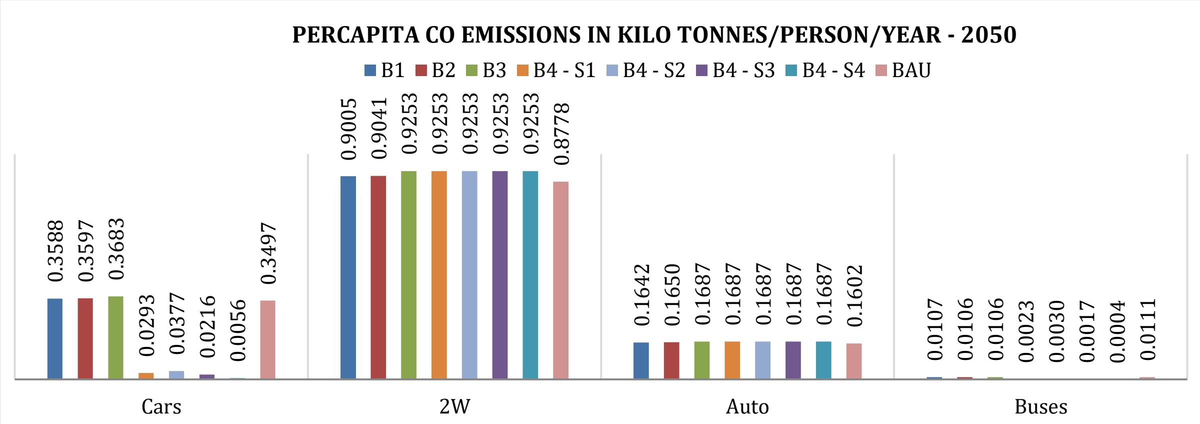


Figure 97: Mode wise Percapita CO Emissions in kilo tonnes/person/Year for 2050

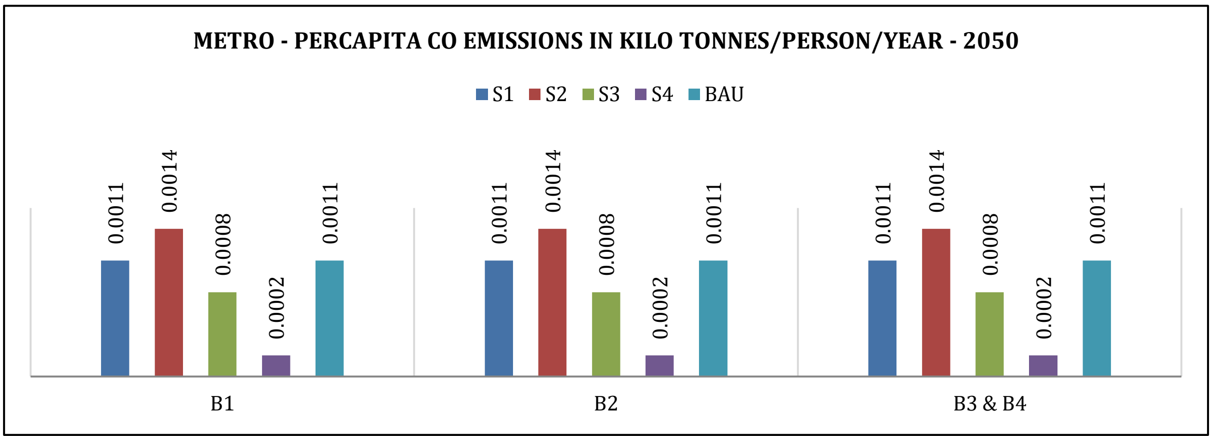
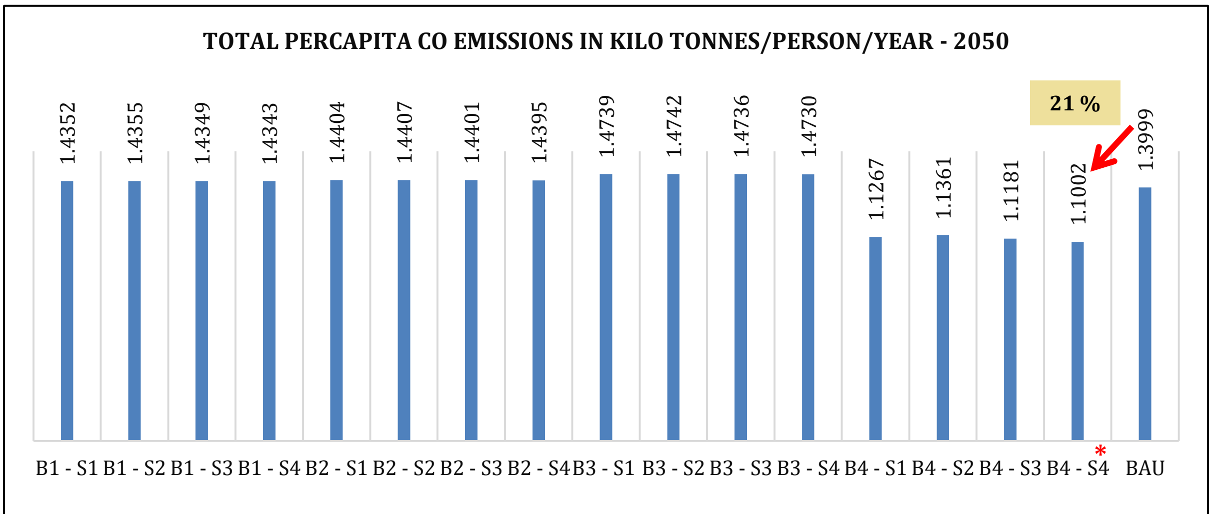


Figure 98: Metro - Percapita CO Emissions in kilo tonnes/person/Year for 2050



*21% reduction in total percapita CO emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, **22%** reduction in total percapita CO emissions can be achieved with respect to BAU scenario

Figure 99: Total Percapita CO Emissions in kilo tonnes/person/Year for 2050

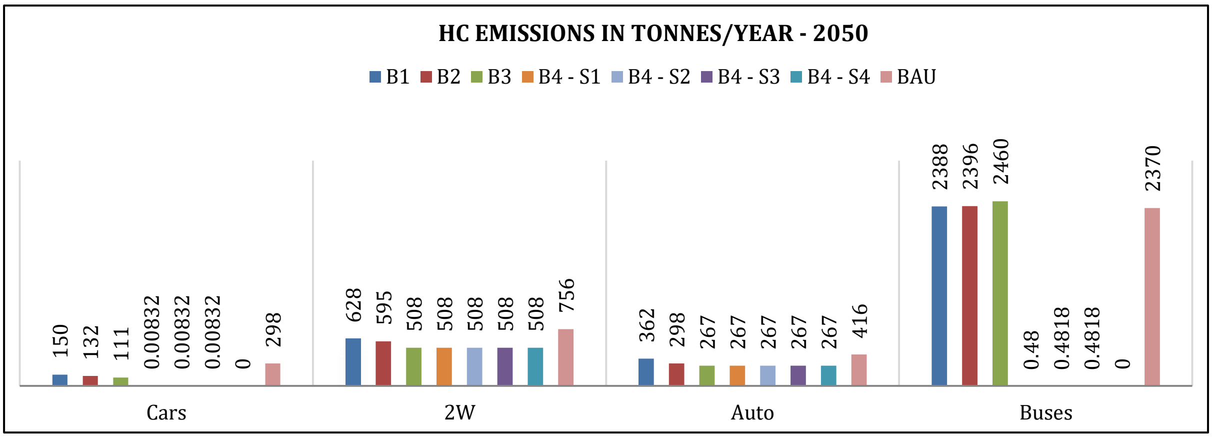


Figure 100: Mode wise HC Emissions in tonnes/year for 2050

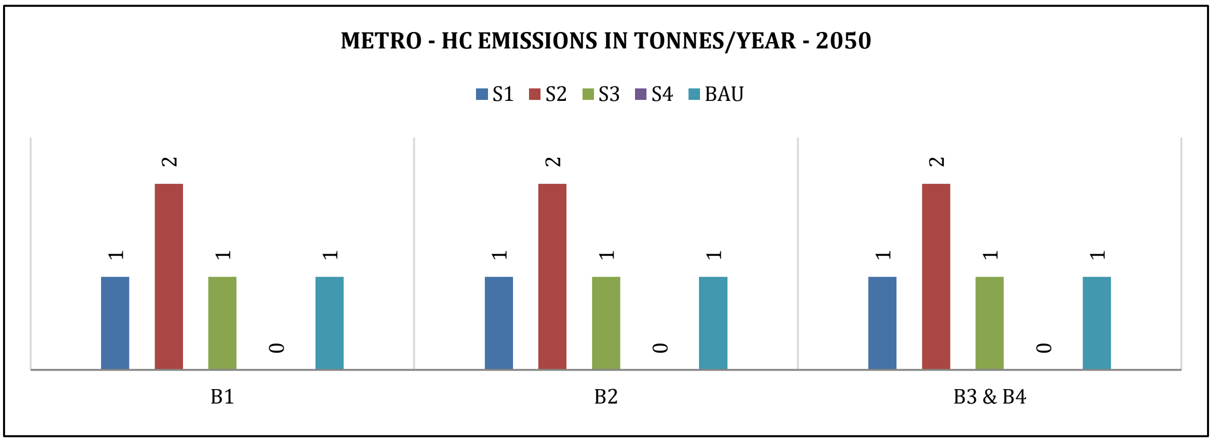
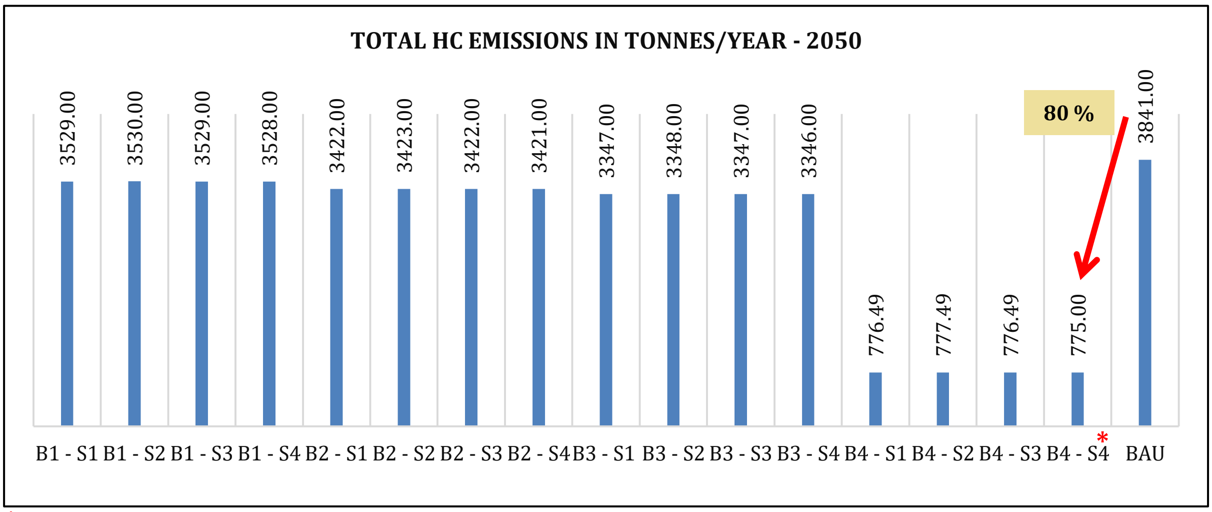


Figure 101: Metro - HC Emissions in tonnes/year for 2050



*80% reduction in total HC emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, **80%** reduction in total HC emissions can be achieved with respect to BAU scenario

Figure 102: Total HC Emissions in tonnes/year for 2050

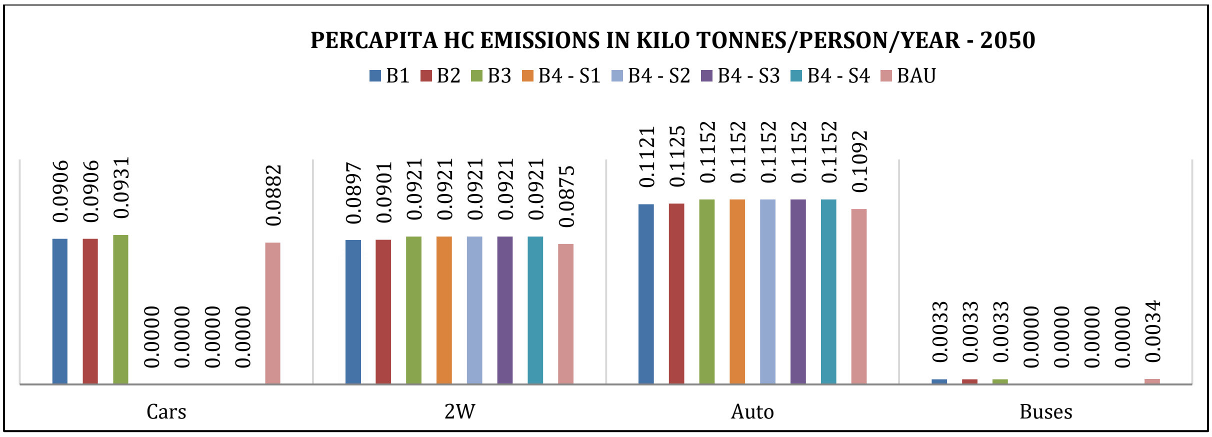


Figure 103: Mode wise Percapita HC Emissions in kilo tonnes/person/Year for 2050

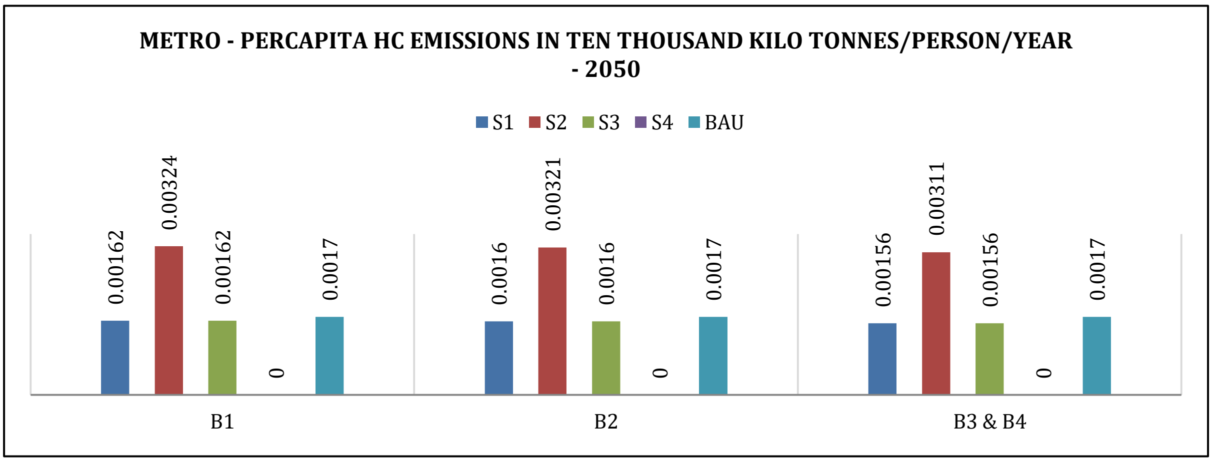
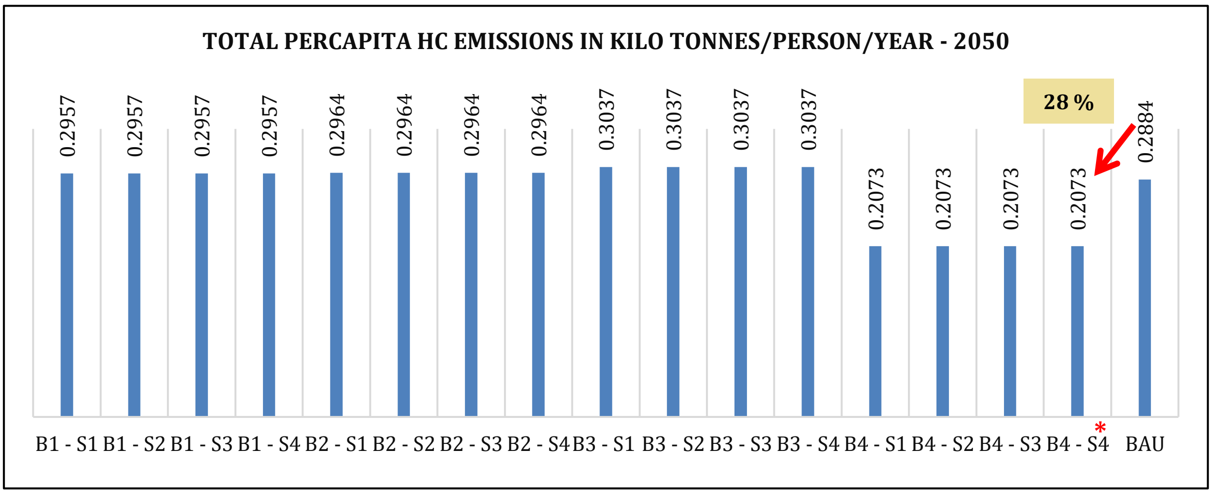


Figure 104: Metro - Percapita HC Emissions in ten thousand kilo tonnes/person/Year for 2050



*28% reduction in total percapita HC emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, the same percentage reduction as in scenario case is observed with respect to BAU scenario

Figure 105: Total HC Percapita emissions in kilo tonnes/person/Year for 2050

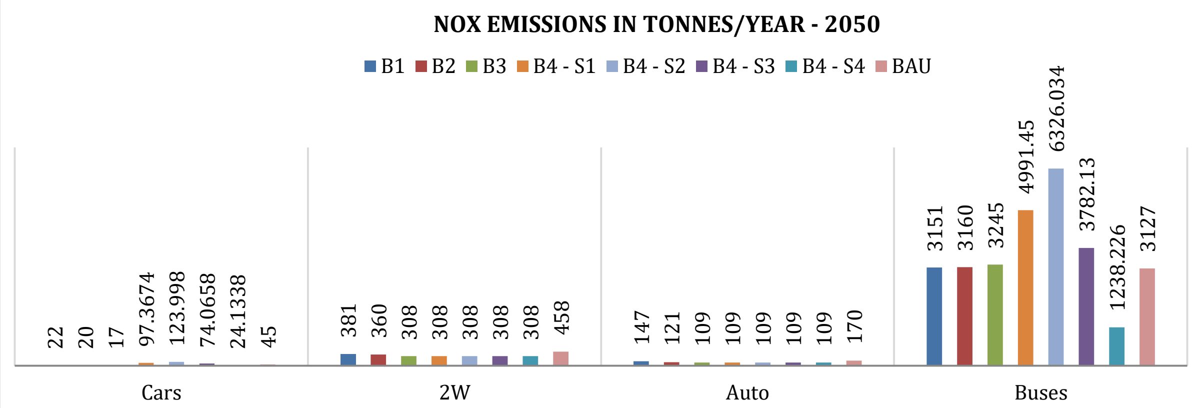


Figure 106: Mode wise NOx Emissions in tonnes/year2050

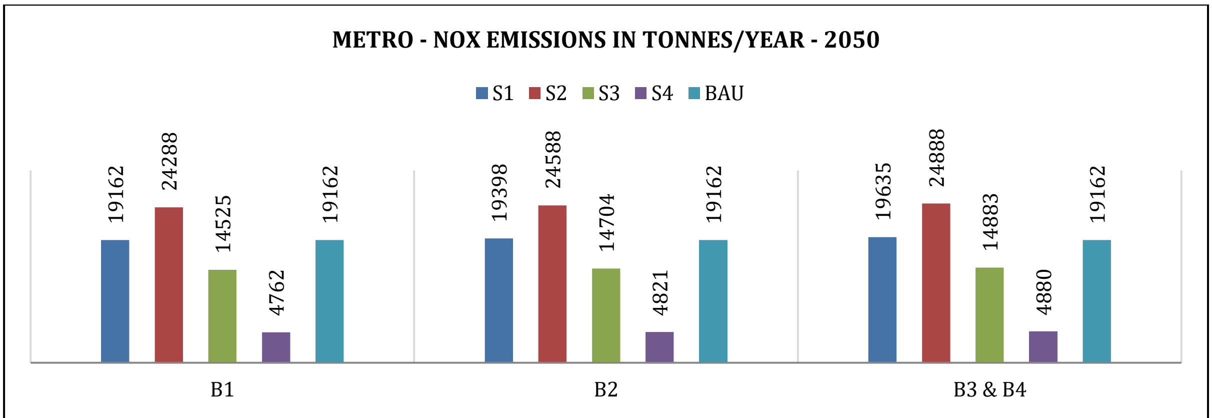
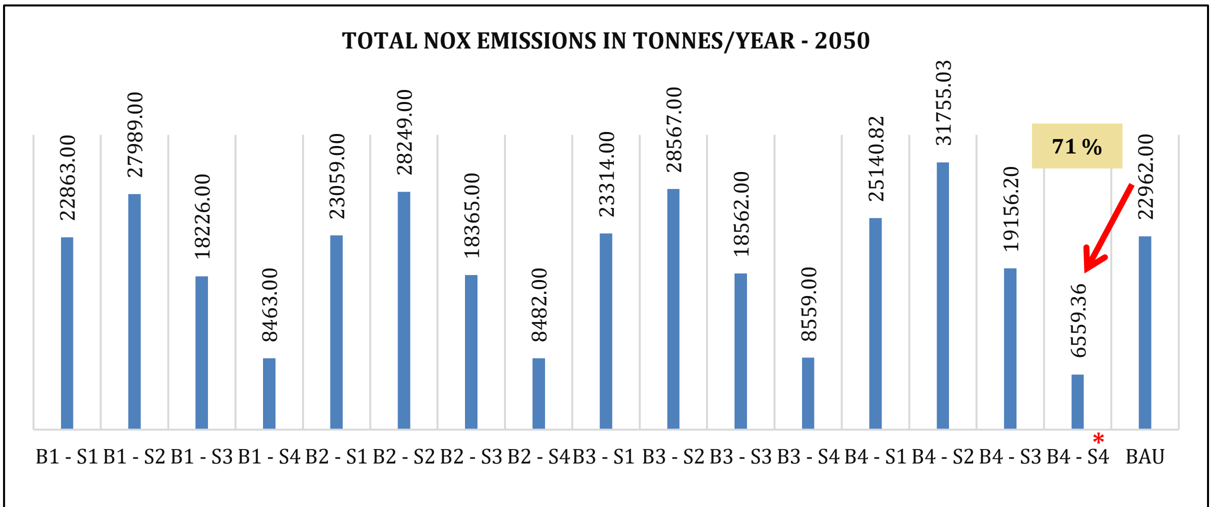


Figure 107: Metro - NOx Emissions in tonnes/year2050



*71% reduction in total NOx emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **83%** reduction in emission is observed even in BAU scenario itself. Further, with the same assumption in B4-S4 scenario, **98%** reduction in total NOx emissions can be achieved with respect to BAU scenario

Figure 108: Total NOx Emissions in tonnes/year for 2050

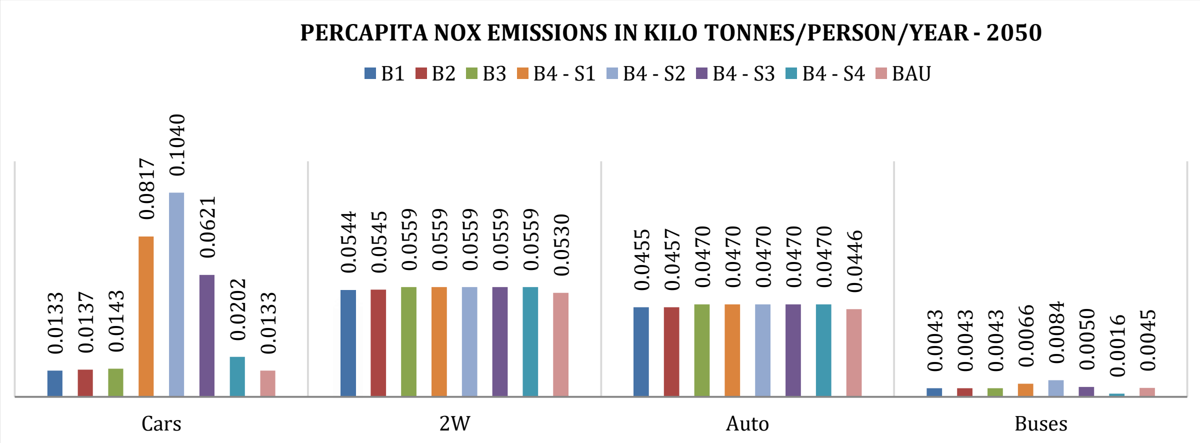


Figure 109: Mode wise Percapita NOx Emissions in kilo tonnes/person/Year for 2050

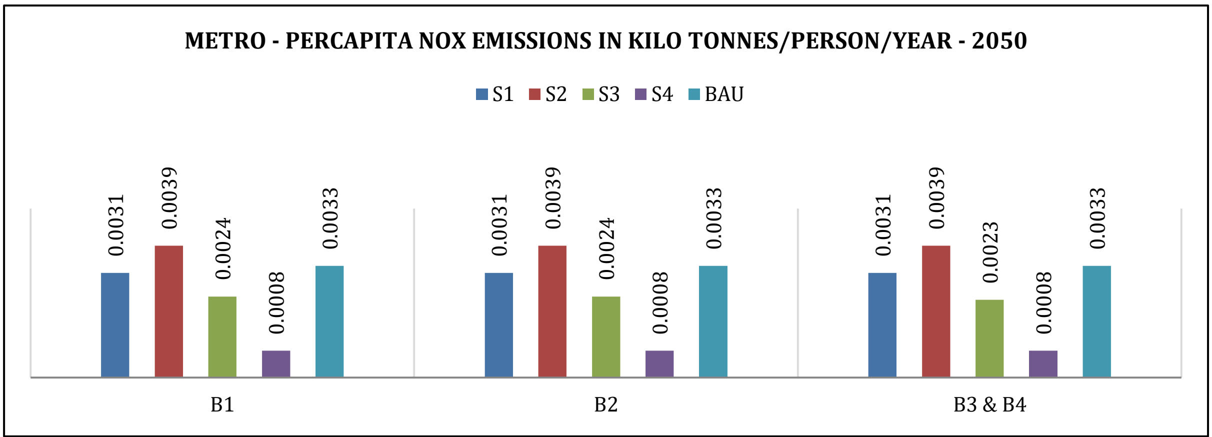
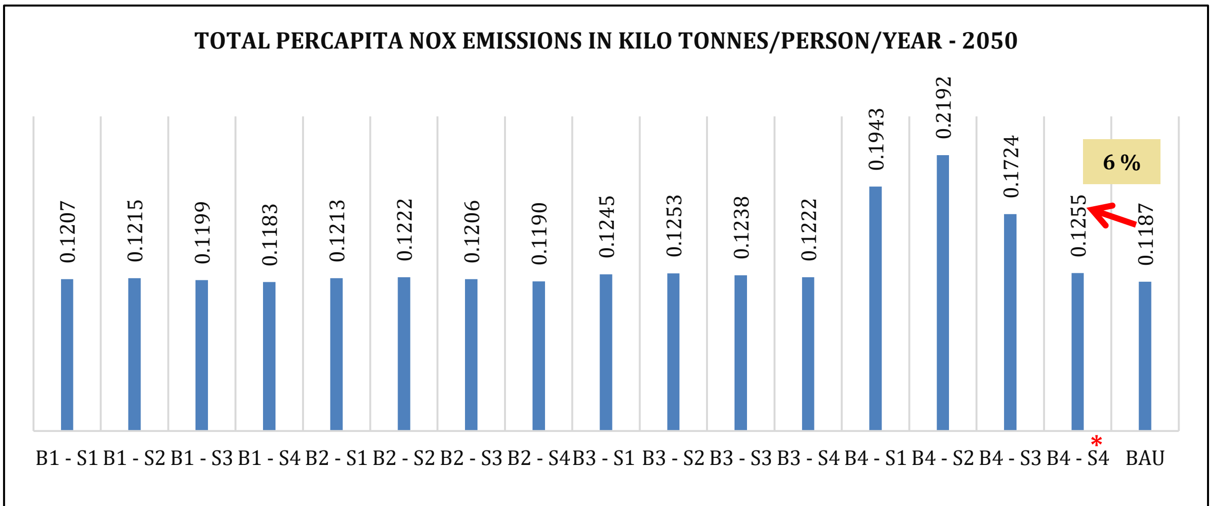


Figure 110: Metro - Percapita NOx Emissions in kilo tonnes/person/Year for 2050



*6% reduction in total percapita NOx emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **3%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario,**13%** reduction in total percapita NOx emissions can be achieved with respect to BAU scenario

Figure 111: Total NOx Percapita Emissions in kilo tonnes/person/Year for 2050

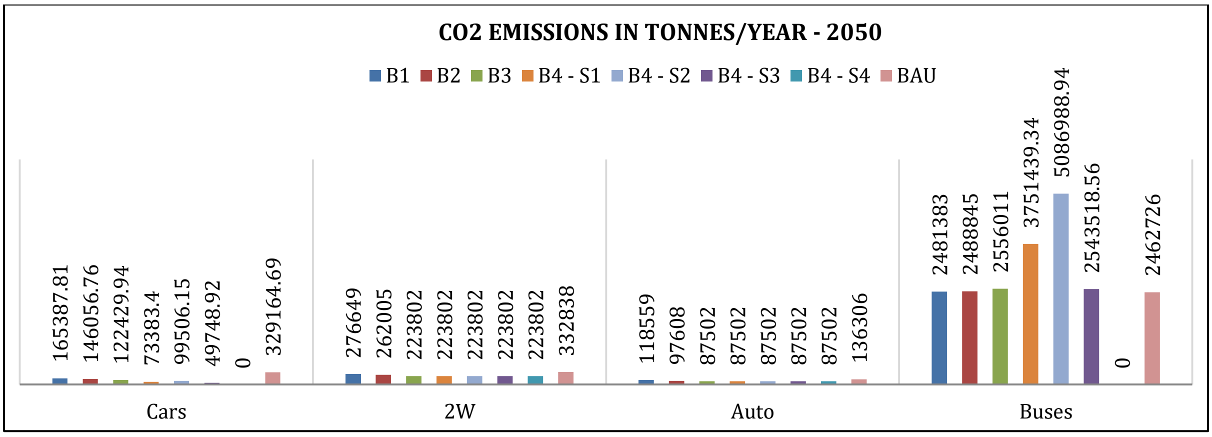


Figure 112: Mode wise CO_2 emissions in tonnes/year for 2050

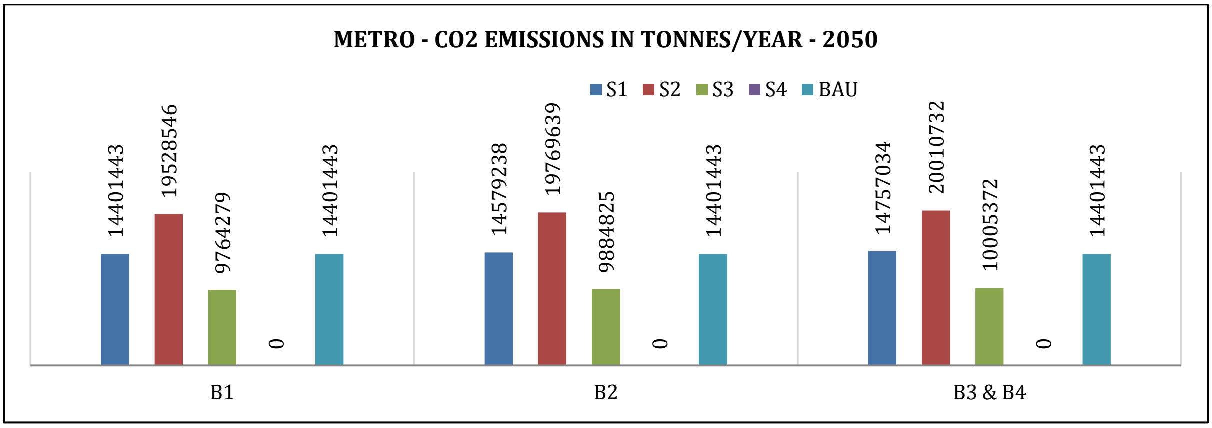
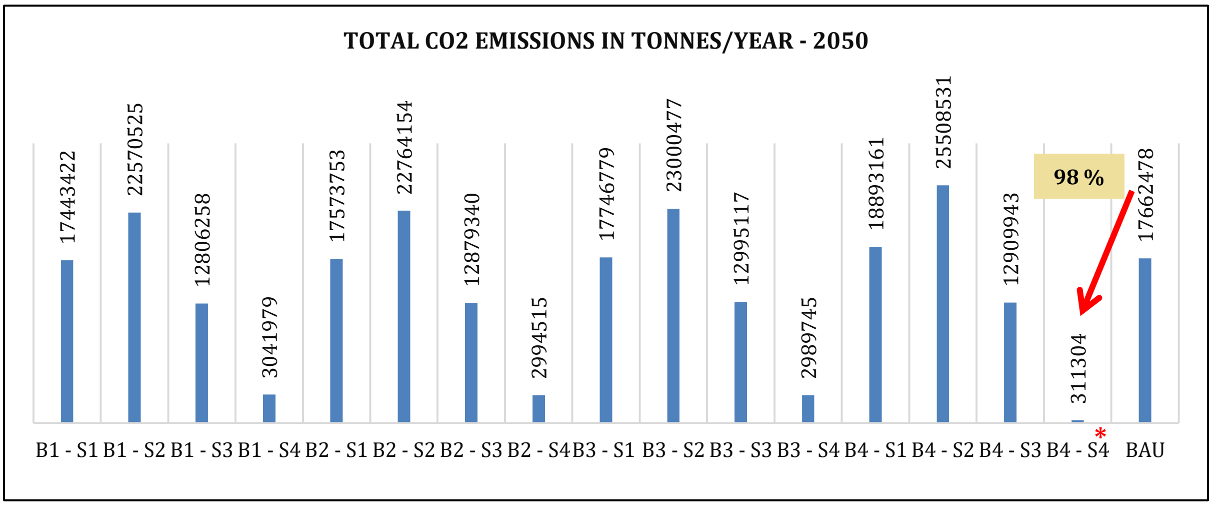


Figure 113: Metro CO_2 emissions in tonnes/year for 2050



*98% reduction in total CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **82%**reduction in emission is observed even in BAU scenario itself. Further, with the same assumption in B4-S4 scenario, the same percentage reduction as in scenario condition is observed with respect to BAU scenario.

Figure 114: Total CO_2 emissions in tonnes/year for 2050

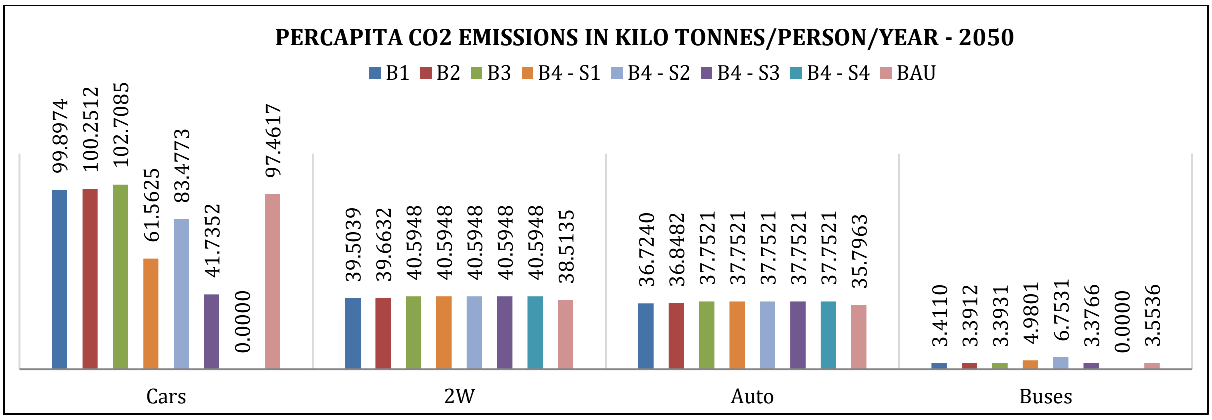


Figure 115: Mode wise PercapitaCO_2 Emissions in kilo tonnes/year for 2050

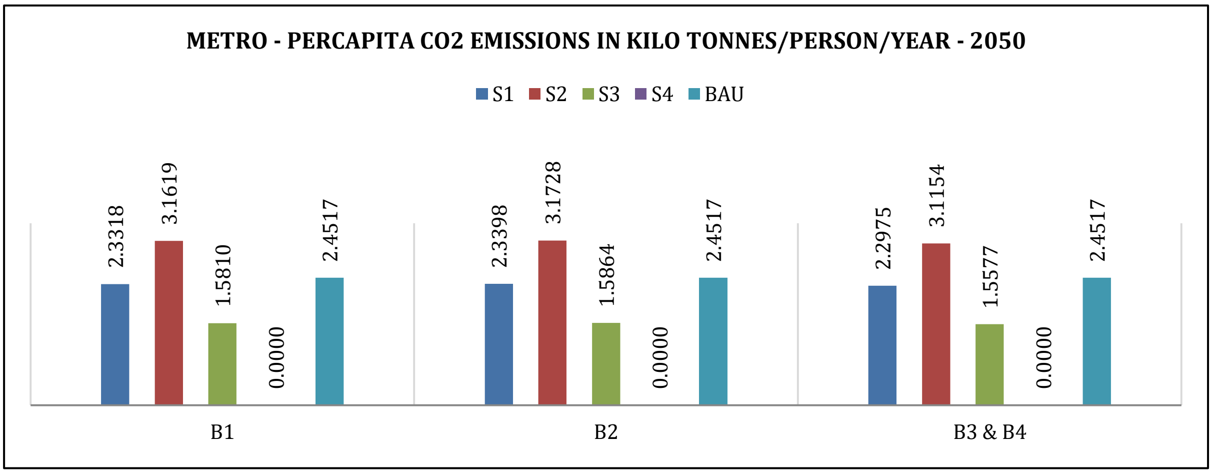
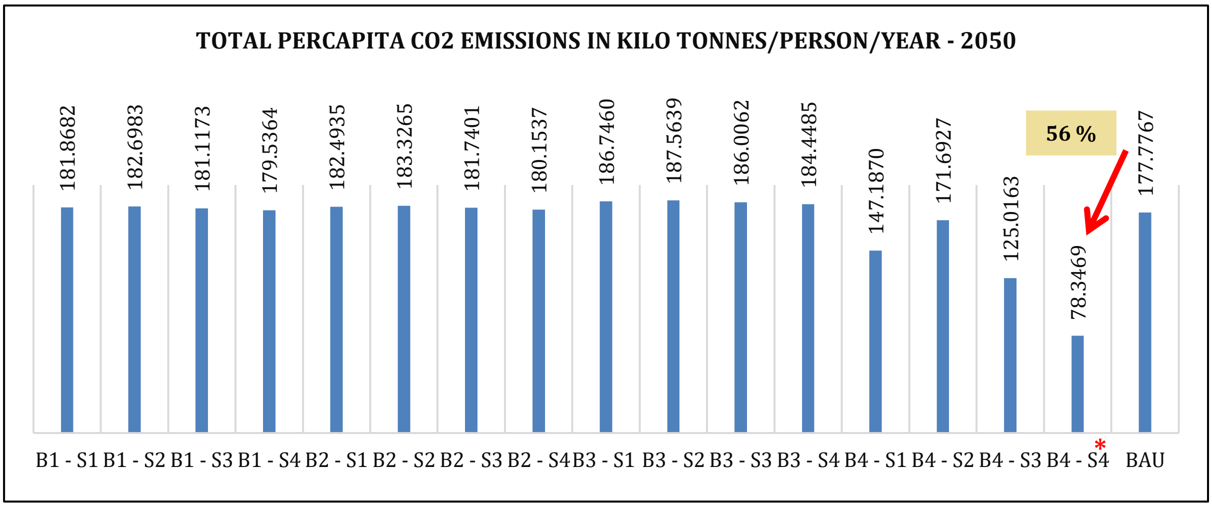


Figure 116: Metro - PercapitaCO_2 Emissions in kilo tonnes/year for 2050



*56% reduction in total percapita CO_2 emissions is observed in B4-S4 w.r.t. BAU. Further, with the same assumption in B4-S4 scenario, the same percentage reduction as in scenario condition is observed with respect to BAU scenario.

Figure 117: Total PercapitaCO_2 Emissions in kilo tonnes/year for 2050

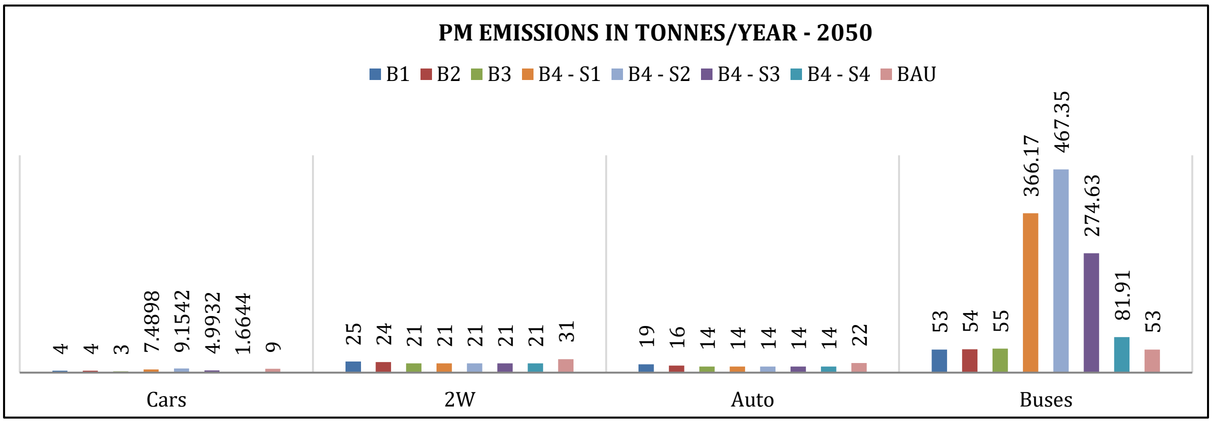


Figure 118: Mode wise PM Emissions in tonnes/Year for 2050

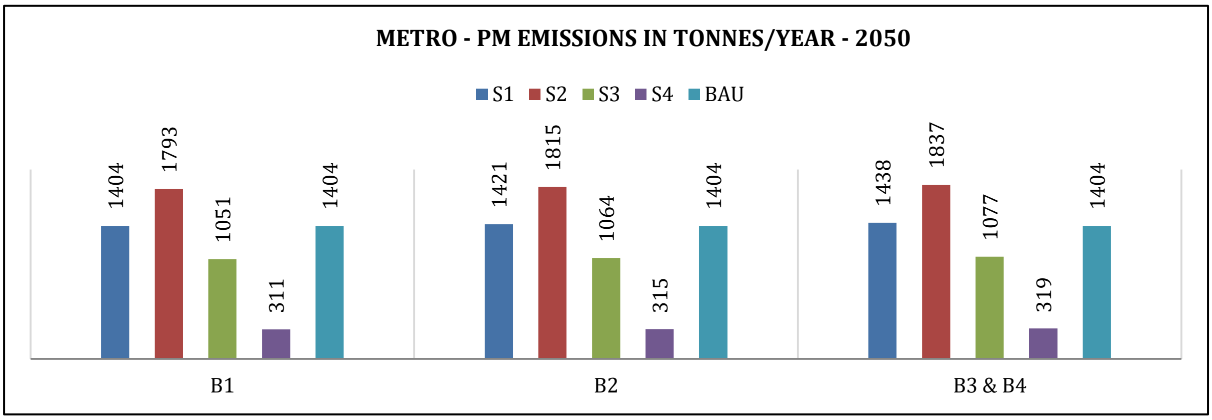
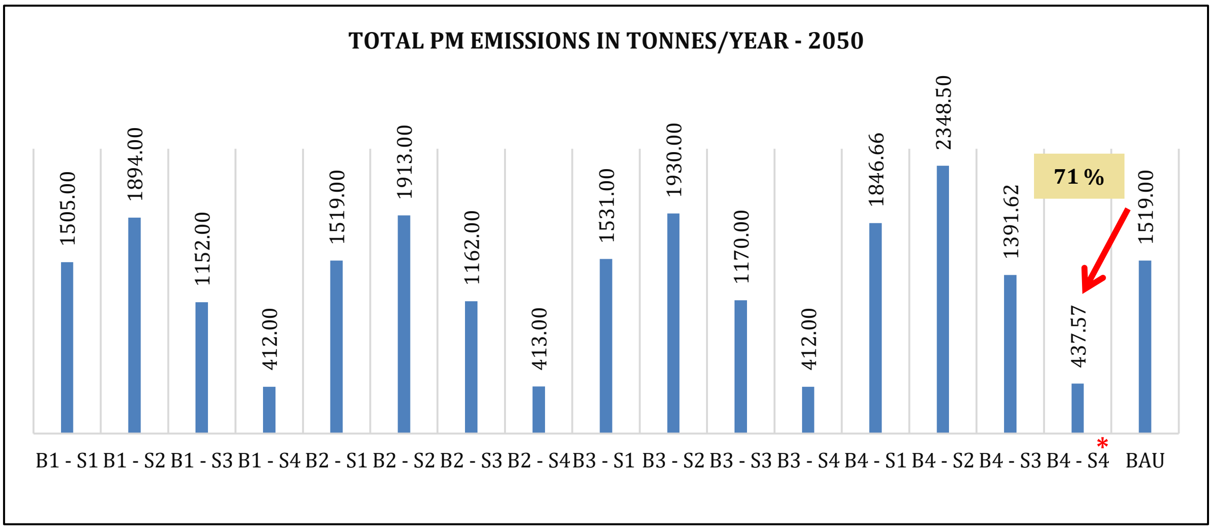


Figure 119: Metro - PM Emissions in tonnes/Year for 2050



*71% reduction in total PM emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy, **92%** reduction in emission is observed even in BAU scenario itself. Additionally, with the same assumption in B4-S4 scenario, **98%** reduction in total PM emissions can be achieved with respect to BAU scenario

Figure 120: Total PM Emissions in tonnes/Year for 2050

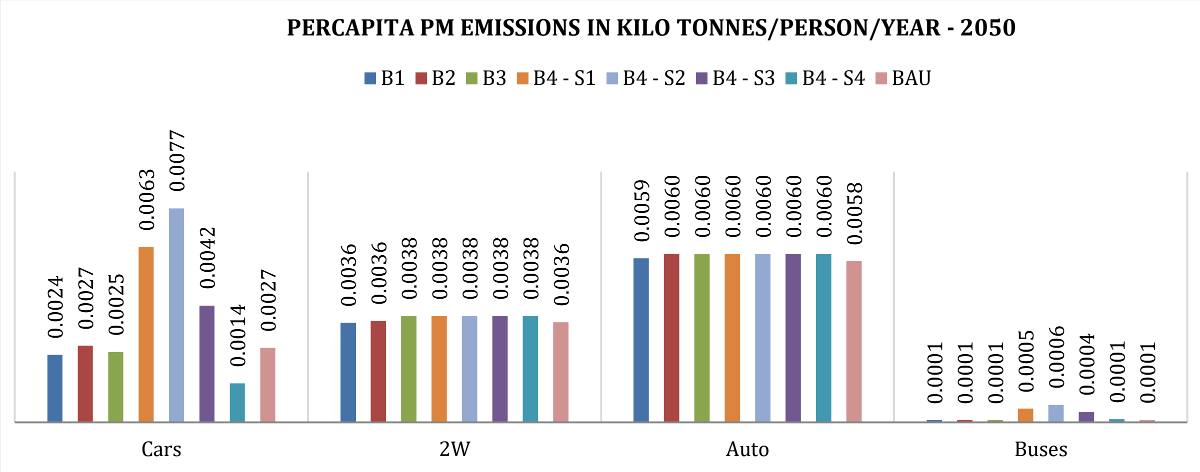


Figure 121: Mode wise Percapita PM Emissions in kilo tonnes/person/year for 2050

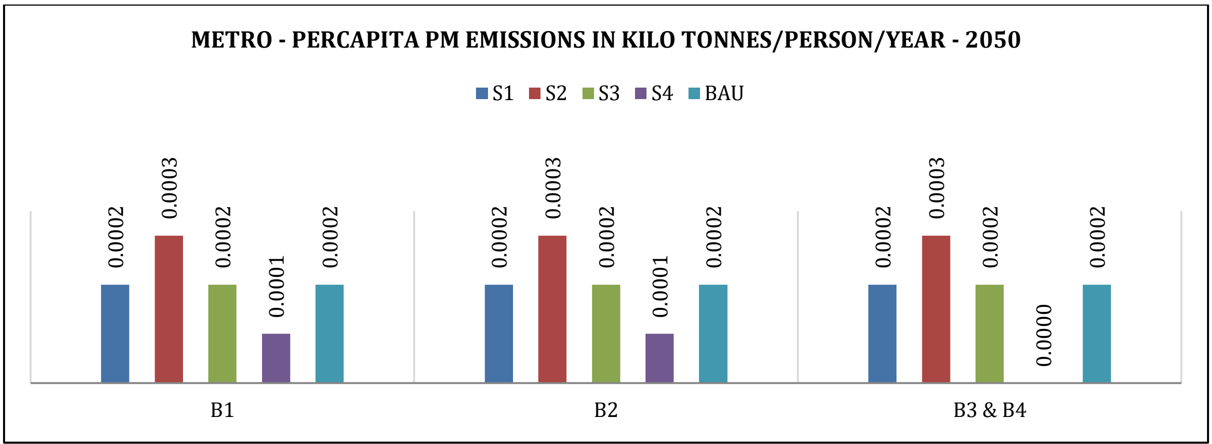
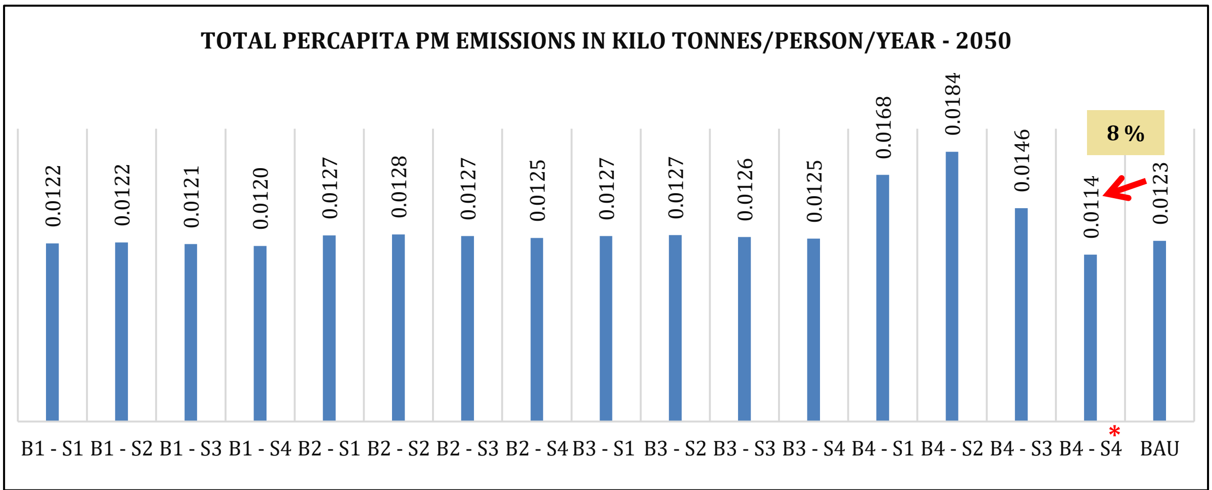


Figure 122: Metro - Percapita PM Emissions in kilo tonnes/person/year for 2050



*8% reduction in total percapita PM emissions is observed in B4-S4 w.r.t. BAU. Further considering extreme scenario where electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario, **20%** reduction in total percapita PM emissions can be achieved with respect to BAU scenario

Figure 123: Total Percapita PM Emissions in kilo tonnes/person/year for 2050

From the above figures it is clearly observed that Bundle 4 with scenario 4 is giving best emission reduction because of 100% electrification from renewable sources of energy. The total emissions values of Mass transportation systems like metro and bus may seem higher but when the emissions are converted to percapita emissions, their share is quite low due to high occupancy. Also, if the electricity generated from renewable sources is coming exclusively from wind, hydel and solar and **'NO BIO WASTE'** included then the emissions reduces by a great amount.

5.11 RESULTS AND DISCUSSIONS

- Bundle 3 (bundle 4) which is a Combination of **Planning, Regulatory & Economic Instruments** showed the maximum reduction in VKT in comparison to BAU for 2030 & 2050.
- Adding technological policy instruments further reduced emissions by a great level as seen in Bundle 4.
- Total CO_2 emissions in Bundle 3 are higher than B1 & B2 due to large mode shift towards Public Transport while the Percapita emissions seems to be reducing due to the same mode shift.
- For the horizon year 2030 and 2050 Bundle 4 - Scenario 4 showed the maximum reduction of total emissions for all the pollutants CO, HC, NOx, CO_2 and PM respectively
- The total emissions of CO, HC, NO_x and PM are showing almost 70% reduction in emission with the implementation of B4-S4 scenario whereas 98% reduction can be achieved in CO_2 emissions.
- Total percapita NOx values in 2050 are higher in Bundle 4 for scenario 4 because of the higher NOx values from electric cars compared to conventional cars. Since, there is a shift towards public transportation the percapita emissions from cars seems to be higher.
- Electrification of vehicles does more **BAD** than **GOOD** if electricity is generated from non-renewable power sources. Nonrenewable power sources involve in high PM, NOx and CO values which leads to higher emissions.
- If electricity is assumed to be purely generated from hydropower, solar and wind without using bio energy in B4-S4 scenario,
    - **73%** reduction in total CO emissions and **26%** reduction in percapita CO emissions can be achieved with respect to BAU 2030 where, 77% reduction in total CO emissions and 22% reduction in percapita CO emissions can be achieved with respect to BAU 2050
    - **99%** reduction in total NOx emissions and **44%** reduction in percapita NOx emissions can be achieved with respect to BAU 2030 where, **98%**

reduction in total NOx emissions and **13%** reduction in percapita NOx emissions can be achieved with respect to BAU 2050

- **97% & 98%** reduction in total PM emissions and **15% & 20%** reduction in percapita PM emissions can be achieved with respect to BAU scenario.

6 CARBON EMISSION INTENSITY ESTIMATION FOR TRANSPORT SECTOR MITIGATION POLICY BUNDLES

6.1 INTRODUCTION

In the international negotiations summit held at Paris in 2015 under the UNFCCC to tackle the global issue of climate change, India declared a voluntary goal as a part of its Intended Nationally Determined Contributions to reduce the emissions intensity of its GDP by 33 - 35% by 2030 from 2005 level. However, the INDC did not state the percentage share of emission intensity reduction from transport sector, hence the same intended emission intensity reduction percentage is assumed for transport sector. Emissions intensity is the level of GHG emissions per unit of economic activity. It is generally calculated by calculating the volume of emissions per unit of GDP.

In this report, we have forecasted the economic growth of Bangalore Metropolitan Region (BMR). We have also estimated the reduction in emission intensity for the horizon years from the base year due to the reduction in emissions resulting from the mitigation policy scenarios in transport sector for BMR.

6.2 PAST TREND OF GDP IN INDIA

India is one of the fast growing economies of the world. India has highly conducive environment because of the demographic advantage and increasing incomes to continue on the path of a faster economic growth (Economic Survey of India 2016-17). The following figure 124 shows the trend of Gross Domestic Product for all India at 2004-05 constant prices.

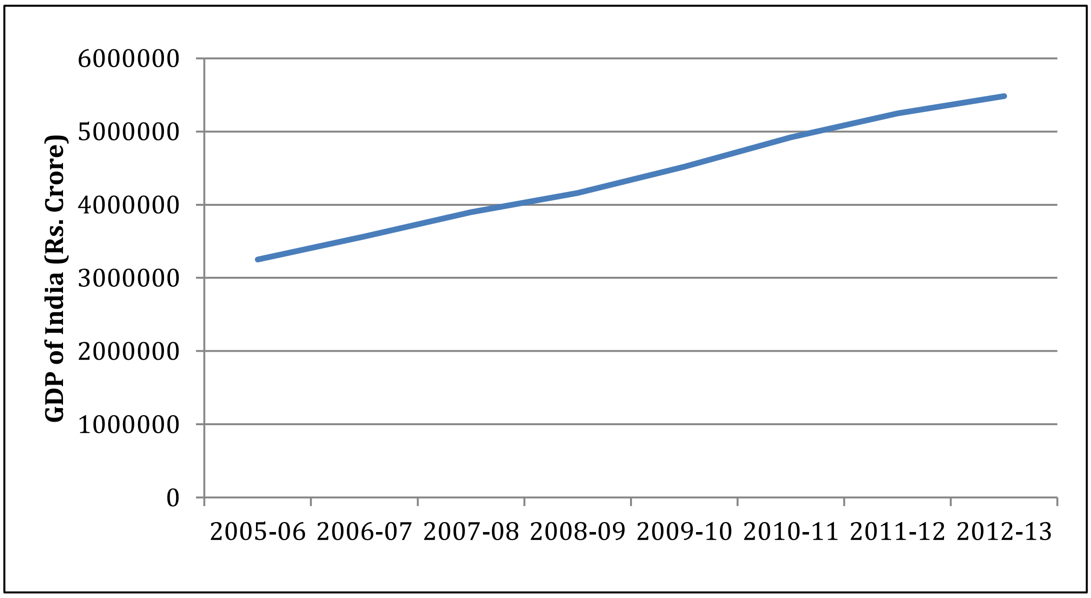


Figure 124: Past trend of GDP of India (in Rs. Crore at 2004-05 constant prices)

Table 34: GDP and Growth Rate of India

Year	GDP (Rs. Crore) All-India At Constant Prices	India Growth Rate
2005-06	3253073	
2006-07	3564364	9.57%
2007-08	3896636	9.32%
2008-09	4158676	6.72%
2009-10	4516071	8.59%
2010-11	4918533	8.91%
2011-12	5247530	6.69%
2012-13	5482111	4.47%
GR (2005-13)		7.75%
CAGR (2005-13)		**7.74%**

6.3 PAST TREND OF GDDP FOR BENGALURU METROPOLITAN REGION

According to the report State and District Domestic Product of Karnataka by Directorate of Economics and Statistics, Bengaluru the annual average growth rate of GDDP and percapita GDDP for Bengaluru Urban, Bengaluru Rural and Ramanagaram were used and the compound annual growth rate of GDDP and percapita GDDP for the period 2005-06 to 2012-13 at 2004-05 constant prices is estimated to be 9.25 % and 12.7% respectively. The distribution of GDDP and percapita GDDP is given in the table 35 and table 36.

Table 35: CAGR of GDDP within BMR

Year	GDDP (Rs. Crore) BMR At Constant Prices	BMR Growth Rate (%)
2005-06	60561.00	
2006-07	68939.45	13.83
2007-08	84325.97	22.32
2008-09	93390.43	10.75
2009-10	94705.27	1.41
2010-11	98907.90	4.44
2011-12	108459.81	9.66
2012-13	112522.24	3.75
GR (2005-13)		9.45
CAGR (2005-13)		**9.25**

Table 36: CAGR of Percapita GDDP within BMR

Year	Percapita GDDP (Rs. Crore) BMR At Constant Prices	BMR Growth Rate (%)
2005-06	1118.76	
2006-07	1260.4	12.66
2007-08	1911.45	51.65
2008-09	2095.59	9.63
2009-10	2196.44	4.81
2010-11	2356.74	7.30
2011-12	2472.57	4.91
2012-13	2586.15	4.59
GR (2005-13)		13.65
CAGR (2005-13)		**12.72**

6.4 COMPARISON OF GDP OF INDIA AND GDDP OF BMR

The relation between the annual average growth rate of the GDP of India and the annual average growth rate GDDP and percapita GDDP of BMR for the years 2005-13 at 2004-05 constant prices is established in the following table 37. The ratio factor of 1.20 between the growth of BMR and the growth of India for years 2005-13 is observed.

Table 37: Relation Between the Growth of BMR and the Growth of India

Region	India GDP	BMR GDDP	BMR GR: India GR (GDP)	Percapita BMR GDDP	BMR GR: India GR (percapita GDP)
CAGR (2005-13)	7.74	9.25	1.20	12.7	1.64

6.5 FORECAST OF GDP OF INDIA AND GDDP OF BMR

Various international organizations like OECD, PwC, World Bank and ADB have tried to estimate the economic growth of India in future considering numerous national and international factors. However only 2 organizations OECD and PwC have tried to forecast India's growth till 2050. For this study we will use the estimates as per the PwC forecast which predicts the annual average growth rate of India for future time periods as mentioned in the table 38. We have already calculated the ratio of growth rate of India to the growth rate of BMR in the table 37. We use the same ratio for estimating the average annual growth of GDDP of BMR for future time periods.

Table 38: Estimation of GDDP and Percapita GDDP Growth Rate for BMR

Year	Future Growth projections for India by PwC	Ratio of Growth India Vs. BMR (2005-13)	Estimated GDDP Growth rate for BMR	Ratio of percapita Growth India Vs. BMR (2005-13)	Estimated percapita GDDP Growth rate for BMR
2016 - 2020	7.80%	1.2	9.36%	1.64	12.79%
2021 - 2030	5.00%	1.2	6.00%	1.64	8.20%
2031 - 2040	4.40%	1.2	5.28%	1.64	7.22%
2041 - 2050	3.90%	1.2	4.68%	1.64	6.40%

Using the estimated GDDP growth rate for BMR for different decades till 2050, table 38 shows the estimated GDDP of BMR till horizon year 2050 in Rs. Crores at 2004-05 constant prices.

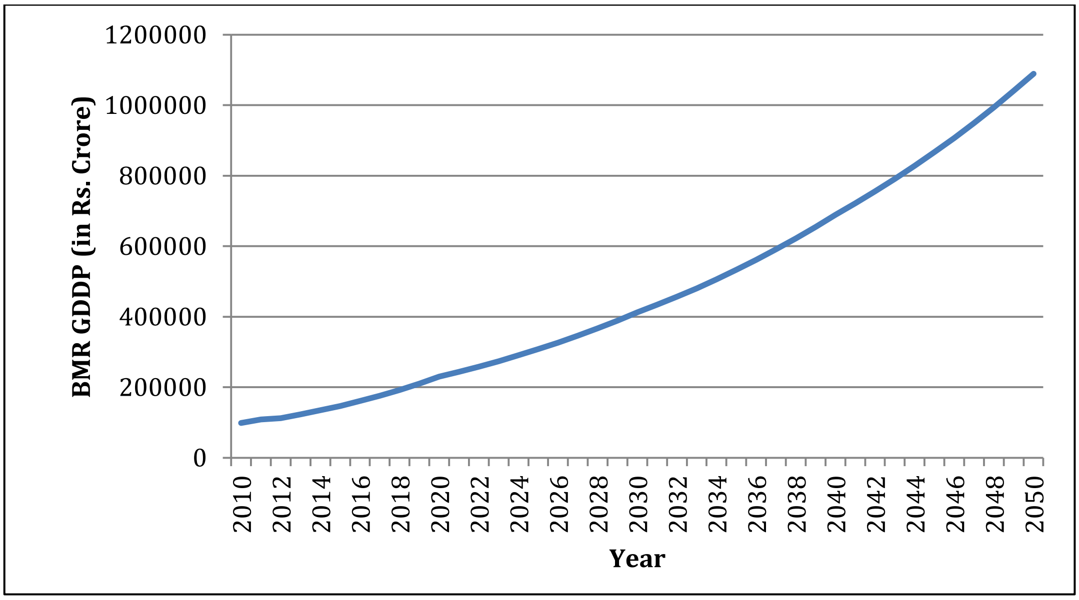


Figure 125: GDDP of BMR till 2050 (in Rs. Crore at 2004-05 constant prices)

Table 39: GDDP of BMR for horizon years

Year	GDDP of BMR in Rs. Cr (at 2004-05 constant prices)
Base Year	93390
2030	412254
2050	1089585

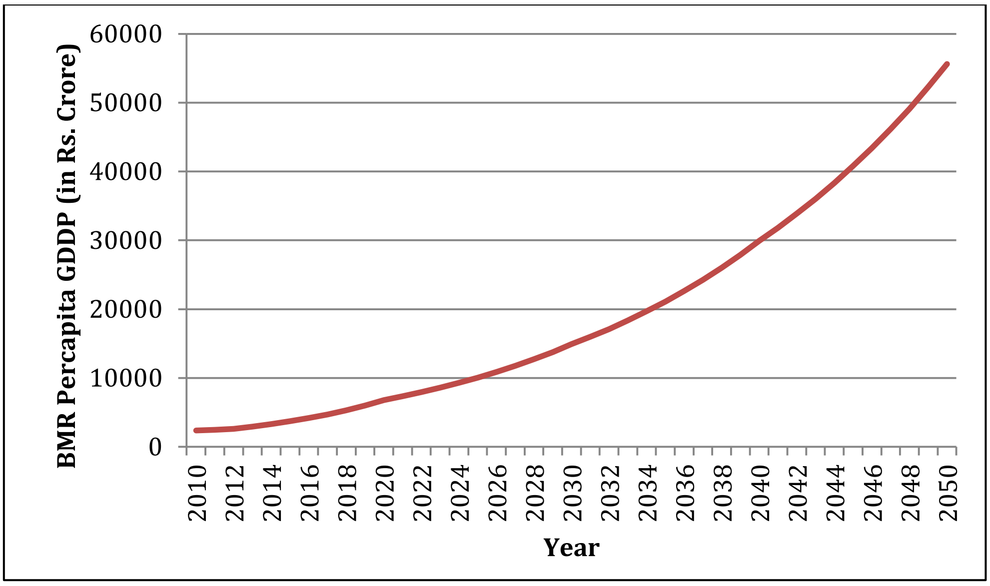


Figure 126: GDDP of BMR till 2050 (in Rs. Crore at 2004-05 constant prices)

Table 40: Percapita GDDP of BMR for horizon years

Year	Percapita GDDP of BMR in Rs. Cr (at 2004-05 constant prices)
Base Year	2096
2030	14897
2050	55624

6.6 EMISSION INTENSITY FROM TRANSPORT SECTOR

In earlier work packages, we have modelled the emissions from the transport sector in the Business as Usual (BAU) scenario for base year and horizon years 2030 and 2050 for Bangalore Metropolitan Region (BMR) along with the alternate sustainable transport policy scenarios. The base year total CO_2 has been estimated as 695617 tonnes/year. The emission levels of CO_2 and other local pollutants due to transportation sector have also been estimated in this study. The estimated CO_2 emissions are used to calculate the emission intensity of transportation sector of BMR.

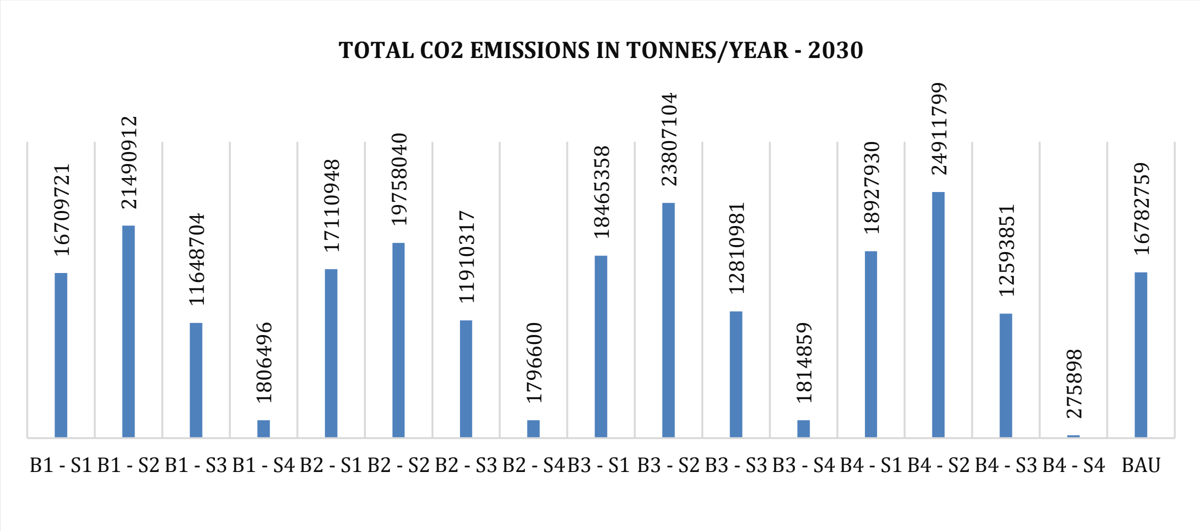


Figure 127: Total CO2 emissions under BAU and policy scenarios for 2030

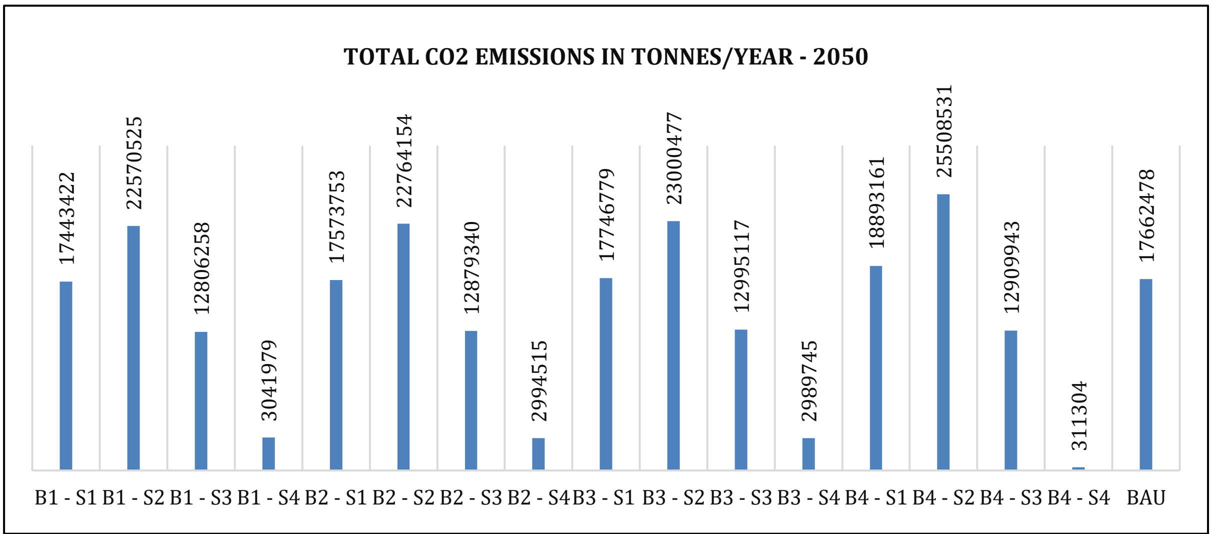


Figure 128: Total CO2 emissions under BAU and policy scenarios for 2050

$$\text{GHG Emission Intensity} = \frac{CO2\ Emissions}{GDP}$$

Figures 127 and 128 shows GHG emission for the horizon year. Figures 129 and 131 displays the GHG emission intensity calculated under various mitigation policy scenarios for the horizon years 2030 and 2050.

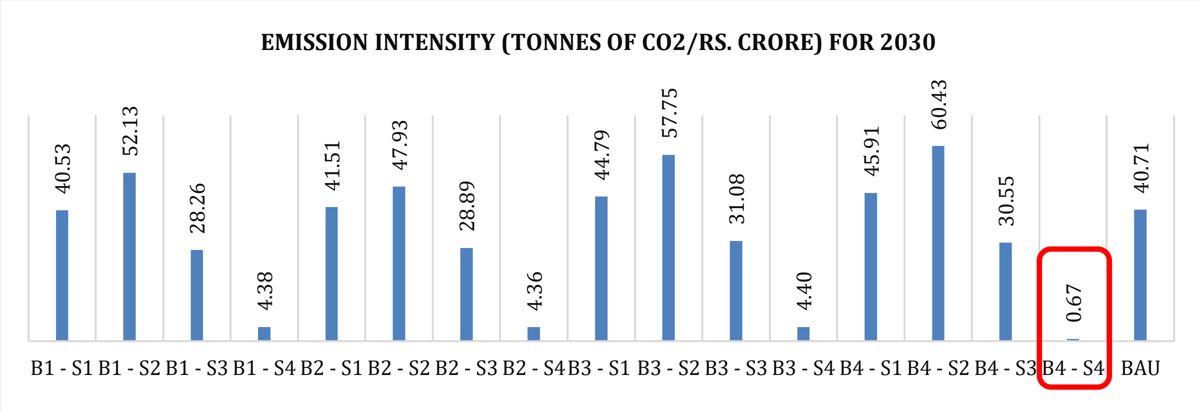
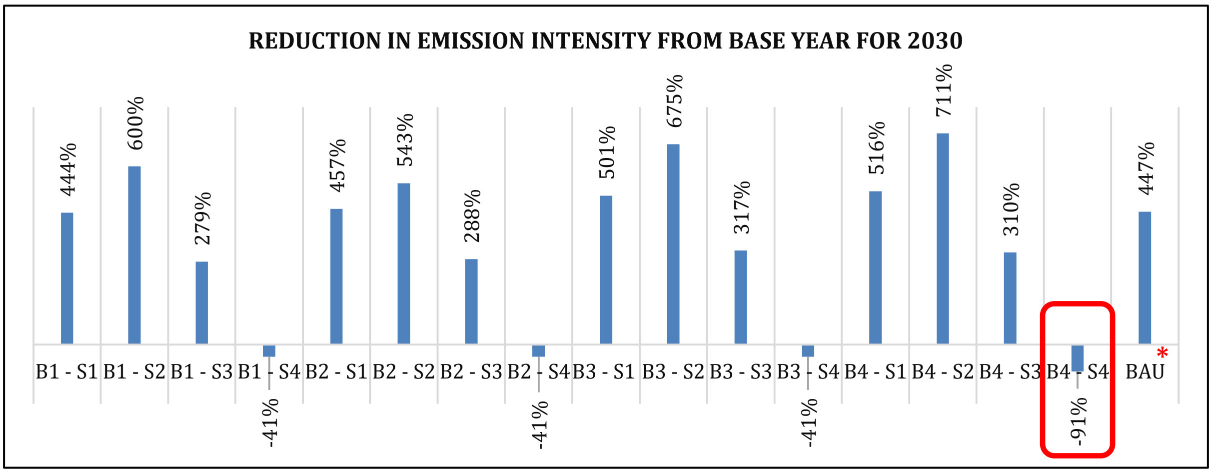


Figure 129: GHG Emission intensity under BAU and alternate policy scenarios for 2030



*The carbon emissions intensity is increasing at the greater rate in BAU 2030 scenario because Metro is not available in Bengaluru during base year and it is the only electricity based transportation with high emission factor values. Further, assuming electricity will be purely generated from hydropower, solar and wind without using bio energy in BAU scenario, **39%** reduction in total CO2 emission intensity can be achieved in BAU 2030 with respect to base year

Figure 130: Reduction in Emission intensity under BAU and alternate policy scenarios for 2030

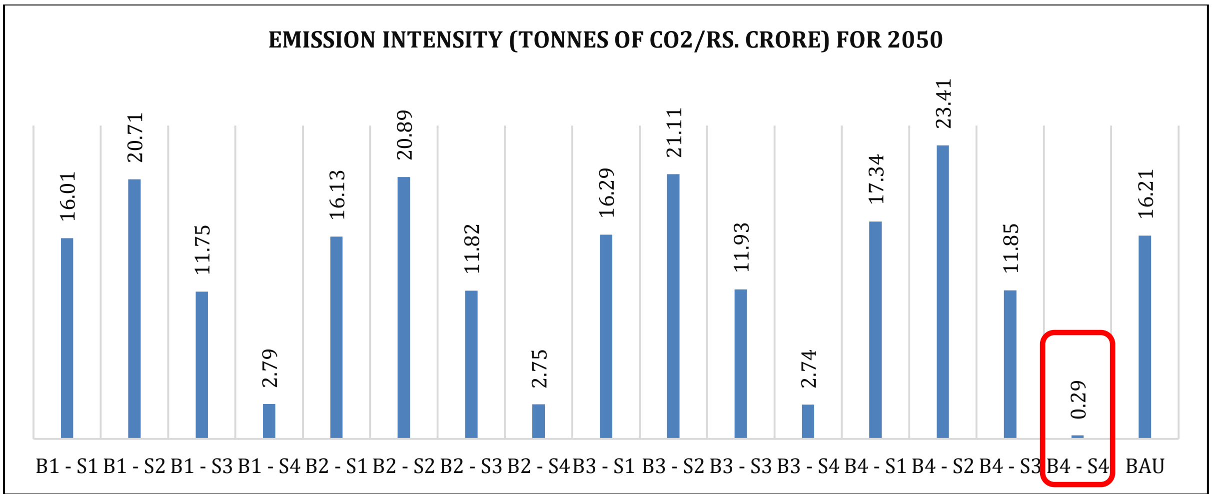
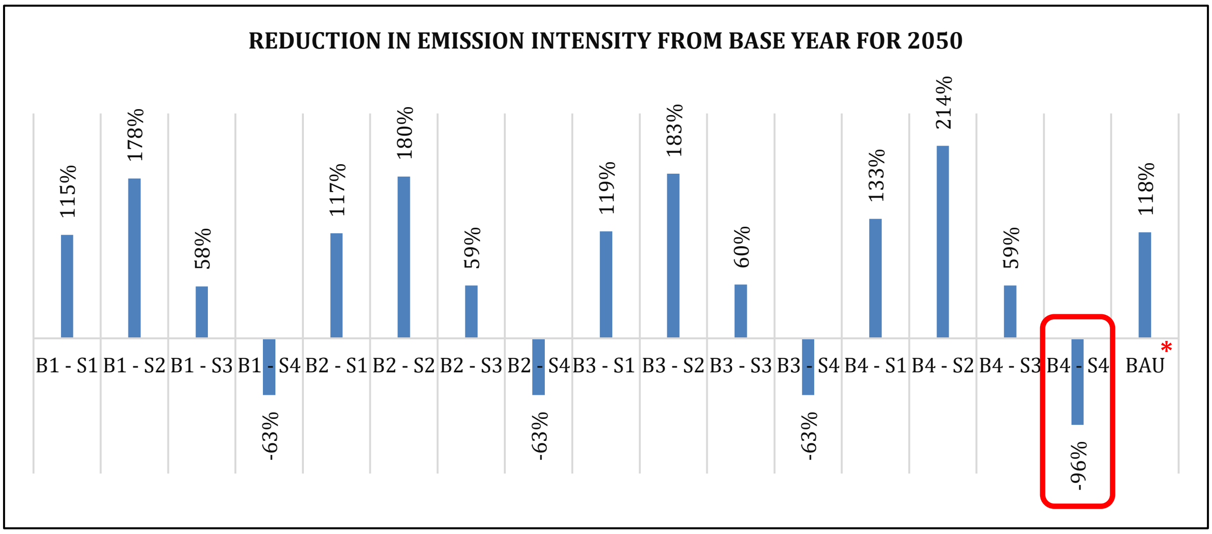


Figure 131: GHG Emission intensity under BAU and alternate policy scenarios for 2050



* The carbon emissions intensity is increasing at the greater rate in BAU 2050 scenario because Metro is not available in Bengaluru during base year and it is the only electricity based transportation with high emission factor values. Further, assuming electricity is purely generated from hydropower, solar and wind without using bio energy in BAU scenario, **60%** reduction in total CO2 emission intensity can be achieved in BAU 2050 with respect to base year.

Figure 132: Reduction in Emission intensity under BAU and alternate policy scenarios for 2050

The percentage reduction in GHG emission intensity of the transport sector of BMR in the horizon years 2030 and 2050 from the base year under BAU and alternate mitigation policy scenarios is demonstrated in the figure 130 and figure 132. The total percapita CO_2 emissions for base year is estimated as 242 kilo tonnes/person/year.

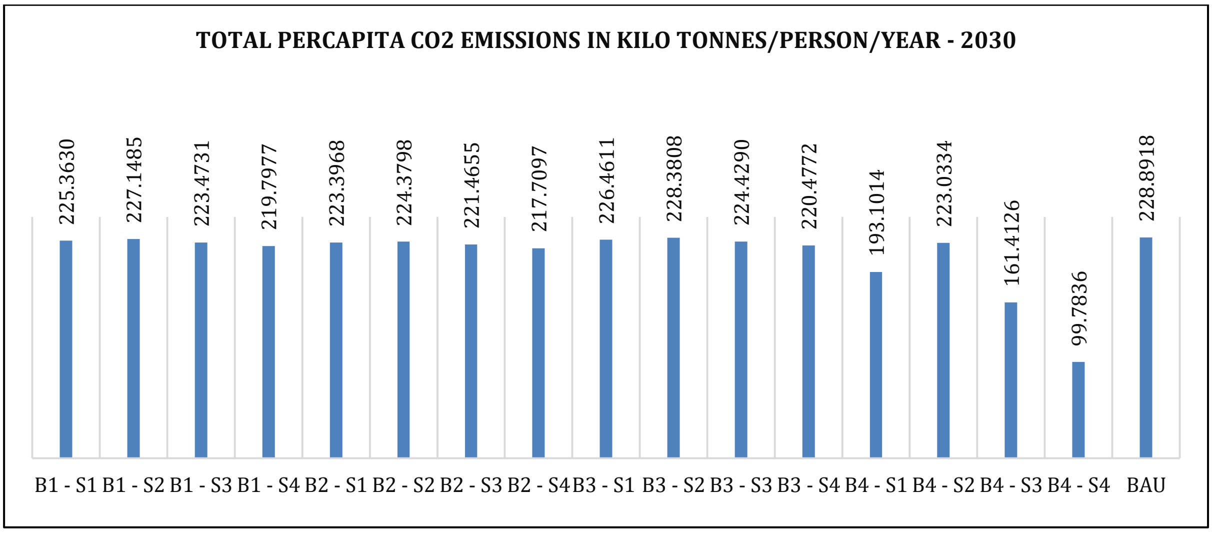


Figure 133: Total Percapita CO2 Emissions under BAU and alternate policy scenarios for 2030

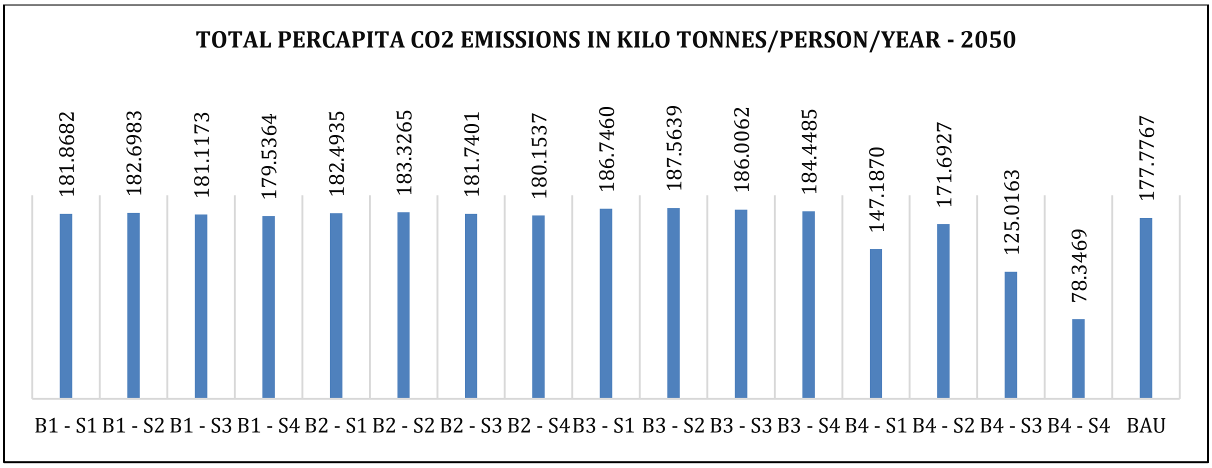


Figure 134: Total Percapita CO2 Emissions under BAU and alternate policy scenarios for 2050

Figure 133 and figure 134 shows the percapita GHG emission intensity calculated under various mitigation policy scenarios for the horizon years 2030 and 2050.

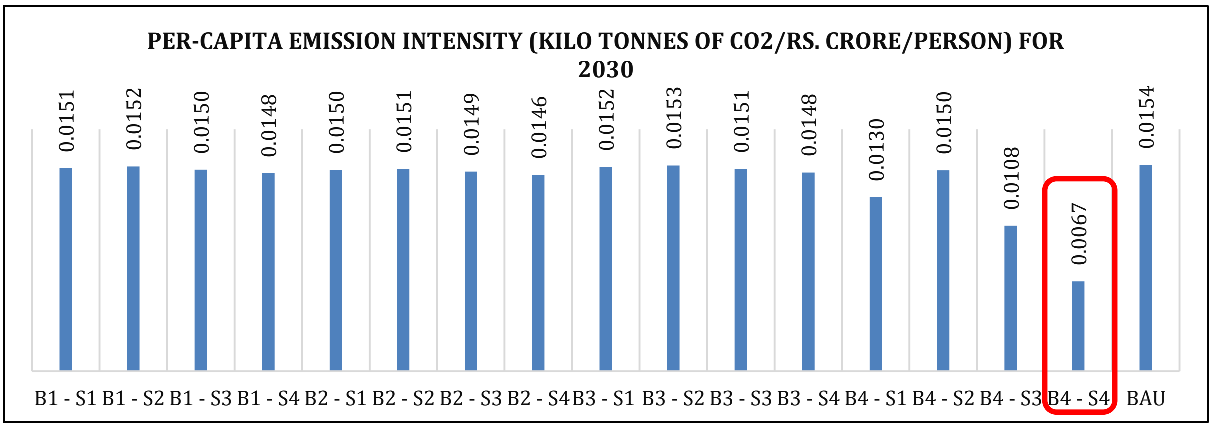
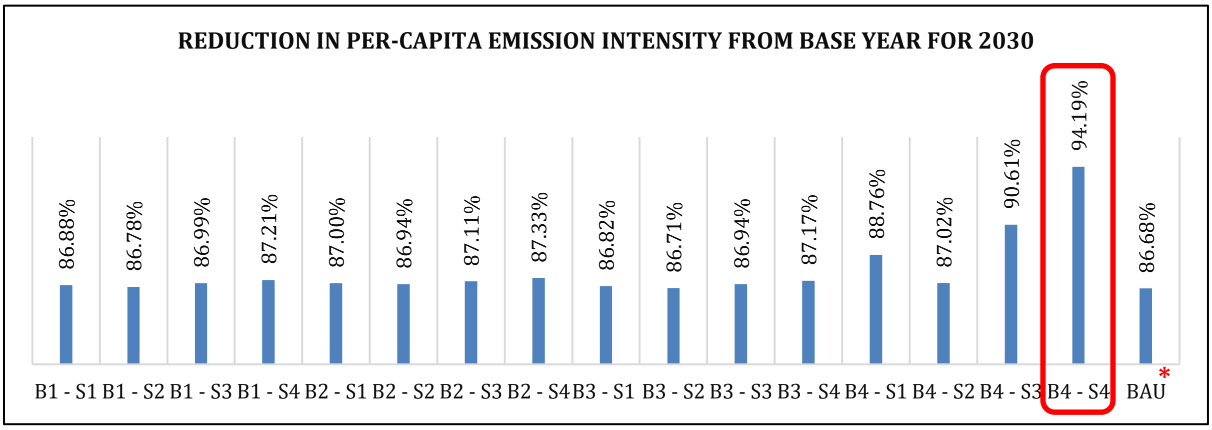


Figure 135: Percapita GHG Emissions intensity under BAU and alternate policy scenarios for 2030



*Assuming electricity is purely generated from hydropower, solar and wind without using bio energy in BAU scenario, **87%** reduction in total percapita CO2 emission intensity can be achieved in BAU 2030with respect to base year.

Figure 136: Percentage reduction in Percapita GHG emission intensity of the transport sector of BMR for 2030

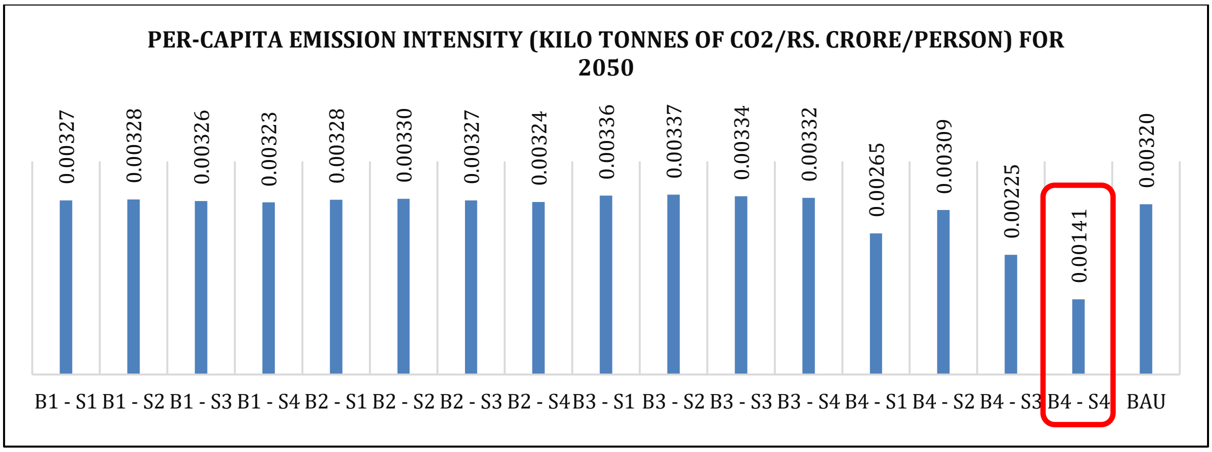
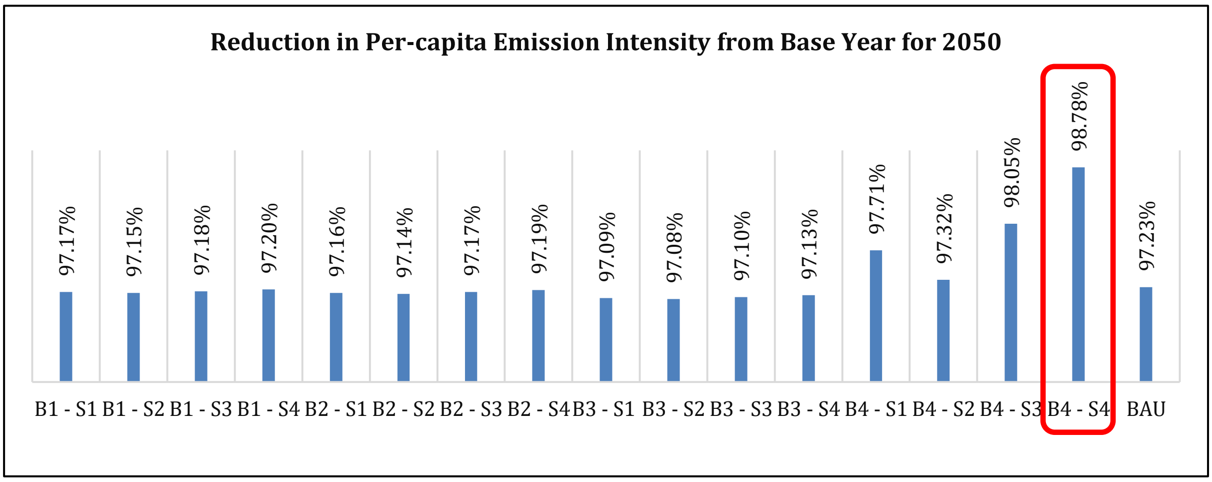


Figure 137: Percapita GHG Emissions intensity under BAU and alternate policy scenarios for 2050



*Assuming electricity is purely generated from hydropower, solar and wind without using bio energy in BAU scenario, **97%** reduction in total percapita CO2 emission intensity can be achieved in BAU 2050 with respect to base year.

Figure 138: Percentage reduction in Percapita GHG emission intensity of the transport sector of BMR for 2050

The percentage reduction in percapita GHG emission intensity of the transport sector of BMR in the horizon years 2030 and 2050 from the base year under BAU and alternate mitigation policy scenarios is displayed in figure 135 and figure 137. The carbon emissions intensity is increasing at the greater rate in BAU 2030 scenario because Metro is not available in Bengaluru during base year and it is the only electricity based transportation with high emission factor values. The share of generation of electricity from renewable and non-renewable sources plays a significant role in emission intensity. The study clearly states that the emission reduction reaches the INDC targets even for the BAU scenarios of 2030 and 2050 with the extreme scenario case of assuming that the electricity will be purely generated from renewable sources. The substantial reduction in emission intensity of the transportation sector of 91% and 96%is observed for the horizon year 2030 and 2050 respectively under the BAU and the best mitigation policy scenario of Bundle 4-Scenario 4. Similarly, up to 98% reduction in percapita emission intensity has been observed for the horizon year 2050.

6.7 RESULTS ANS DISCUSSIONS

- All the policies lead to a significant reduction in the emission intensity with respect to total and per-capita CO2 emissions when compared to the business as usual scenario.
- India's INDC are achieved even in the BAU scenario, if renewable sources such as hydro power, solar and wind energy is used for electricity generation.
- Assuming electricity is purely generated from hydropower, solar and wind without using bio energy in BAU scenario, there is **39%** reduction in total CO2 emission intensity from BAU 2008
- Assuming electricity is purely generated from hydropower, solar and wind without using bio energy in BAU scenario, there is **87%** reduction in total percapita CO2 emission intensity from BAU 2008 for 2030.
- Electrification of buses and cars are leads to a great deal of GHG emissions reductions.
- The bundle 4 – scenario 4 is implemented the total emission intensity will reduce by 91% for the year 2030 and 96% for 2050.
- The bundle 4 – scenario 4 is implemented the per-capita emission intensity will reduce by 94% for the year 2030 and 99% for 2050, highlighting that electrification of vehicles is the best solution with 100% electricity generation from renewable sources.

7 CONSUMER SURPLUS CALCULATIONS FOR EVALUATED POLICY BUNDLES BANGALORE

7.1 INTRODUCTION

Consumer surplus is defined as the difference between the consumers' willingness to pay in terms of travel costs (travel time, etc.) and what they actually pay is called consumer surplus.

Calculation of consumer surplus using rule of half: The rule of one-half estimates the change in consumer surplus for small changes in supply with a constant demand curve.

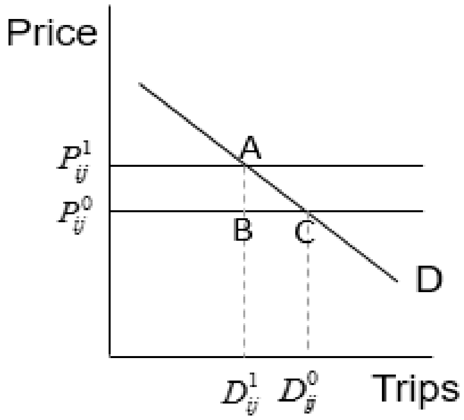


Figure 139: Change in Consumer Surplus

When price of travel changes from P_{ij}^0 to P_{ij}^1 demand changes from Dij^0 to D_{ij}^1 as illustrated in the figure. Then the change in consumer surplus (user's benefit or costs) due to a change is equal to the area of the triangle ABC.

7.2 CALCULATION OF CONSUMER SURPLUS

7.2.1 Private Transport

Consumer surplus for year 2030 and 2050 for each of the vehicle types that share road network will be calculated according to the following:

$$CS_{2030}^{M} = 1/2 \times VoT^{M} \times \sum_{i \in I}\sum_{j \in J}(D_{ij}^{M1} - D_{ij}^{M0}) \times (T_{ij}^{M1} - T_{ij}^{M0}) + 1/2 \times \sum_{i \in I}\sum_{j \in J}(D_{ij}^{M1} - D_{ij}^{M0}) \times (FC^{M1} \times Dist_{ij}^{M1} - FC^{M0} \times Dist_{ij}^{M0})$$

Where, M modes that use road network

- VoT is value of travel time for mode M, Rupee/minutes
- D is travel demand for mode M
- T is travel time for mode M in minute
- Dist is travel distance for mode M in km
- FC is fuel cost, Rupee/ km

7.2.2 Public Transport

For public transport mode the calculation will be made according to the following

$$CS_{2030}^{PT} = 1/2 \times VoT^{PT} \times \sum_{i \in I} \sum_{j \in J} (D_{ij}^{PT1} - D_{ij}^{PT0}) \times (T_{ij}^{PT1} - T_{ij}^{PT0})$$

Where, PT stands for public transport
VoT is value of travel time for public transport
D is travel demand for public transport
T is total travel time for public transport

- The fuel cost is calculated by making a shortest path assignment for a distance matrix. The distance matrix multiplied by mode specific fuel cost is travel cost related to fuel cost.
- Parking costs have been added wherever it is applicable once the fuel cost matrix is carried.
- Congestion pricing is multiplied with the distance travelled wherever applicable and added to the total costs.

7.3 VALUE OF TIME

Value of Travel Time (VOT)-Traveller's value of time can be estimated from the degree to which they are either willing to pay money to save travel time or incur extra travel time to save money.

Table 41: Value of Time adopted for the study

Mode	VOT/hr	VOT/min
Taxi	54	0.9
Auto rickshaw	36	0.6
Two wheeler	25.8	0.43
Car/Van	63	1.05
Bus	14.4	0.24
Metro	14.4	0.24

(Source: Comprehensive traffic and transportation study, Bangalore 2010)

The CTTS report doesn't provide the VOT values for Metro and NMT. Considering metro is a public transportation mode, VOT which is used for Bus is adopted for metro. This report doesn't consist the consumer surplus values of NMT due to the unavailability of VOT.

7.4 EVALUATED POLICY BUNDLES AND CONSUMER SURPLUS

7.4.1 Policy Bundle 1

The policies in the policy bundle 1 are listed below:

a. *Increasing network of public transit*
b. *Cycling and Walking Infrastructure*
c. *Additional taxes on new vehicle purchase*

By implementing this policy bundle there has been a shift in the mode share from private mode to public transportation. Since the VOT is considered as 1 all the consumer surplus values will be defined in terms of money saved or money lost.

Figure 140 shows the consumer surplus values by implementing the policy bundle 1. It is found that the 2wheelers are losing more money compared to other modes. The consumer surplus values for public transport modes like bus and metro are positive which signifies that they are saving money by using that mode.

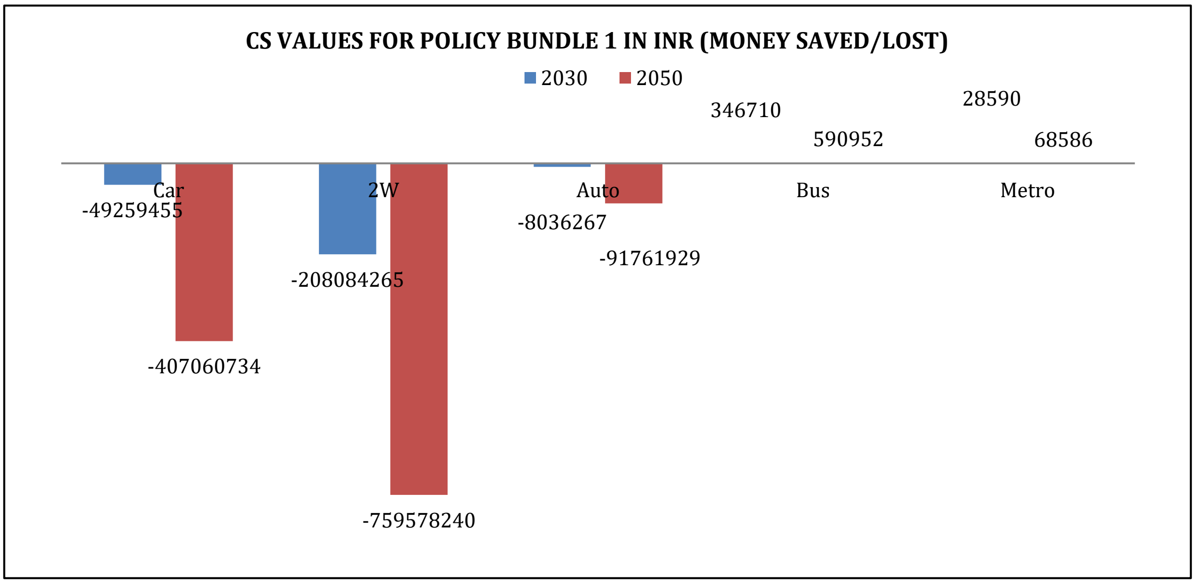


Figure 140: CS values for policy bundle 1 (Money saved/lost)

7.4.2 Policy Bundle 2

The policies in the policy bundle 2 are as follows:

a. *Additional taxes on new vehicle purchase*
b. *Strict Vehicles inspection/ Improvement in standards for vehicle emission*
c. *Increase in fuel cost*

This bundle aim is to increase the operating costs of private vehicles. By implementing this bundle, it was found that there is a shift from private mode to public transport. Figure 141 shows the consumer surplus for the various modes upon implementing bundle 2.

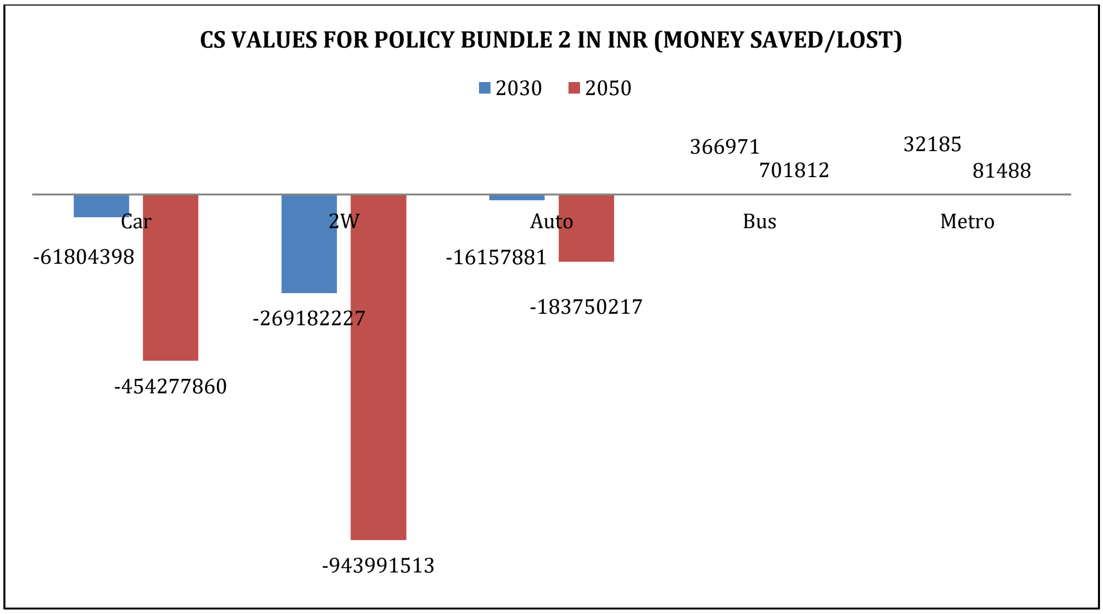


Figure 141: CS values for policy bundle 2 (Money saved/lost)

7.4.3 Bundle 3

The policies in the policy bundle 3 are listed below:

a. Increasing network coverage of Public Transit
b. Defining car restricted zones
c. Congestion Pricing
d. Park and Ride
e. Cycling and Walking infrastructure
f. Encouraging car-pooling and High Occupancy Lanes
g. High density mix building use along main transport corridors

This bundle concentrates on providing proper network coverage for public transport, increasing the operation costs for private vehicles and providing proper infrastructure for mass transport and non-motorized transport. It is observed that this bundle is efficient in reducing the emissions because of the considerable shift from private to public transport.

Figure 142 shows the consumer surplus values obtained by implementing this policy bundle. As mentioned earlier negative sign signifies losing money by using that particular mode. It is observed that 2 wheelers loose more in this case as well. This is because of the shift in the mode of transport upon the bundle implementation.

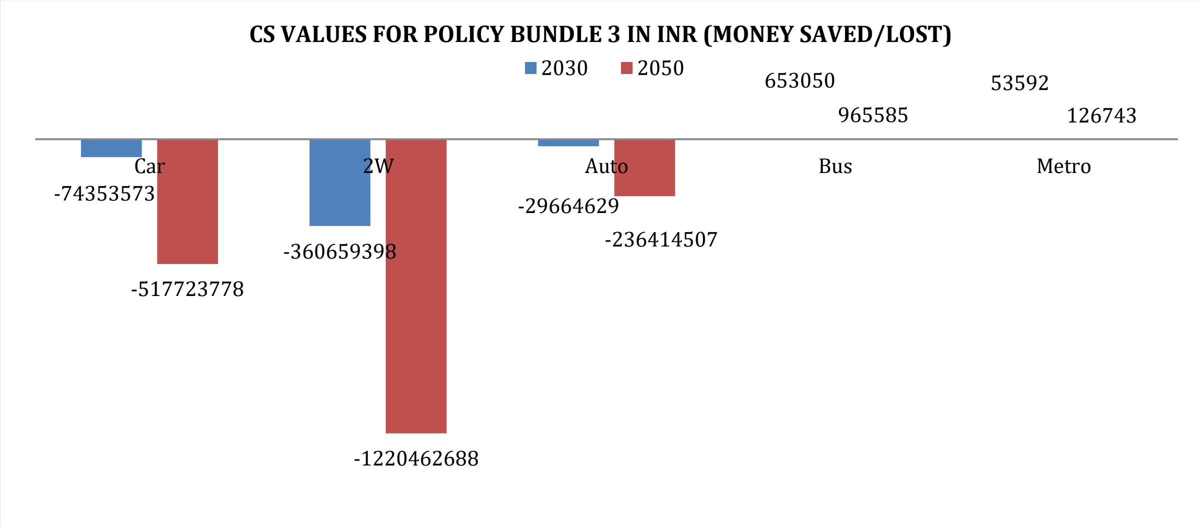


Figure 142: CS values for policy bundle 3 (Money saved/lost)

7.5 SUMMARY

Consumer surplus costs associated with bundles 1, 2 & 3 have been estimated and it was found that Bundle 3 consumers who use Public transportation gain about Rs. 0.71 million/day in the year 2030 and Rs. 1.1 million/day in 2050 while the 2 wheeler users are at the major loss with Rs. 360 million/day in 2030 and Rs. 1220 million/day in 2050.

The reason for high consumer surplus values for two wheeler and auto rickshaw could be because of the mode shift between BAU and policy bundles. Added to that, the private vehicle formula above also includes fuel costs as well which further increases their value.

8 ADAPTATION POLICY BUNDLES FOR TRANSPORTATION SECTOR

8.1 INTRODUCTION

Urban floods are the main focus for the adaptation part of the project and so most of the policies have been formulated keeping urban flooding in mind. Climate change is inevitable; however, adaptive strategies help in strengthening the road network system act as resilient measures against urban floods. Figure 143 shows the sequential steps followed in Policy formulation for Adaptation.

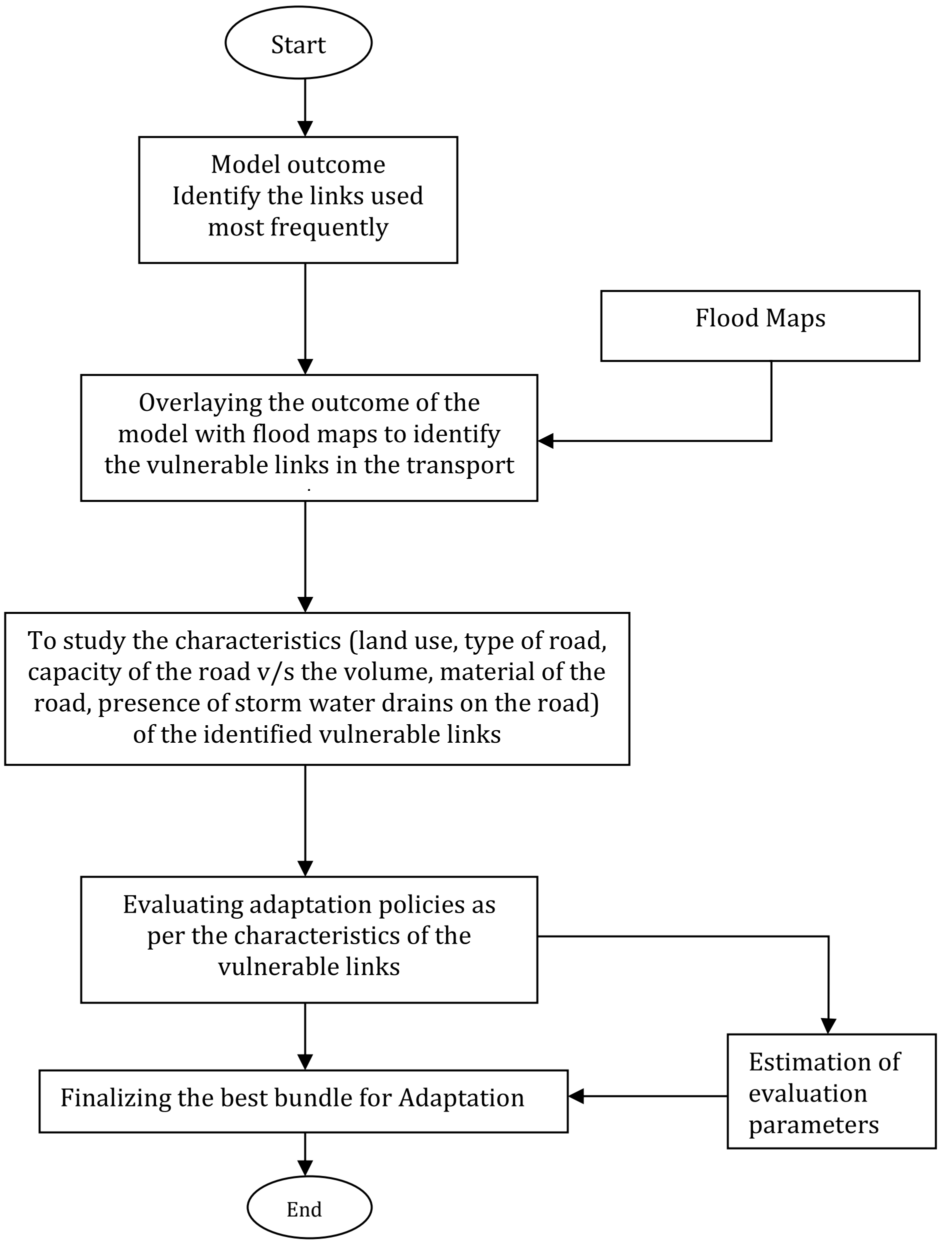


Figure 143: Policies Formulation for Adaptation Flow Chart

8.2 BUSINESS AS USUAL SCENARIO

Bangalore Metropolitan Region flood map is prepared based on the heavy rainfall occurred on November 3rd 2015 (total rainfall - 266mm, duration - 4 hrs 10 mins, return period – 100yrs).

Figure 144: DEM Map - BMR

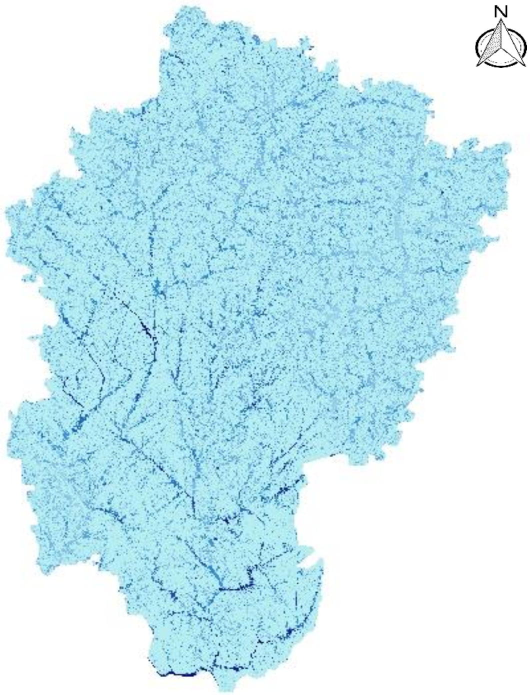


Figure 145: Flood Map - BMR

For business as usual scenario we considered the base road network which was used for mitigation. Flood map is overlaid over the road network to find out the vulnerable locations. The road network showing the flood depth is presented in figure 145. For the BAU network each road link is divided into multiple small links depending on the level of flood in that particular link. The percentage share of flood depth on road network of BMR is shown in Figure 147. Flooding reduces the vehicle speeds and the percentage change in speed with flood depth is shown in table 42.

Table 42: Relation between Flood Depth and Travel Speed Reduction

FLOOD DEPTH (m)	TRAVEL SPEED REDUCTION
0 - 0.1	No Change
0.1 - 0.2	0 - 25%
0.2 - 0.3	25% - 50%
0.3 - 0.5	50% - 75%
Above 0.5	75% - 99%
	Road Closed

(Source: Pregnolato et al. 2016)

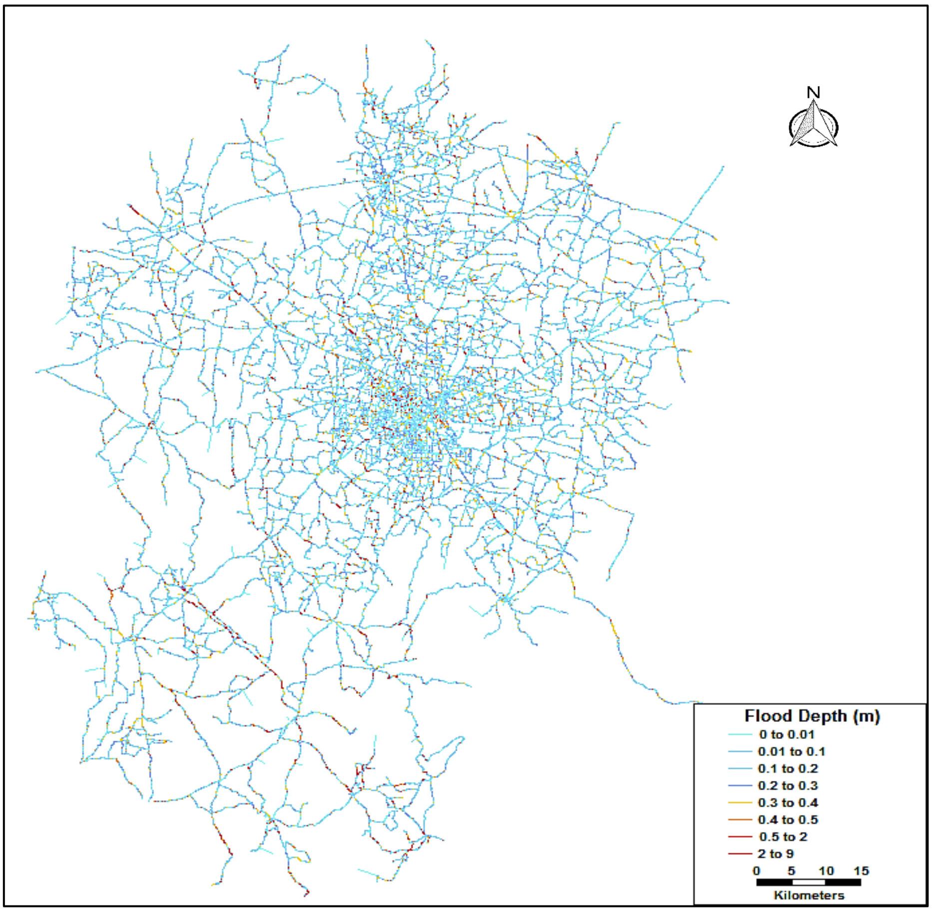


Figure 146: Road network with flood level Map - BMR

For the BAU network each road link is divided into multiple small links depending on the level of flood in that particular link. Links which carry a flood depth above than 0.5 m are not considered in the BAU model. Roads that are heavily flooded and the zones that do not have redundant roads for the trip to happen are considered to have no trips from those zones. There are about 7 such zones in which the trips are cancelled.

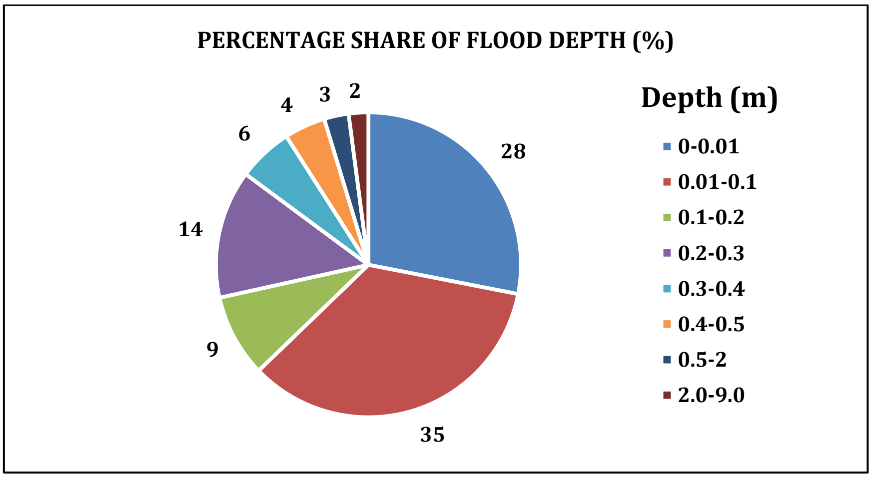


Figure 147: Percentage Share of Flood Depth in Road Network

Bengaluru has about 180-200 km length of primary and secondary storm water drainages and nothing was added in the BAU model. BAU modelling is done for the base year and for the future years 2030, 2050 for both private and public transport networks. Since this is not a frequent event and not a usual scenario the mode shift is kept the same even though trip lengths change. Due to the flooding of roads, people who commute in their usual shortest paths change their course which leads to longer paths and longer travel time.

8.3 BAU ADAPTATION RESULTS

8.3.1 Comparison of Vehicle kilometres travelled

Vehicle kilometres travelled are compared between no flooding and flooding scenarios for base year, 2030 & 2050.

Table 43: Comparison of VKT for BAU scenarios Base Year, 2030 and 2050

	BAU- No Flooding (VKT in millions) (km)			BAU- Flooding (VKT in millions) (km)		
	Base Year	**2030**	**2050**	**Base Year**	**2030**	**2050**
PVT	28.69	39.3	55.8	29.6	41.2	57.2
PT	2.3	8.7	16.3	2.8	9.6	18.1
Total	**30.99**	**48**	**72.1**	**32.4**	**50.8**	**75.3**

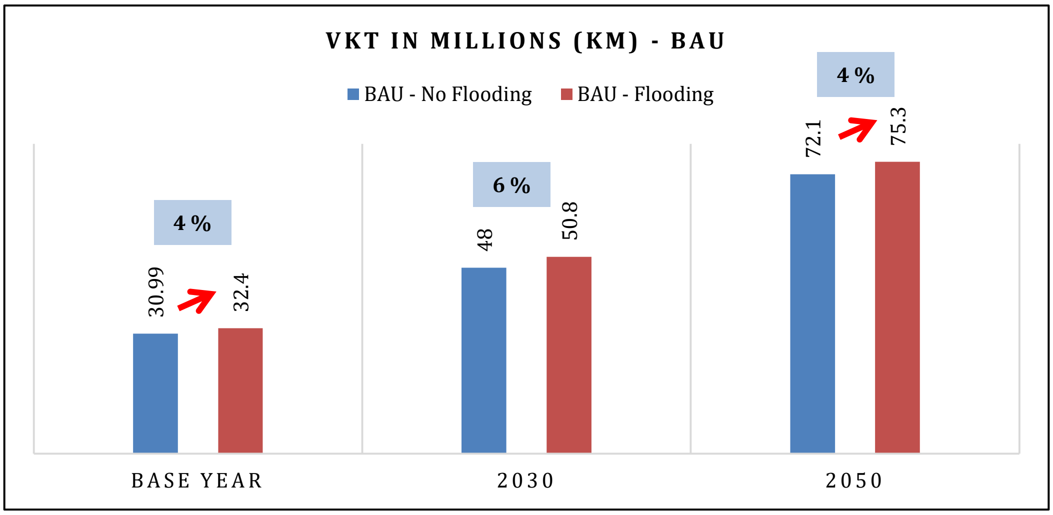


Figure 148: Comparison of VKT for No Flooding and Flooding BAU scenarios - BAU

It is observed from the figure 148 that the vehicle kilometres travelled are increasing due to the fact that the shortest paths are flooded and the commuters are taking another path which is longer than the usual path.

8.3.2 Vehicle Hours Travelled

Due to flooding and blockage of roads people tend to use alternative routes which will be longer than the usual paths which increase the travel times. The figure 149 illustrates the comparison between vehicle Hours Travelled (VHT) for Non- flooding and flooding BAU scenarios for base year, 2030 & 2050.

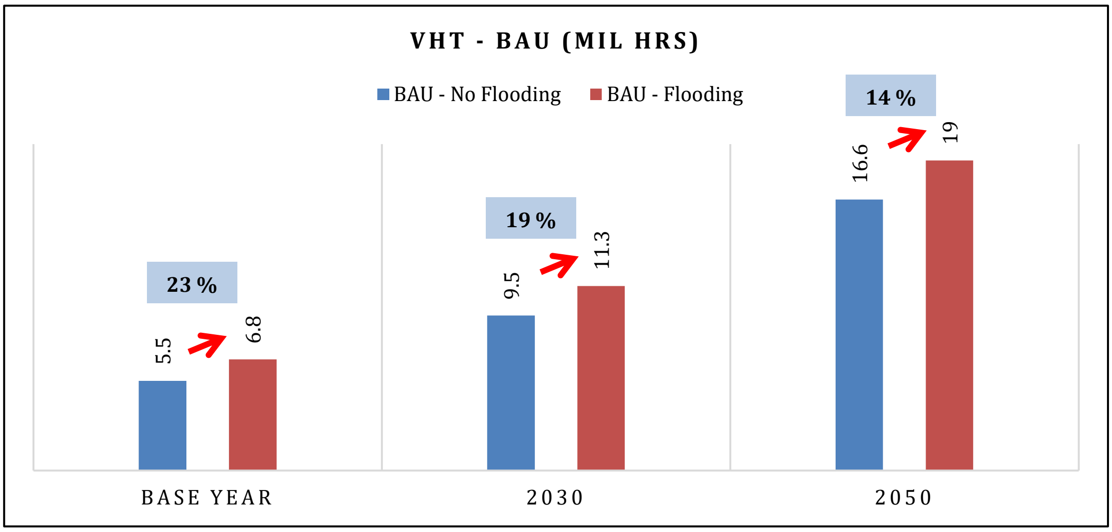


Figure 149: Comparison of VHT between BAU No flooding and BAU flooding scenarios – BAU

8.3.3 Average Travel Speeds

The relation between flood depth and speed clearly explains that as the level of flood increases vehicle speeds decrease. Using this relation new vehicle speeds and travel times are estimated which will then be fed in to model for assigning trips to the road network. From the figure 150, it is evident that the average daily vehicle speed reduces from 27kmph in base year no flooding to 13kmph during flooding in 2050.

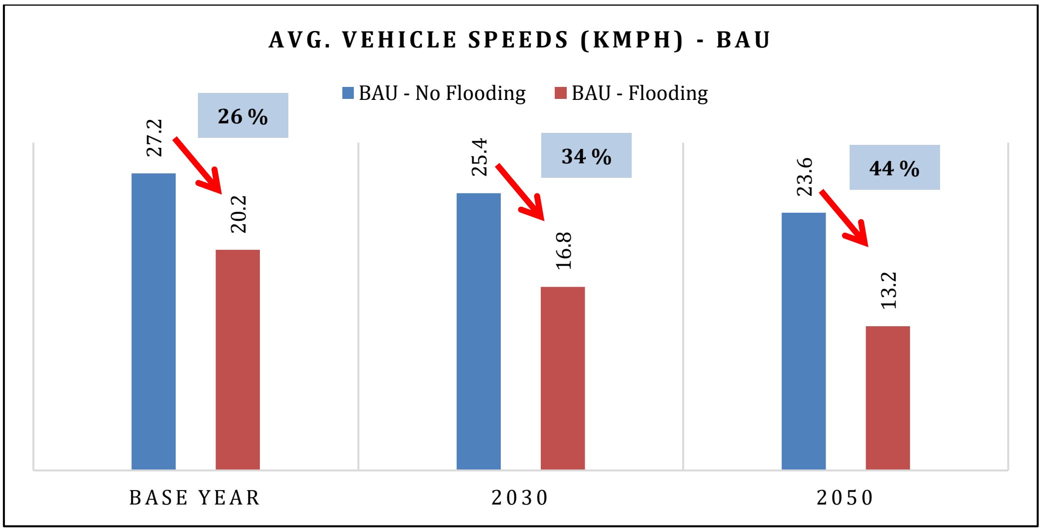


Figure 150: Comparison of Average Travel Speeds between BAU No Flooding and BAU Flooding Scenario

8.3.4 Average Trip Lengths

It is observed from the figure 151, that the average private transport trip lengths increase from14.1 km in BAU base year (no flood scenario) to 21.7 km in 2050 for a flood scenario. For public transport the average trip lengths increase from 11.4 km in BAU base year no flooding scenario to 20.4 km in 2050 flooding scenario.

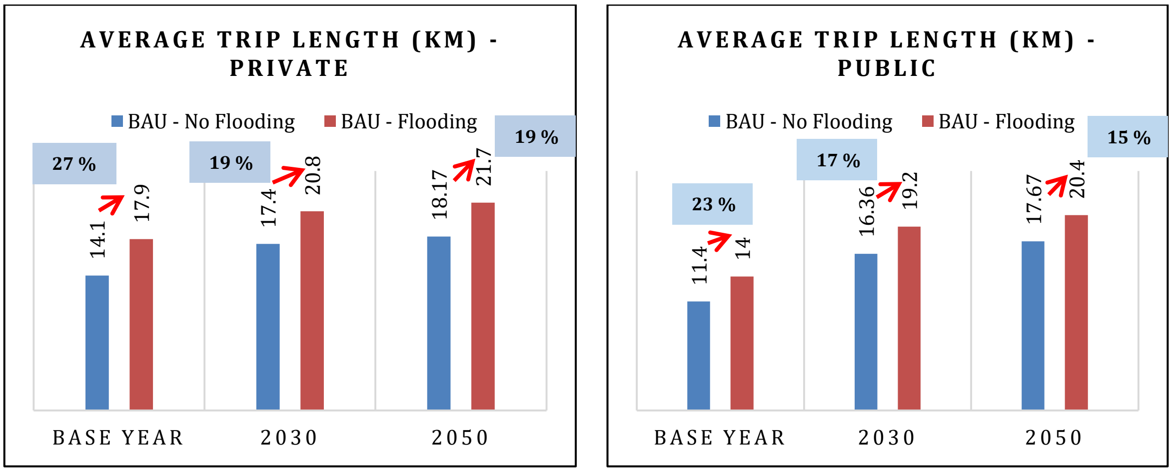


Figure 151: Comparison of Avg. trip lengths for base year, 2030 and 2050 for Private and Public Transport

8.3.5 Cancelled Trips

It is assumed that the zones which are flooded and have no access to other zones are considered to have cancelled their trips. Table 44 shows the total trips cancelled due to flooding for BAU scenario.

Table 44: Cancelled trips for BAU No flooding and BAU Flooding case for BAU

Cancelled Trips			
BAU - No flooding	**BAU Flooding**	**Total Trips assigned**	**% Trips cancelled**
0	160786	6 million	2.8

8.3.6 Trip Assignment Figures

The figures152 - 154 shows the flows on the BMR road network for the base year, 2030 & 2050 for private and public transport for BAU scenario.

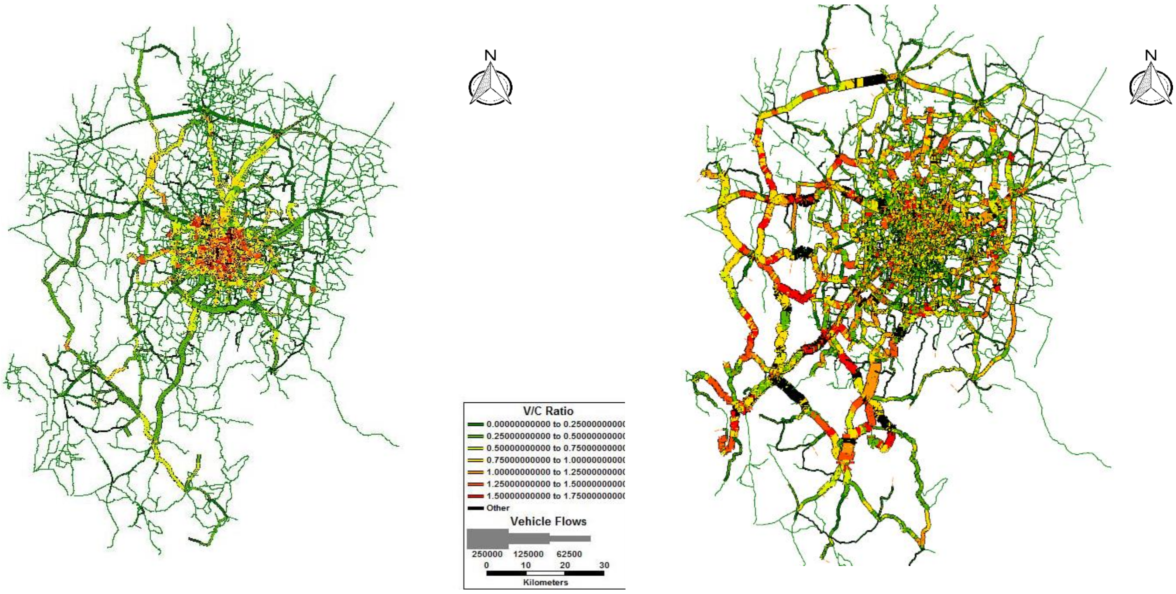


Figure 152: Vehicle flows on BMR road network for base year for BAU flooding

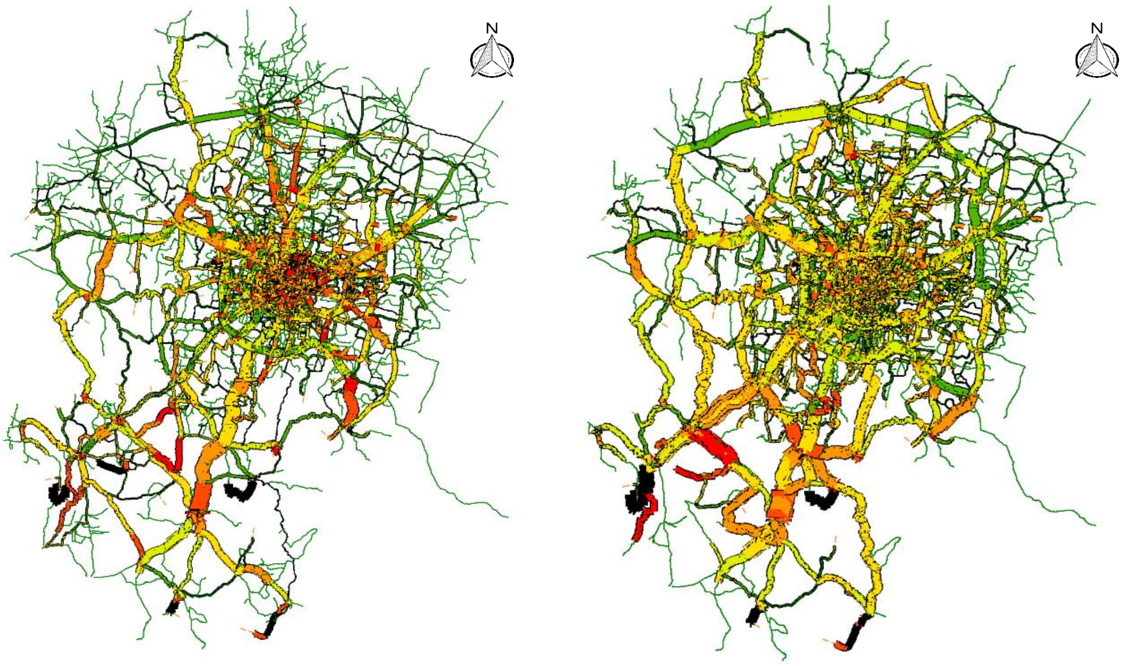


Figure 153: Vehicle flows on BMR road network for 2030 for BAU flooding

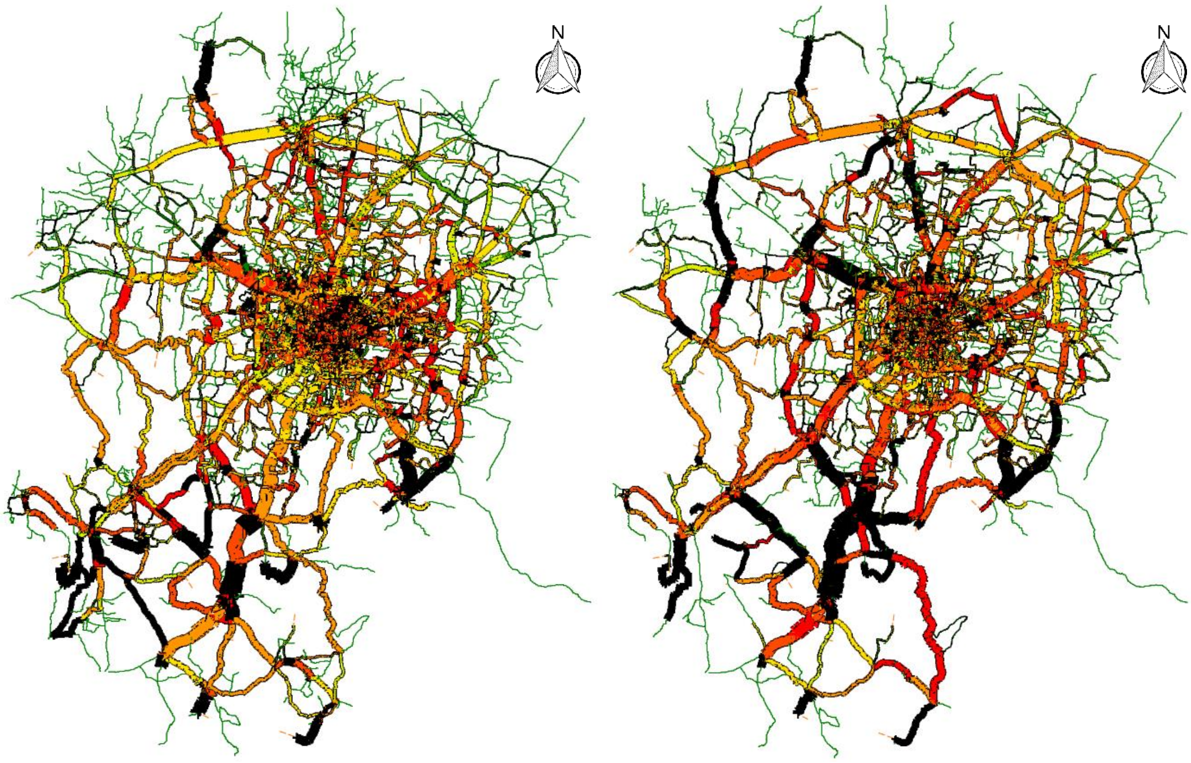


Figure 154: Vehicle flows on BMR road network for 2050 for BAU flooding

8.4 ADAPTATION POLICY BUNDLES

Adaptive measures are seen as a tool to reduce the vulnerability to the potential negative impacts of climate change and strengthen the inherent capacity of a system to undertake defensive as well as protective actions that help to avoid loss and facilitate recovery from any impact by increasing the resilience of the entire system. The main objective of the adaptation strategies is to create a transportation system that is resilient to urban flooding.

Urban floods are the main focus for the adaptation part of the project and so most of the policies have been formulated keeping urban flooding in mind. Climate change is inevitable; however, adaptive strategies will help in strengthening the road network system and act as resilient measures against urban floods. Bundles are formulated in such a way that there is resilience in the infrastructure and also a reduction in runoff on the road network. The policy bundles for adaptation are listed in the table 45**.**

Table 45: Policy Bundles for Adaptation

Policy Bundles
BUNDLE 1
Replacement of impermeable road surface with permeable material in vulnerable areas
Slum relocation and rehabilitation
Providing proper drainage facilities at vulnerable areas
Construction of redundant infrastructure
BUNDLE 2
Rerouting people during flooding
Restricting development in low lying or vulnerable areas
Slum relocation and rehabilitation
BUNDLE 3
Replacement of impermeable surfaces with permeable material in vulnerable areas
Providing proper drainage facilities at vulnerable areas
Rerouting people during flooding

Each policy bundle has a certain number of policies amalgamated together to bring out specific results after implementation. These sub-policies affect the travel demand modelling at various stages. A particular policy from a policy bundle might have an impact on more than one stage of the Travel Demand Model (TDM). In the following sections, the above policies are discussed and the impact of the policies on the TDM is explained for each policy bundle separately.

8.5 POLICY BUNDLES AND THEIR IMPACT ON THE TDM

8.5.1 Policy Bundle 1

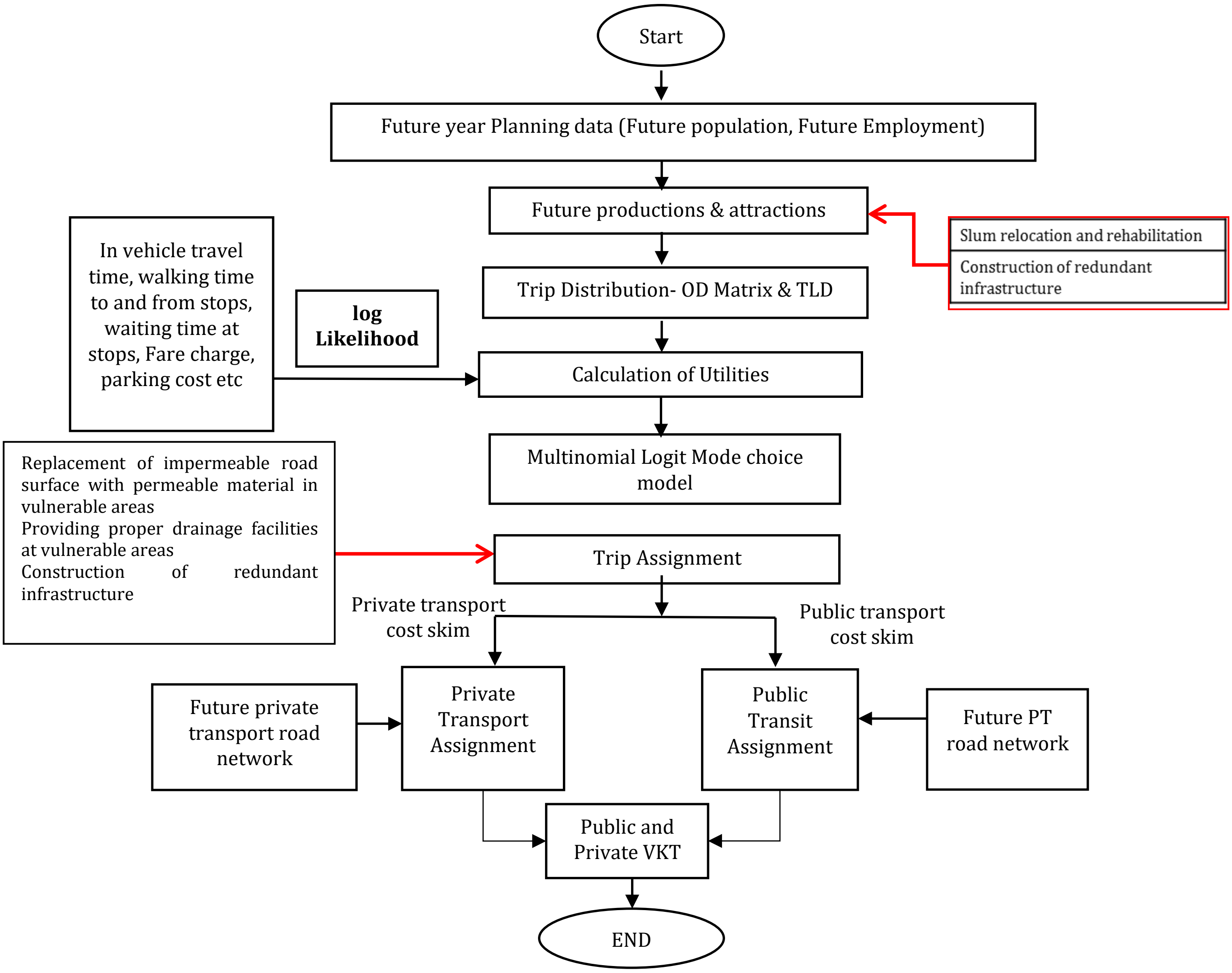


Figure 155: Impact of policy bundle 1 in Four stage modelling

8.5.2 Policy Bundle 2

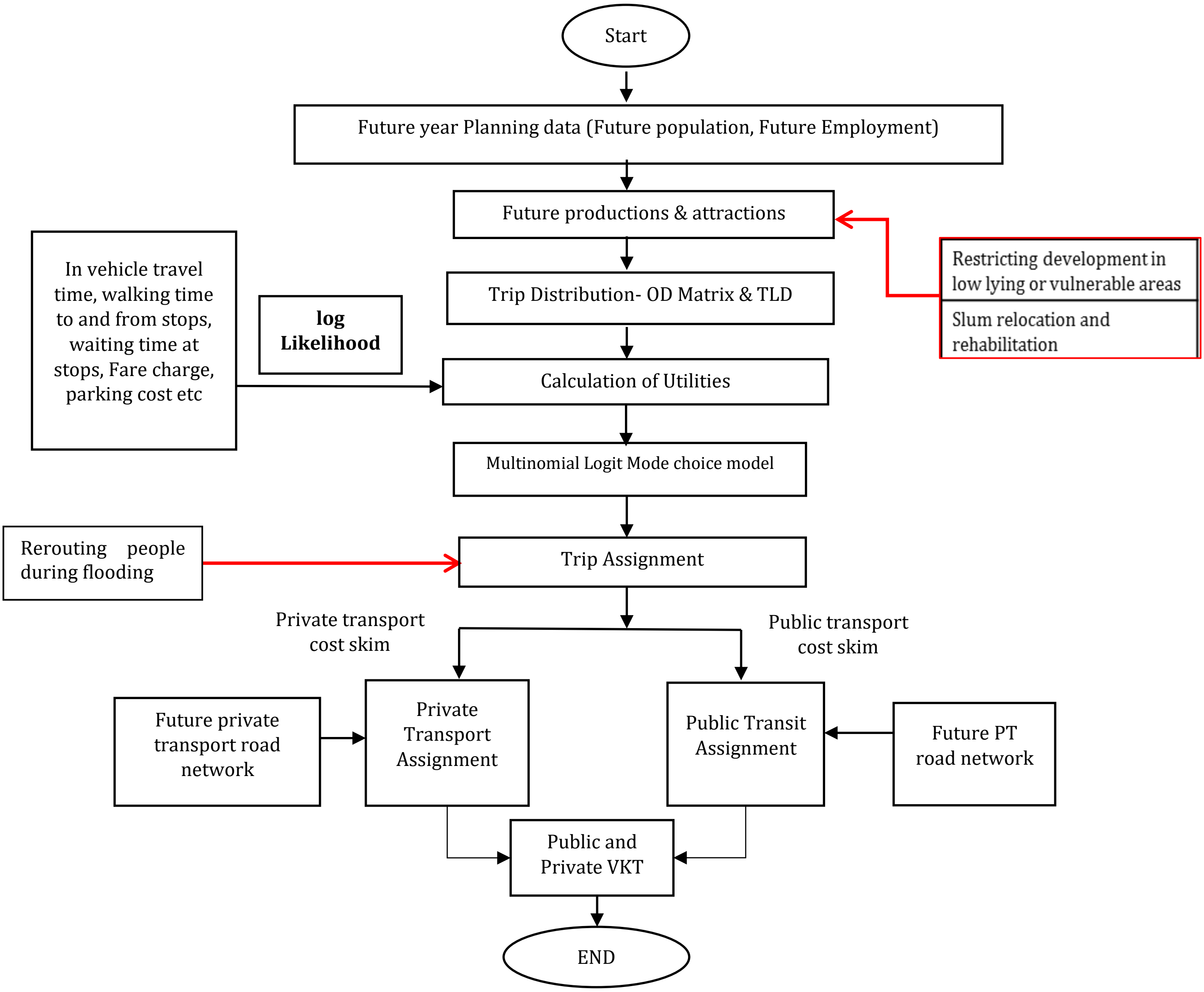


Figure 156: Impact of policy bundle 2 in Four stage modelling

8.5.3 Policy Bundle 3

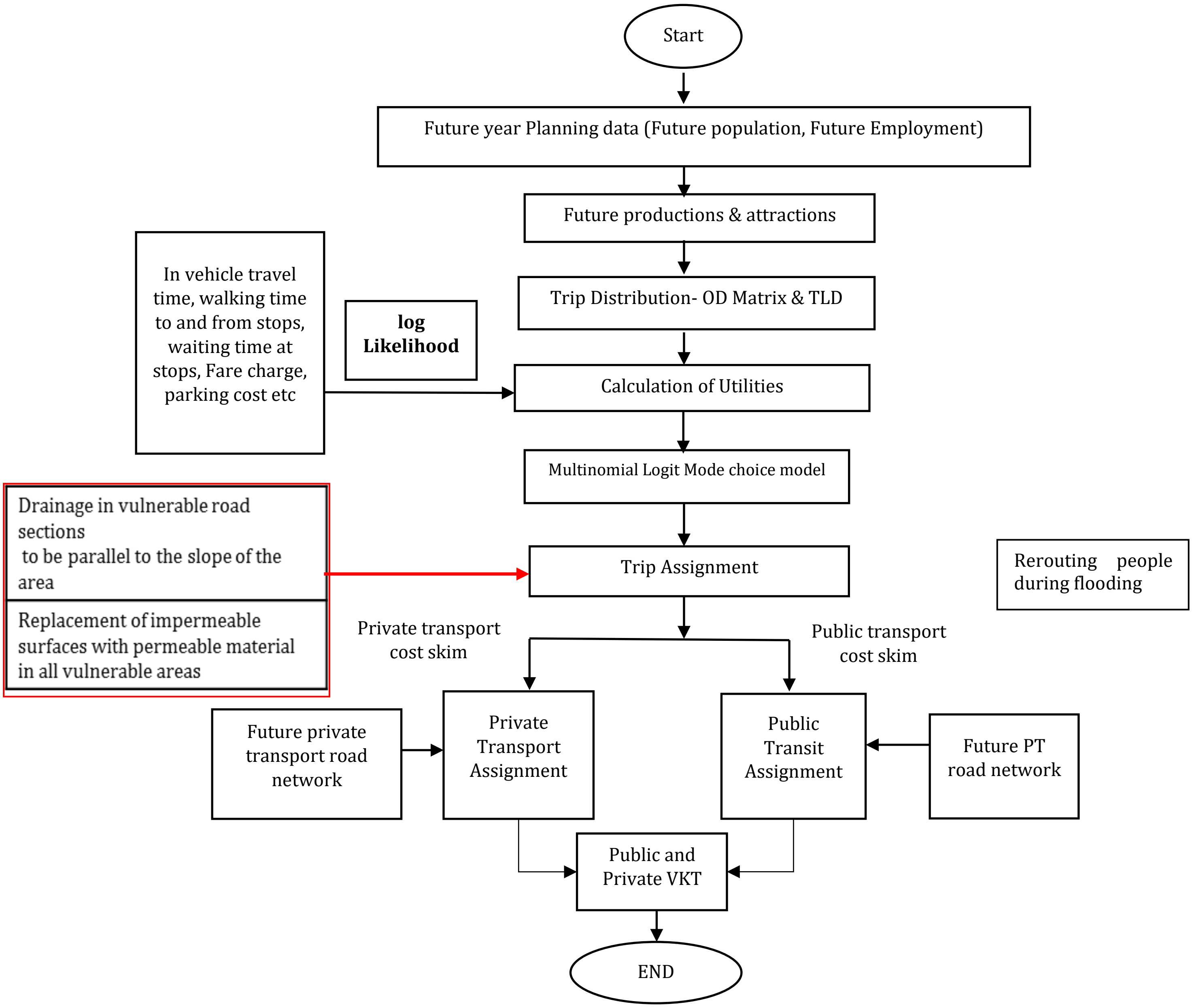


Figure 157: Impact of policy bundle 3 in Four stage modelling

8.6 EVALUATION READY DESCRIPTION OF ADAPTATION POLICIES

The bundles mentioned in table 45 have some policies common across the bundles. Evaluation of each of these policies is described below.

8.6.1 Replacement of impermeable road surface with permeable material in vulnerable areas

Most of the Bengaluru road networks have impermeable pavement systems. If there is improper drainage system, then even less intense rainfall accumulates certain depth of water on the surface of the pavement, thereby blocking the road, resulting higher vehicle hours travelled and higher vehicle kilometres travelled. As a strategy to increase the water permeation into the road, the above policy was adopted. It aims the replacement of impermeable road surface by permeable material in the high flooding road networks. Vulnerable links are identified depending on flood depth (above 0.3m), connectivity and the policy is being suggested.

The replacement of impermeable to permeable reduces the runoff rates and growing volumes of storm water collected in urbanised areas. Porous asphalt eliminates splash and spray behind vehicles and avoid reflections from the surface of the pavement at both day and night thus making road marks more visible. There is also a significant reduction of evaporation.

This policy will have an impact on the Trip Assignment of the TDM. This is because if the material of the roads in vulnerable sections gets replaced by permeable material then flood depth will reduce and thus people will be able to travel at the same speed without much variation, to their destinations.

The following variables are subject to change:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)
- Vehicle Kilometres Travelled (VKT)
- Average Trip Length

According to literature, in comparison to conventional asphalts, permeable and porous pavements provide effective peak flow reductions up to 42% and longer discharging times. Thus keeping other parameters constant, the flood depth reduces by 42%. From the assumption the range of flood depth (0.3m - 0.5m) was fixed and 25 vulnerable road links that were selected for incorporating in the model is shown in table 46 and the map depicting the identified location are given in figure 157.

Table 46: Locations to implement the policy

1. Vivekananda Park Road	2. State Bank Road	3. Tannery Road
4. Ramakrishna Road	5. 1st Main (Prashanth Nagar Main Road)	6. Elephant Cave Road
7. Temple Street	8. Main Guard Cross Road	9. C J Venkatesa Das Road
10. Bagalgunte Main Road	11. Byrasandra Main Road	12. JeevanBhima Nagar 10th Main Road
13. Jeevanahalli Main Road	14. Nehru Road	15. Arumugam Circle
16. Annapoorneshwarinagar Main Road	17. Sundaramurthi Road	18. New Mission Road
19. Madhava Rao Circle	20. Shani Mahatma Temple Road	21. Dairy Circle Flyover
22. Dickenson Road	23. Lady Curzon Road	24. Halasuru Road
25. Central Street		

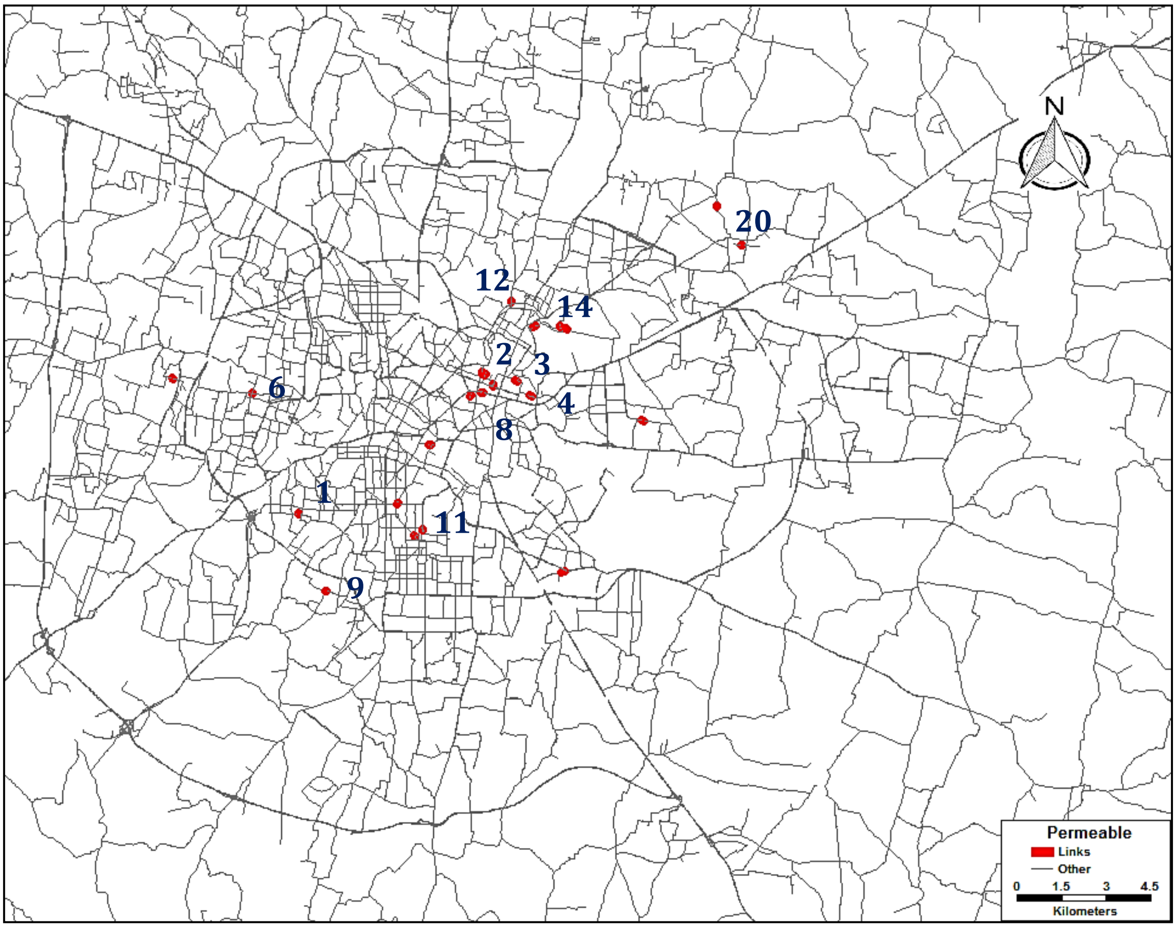


Figure 158: Locations to implement the policy

Cancelled trips will be estimated by looking at the number of vehicles that are going to pass through a heavily flooded link. This indicator value will be estimated before and after the implementation of the policy.

8.6.2 Slum relocation and rehabilitation

Slums are usually found in the low lying areas because these areas are cheaper or no development exists there. When urban floods occur, their neighbourhood gets flooded with water which further blocks the roads. Due to this, their mobility is hindered. Since other areas are unaffordable for these people, they continue to stay in such conditions. This policy aims to put an end to their grievances by relocating them to other areas which are not vulnerable to urban floods. This can be done by providing incentives to these people to shift to better quality spaces.

Since the slums will be relocated to a new place, this will affect the number of trips being produced and attracted to zones. This policy thus impacts the productions and attractions to each zone in the demand model. Thus, the following variables are subject to change:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)

- Vehicle Kilometres Travelled (VKT)
- Average Trip Length
- Zone Specific Trip Production

Slums in the low-lying areas are identified by overlaying DEM map & Flood map on the zonal map of BMR using ArcGIS. Slums which are lying in the lower elevation and are flooded have been considered for analysis. A total of 34 slums are identified for incorporating in the model and are presented in figure 158 and table 47.

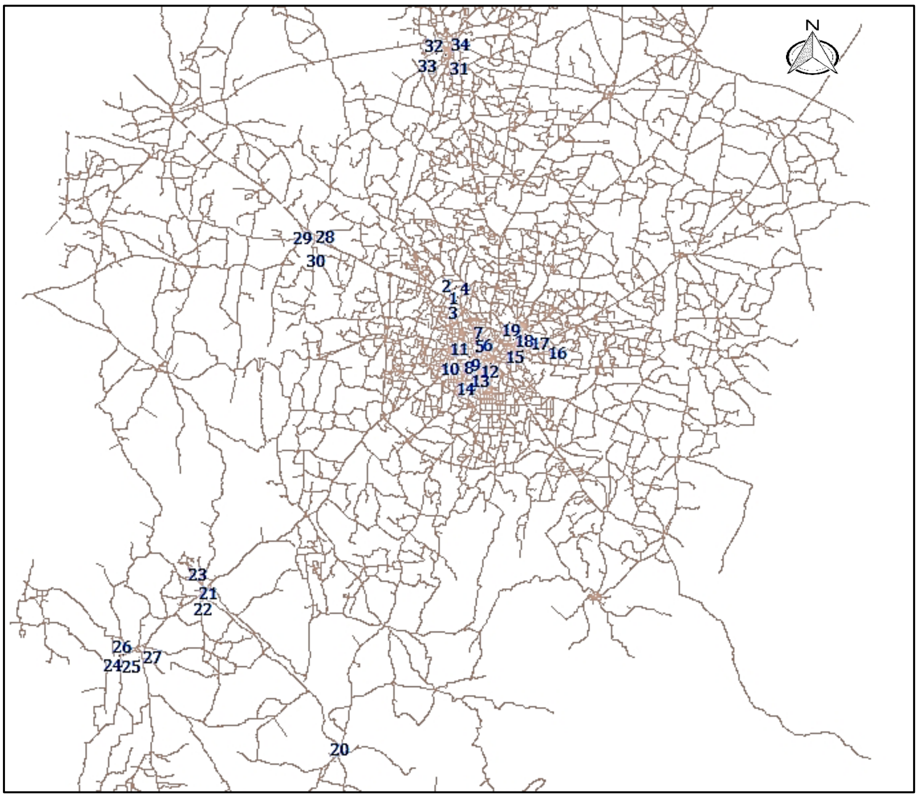


Figure 159: Flooded slum areas

Table 47: Locations of various slums that are flooded

1. Thannirhalli	2. Risaldar Road	3. Kadapaswamy Mutt	4. Krishnappa Garden
5. Muneswar Nagar (Muthyalammanagar)	6. Shastrinagar,Seshadripuram	7. Vinobhanagar	8. Sarvajna Nagar
9. Bundappa Huts	10. Anjanappa Garden	11. Chikkana Garden	12. Appanna garden, Doddigunta
13. Akkiyappa Garden	14. Bakshi Garden	15. Gavipura	16. Syed Khader Garden
17. V.V.Giri Colony	18. Nagammanagar,Binnymill	19. Nala Road	20. Behind KSRTC Bus stand
21. Shettihalli	22. Chikkamalur	23. Thattekere	24. Indira Nagar
25. Yarabnagar	26. Tamil Colony	27. Jayanagara	28. Khasbag
29. Iljoor	30. New A K Colony	31. Rayan nagara	32. Sanjayanagara
33. Veerabadranapalya	34. Gangadharpur		

Slums in the low lying areas are relocated to other areas which are not vulnerable to urban floods within the same zone or nearby zone. The population of the slums in the low lying area is shifted to the nearby zone and the new trip productions are estimated using the following trip end equations, the value is then used for modelling.

Table 48: Trip End equations

Mode	P-A	Trip End Equations
Private	*Production*	0.56 x POP + 1344.34
Public	*Production*	0.42 x POP + 4080

Slums clearance is the most satisfying method, where submerged slums or those prone to more flood depth will be shifted to new house unit of cost 1.00lakhs (50% of which will be contributed by government of India, and 50% by State government) under Karnataka slum board scheme. With the change in the location of the slum, there will be a change in the distance of their travel. The relocation and rehabilitation should be done in such a way that there will less VHT and VKT.

8.6.3 Construction of Redundant infrastructure

It is always better to have redundancy in the road network. During the times of unfortunate events like flooding, if a certain section of people are connected with only one single road and it gets flooded, then that particular section is cut off from their usual activities. In such situations it is always good to have another road link that can connect to a location where there is no flooding. This policy will have an impact in route assignment. The indicator variables that are subject to change are as follows:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)
- Vehicle Kilometres Travelled (VKT)
- Average Trip Length

For implementing this policy heavily flooded areas such as underpasses and arterial roads are identified in Bengaluru. The road links with no redundancy identified for the implementation of the policy are as follows and the map showing the location is given in figure 159.

1. Marathahalli Underpass
2. Bellari Road
3. Khodays Circle
4. GubbiThotadappa Road
5. Hosakerehalli Main Road
6. Kodichikkanahalli Road
7. 80 Feet Road (Sir C. V. Raman Hospital Road)
8. Taverekere Main Road
9. Old Airport Road
10. Bannerghatta Road

And a few other locations wherever required

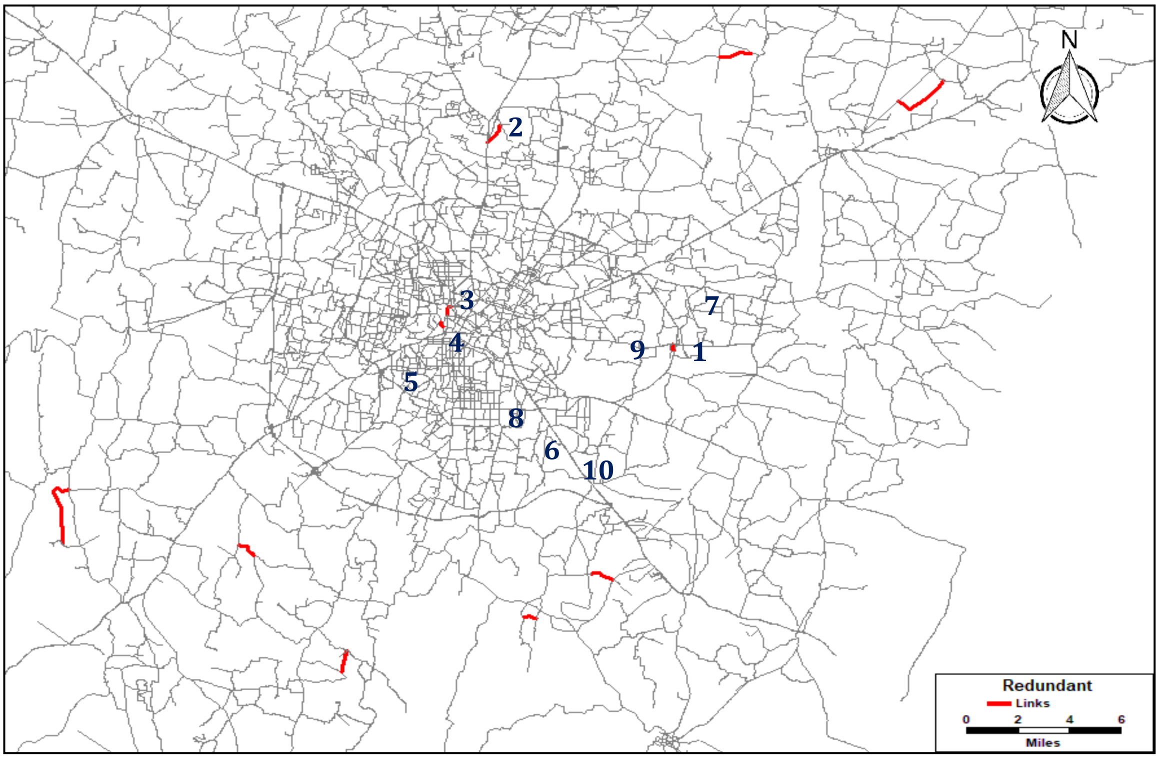


Figure 160: Locations selected for constructing redundant infrastructure

The heavily flooded links are identified from the flood maps and the policy is evaluated by adding extra links to the roads (which bypass the flooded links). This helps in reducing the vehicle hours travelled during flooding, and also reduces the cancellation of trips.

8.6.4 Rerouting people in case of unfortunate activity

In case of flooding, people could be assigned different routes to their respective destination thus avoiding the flooded routes and saving the extra kilometres and hours travelled. Therefore, this policy affects the trip assignment in the TDM. The following variables are subject to change:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)
- Vehicle Kilometres Travelled (VKT)
- Average Trip Length
- Congestion

For implementing this policy, vulnerable links depending on flood depth (above 0.5m) are identified. In modelling, when the re-routing happens the links that are flooded will be removed from the road network. This allows the modeller to choose the next route with higher speed and less travel time. In this way we can estimate the reduction in VHT and VKT. Congestion will be evaluated by calculating the volume of vehicles on the road at a particular location before and after the implementation of policy.

8.6.5 Restricting development in low lying or vulnerable areas

The low lying or the vulnerable areas are usually at the outskirts of the town and prone to floods. As the areas are cheaper (with no restrictions by the municipality), some people construct homes and due to high economic demands at other places, they continue to stay in such conditions. Through this policy, the development of residences will be restricted at such low lying and vulnerable areas and incentives can be provided for the people to shift near the city centres. This policy will affect the trip generation phase of the model. This because of the change in the locations of certain groups the productions of the zones will change. The following variables are subject to change:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)
- Vehicle Kilometres Travelled (VKT)
- Average Trip Length
- Zone Specific Trip Production

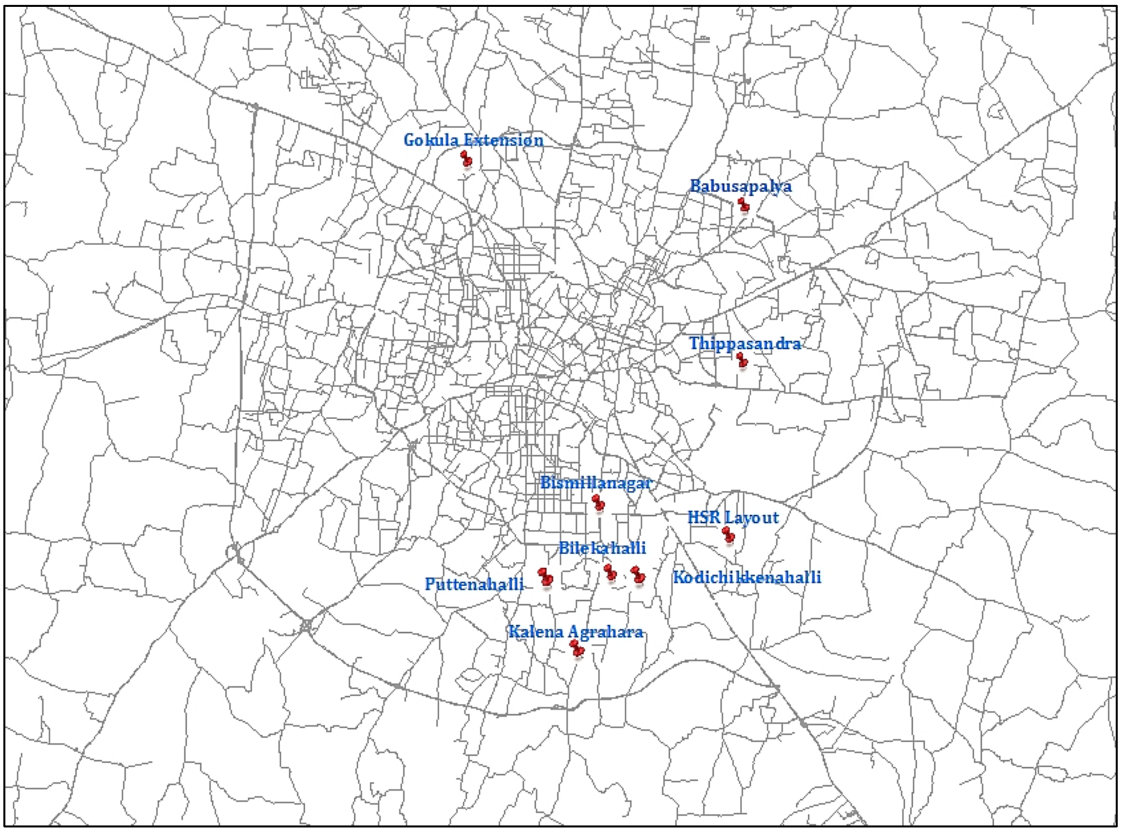


Figure 161: Identified low lying areas

The following vulnerable areas are identified for implementation of the policy:

1. Bismillanagar
2. Bilekahalli
3. Babusapalya
4. HSR Layout
5. Kodichikkenahalli
6. Puttenahalli
7. KalenaAgrahara
8. Gokula Extension
9. Thippasandra

This process involves transfer development right costs. To evaluate this policy the low lying or the vulnerable areas to flooding are identified using the zone level flood maps. The households in these vulnerable areas will be shifted to another place either in the same zone or to a different zone. As the vulnerable areas are restricted from development, there will not be much activity in those areas and the vehicle hours travelled by the commuters who earlier used these areas will be reduced. In order to estimate the population that will be shifted from these areas we have considered the ratio of the total zonal area to the low lying area. The same ratio is applied to the zonal population and estimated the low lying area population. This population are shifted to the nearest place which is at a higher elevation and non-flooded. If the shifting is beyond the original zone the productions have been changed with the use of trip end equations.

8.6.6 Providing proper drainage facilities at vulnerable areas:

The storm water drainage system helps the water to flow from the tertiary pipelines to the trunk line. In case the drains are not properly provided, the water might stop flowing in the pipelines and thus lead to ineffectiveness of the drainage system to seep water off the roads.

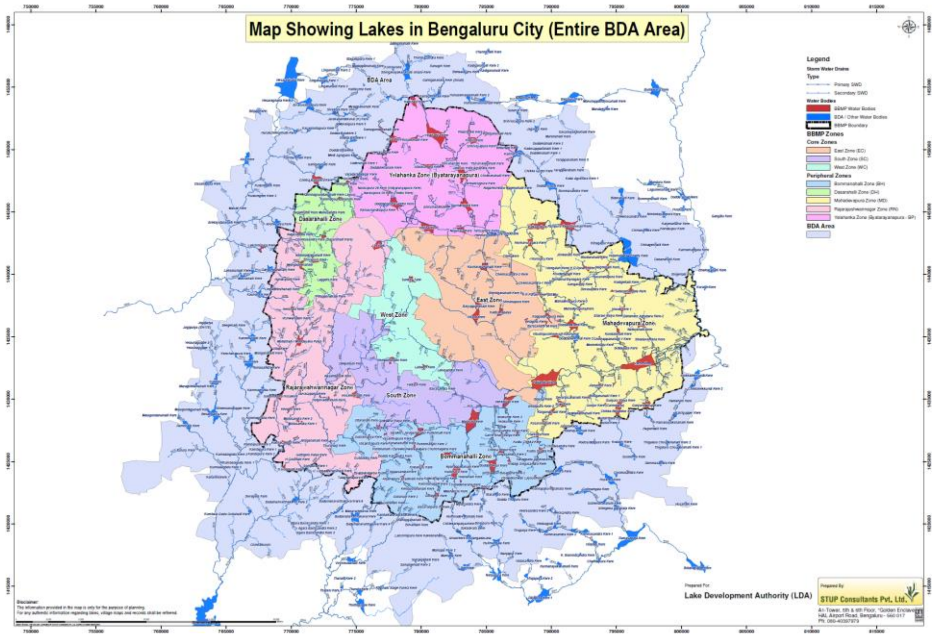


Figure 162: Map showing lakes in Bangalore City

**Red patches are the water bodies*

This policy will also impact the Trip Assignment as people can take alternate and shorter routes due to the reduction in the level of vulnerability of the roads. The following variables are subject to change:

- Cancelled Trips
- Vehicle Hours Travelled (VHT)
- Vehicle Kilometers Travelled (VKT)
- Average Trip Length
- Average speeds

Locations selected for policy implementation are given in table 49 and figure 162.

Table 49: Locations where this policy is tested

1. State Bank Road	2. Saint Mark's Road	3. Ayodhyarama Road
4. Venkataswamy Naidu Road	5. Chikpete Road	6. Saunders Road
7. K R Circle	8. Nrupathunga Road	9. CV Raman Avenue
10. Benson Cross Road	11. Ananda Rao Flyover	12. Gayathri Nagar Main Road
13. Dr B R AmbedkarVeedhi	14. Haines Road	15. District Office Road
16. Chord Road(D. R Bendre Road)	17. Diagonal Road	18. Bangalore Exit
19. K.H. Double Road	20. Coles Road	21. Davis Road

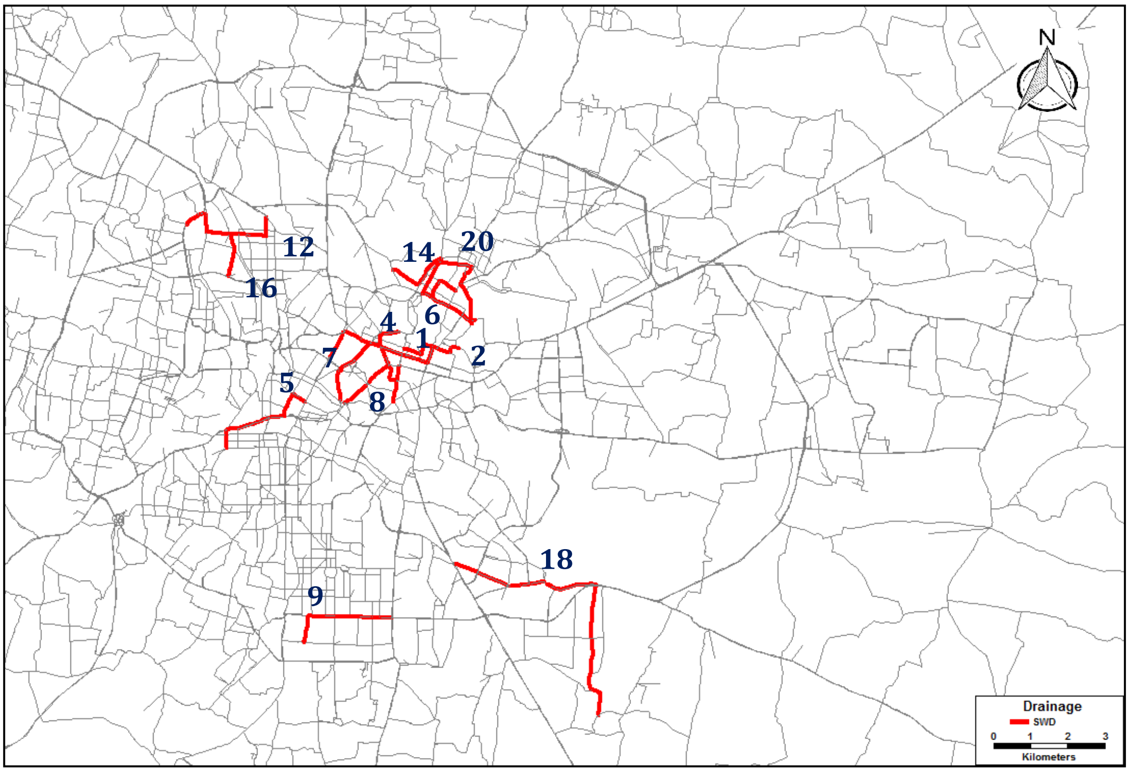


Figure 163: Identified locations for providing proper drainage facilities

This helps in reducing the level of flood on the road which reduces the VHT, damages to road and also vehicles. The reduction in flood also reduces the cancelled trips and congestion. A typical length and width of storm water drainage is 1m x 1.5 m for a meter length. The capacity of the drain would be 1.5 m^3. Assuming an upper cap of about 0.2m the holding capacity of the drainage is 1.3 m^3. If this drainage is provided on both sides of the road then the total capacity of the drainage will be 2.6 m^3. So, for a road width of 3.5 m the reduction in flood depth on road will be 74.3%, for 5.5 m road with the reduction in flood depth on road will be 47.2% and for a 7m road width it will reduce by 37.1%. In the selected locations these reductions in flood depth were considered for modelling. These drainages are provided at the locations mentioned above and extended till the nearest water body. Bengaluru has about 180-200 km primary and secondary drains which will be extended by another 110 km.

8.7 ADAPTATION POLICY BUNDLE 1 EVALUATION RESULTS

Table 50: Policy Bundle 1

ADAPTATION POLICY BUNDLE 1
Replacement of impermeable road surface with permeable material in vulnerable areas
Slum relocation and rehabilitation
Providing proper drainage facilities at vulnerable areas
Construction of redundant infrastructure

8.7.1 Vehicle Kilometres travelled

The figure below shows the comparison of VKT between the flooded conditions and the implementation of bundle 1.

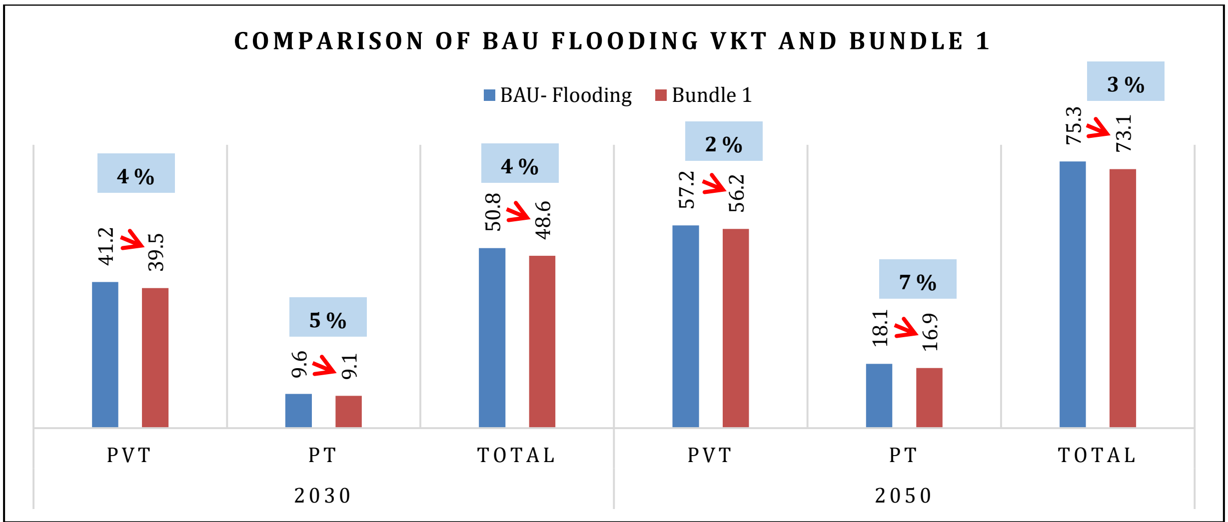


Figure 164: Comparison of BAU Flooding VKT and Bundle 1

8.7.2 Cancelled Trips

Table 51: Comparison of cancelled trips for BAU flooding case and Bundle 1

Cancelled Trips			
BAU Flooding	**% Trips Cancelled**	**B1**	**% Trips Cancelled**
160786	2.8	0	0

Even though the drainage provision and replacing impermeable road material with permeable material reduces the level of flood there is still some level of flooding that will result in the trip cancellation. This is addressed by providing redundancy in the road network, even though some roads are still above 0.5 m level of flood the people in these zones can still make their trips.

8.7.3 Average Travel Speeds

The evaluation of bundle 1 shows that the average travel speed increases to 21.3 kmph and 19.1 kmph for the years 2030 and 2050 with the implementation of these policies.

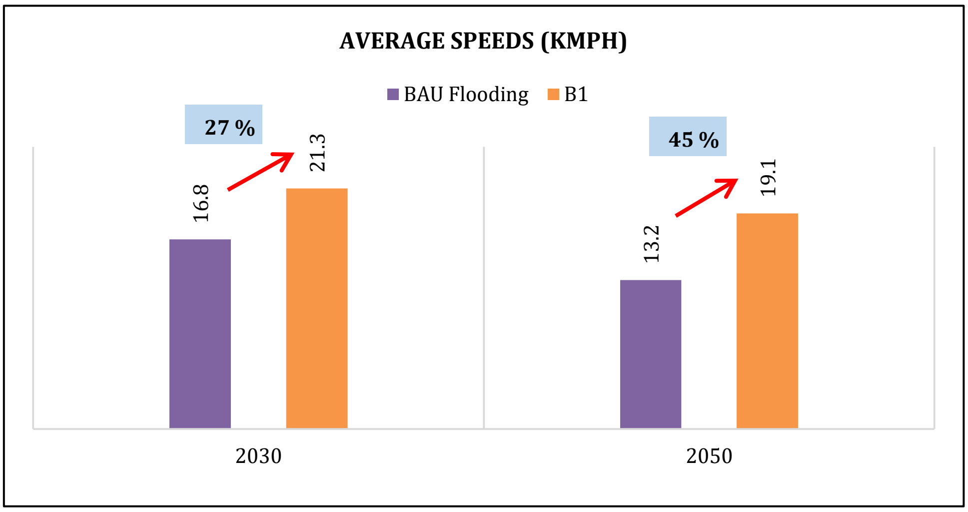


Figure 165: Comparison of travel speeds for BAU flood and Bundle 1 case

8.7.4 Average Trip Lengths

The evaluation of policy bundle 1 shows that there is decrease in the average trip length for both public and private transport.

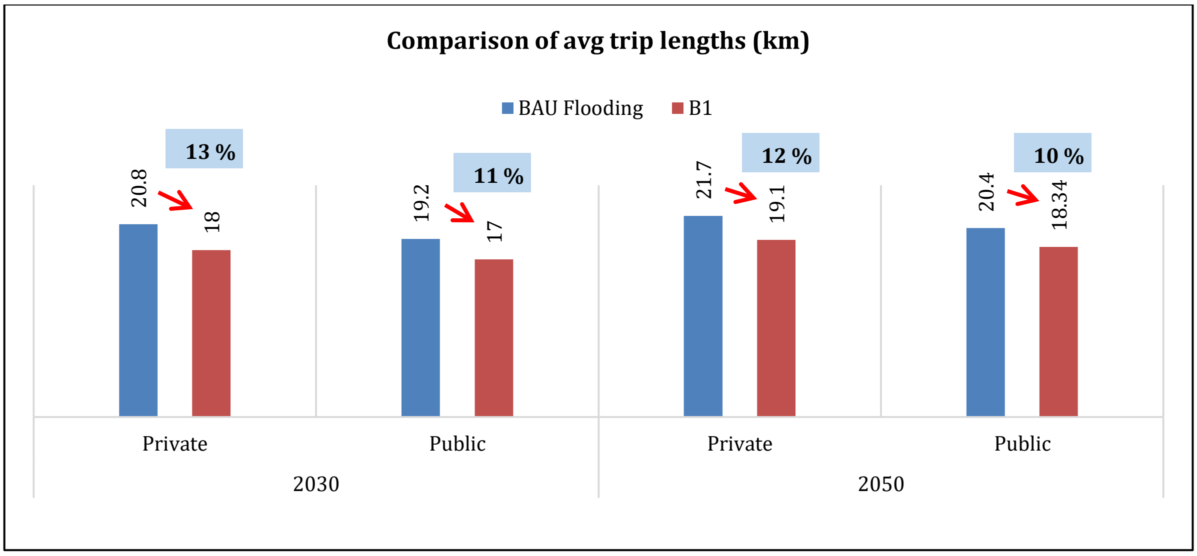


Figure 166: Comparison of average trip lengths for Private and Public transport BAU flooding and bundle 1 cases

8.7.5 Vehicle Hours Travelled (VHT)

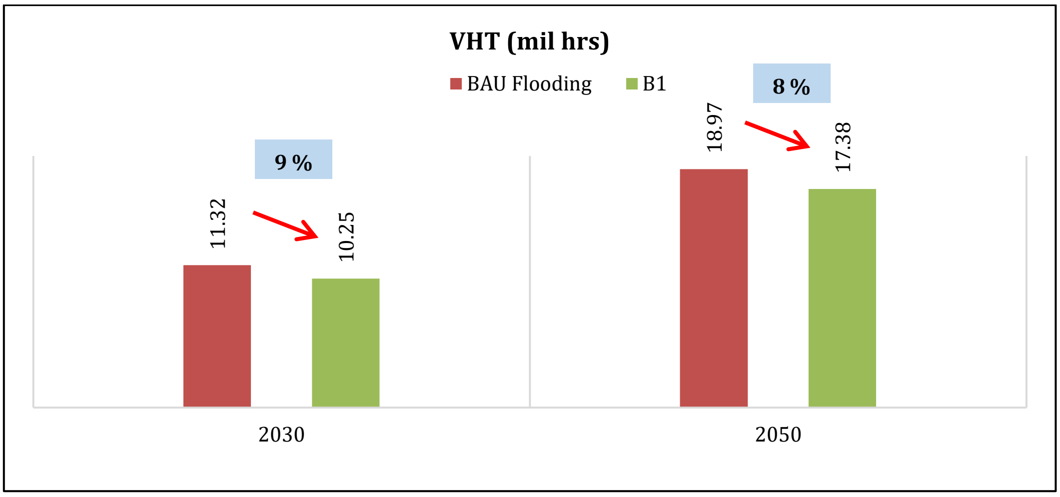


Figure 167: Vehicle Hours Travelled for flooded and Bundle 1

The above figure shows the comparison of VHT between flooded scenario and bundle 1.

8.8 ADAPTATION POLICY BUNDLE 2 EVALUATION RESULTS

Table 52: Policy Bundle 2

BUNDLE 2
Rerouting people during flooding
Restricting development in low lying or vulnerable areas
Slum relocation and rehabilitation

8.8.1 Vehicle Kilometres travelled

The table below shows the comparison of VKT between the flooded conditions and the implementation of bundle 2.

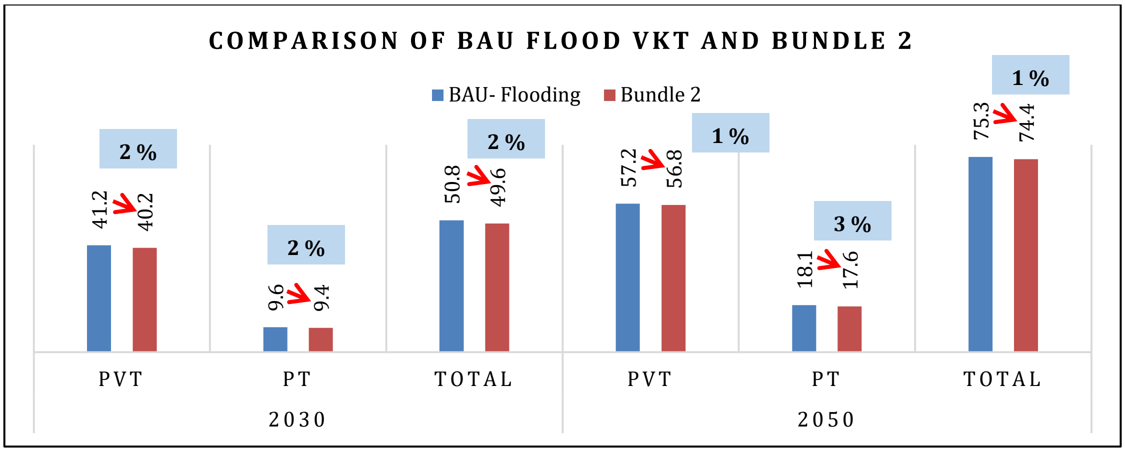


Figure 168: Comparison of BAU Flood VKT and Bundle 2

8.8.2 Cancelled Trips

Table 53: Comparison of cancelled trips for BAU flooding case and Bundle 2

	Cancelled Trips		
BAU Flooding	**% Trips Cancelled**	**B2**	**% Trips Cancelled**
160786	2.8	144707	2.47

8.8.3 Average Travel Speeds

The evaluation of bundle 2 shows that the average travel speed increases to 18.7kmph and 14.3kmph for the years 2030 and 2050 with the implementation of these policies.

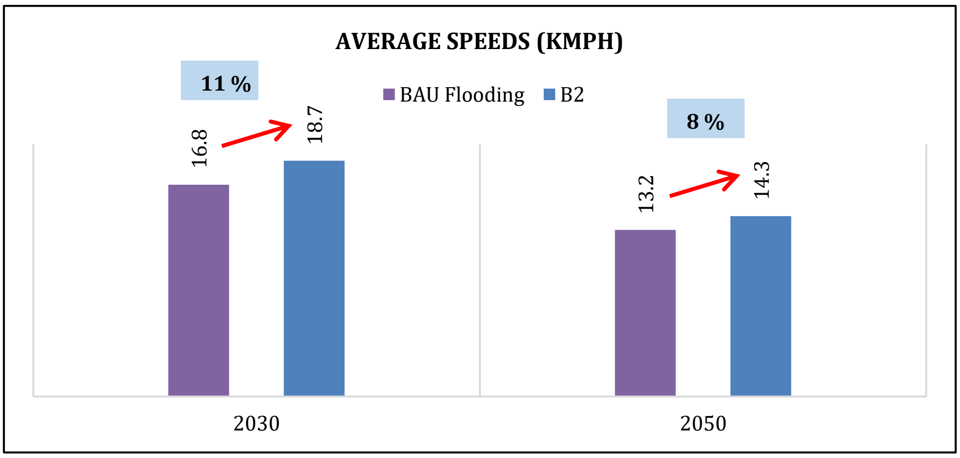


Figure 169: Comparison of travel speeds for BAU flood and Bundle 2 cases

8.8.4 Average Trip Lengths

The evaluation of policy bundle 2 shows that there is decrease in the average trip length by 1 km for both public and private transport.

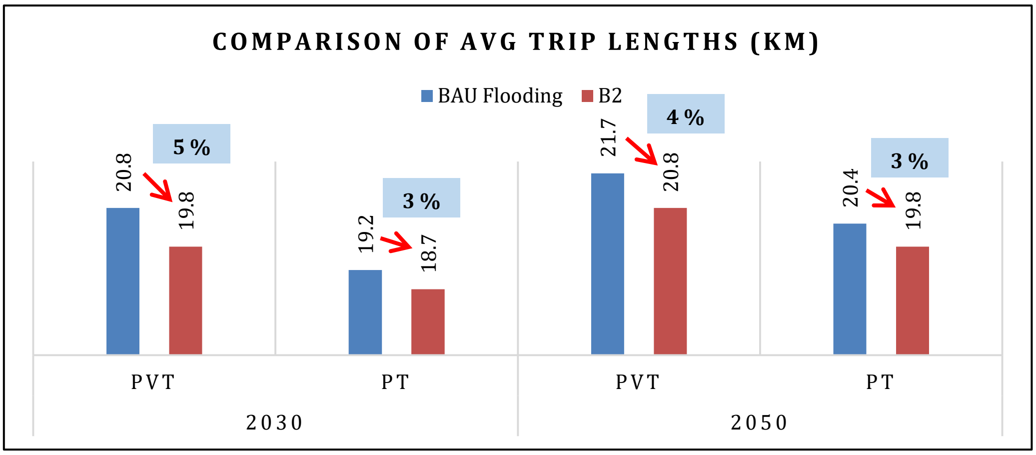


Figure 170: Comparison of average trip lengths for Private and Public transport BAU flooding and bundle 2 cases

8.8.5 Vehicle Hours Travelled (VHT)

There is very minimum reduction in VHT with the implementation of adaptation policy bundle 2.

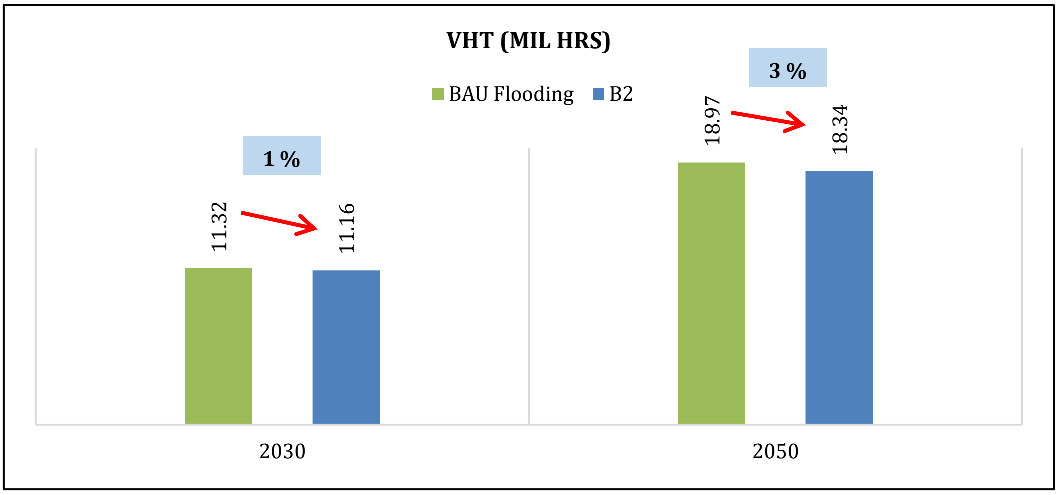


Figure 171: Vehicle Hours Travelled for flooded and Bundle 2

8.9 ADAPTATION POLICY BUNDLE 3 EVALUATION RESULTS

Table 54: Policy Bundle 3

BUNDLE 3
Replacement of impermeable surfaces with permeable material in vulnerable areas
Providing proper drainage facilities at vulnerable areas
Rerouting people during flooding

8.9.1Vehicle Kilometres travelled

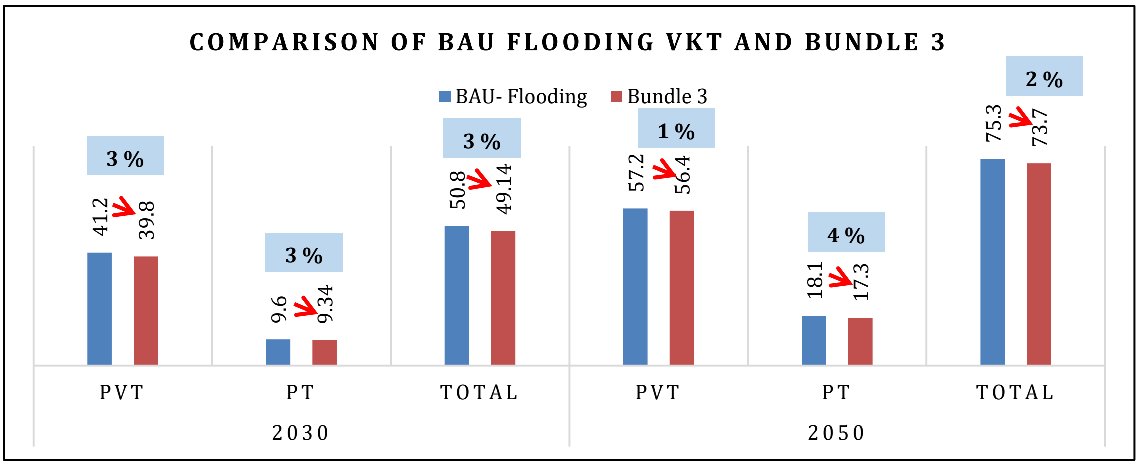


Figure 172: Comparison of BAU Flooding VKT and Bundle 3

8.9.2 Cancelled Trips

The number of cancelled trips has been reduced from 2.8% in BAU scenario to 1.3% with the implementation of bundle 3.

Table 55: Comparison of cancelled trips for BAU flood case and Bundle 3

Cancelled Trips			
Flooding	**% Trips Cancelled**	**B 3**	**% Trips Cancelled**
160786	2.8	80393	1.3

8.9.3 Average Travel Speeds

The evaluation of bundle 2 shows that the average travel speed increases to 20.2kmph and 17.6kmph for the years 2030 and 2050 with the implementation of these policies. Since, this policy involves providing proper drainage facilities and also improving the pavement surface there is considerable increase in the average vehicle speed.

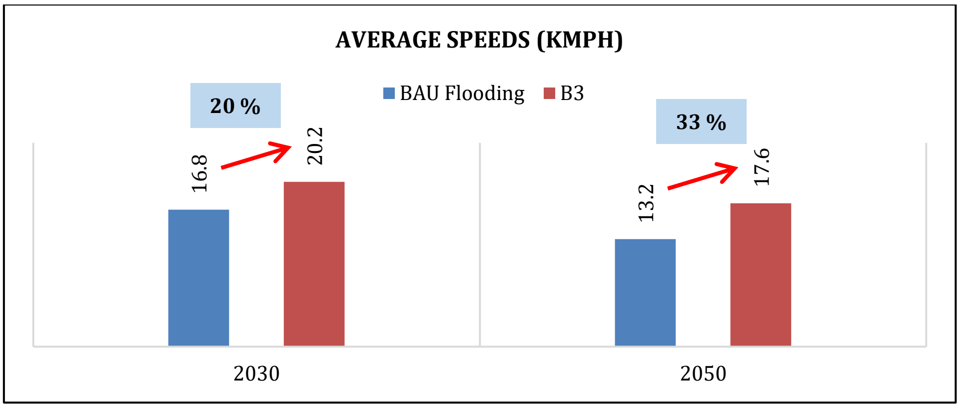


Figure 173: Comparison of travel speeds for BAU flooding and Bundle 3 cases

8.9.4 Average Trip Lengths

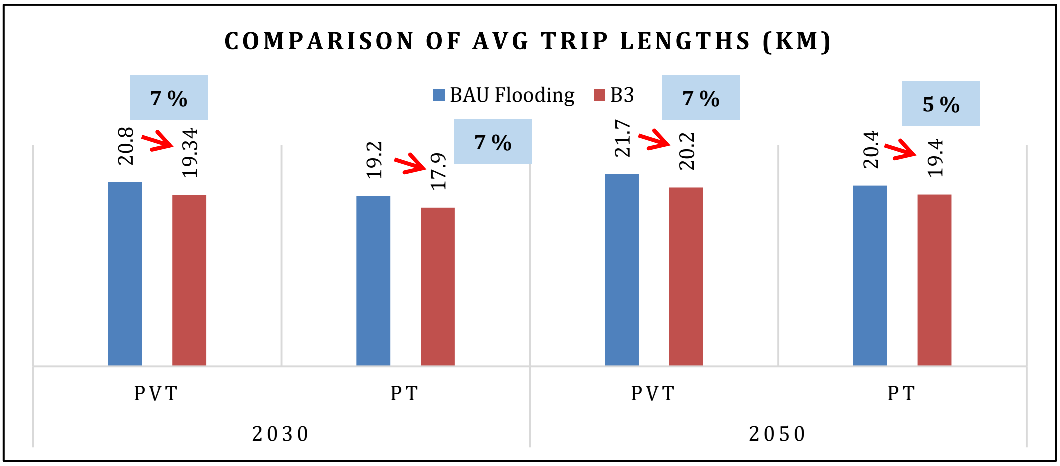


Figure 174: Comparison of average trip lengths for Private and Public transport BAU flooding and bundle 3 cases

8.9.5 Vehicle Hours Travelled

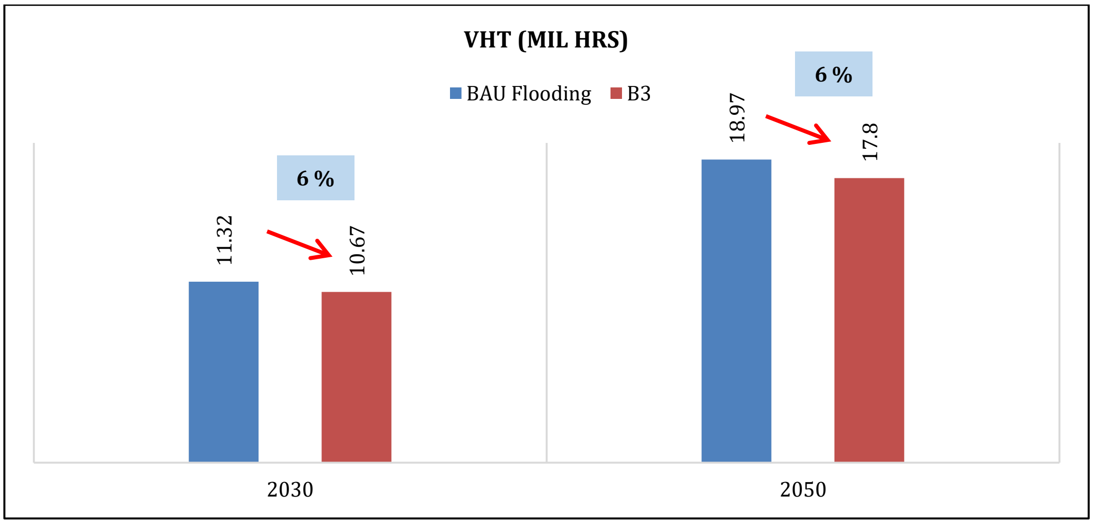


Figure 175: Vehicle Hours Travelled for flooded and Bundle 3

8.10 COMPARISON OF ADAPTATION POLICY BUNDLES RESULTS

8.10.1 Comparisons of VKT

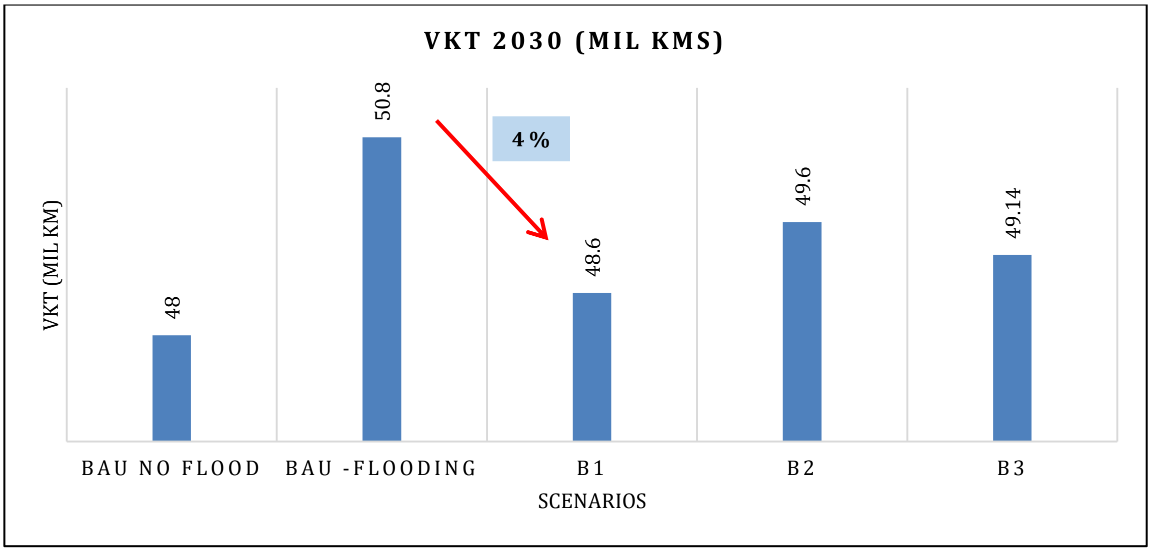


Figure 176: Comparison of VKT's between all scenarios for 2030

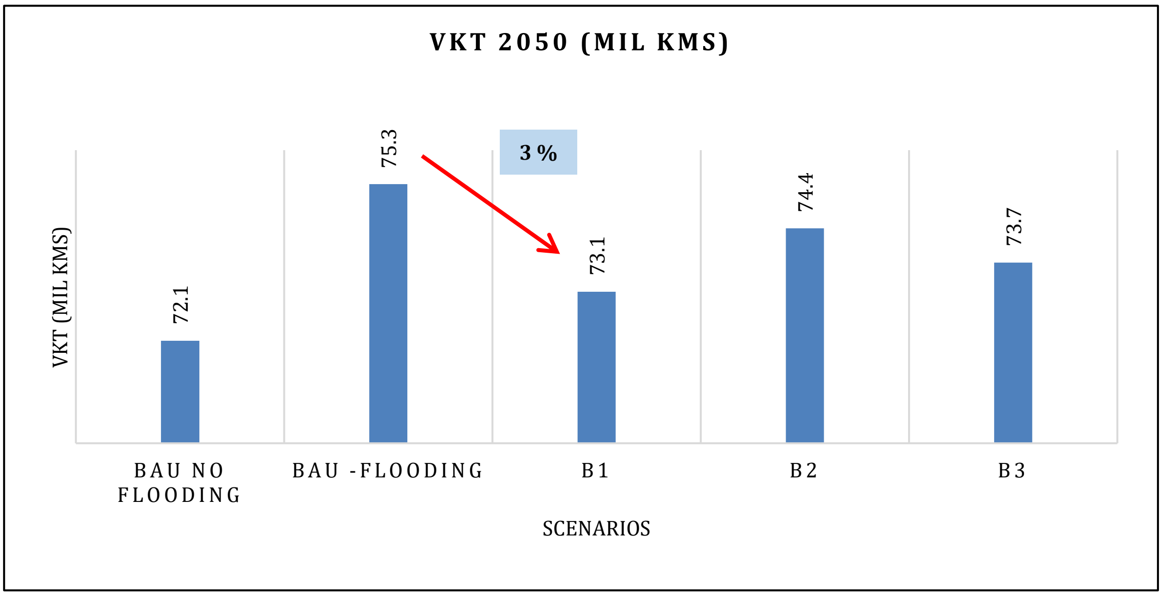


Figure 177: Comparison of VKT's between all scenarios for 2050

Bundle 1 gives the best result comparing to other policy bundles. There is 4% and 3% reduction in the vehicle kilometers travelled for the years 2030 and 2050 when comparing with the BAU flooding condition.

8.10.2 Comparison of Vehicle travel speeds

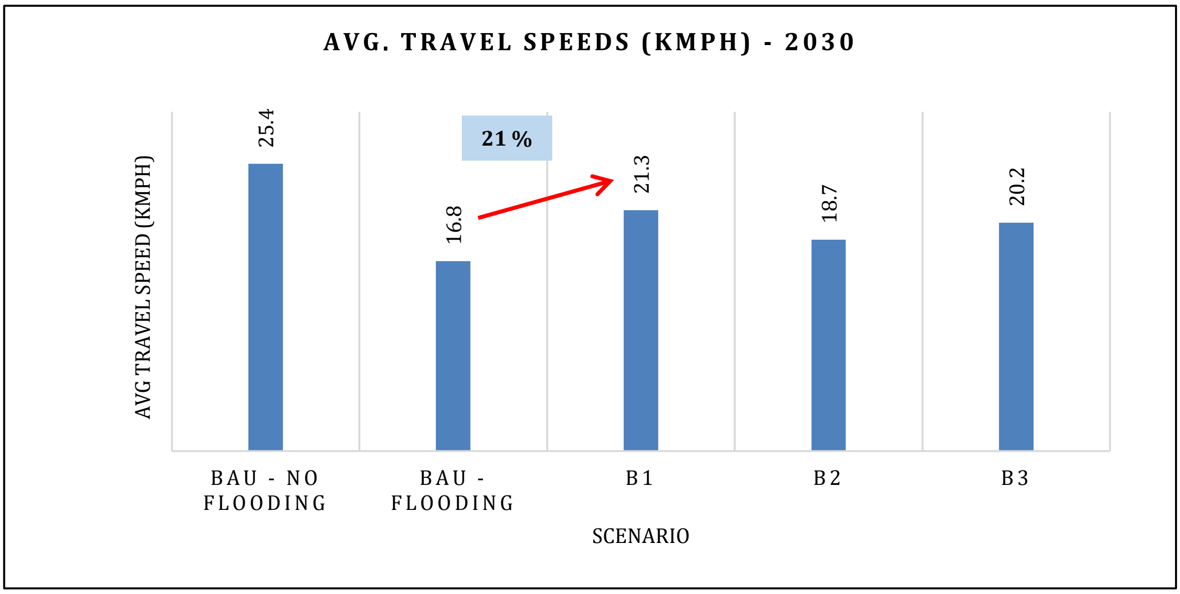


Figure 178: Comparison of Avg. travel speed of all scenarios for 2030

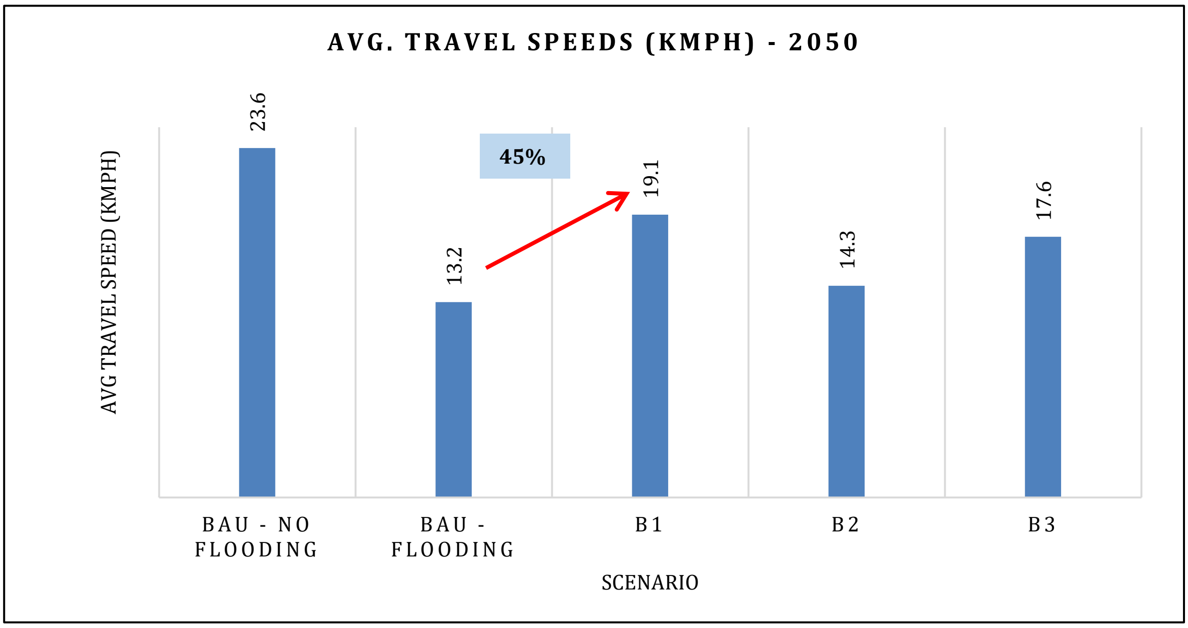


Figure 179: Comparison of Avg. travel speed of all scenarios for 2050

The policies in bundle 1 include both land use and infrastructure development and hence the average vehicle speed has been increased by 21% and 45% for the years 2030 and 2050 when comparing with the BAU flooding condition.

8.10.3 Comparison of average trip lengths

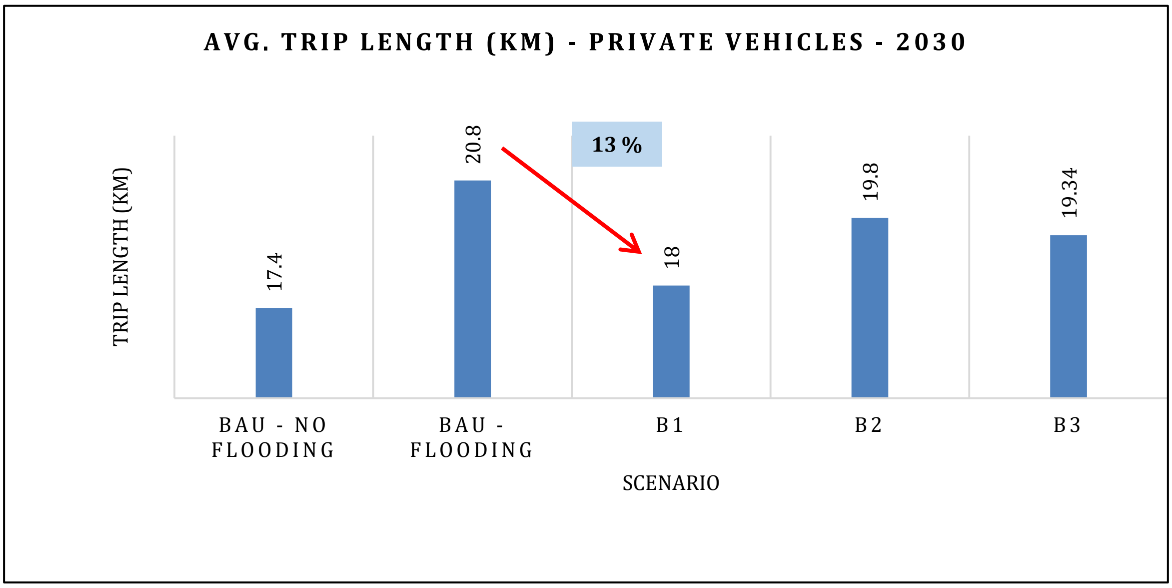


Figure 180: Comparison of Avg trip length of PVT vehicles for 2030

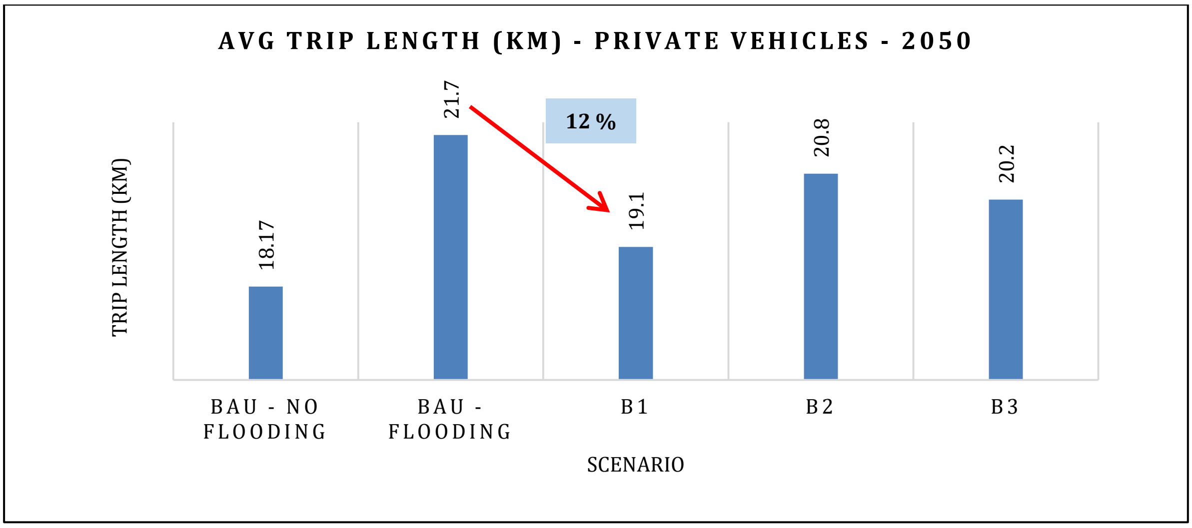


Figure 181: Comparison of Avg trip length of PVT vehicles for 2050

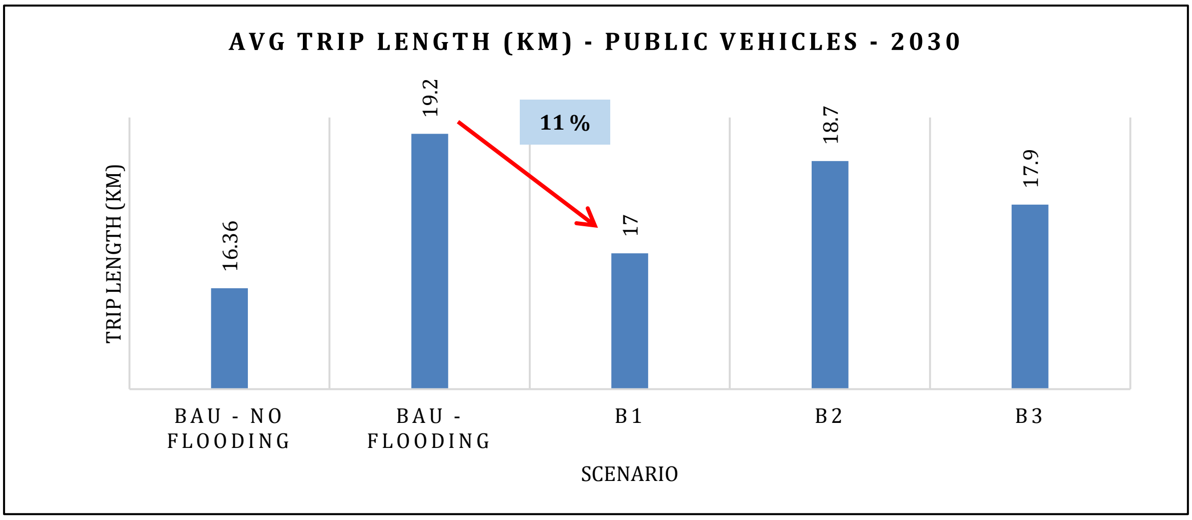


Figure 182: Comparison of Avg trip length of Public vehicles for 2030

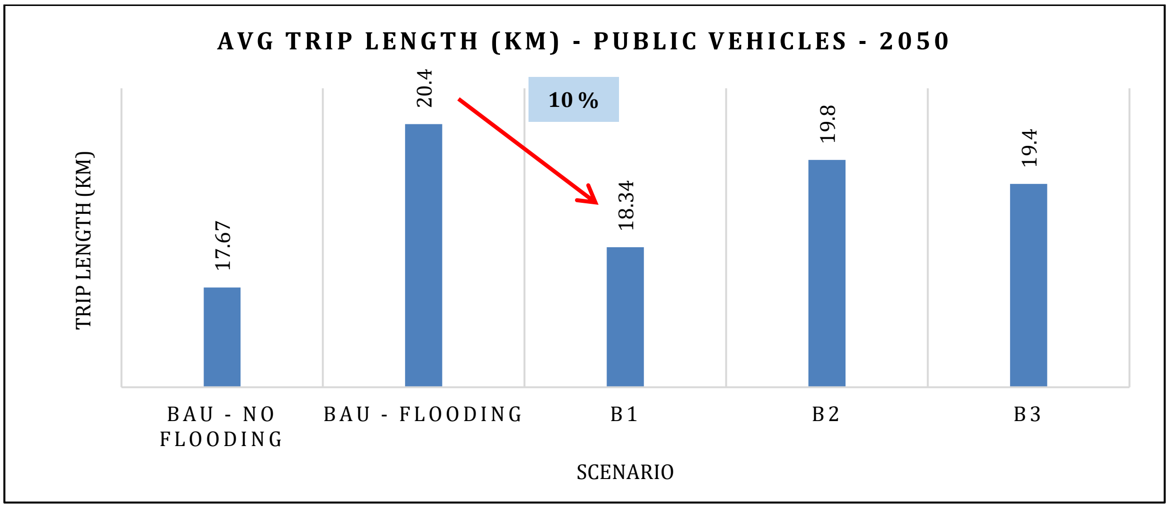


Figure 183: Comparison of Avg trip length of Public vehicles for 2050

Average trip lengths have reduced after implementing these adaptation policies. It is observed that Bundle has less average trip length for 2030 and 2050 making it the best bundle to use.

8.10.4 Comparison of Vehicle Hours Travelled

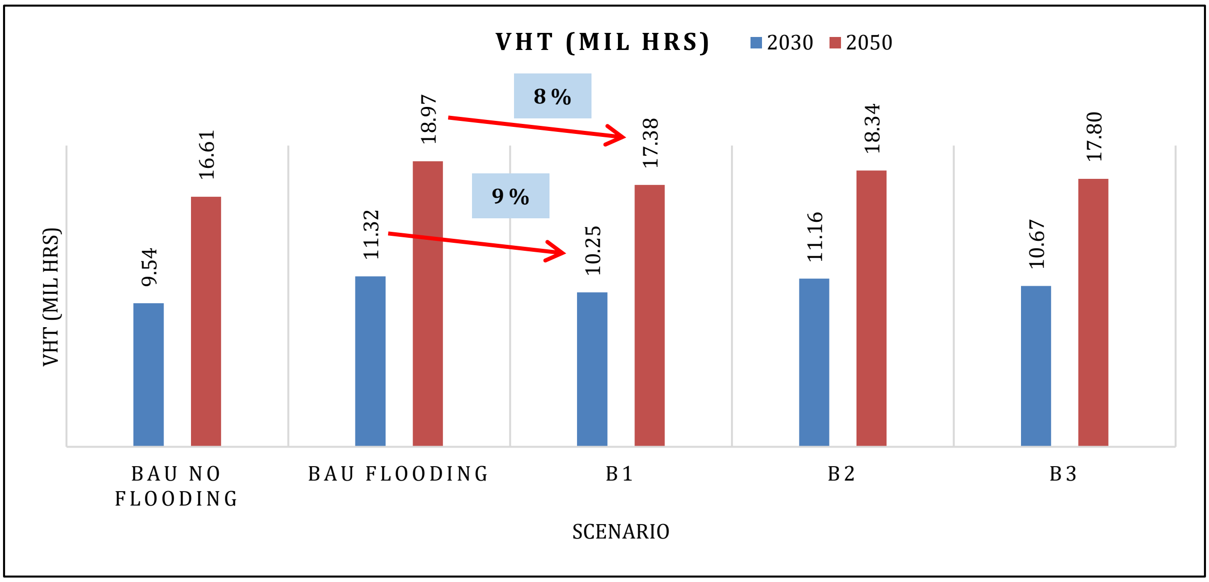


Figure 184: Comparison of VHT for BAU flood and BAU No flood scenarios and Policy Bundles for 2030 & 2050

There is 9% and 8% reduction in vehicle hours travelled with the implementation of policy bundle 1 compared to bundle 2 & 3 for the years 2030 & 2050 respectively.

8.10.5 Comparison of Cancelled Trips

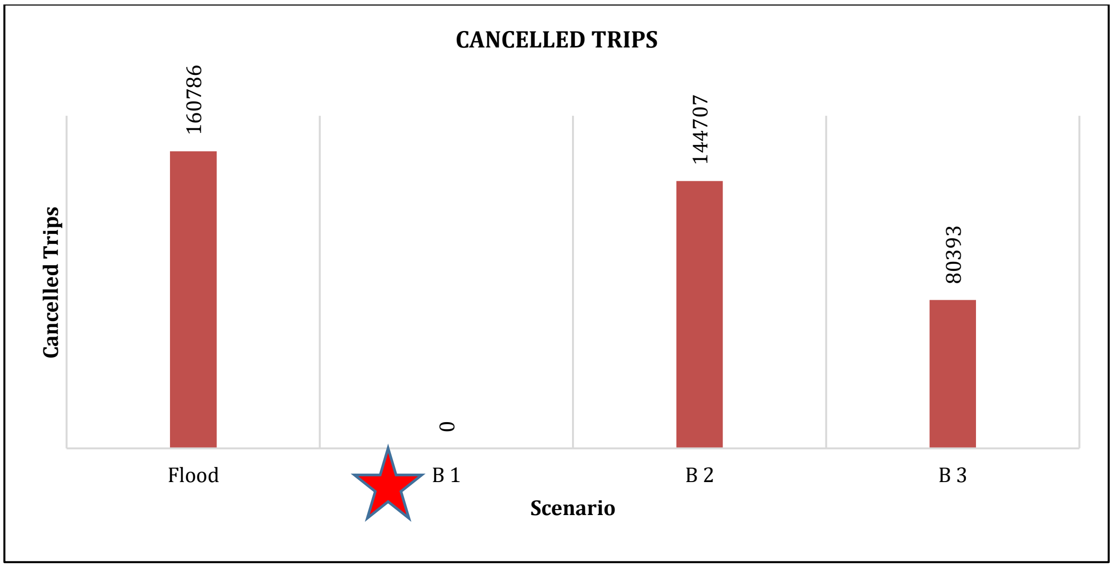


Figure 185: Comparison of cancelled Trips for Adaptation Bundles

The evaluation of policy bundles shows that with the implementation of policy bundle 1 the cancelled trips can be zero which means that no trips will get cancelled with these policies.

8.11 RESULTS AND DISCUSSIONS

In this chapter, adaptation modelling for urban transport identified locations that are vulnerable to flooding are identified using flood maps.

- It is clearly observed that the vehicle take longer paths than usual and some trips even get cancelled due to this. To address these issues 3 policy bundles have been formulated and evaluated for the flooding scenarios.
- It is observed from the results, that the policy bundle 1 is giving best results compared to bundle 2 and 3.
- By implementing bundle 1 it is seen that the average trip length of the vehicles reduced compared to BAU flooding scenario.
- Likewise total vehicle kilometres travelled and cancelled trips are less bundle 1 scenario compared to bundle 2 & 3.
- Zero cancelled trips are achieved with the implementation of bundle 1.

9 CONCLUSION

- This report contains the mitigation and adaptation measures that are quantitatively evaluated thereby improving the liveability of Bengaluru in terms of; reduced traffic congestion (VKT), reduced exhaust emissions (PM, CO, NO_X, HC), reduced greenhouse gas emissions (CO_2), reduced carbon emission intensity, increased consumer surplus of sustainable modes and also improved resiliency of transportation system.
- All the policies lead to a significant reduction in the total VKTs travelled when compared to the business as usual scenario.
- Total emissions from bus are higher compared to other modes. But when emissions are estimated in terms of per capita (per passenger km), they are considerably low.
- Bundle 3 (Bundle 4) which is a comprehensive mixture of 7 policies gives the best results with respect to VKT reduction, Improved Public Transport Share and reduction in emissions.
- The significant reduction in emissions is observed with the implementation of bundle 4-scenario 4 which includes the electrification of all buses and cars.
- Bundle 4 is a mixture of planning, regulatory, economic and technology instruments.
- The bundle 4 is evaluated with respect to four scenarios out of which the scenario 4 with the assumption that electricity will be produced 100% from the renewable sources shows substantial reduction in emissions.
- Thus, it is concluded and recommended that the implementation of bundle 4 along with scenario 4 will result in considerable reduction in emissions from transport sector. Although CO_2 emission factor values are zero in scenario 4 it is suggested that shifting towards mass transportation systems like Bus & Metro not only reduces the emissions but also reduces the congestion on the roads by a great amount.
- A proper amalgamation of **planning, regulatory, economic and technology** instruments incorporating the complete clean energy can help in improving the sustainability of transportation systems thereby enhancing liveability of the city.
- The bundle 4 – scenario 4 is implemented the total emission intensity will reduce by 91% for the year 2030 and 96% for 2050.
- The bundle 4 – scenario 4 is implemented the per-capita emission intensity will reduce by 94% for the year 2030 and 99% for 2050, highlighting that electrification of vehicles is the best solution with 100% electricity generation from renewable sources.

- Urbanization has led to reduction in the pervious area thus leading to urban flooding. Proper drainage facilities and using permeable roads at vulnerable locations can reduce the surface runoff on the roads and helps in a better movement of traffic.
- In adaptation policy bundles, it is observed that implementation of policy bundle 1 is more effective compared to bundle 2 & 3. It is suggested a proper mixture of land use and infrastructure related policies can help the city come out of the urban flooding muddle.
- Due to heavy flooding at certain locations it is observed that the trips from those zones are cancelled. One interesting thing observed in this study is that the implementation of Adaptation Bundle 1 resulted in zero cancelled trips. This clearly states that with a proper management of land use and infrastructure policies we can nullify the trips that get cancelled due to flooding and people can still make trips in such extreme events.

REFERENCES

1. Chandel M., “Estimation of Emission Factors for Different Vehicles” Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, 2018.
2. CSTEP (2015). Need for Government Support for Public Bus Transport (CSTEP-Report-2015-05)
3. Directorate of Census Operations Karnataka, "District Census Handbook Bangalore" 2011.
4. Directorate of Economics and Statistics, Bangalore,"State and District Domestic Product of Karnataka", 2014 - 15.
5. Groupe SCE India Pvt. Ltd., "Bangalore Metropolitan Region Revised Structure Plan - 2031"
6. Pregnolato M, Ford A, Glenis V, Wilkinson S., and Dawson R., "Impact of Climate Change on Disruption to Urban Transport Networks from Pluvial Flooding" Journal of Infrastructure Systems, 23(4), 2017.
7. Rahul T. M., and Verma A., “A study of acceptable trip distances using walking and cycling in Bangalore”, Journal of Transport Geography, vol. 38, pp. 106 - 113, 2014.
8. Ramachandra. T.V., Bharath Setturu and Bharath H. Aithal., 2012. "Peri-Urban to Urban Landscape Patterns Elucidation through Spatial Metrics", *International Journal of Engineering Research and Development*. Volume 2, Issue 12 (August 2012), pp. 58-81.
9. Transport Department, Government of Karnataka, "Annual Report", 2015 - 16.
10. Verma, Rahul T. M., and Dixit M., “Sustainability impact assessment of transportation policies – A case study for Bangalore city”, Case Studies on Transport Policy, vol. 3, pp. 321 - 330, 2015.
11. Wilbur Smith Associates, "Comprehensive Traffic and Transportation Study for Bangalore Metropolitan Region (CTTS)”, June 2010.
12. https://scroll.in/article/847397/how-bangalore-went-from-being-indias-most-liveable-city-to-a-dystopia-in-the-making
13. http://ces.iisc.ernet.in/energy/wetlands/sarea.html
14. https://www.mybmtc.com/en/bmtc_glance
15. http://english.bmrc.co.in/News/NewsSection

Which role shall the different transport modes play?

Push-and-Pull concept:
Which modes need support, which modes need restrictions?

Push: parking management, access restrictions, etc.
Pull: dense bus network, high quality bus services, etc.
Push and Pull: separate bus lanes, priority for buses at traffic signals, etc.

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