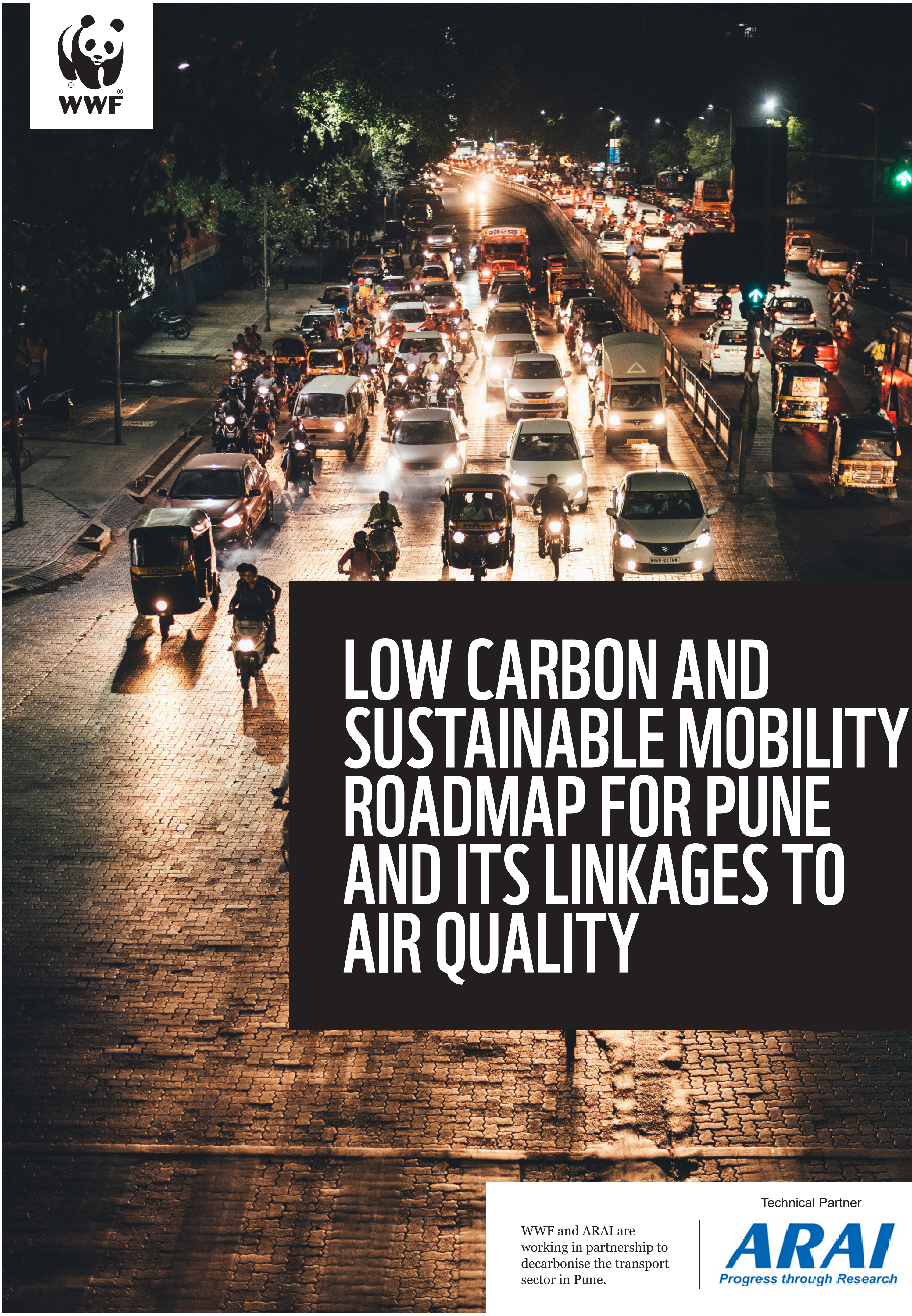

LOW CARBON AND SUSTAINABLE MOBILITY ROADMAP FOR PUNE AND ITS LINKAGES TO AIR QUALITY

WWF and ARAI are working in partnership to decarbonise the transport sector in Pune.

Technical Partner

ARAI

Progress through Research

ACKNOWLEDGEMENT

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AERMOD	AMS/EPA Regulatory Model
CAAQMS	Continuous Ambient Air Quality Monitoring Station
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CPCB	Central Pollution Control Board
E20	20% Ethanol blended Gasoline
EV	Electric Vehicles
HAS	High Ambition Scenario
HCMTR	High Capacity Mass Transit Corridor
HDV	Heavy Duty Vehicle
LAS	Low Ambition Scenario
LCV	Light Commercial Vehicle
MRTS	Mass Rapid Transit System
NAAQS	National Ambient Air Quality Standards
NAMP	National Ambient Monitoring Programme
NFC	No Further Control
NG	Natural Gas
NGV	Natural Gas Vehicles
NMB	Normalized Mean Bias
NMT	Non-Motorised Transport
NO_2	Nitrogen dioxide
NO_x	Oxides of Nitrogen
PM	Particulate Matter
PM_{10}	Particulate Matter having aerodynamic diameter less than or equal to 10 μm
$PM_{2.5}$	Particulate Matter having aerodynamic diameter less than or equal to 2.5 μm
PTI	Public Transport Improvement
RMSE	Root mean squared error
SHMO	Shared Mobility
SO_2	Sulphur dioxide
TPY	Tonnes per year
US EPA	United States Environmental Protection Agency
VKT	Vehicle Kilometres Travelled

THE TRANSPORTATION SECTOR IN INDIA PLAYS A VITAL ROLE IN ECONOMIC GROWTH CONTRIBUTING ABOUT 3.0 PER CENT TO THE NATION'S GROSS DOMESTIC PRODUCT AND CATERING TO THE NEED OF MORE THAN 1.1 BILLION PEOPLE AND FREIGHT TRANSPORT DEMANDS*

*(World Bank, 2005; Paladugula et al., 2018)


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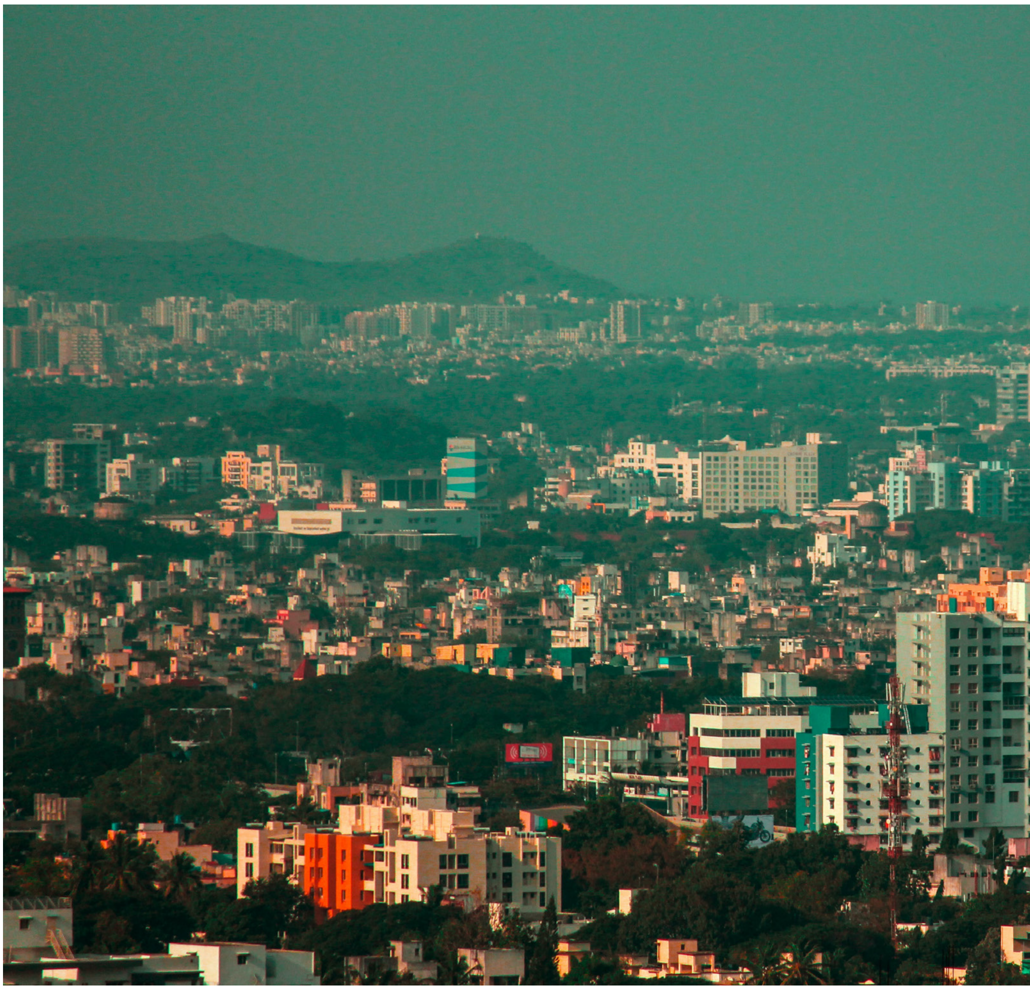
EXECUTIVE SUMMARY

The need of the times to address the growing issue of climate change necessitates reduction in emissions from the Indian transport sector as well. Consequently, FICCI, along with knowledge partners - WWF-India, Paris Process on Mobility and Climate (PPMC) and Shakti Sustainable Energy Foundation (SSEF) prepared a roadmap to provide directional inputs for policy interventions in India on 'Low Carbon and Sustainable Mobility with thrust on decarbonisation of the Indian transport sector'. The India roadmap made relevant recommendations for rapidly growing urban cities like Pune. These recommendations were primarily concerned with matters of policy, regulations and standards; technology; governance and institutional aspects, and infrastructure related control interventions for reducing emissions from the transport sector.



Pune city a.k.a. 'The Oxford of the East', is the second-largest urban agglomeration in Maharashtra after Mumbai

Recommendations for controlling air pollution from transport sector in urban centres are mainly targeted to achieve reduction in tailpipe emissions (technology options) and reduction in travel demand or vehicle kilometres travelled (management options) of different categories of vehicles.

During the initial phase, a stakeholder consultation workshop was conducted to disseminate information on India road map and to get views/ opinions of stakeholders on the relevant transport sector emission control interventions for Pune.

Accordingly, the following eight control interventions for transport sector were evaluated for Pune city, for their pollution reduction potential in the short term (Year 2025) and Mid-term (Year 2030):-

1. Impact of BS VI implementation (BS-VI)
2. Roll-out of E20 fuel (E20)
3. Increased penetration of Electric Vehicles (EV)
4. Non-motorised transport (NMT)
5. Use of Metro rail services for public transport (METRO-Mass rapid transit system)
6. Improved public transport system (PTI)
7. Increased Shared Mobility (SHMO)
8. Implementation of HCMTR corridor (HCMTR)

Additionally, three future scenarios (for Year 2025 and Year 2030), were designed with varying levels of application. These are:

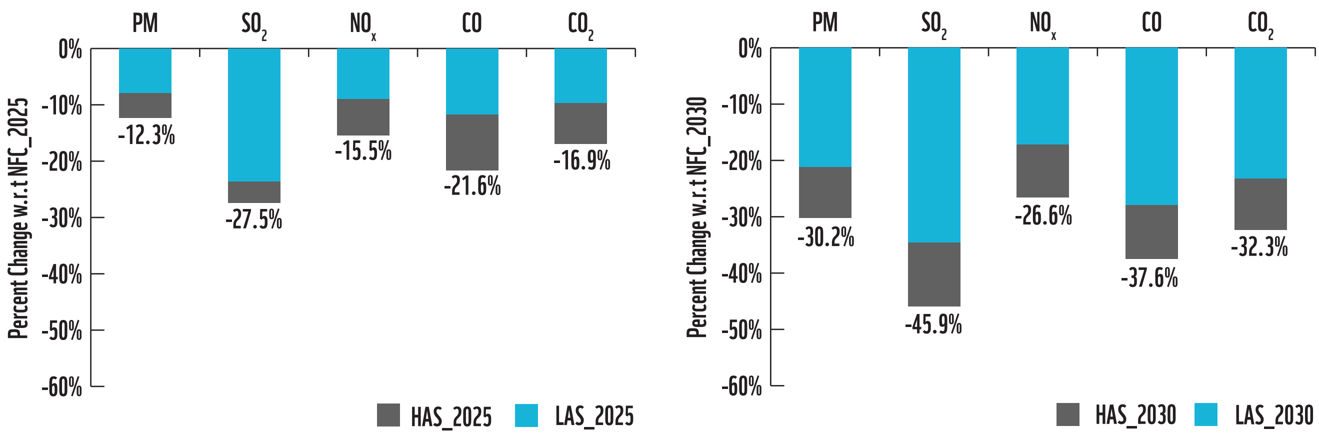
1. The **No Further Control (NFC)** scenario: This scenario assumes that policy measures and associated technologies already adopted, would continue in future years 2025 and 2030 and no other improvements would take place.

1. The **Low Ambition Scenario (LAS)**: This represents policies and technologies that are planned or in pipeline and could be implemented by 2025 and 2030, respectively.

1. The **High Ambition Scenario (HAS)**: This represents a bunch of policy measures considered in LAS that could be adopted in Pune city more aggressively by 2025-and 2030, in order to get additional emission reductions.

The bottom-up approach was used for generation of gridded (2 km x 2 km) baseline emission inventory for Pune (including new villages added recently) in 2021. The pollutants being considered include $PM_{2.5}$, PM_{10}, CO, NO_x, SO_2, and CO_2.

Fig. I: Estimated potential changes (in percentage) in vehicular exhaust emissions of selected pollutants in years 2025 and 2030.



Activity data of vehicle kilometres travelled by various categories of vehicles (two-wheelers, three-wheelers, cars, LCV, HDV, buses) was calculated in all the grids using road lengths and traffic flow for different road types (highways, major, minor and residential). Fleet composition including information on vehicle type, size, fuel type, age and emission control technologies was generated using registration data and primary data of vehicle counts on different road types.

Emission factors previously developed by Automotive Research Association of India (ARAI) during 2010 and 2018 were used. As BS-VI vehicles were recently introduced in 2020, the mass emission factors for in-service vehicles in India were not available. Hence, emission factors for such vehicles were derived using BS-VI emission limits. Pollutant-wise emission reduction potential for different control interventions were used from literature data after quality assurance.

Future projections of vehicle numbers, for year 2022 to 2030, were made using historical data on yearly and cumulative vehicle registration in Pune RTO office starting from 1998 till 2021.

The pollutant-wise per cent reduction in tail-pipe emissions (tonnes per year) is evaluated with respect to NFC scenario to represent impact of control interventions (Figure I). It is important to note that the vehicular exhaust PM emissions predominantly consist of fine particles having aerodynamic diameter less than or equal to 2.5 µm. Therefore, vehicular exhaust emission factors available for Indian vehicles are assumed to be same for $PM_{2.5}$ and PM_{10}. Hence, in this report, a common term, particulate matter (PM) is used to describe the particulates from vehicle exhaust.

Impact of individual control interventions, from transport sector, in tail-pipe emissions (tonnes per year) of selected pollutants under different scenarios has been presented below in Figure II.

Fig. II: The control-intervention-wise estimated potential percentage change in vehicular exhaust emissions for LAS and HAS in 2025 and 2030, respectively

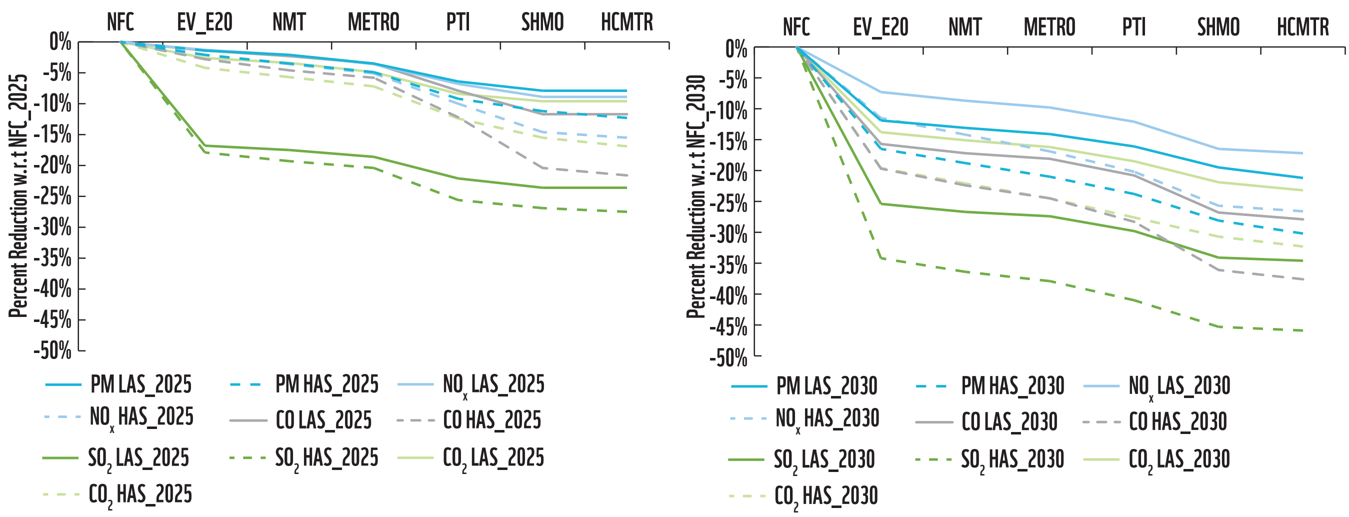
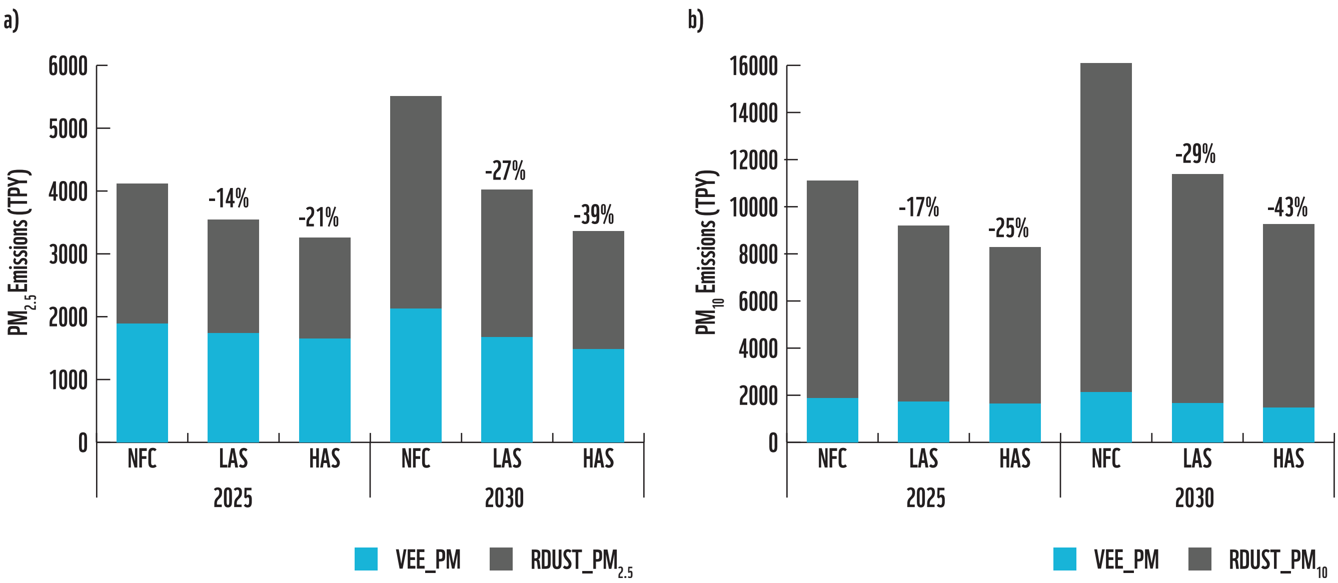


Fig. III: Changes in $PM_{2.5}$ (a) and PM_{10} (b) emissions from vehicular exhaust and re-suspended road dust with NFC, LAS and HAS in 2025 and 2030. The numbers on top of bars indicate potential percent reduction compared to respective NFC scenarios.

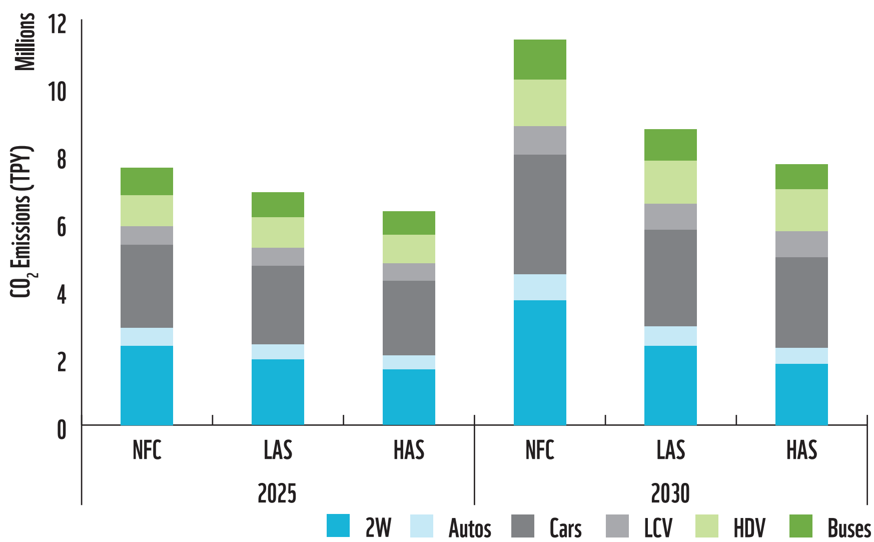


Re-suspended road dust is one of the major contributors to particulate matter emissions in Pune city and is directly related to on-road vehicle activity. Re-suspension of road dust is reduced either by reduction in VKT and/or reduction in silt loading on different types of roads. The combined impact of reducing vehicular exhaust emissions and road dust re-suspension is also evaluated for $PM_{2.5}$ and PM_{10} emissions in Pune and the results are presented below in Figure III .

Carbon dioxide emissions from vehicle exhaust are not only associated with air pollution but are also one of the key factors responsible for climate change. Carbon dioxide emission loads (tonnes per year) for transport sector were calculated for the above three scenarios for 2025 and 2030 and are presented in Figure IV. Substantial reduction in CO_2 emission loads were observed as a result of control interventions, which will also benefit in terms of climate change mitigation.

Emission loads (tonnes per year) for all the sectors including transport, residential, industrial, etc. for various scenarios were used for assessment of impact on ambient air quality (µg/m³). Dispersion modelling was taken up using AERMOD system and air quality benefits of LAS and HAS were assessed for 2025 and 2030. It is important to note that dispersion modelling included emission changes in both vehicular exhaust and re-suspended road dust. The potential predicted change in annual average pollutant concentrations at selected locations in Pune is presented in Table I and II.

Fig. IV: Vehicle category-wise projected emissions of carbon dioxide (CO_2) with NFC, LAS and HAS in 2025 and 2030



RE-SUSPENDED ROAD DUST IS ONE OF THE MAJOR CONTRIBUTORS TO PARTICULATE MATTER EMISSIONS IN PUNE CITY AND IS DIRECTLY RELATED TO ON-ROAD VEHICLE ACTIVITY.

Table I: AERMOD predicted air pollutant concentrations (μg/m³) at selected locations for NFC, LAS and HAS scenarios in 2025. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)						
Location	**Scenario**	**$PM_{2.5}$**	**PM_{10}**	**NO_2**	**CO**	**SO_2**
Karve Road	**NFC**	32.8	86.5	34.3	333.3	11.9
	LAS	29.1 (-11.2%)	73.1 (-15.6%)	31.7 (-7.4%)	298.2 (-10.5%)	11.8 (-0.4%)
	HAS	28.5 (-13%)	69.9 (-19.3%)	30.6 (-10.8%)	280 (-16%)	11.8 (-0.4%)
Nal Stop	**NFC**	32.9	86.8	35.4	335.8	11.5
	LAS	29.2 (-11.3%)	73.1 (-15.8%)	32.9 (-7.2%)	300.0 (-10.6%)	11.5 (-0.4%)
	HAS	28.8 (-12.4%)	70.3 (-19%)	31.3 (-11.6%)	282.6 (-15.9%)	11.5 (-0.4%)
Swargate	**NFC**	40.7	106.8	43.7	420.3	13.9
	LAS	36.1 (-11.3%)	90.1 (-15.7%)	40.6 (-7.2%)	376.2 (-10.5%)	13.9 (-0.4%)
	HAS	34.6 (-15%)	84.7 (-20.7%)	39.1 (-10.7%)	344.8 (-18%)	13.9 (-0.5%)

Table II: AERMOD predicted air pollutant concentrations (μg/m³) at selected locations for NFC, LAS and HAS scenarios in 2030. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)						
Location	**Scenario**	**$PM_{2.5}$**	**PM_{10}**	**NO_2**	**CO**	**SO_2**
Karve Road	**NFC**	40.8	116.8	35.9	396.0	12.7
	LAS	29.8 (-26.9%)	83.8 (-28.2%)	31.6 (-11.8%)	286.1 (-27.8%)	12.6 (-0.7%)
	HAS	29.1 (-28.6%)	74.3 (-36.4%)	30.5 (-15.1%)	272.2 (-31.3%)	12.6 (-0.9%)
Nal Stop	**NFC**	40.9	117.0	37.1	397.7	12.2
	LAS	29.8 (-27.1%)	83.9 (-28.3%)	33.5 (-9.9%)	287.7 (-27.7%)	12.1 (-0.7%)
	HAS	29.4 (-28.2%)	74.7 (-36.2%)	32.5 (-12.5%)	275.1 (-30.8%)	12.1 (-0.9%)
Swargate	**NFC**	50.1	143.5	45.5	497.0	14.4
	LAS	35.5 (-29.2%)	100.6 (-29.9%)	38.4 (-15.5%)	345.2 (-30.6%)	14.3 (-0.8%)
	HAS	34.7 (-30.7%)	88.8 (-38.1%)	36.6 (-19.5%)	325.8 (-34.5%)	14.3 (-1.1%)

The dispersion modelling results suggest that even if stringent control interventions in vehicular sector are implemented in Pune, it is difficult to achieve the NAAQS for pollutants such as PM_{10}. Several control actions/ measures in other sectors such as construction, industries, residential, and open waste burning must also be introduced to reduce the PM_{10} concentrations at city level.

The information generated in this study, on probable impacts of various control interventions from transport sector, can provide useful insights on benefits that can be accrued in terms of reduction in air pollution for different pollutants.

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INTRODUCTION

The transportation sector in India plays a vital role in economic growth contributing about 3.0 per cent to the nation's Gross Domestic Product and catering to the need of more than 1.1 billion people and freight transport demands (*World Bank,* 2005*; Paladugula* et al., 2018). The transportation sector in India has observed an exponential growth since independence and the number of vehicles on road has been rising at an alarming rate, especially in urban areas. According to a recent analysis, the total vehicle sales (including motorcycles) increased from about 10 million in 2007 to over 21 million in 2016, and it is further expected to reach 200 million by 2030 (*ICCT,* 2021). With ever-increasing demand for transportation, the transportation sector in India has been one of the main causes of air pollution and climate change (*CPCB,* 2010*; FICCI,* 2020).

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1.1 LINKAGES BETWEEN AIR POLLUTION AND CLIMATE CHANGE

The extraction and burning of fossil fuels as the main sources of carbon dioxide emissions are not only key drivers of climate change, but are also major sources of air pollutants. Though the issues of climate change and air pollution are usually addressed independently, an integrated approach for tackling both the issues will certainly accrue long-term benefits for the environment as well as human health. Such integrated strategies, targeting both climate change and air pollution, will result in reduction of resources required for administration and implementation.

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This roadmap emphasises the need to deliver a concerted and holistic pathway towards the decarbonisation of the mobility sector by setting a strategic direction towards policy formulation and effective implementation

1.2 CO-BENEFITS OF ADDRESSING AIR POLLUTION AND CLIMATE CHANGE

Electrification of vehicles directly reduces air pollutants in addition to the reduction in carbon dioxide emissions, particularly in densely populated areas in the urban centres. However, for effective long-term benefits, it must be coupled with the policies and emission standards for internal combustion engines and power generation using coal as a fuel. In addition, focused approach and structured actions towards increasing share of renewable sources in the overall power generation mix is imperative. Impact of electrification, advanced vehicle emission standards (BS-VI) along with power sector's revised emission standard provide insights for extracting optimum benefits of electrification.

1.3 LOW CARBON SUSTAINABLE MOBILITY - INDIA ROADMAP

To reduce emissions from the Indian transport sector, FICCI, along with knowledge partners, WWF-India, Paris Process on Mobility and Climate (PPMC), and Shakti Sustainable Energy Foundation (SSEF) has prepared a roadmap for providing directional inputs for policy interventions for India on 'Low Carbon and Sustainable Mobility with thrust on decarbonisation of the Indian transport sector'. This roadmap emphasises the need to deliver a concerted and holistic pathway towards the decarbonisation of the mobility sector by setting a strategic direction towards policy formulation and effective implementation. The roadmap provides the clear thrust needed on public transportation, shifting the paradigm to the movement of people more than the paradigm of movement of vehicles as the effective means to reduce congestion, air pollution, and vehicle kilometres. It provides a direction for greater policy visibility on India's low carbon and sustainable mobility ecosystem through an integrated approach and actionable recommendations for the short-, medium-, and long-term (*FICCI, 2020*).

The India Roadmap provides actionable recommendations on various components including, (a) Urban transformation for healthier, inclusive lifestyles and efficient, resilient, prosperous cities; (b) Low-carbon energy supply strategy; (c) Improve intermodal and mode-wise system efficiencies; (d) Optimise supply chains to manage freight transport emissions; (e) Avoid vehicle kilometres for commuting, shopping and accessing services; (f) Provide low-carbon solutions for the rural (non-urban) populations; (g) Accelerate action on adaptation in the transport sector; and (h) Large-scale deployment of economic instruments and leveraging finance. India roadmap can be referred to at: URL: https://ficci.in/spdocument/23273/India-Roadmap-on-LCSM.pdf for details of the challenges in decarbonisation of transport sector and recommendations made for short-, mid- and long-term.

While India Roadmap makes overarching recommendations for reduction of emissions from transport sector, recommendations relevant for rapidly growing urban centres like Pune city are presented in Annexure I.

1.4 ABOUT PUNE

Pune city a.k.a. 'The Oxford of the East', is the second-largest urban agglomeration grown in Maharashtra after Mumbai. Pune has not only made its remarkable contribution in the education sector over extensive period of time. Currently, it has also become home to various industrial sectors comprising Information Technology (IT), Engineering and Automotive industries. There are hundreds of large- and small-scale IT companies in Pune along with well-established sugar, glass, and forging industries in the region.

GEOGRAPHY

Pune city is situated at the elevation of approximately 560 m above mean sea level, in the Sahyadri's Western Ghats on the west coast of India. Pune Municipal Corporation (PMC) is the local governing body for Pune city. In 2011, PMC limits covered an area of ~243 sq. km. PMC limits have been expanding in the last decade. Eleven new villages were added to PMC limits in 2017 and another 23 villages were added in 2021. With inclusion of 23 villages in PMC limits, the current geographical area of Pune city has now expanded to ~519 sq. km. Figure 1 shows a map of Pune city with revised limits and cantonment boards.

Fig. 1: Map showing Pune city with old wards and newly added villages along with two cantonment boards

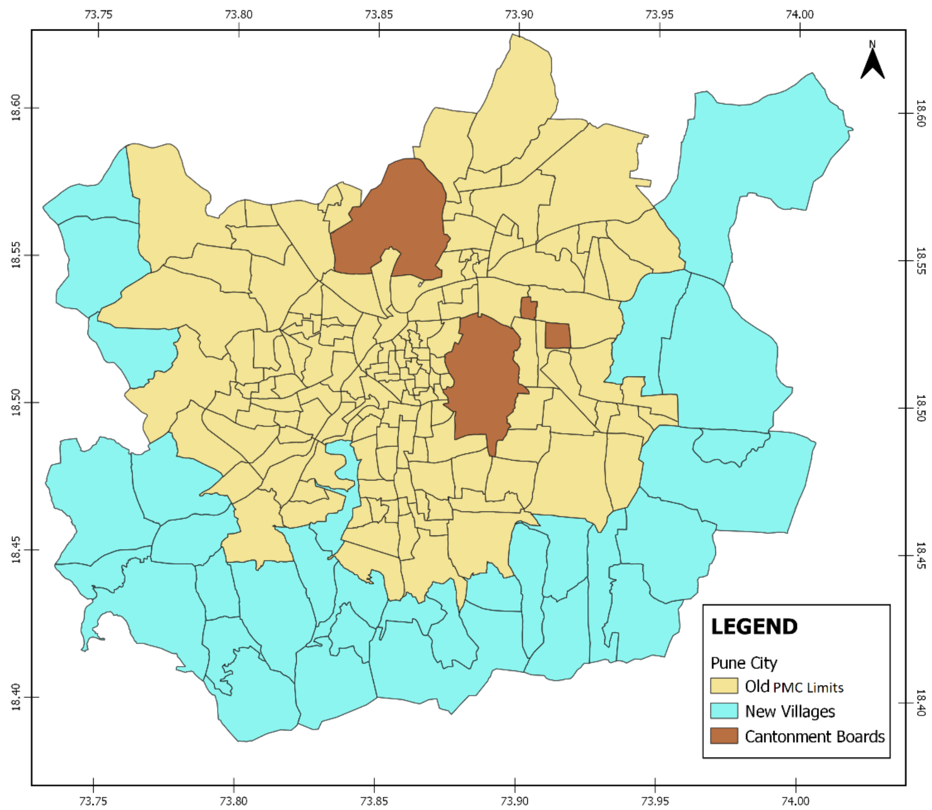
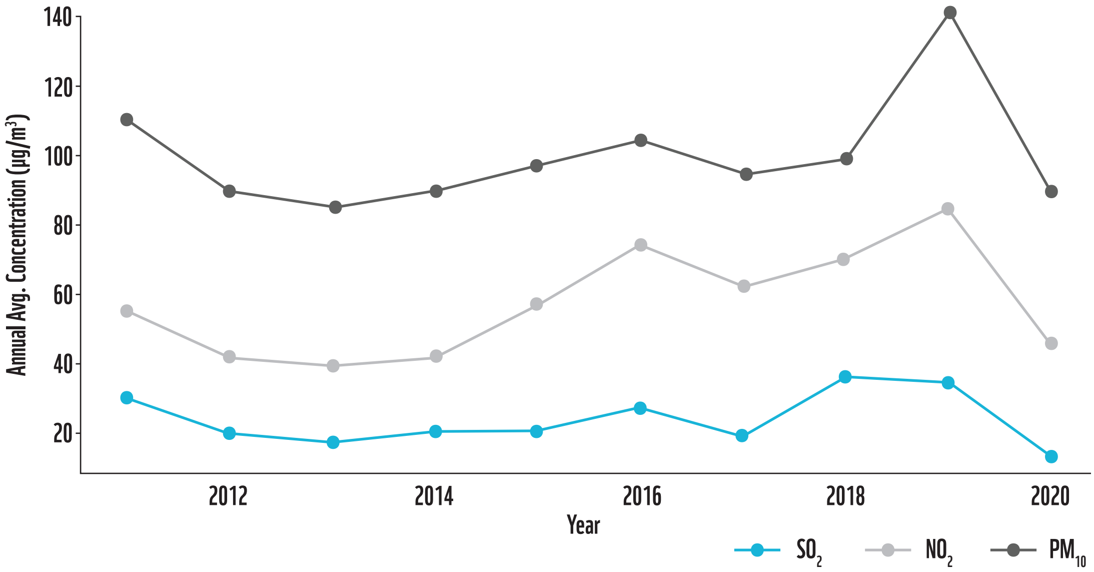


Fig. 2: Time-series plot showing annual average concentrations of SO_2, NO_2 and PM_{10} observed in Pune city under National Ambient Monitoring Program (NAMP)



CLIMATE

Pune experiences three distinct seasons: summer, monsoon and winter. Typical summer season is from March to May, with maximum temperatures ranging from 35 °C to 39 °C and with high diurnal variations in temperatures. The prominent wind directions of Pune city are westerly and north-westerly.

DEMOGRAPHY

According to the Census in 2011, Pune city hosted a population of 31.15 lakh. With the inclusion of 34 new villages during the last decade, the total population would have grown to ~37.72 lakh as per Census 2011. The population in Pune is estimated to reach ~55.11 lakh in 2021. Increasing population and urbanisation are the main contributors to the rising air pollution levels in the city.

AIR QUALITY

Figure 2 presents the trend of annual average air pollutants observed in Pune city. The annual average concentration is calculated using air quality data from three stations operated by CPCB/ MPCB i.e. Karve Road, Nal stop, and Swargate. Pune can be considered as a non-attainment city due to violation of NAAQS in terms of PM_{10} (60 µg/m³) and NO_2 (40 µg/m³). The annual average concentration of SO_2 did not exceed the annual limit (50 µg/m³) during the period from 2011 to 2020. The trend depicts an increase in air pollutants in PM_{10} and NO_2 with 2019 experiencing the highest annual concentrations of PM_{10} (143.0 µg/m³) and NO_2 (86.7 µg/m³). The spike in PM_{10} and NO_2 concentrations in 2019 could be partially attributed to the ongoing Pune metro construction activities near Nal stop and Swargate monitoring stations.

The Covid-19 pandemic-spurred lockdown to control the Corona virus disease in Pune from 21st March, 2020 onwards, resulting in the lowest levels of air pollutants during the last decade. Sathe et al. (2021) also reported about 62 per cent reduction in PM_{10} concentrations in Pune city primarily due to the reduction in vehicular activity which not only prevented the exhaust emissions but also reduced non-exhaust emissions (tyre, brake and clutch wear) and re-suspended road dust. Further, the absence of construction activities during the lockdown period also resulted in lowered PM_{10} concentrations. The reduction in NO_2 and SO_2 concentrations during the lockdown could be mainly attributed to restrictions on vehicular movement and ban on industrial operations.

CONTROL ACTIONS FOR AIR POLLUTION

The transport sector contributes significantly to air pollutants such as $PM_{2.5}$ (45.6 per cent), PM_{10} (25.2 per cent), NO_x (73.3 per cent), CO (66.3 per cent), SO_2 (15.8 per cent) and VOCs (77.1 per cent) in the Pune region (*IITM, 2020*). To control emissions from the transport sector, several policy regulations such as introduction of BS-VI emission norms have been already implemented and use of alternative fuels such as E20 will be implemented in near future at national level. Apart from this, there are multiple actions being taken in Pune city to reduce air pollution (*PMC,* 2021a).

ALTERNATIVE FUELS

Promotion of CNG in city

Considering the increase in requirement of fossil fuels like gasoline and diesel for vehicles in the city, Pune Municipal Corporation is promoting the use of CNG, especially for auto-rickshaws. The auto-rickshaws using gasoline and diesel are given a subsidy of INR 12,000 for conversion to CNG. The scheme was going on from 2011 till 2018. About 16,533 autos have taken benefit of this scheme.

Encouraging more CNG stations within city

There are about 79 CNG stations currently operational in city in nearby areas. The total CNG consumption has gone up to 1,52,000 MT in year 2019-20.

Encouraging registration of CNG based vehicles

As on March 2018, the CNG based registered vehicles are: 30,670 three wheelers, 36,888 four wheelers and 1226 public transport buses. When CNG was launched by Maharashtra Natural Gas Ltd. in the city in 2011, the consumption was barely 20,000 MT per year. With increase in availability, the consumption of CNG has also gone up and many citizens are now using CNG based vehicles.

Purchasing of new CNG buses for public transport.

Out of a current fleet of 2431 public transport buses, 1759 buses are CNG powered and about 233 mid-sized diesel buses will be converted to CNG in near future.

The Pune Cycle Plan prepared in 2016 to help make Pune a cycle-friendly city has made significant progress over the past years by achieving approximately

300 km

bicycle track in the city.

PUBLIC TRANSPORT

Public Transport Buses

Pune Mahanagar Parivahan Mahamandal Ltd. (PMPML) is the public transport bus provider service in Pune city. The city buses are witnessing a change from diesel buses to CNG. More than 50 per cent of buses are running on CNG. Recently, around 150 electric buses have been added to the fleet. Additionally, PMC is planning to add about 500 more e-buses in the near future.

Phasing out Bus Fleet

The city buses that have been plying on the roads for more than 12 years, are being phased out from service on periodic basis.

Metro Rail Transport

The proposed metro rail system comprises three lines with a total length of 54.58 km. The 16.59 km Line 1 PCMC Bhavan – Swargate will be elevated between PCMC Bhavan to Range Hills, from where it will run underground. Line 2 will run from Vanaz to Ramwadi covering a distance of 14.66 km on an elevated viaduct (DMRC, 2015). The 23.33-km elevated Line 3 will run from the Rajiv Gandhi Infotech Park in Hinjewadi via Balewadi to Civil Court (DMRC, 2016). A few stretches of Pune metro rail are expected to be operational by 2023.

NON-MOTORISED TRANSPORT (NMT)

Pune Cycle Plan was prepared in 2016 to help make Pune a cycle-friendly city and significant progress has been made over the past years to achieve approximately 300 km bicycle track in the city (PMC, 2021b).

TRAFFIC MANAGEMENT

PMC, along with relevant stakeholders, is taking up several steps including synchronisation of traffic movements, introduction of Intelligent Traffic systems for lane driving, action plan for widening of road and improvement of infrastructure for decongestion of Roads, and maintaining pothole-free roads for easy flow of traffic.

STREET DESIGN

The new roads are constructed as per the urban street design guidelines. These guidelines include the latest technologies in road development as well as the specifications given under Indian Road Congress guidelines and National Urban Transport Policy. The selected roads in the city are designed to include cycle tracks, footpaths, service ducts, storm water drain etc. In addition, PMC is also working on black topping of metaled roads including pavement of road shoulders.

CREATING AWARENESS

Given that children are extremely vulnerable to air pollution with their developing lungs and bodies, focused activities on health risk communication to protect children is critical. SAFAR-IITM along with the PMC and partners have launched a “school flags programme” in Pune. Additionally, the PMC will develop a programme to disseminate pamphlets, hoardings, videos, SMSs to increase awareness about air pollution with regard to vulnerable groups such as the elderly and school-going children. For the school flags programme, the PMC and partners would focus on coordinating with schools to display coloured flags corresponding to AQI levels for each day; studying chronic respiratory illness patients and children sensitisation programmes with the help of government and private doctors; develop specific sensitisation programmes for communities living in high level AQI communities in the city; conducting asthma clinics and pulmonary health promotion programme; and sending SMS and WhatsApp alerts to school officials and asthmatic or chronic obstructive pulmonary disease patients.

1.5 SCOPE AND OBJECTIVES

The main objective of this study is to evaluate potential changes in emissions and air quality benefits of implementing various control measures focused at low carbon and sustainable mobility in Pune. The scope of this study includes:

Eight major strategies appropriate for Pune city: Implementation of Bharat Stage (BS) - VI standards, roll-out of Ethanol blended Gasoline (E20), increasing Electric Vehicle (EV) penetration, Non-Motorised Transport (NMT), Mass Rapid Transit System (MRTS), improvement in public transport (PTI), shared mobility (SHMO) and High Capacity Mass Transit Corridor (HCMTR).

Six pollutants of concern: the major air pollutants being $PM_{2.5}$, PM_{10}, NO_x, CO, SO_2 and a climate pollutant i.e. CO_2.

Major transportation modes and segments: including two wheelers, autos, passenger cars, LCV, HDV and buses

Dispersion modelling: using state-of-the-science AERMOD system.

This report is divided into the following four major sections:

- Details about the stakeholder's workshop conducted to gather views and inputs for low carbon and sustainable mobility options appropriate to Pune city
- The methodology and framework adopted to evaluate the impact of control strategies and air quality benefits
- A detailed analysis on changes in city-level emissions w.r.t. pollutants, vehicle categories, and control interventions and the air quality benefits in terms of annual average concentration of selected pollutants at city-scale
- The summary of the findings of the study

STAKEHOLDER’S WORKSHOP

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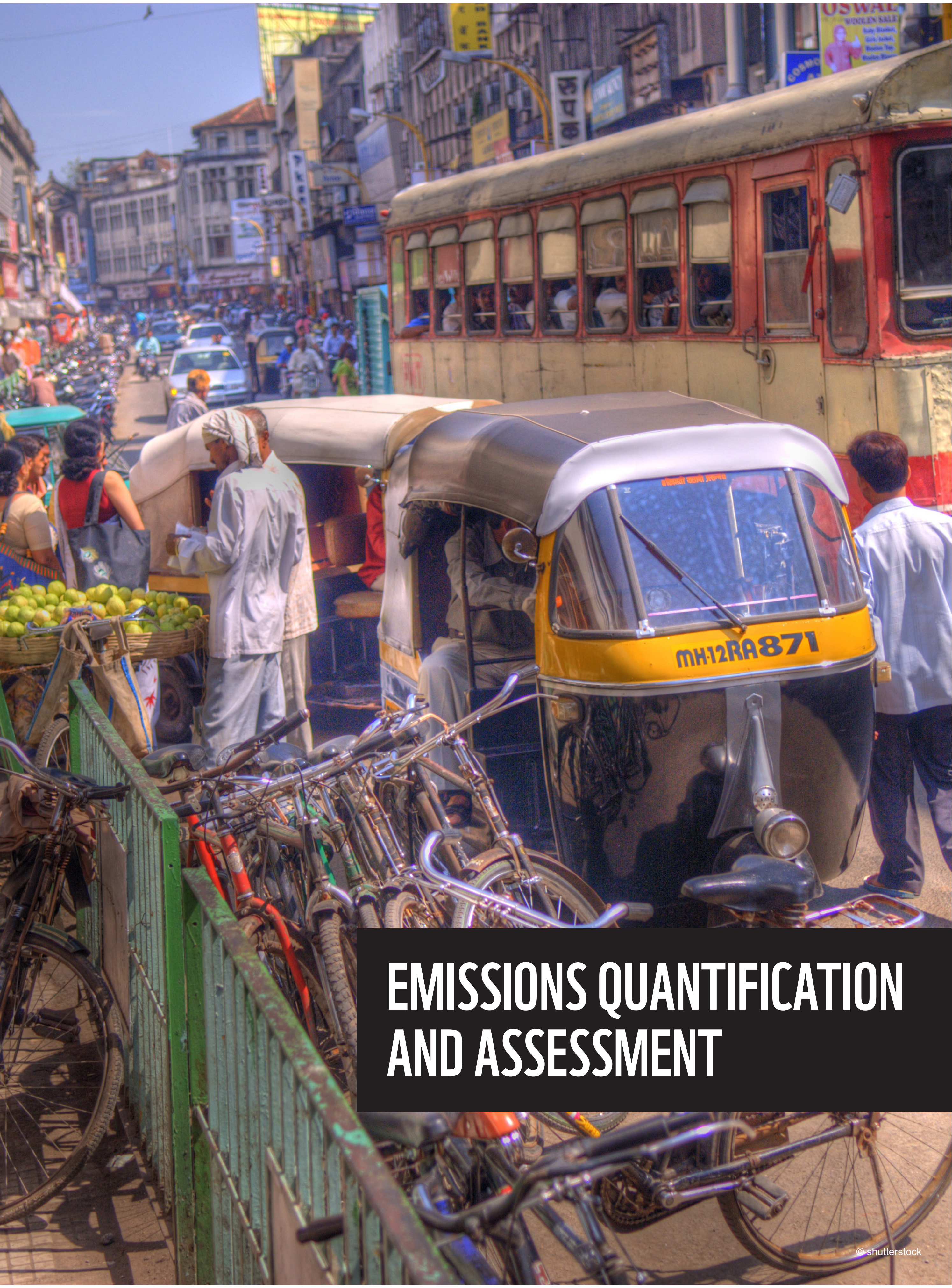
ARAI, Pune and WWF-India, New Delhi, jointly hosted a stakeholder's workshop as a part of this study. The workshop was conducted on Friday, 8th October 2021 in a hybrid mode of virtual participants as well as in-presence ones.

The main objective of the workshop was to undertake in-depth consultations for gathering the views / perceptions of various stakeholders (city officials, representatives from various department, think tanks / academic institutions, CSOs, and experts) towards the challenges and potential of low carbon and sustainable mobility in Pune and to prioritise actions for their further uptake. Further, key findings of the 'India Roadmap on Low Carbon and Sustainable Mobility' were also disseminated to the participants.

Representatives of key stakeholders in Pune city participated in this workshop and provided their inputs on various aspects of low carbon and sustainable mobility in the city. The glimpses of workshop are presented in Figure 3 and a summary of key inputs provided by different stakeholders is provided in Annexure II.

Fig. 3: Photographs from the Stakeholder's workshop conducted in October, 2021



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EMISSIONS QUANTIFICATION AND ASSESSMENT

In this section, the future vehicular emissions have been calculated with 2021 as the base year and projections have been made for 2025 and 2030. The base year (2021) city-level emission inventory for Pune city is recently developed by the Automotive Research Association of India (ARAI) under Swiss Agency for Development and Cooperation's (SDC) Clean Air Project in India (CAP India).

This emission inventory database includes gridded emissions from eight sectors viz. Transport (TRAN), Dust (DUST), Open Waste Burning, (WAST), Residential (RESI), Industries (INDU; includes industries, brick kilns and ready-mix concrete plants), Diesel generators (DSGN), Hotels, Restaurants and Bakeries (HRBE), and Others (OTHR; which includes Crematoria, Aircraft and construction sectors). This emission database includes pollutants such as $PM_{2.5}$, PM_{10}, SO_2. NO_x and CO. The horizontal spatial resolution of emission database is 2 x 2 km^2 and temporal

The projections for future years suggest that there will be approximately **5.4 and 7.7 million** cumulative **vehicle registrations in 2025 and 2030,** respectively, with an overall compound annual growth rate (CAGR) of 7.0 per cent.


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resolution is on a daily basis. The detailed methodologies and source data on developing emission inventory could be referred to in the previous study (ARAI, 2021). Natural sources were not considered in this study because these are difficult to be controlled through human interventions. The air emissions from eight sectors listed above, for year 2021 are considered as the baseline emissions. The gridded emissions for years 2025 and 2030 are computed using growth rate method. The growth rate method uses suitable assumptions for each sector based on current and future government policies. The details of the methodology for the calculation of the emissions are discussed in the following segments.

3.1 METHODOLOGY

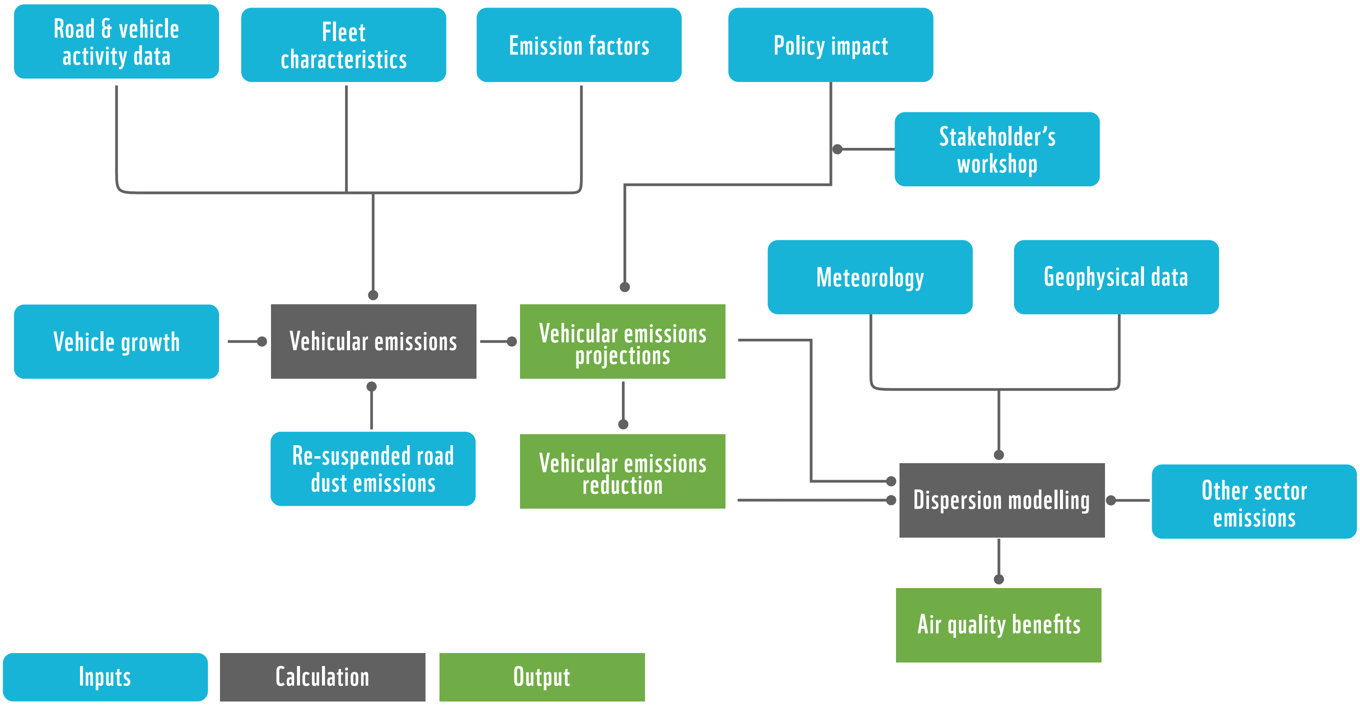
We developed three emission scenarios to include major policy and technology considerations such as Bharat Stage (BS) – VI standards, roll-out of Ethanol blended Gasoline (E20), increased penetration of Electric Vehicle (EV), Non-Motorised Transport (NMT), use of Mass Rapid Transit System (MRTS), improved public transport (PTI), increased shared mobility (SHMO) and implementation of High Capacity Mass Transit Corridor (HCMTR). The definition of each scenario is given below:

The **No Further Control (NFC)** scenario assumes that policy measures and associated technologies already adopted and would continue in future years 2025 and 2030, and no other improvements would take place.

The **Low Ambition Scenario (LAS)** represents policies and technologies that are planned or are in pipeline and could be implemented by 2025 and 2030, respectively.

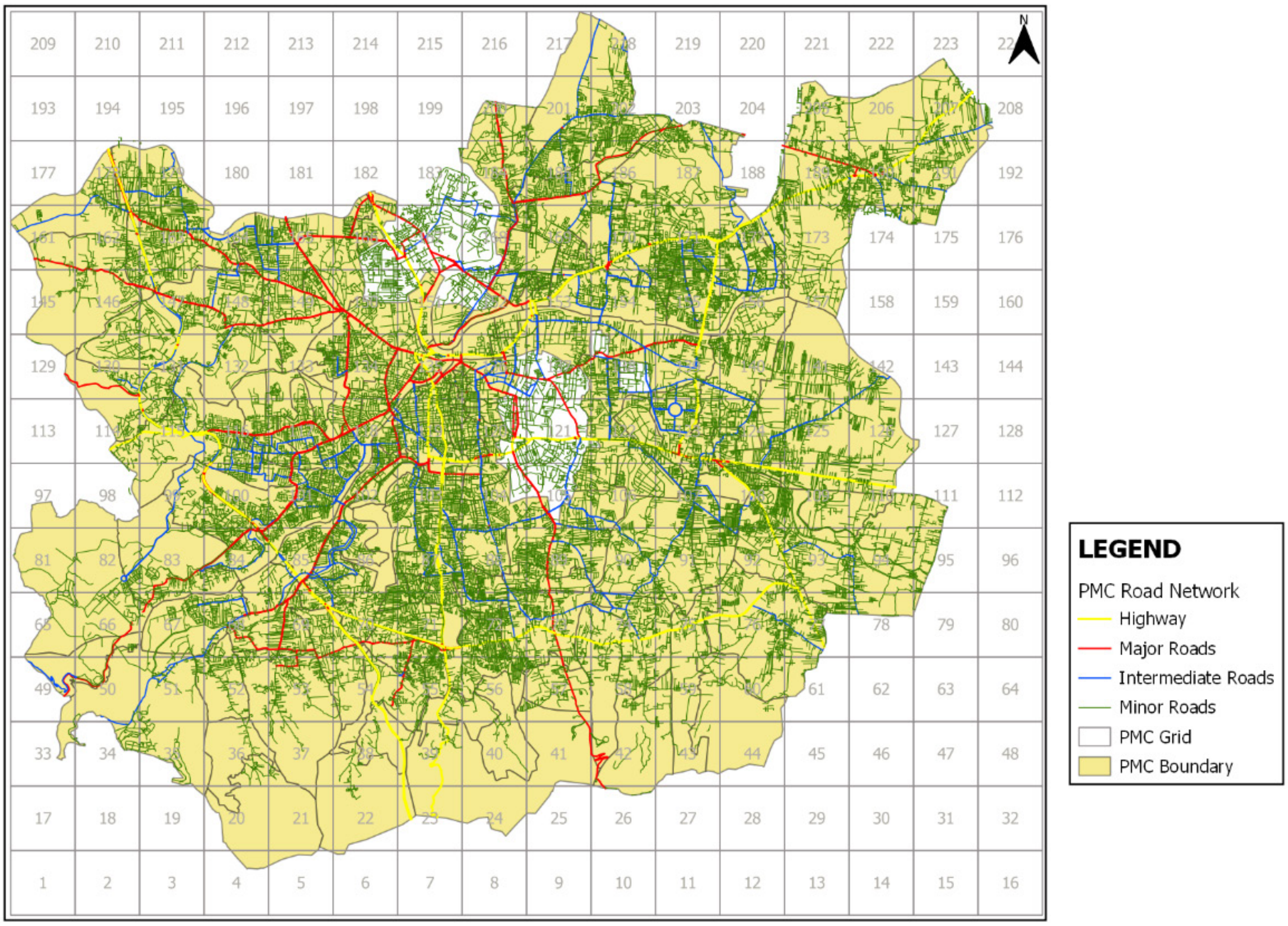
The **High Ambition Scenario (HAS)** represents a bunch of policy measures considered in LAS, that could be adopted in Pune city more aggressively by 2025 and 2030, in order to get additional emission reductions.

Fig. 4: Framework adopted to quantify the emissions and air quality benefits under different emission scenarios in Pune city



The changes in emissions for above defined scenarios and subsequent impact on ambient air quality are calculated following a scientific approach explained in following segments. Figure 4 presents the methodology adopted to quantify the emissions and air quality benefits achievable under three emission control scenarios in Pune city.

Fig. 5: Road network map showing different types of roads in Pune city



ROAD AND VEHICLE ACTIVITY DATA

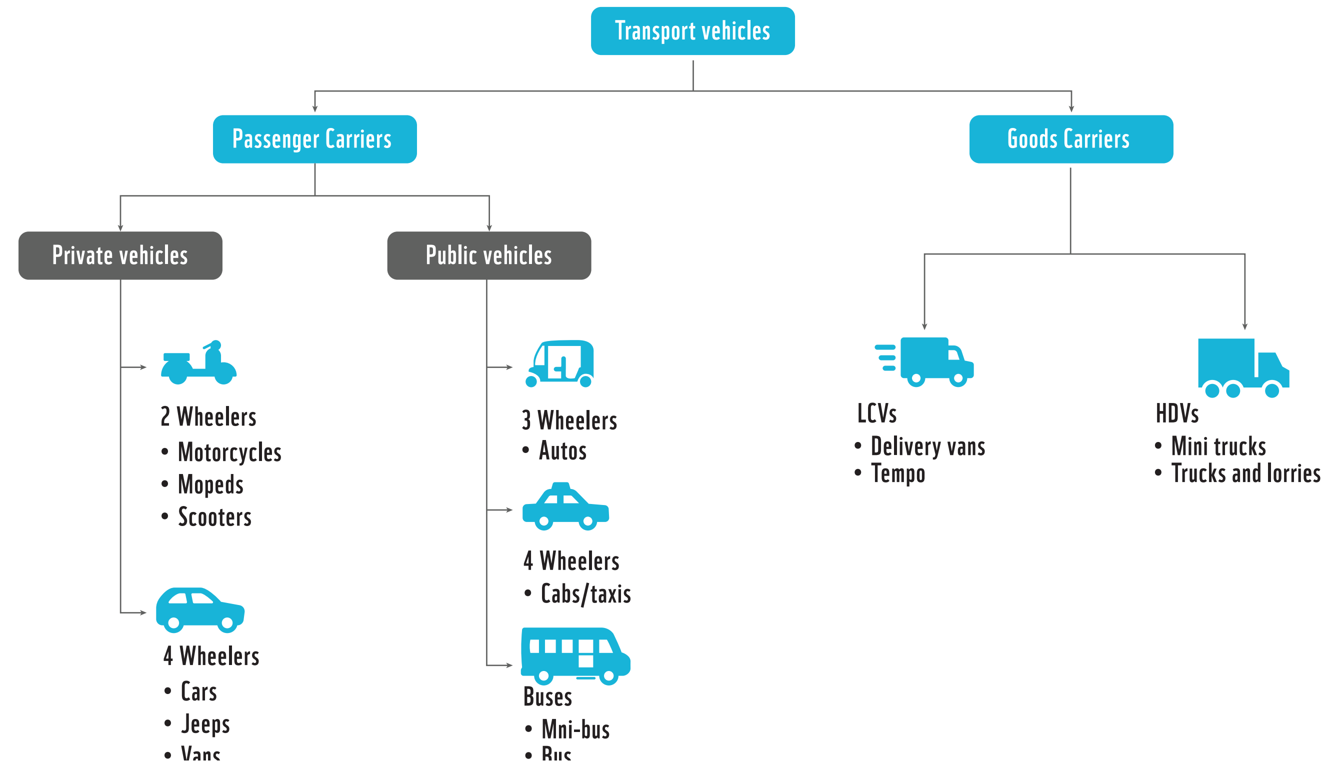
The Pune city road network was digitised using Quantum GIS software and OpenStreetMap database (*OpenStreetMap Contributors, 2021*). This database included information on different road types. After the digitisation, road lengths were calculated for each link in the road network using GIS software. The category-wise gridded road lengths are also computed using GIS software. Figure 5 shows the road network map showing different road types in Pune city. The vehicle activity data i.e. number of vehicles on different types of roads in Pune city was obtained from CAP India project database. This dataset included classified daily vehicle counts on different road types such as highways, major, minor, and residential in Pune city during year 2021.

FLEET CHARATERISTICS

Estimation of reasonably accurate vehicular emissions requires a good characterisation of the in-service vehicle fleet. Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in Pune city was categorised into six categories: the motorised 2-wheelers (motorcycles, scooters and mopeds), autos, passenger cars both private and commercial, light commercial vehicles LCV such as delivery vans, heavy duty vehicles (HDV) such as trucks and lorries and buses and coaches. Figure 6 depicts the vehicle categories used in this study.

Each vehicle category is further differentiated in up to five fuel types or engine concepts respectively: Gasoline, Diesel, Natural Gas, battery-operated or electric vehicles and ethanol-blended gasoline (E20). In addition, vehicular emission calculations require the vehicle fleet by age, as mass emission factors are significantly different for each vehicle type and control technology. Based on approach adopted by *Baidya and Borken-Kleefeld (2009)*, the in-service vehicles were calculated using Survival function which models the vehicle's finite service life. The survival rate, which is a fraction of vehicles survived in the fleet after a certain age, was calculated for each vehicle category considered in Pune city.

Fig. 6: Vehicle categories used in this study



EMISSION FACTORS

Emission factors (EF) are an essential input to calculate the vehicular emissions. It is a unique fraction which indicates emission rate of a pollutant per unit distance and are specific for vehicle type and fuel. Emission factor may vary according to vehicle type, fuel type, engine capacity, age and also according to the speed of the vehicle (*Jaiprakash and Habib,* 2018). Vehicular emission factors are generally developed by following the Chassis dynamometer approach using a standard driving cycle (*ARAI,* 2010). In this study, we used emission factors previously developed by Automotive Research Association of India (ARAI) during 2010 and 2018. As BS-VI vehicles were introduced in April 2020, the mass emission factors for in-service vehicles in India were not available. Hence, the emission factors for such vehicles were derived using BS-VI emission limits.

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As this study involves emission estimation of future years 2025 and 2030, it is very important to correctly represent the emission factors for different types of vehicles operative in future. The exhaust emissions from purely electric or battery-operated vehicles are assumed to be zero (*AFDC*, 2021). Whereas, the emission factors for Ethanol-blended gasoline (E20) fuel vehicles which would be introduced starting 2025 are derived using suitable reduction factors from literature available world-wide. A summary of reduction factors for E20 operated vehicles reported in various literature world-wide is provided in Annexure III.

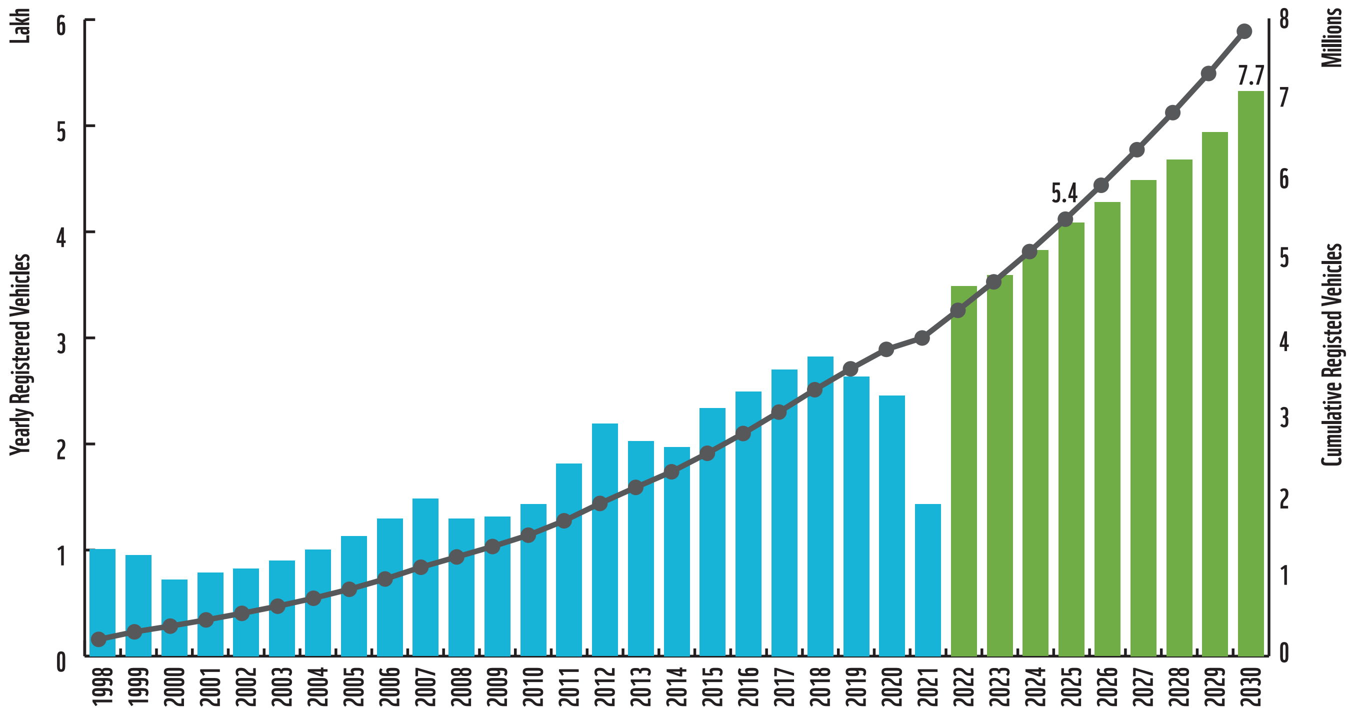
Further, we have also evaluated the changes in emissions due to introduction of dedicated corridor for cars and commercial vehicles in future years. This corridor is focused on providing congestion-free passage for vehicles travelling across the city, which may in turn result in lesser emissions. The specific emission reduction factors, based on literature, are used in this study to model the reduction obtained by maintaining a speed greater than 50km/hr. Annexure III provides the summary of literature-based emission reductions achievable at higher speeds.

VEHICLE GROWTH

The number of vehicles registered in Pune city are required to understand the vehicle fleet details such as age, technology, fuel type, etc. The vehicle registration data was obtained from online registration database maintained by Regional Transport Office (RTO) Pune (MH-12). Yearly registration data from 1998 is used in this study to understand the fleet characteristics. Figure 7 shows the yearly and cumulative vehicle registration in Pune RTO office starting year 1998 till 2021 and future projections for the period from 2022 to 2030. The yearly registration showed a sharp decline in vehicle numbers during 2020-2021, mainly due to the COVID-19 pandemic. The projections for future years suggest that there will be approximately 5.4 and 7.7 million cumulative vehicle registrations in 2025 and 2030, respectively, with an overall compound annual growth rate (CAGR) of 7.0 per cent.

The projections for future years suggest that there will be approximately 5.4 and 7.7 million cumulative vehicle registrations in 2025 and 2030, respectively, with an overall compound annual growth rate (CAGR) of 7.0 per cent

Fig. 7: Yearly (Bars) and cumulative (Line with markers) vehicle registrations in Pune (Source: regional transport office). The green bars show projected vehicle growth in future years, based on historic data.



POLICY IMPACT

As discussed earlier, three emission scenarios are developed for Pune to include various existing and planned control interventions related to transport sector. All emission scenarios investigated in the study are for 2025 and 2030. It is important to note that the emissions from all the sectors except transport and road dust sectors are considered to be constant in three emission scenarios. In order to model vehicular emissions for three emission scenarios, change in fuel-wise vehicle penetration fractions for each category of vehicles, change in emission factors due to new technology and fuels, and reduction in vehicle kilometres travelled was considered for 2025 and 2030. This section explains the approach and assumptions in modelling the impact of eight control interventions used in this study.

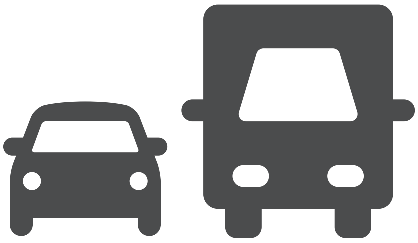
Implementation of Bharat Stage (BS) – VI Standards

In April 2020, the Bharat Stage (BS) - VI standards were introduced and all new vehicles manufactured have to comply with BS-VI. BS-VI vehicles are significantly cleaner than the BS IV counterparts. For example, particulate matter (PM) limit for different segments of diesel cars will be 82 to 93 per cent lower while for trucks and buses it will be 50-67 per cent lower than BS IV level. Similarly, Nitrogen oxide (NO_x) emissions limit will be 68 per cent lower compared to BS-IV norms (*CSE,* 2020). We have modelled the impact of implementation of BS-VI standards in Pune by considering increased penetration levels of these vehicles in vehicle fleet and reduced emissions per unit distance.

Roll-out of Ethanol blended Gasoline (E20) fuel

On the occasion of World Environment Day, 5 June 2021, the government of India released the Roadmap for Ethanol Blending in India. This roadmap is aimed at reducing the country's oil import bill and carbon dioxide pollution. The roadmap proposed some important milestones including: i) raising Pan-India ethanol production capacity from the current 700 to 1500 crore litres; ii) Phased rollout of E10 fuel by April 2022; iii) Phased rollout of E20 from April 2023; its availability by April 2025; iv) Rollout of E20 material-compliant and E10 engine-tuned vehicles from April 2023; and v) Production of E20-tuned engine vehicles from April 2025 (*NITI Aayog and MoPNG,* 2021).

ALL EMISSION SCENARIOS INVESTIGATED IN THE STUDY ARE FOR 2025 AND 2030. IT IS IMPORTANT TO NOTE THAT THE EMISSIONS FROM ALL THE SECTORS EXCEPT TRANSPORT AND ROAD DUST SECTORS ARE CONSIDERED TO BE CONSTANT IN THREE EMISSION SCENARIOS.



IN BS-VI, PARTICULATE MATTER (PM) LIMIT FOR DIFFERENT SEGMENTS OF DIESEL CARS IS

82-93%

LOWER WHILE FOR TRUCKS AND BUSES IT IS

50-67%

LOWER THAN BS-IV LEVEL

We have modelled the impact of 20 per cent ethanol blending in gasoline that is E20 fuelled vehicles in Pune city by 2030. In modelling, the impact of E20 roll-out, it is considered that all vehicle categories which currently use gasoline, will be using E20 as fuel in 2030. It is also assumed that the vehicle fleet produced between the period from 2026 to 2030 will have an E20-tuned engine, which will in turn lead to change in emissions per unit distance. Although vehicles produced before 2025 will be using E20 as fuel in the subsequent years, yet it is assumed that there will not be a significant change in the emission factors for these vehicles. The reduction factors for E20 vehicles produced post-2025 are listed in Annexure IV.

Increased Penetration of Electric Vehicles (EV)

The conventional internal combustion engine (ICE) vehicles are one of the major contributors to city level air pollution and electric vehicles (EVs) are emerging as a promising alternative that could help in mitigating air pollution in urban centres (*GIZ,* 2021). The Government of India (GoI) has introduced several initiatives in EV sector with an aim to improve energy security, curb local air pollution, and curtail GHG emissions from the transport sector (*CEEW, 2020*). For example, India has set a goal of 30 per cent penetration of EV in new sales by 2030 (*GIZ, 2021*). Additionally, several state governments have also set their own targets to increase the electric vehicle penetration in near future by incentivising the EV purchases. For example, the state government of Maharashtra (GoM) have recently released Maharashtra EV Policy 2021, with an aim to make Maharashtra the "topmost producer of battery-powered electric vehicles in India" (basis annual production capacity) and aiming for electric vehicles (EVs) to make up 10 per cent of all new vehicle registrations in the state by 2025 (*GoM, 2021*).

Considering the government policies and initiatives, EV penetration is likely to improve substantially in Pune city as well, which will in turn lead to significant reduction in vehicular exhaust emissions. We have modelled the effect of increased EV penetration in Pune city by referring to policies at national, state and city-level and the expected EV penetration is presented in section 4.1.

Non-Motorised Transport (NMT) Share

Non-motorised transport (NMT) includes mainly walking, cycling and cycle rickshaws. NMT plays an important role in Indian cities as a last mile connector providing access to mass transit systems (*Kumar* et al., 2015). Several government policies and initiatives including but not limited to, National Urban Transport Policy (NUTP), National Mission for Sustainable Habitat (NMSH), and Ministry of Urban Development (MoUD) Service level benchmarks are aiming to adopt NMT as a key component of city's integrated urban transport system (*Kumar* et al., 2015). Pune city administration has also taken several steps to promote non-motorised transport (NMT) in the city. With support from MoUD, Pune city prepared a Comprehensive Mobility Plan (CMP) in 2012 which sets a target to achieve 50 per cent modal share of NMT by year 2030 (*PMC,* 2012). Similarly, the Pune Cycle Plan was prepared in 2016 to help make Pune a cycle-friendly city and significant progress has been made over the past years to achieve approximately 300 km bicycle track in the city (*PMC,* 2021b).

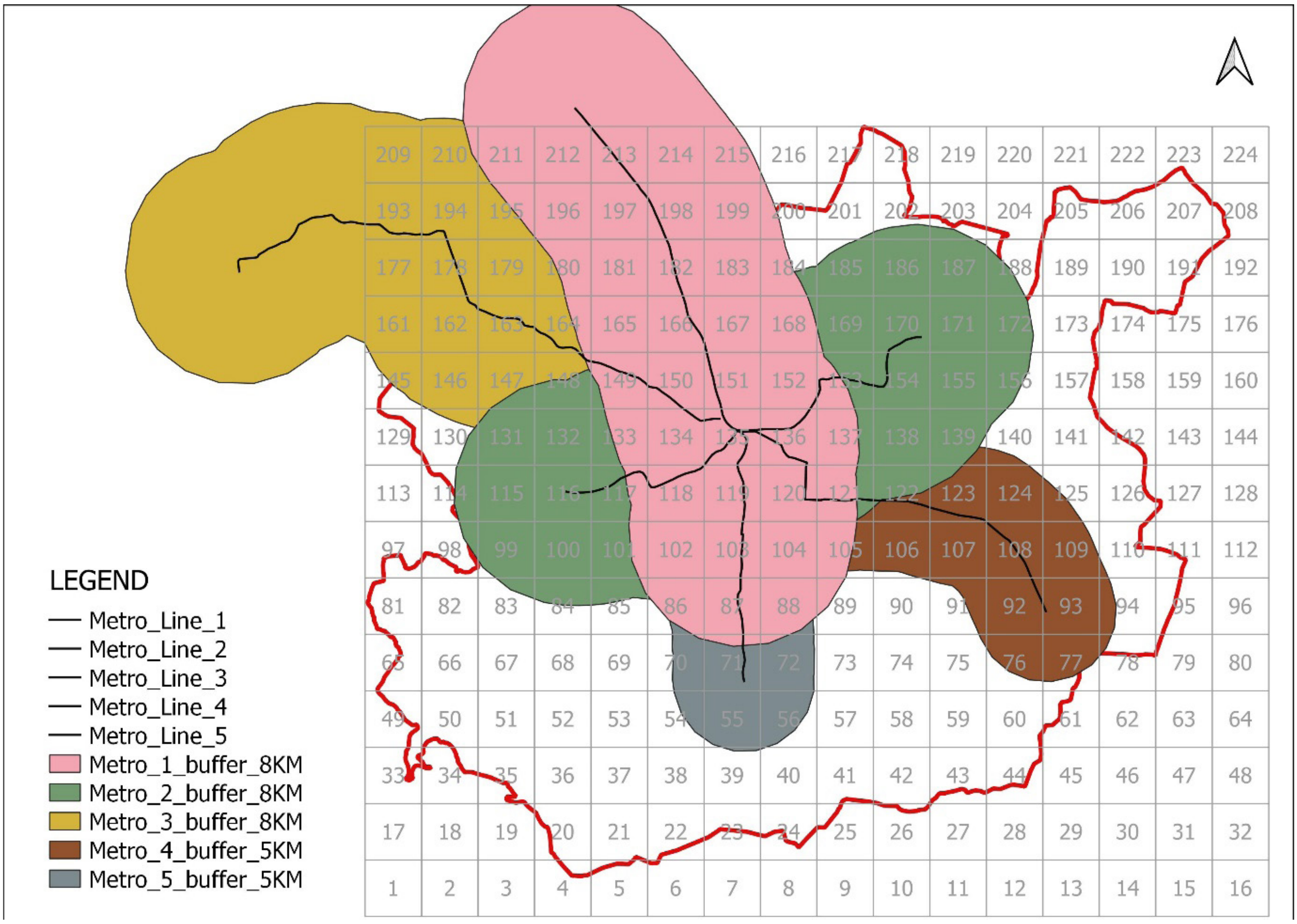
As NMT is likely to play a vital role in Pune's urban transportation system in the years to come, we have evaluated the impact of increasing NMT share on vehicle kilometres travelled and subsequent emission reductions. It is assumed that increasing NMT share in future years would reduce VKT by two wheelers, cars and buses. Table 1 presents summary of expected reduction percentages in vehicle kilometres travelled (VKT) in LAS and HAS for years 2025 and 2030, respectively, due to promotion of NMT in Pune city.

Table 1: Expected percentage VKT reduction assumed in evaluating the impact of NMT in this study			
S. No.	Scenario Year	Expected VKT Reduction in LAS	Expected VKT Reduction in HAS
1.	2025	1%	2%
2.	2030	2%	4%

Mass Rapid Transit System (MRTS)

Pune Metro is a metro rail based rapid transit system under construction to serve the city of Pune, India. The proposed system comprises three lines with a total length of 54.58 km. The 16.59 km first Line PCMC Bhavan–Swargate will be elevated between PCMC Bhavan to Range Hills, from where it will run underground. the second line will run from Vanaz to Ramwadi covering a distance of 14.66 km on an elevated viaduct. Lines one andtwo are expected to be operational in year 2023 (*DMRC, 2015*). The 23.33-km elevated Line three will run from the Rajiv Gandhi Infotech Park in Hinjewadi via Balewadi to Civil Court. All three lines will align at the Civil Court interchange station (*DMRC, 2016*). In addition to three metro lines explained earlier, several metro lines connecting different parts of the city are currently under discussion. In view of this, we have considered only two additional lines that is, Civil Court to Hadapsar and Swargate to Katraj for high ambition scenario (HAS) in year 2030 for which preliminary details are available in the public domain. Figure 8 shows the map of five MRTS lines and their zone of influence considered in HAS_2030 scenario.

Fig. 8: Map showing five proposed MRTS/METRO lines considered in this study and their zone of influence considered in HAS_2030 scenario.



The details of daily ridership, average trip length and zone of influence (ZIF) on different lines of Pune Metro Rail system used in this study for assessment of emissions in future scenario years are presented in Annexure IV. MRTS implementation would subsequently reduce the vehicular kilometres travelled in the zone of influence (ZIF), as people will shift from their current mode of transport to MRTS. In the present study, the methodology for estimation of emissions reduced due to shifting of on-road vehicles after the introduction of metro rail system has been adopted from *Sharma* et al. (2010; 2014).

Public Transport Improvement (PTI)

Public transportation systems play a vital role in reducing traffic and environmental pollution. Many researchers world-wide have demonstrated the potential emission reductions from a shift towards public transport and zero emission buses (*Al-Kheder*, 2021; *Carroll* et al., 2019; *Bakker and Konings,* 2018). Pune city has also taken several steps to improve the public transportation system including introduction of bus rapid transit system (BRTS) on selected routes, ban on procurement of diesel buses and phase-out of buses olderthan 12 years polluting buses, and procurement of CNG and electric buses (*PMC, 2021a*). The local bus administration i.e. Pune Mahanagar Parivahan Mahamandal Ltd. (PMPML) is promoting procurement of electric buses and have recently introduced about 150 buses in the fleet with a plan to add another 500 buses in near future. Table 2 and 3 present summary of current PMPML bus fleet and daily PMPML ridership, respectively.

PUNE MAHANAGAR PARIVAHAN MAHAMANDAL LTD. (PMPML) IS PROMOTING PROCUREMENT OF ELECTRIC BUSES AND HAVE RECENTLY INTRODUCED ABOUT 150 BUSES IN THE FLEET WITH A PLAN TO ADD ANOTHER 500 BUSES IN NEAR FUTURE

Table 2: Summary of Current PMPML Bus Fleet

S. No.	Bus Type	Bus Fuel Type		
		CNG	Diesel	Electric
1.	PMPML	953	522	-
2.	Contractual	806	-	150
3.	Total	1759	522	150

Table 3: Number of Buses and Daily Riders in PMPML Buses

Year	Buses[1]	Daily Riders[1]
2016	1405	10,30,000
2017	1428	10,60,000
2018	1367	10,20,000
2019	1600	11,00,000

As per the recommendations of the Central Institute of Road Transport (CIRT), the number of buses per lakh population shall be 55 in Pune city (PMC, 2021a). PMPML currently possess a total of 2431 buses, which is approximately equivalent to 43 buses per lakh of population. In this study, we have included an analysis on increasing number of buses per lakh of population in step-wise manner and shift of vehicle kilometres travelled. It is assumed that PMPML would at least meet CIRT recommendation i.e. 55 buses per lakh of population in LAS scenario while it would achieve a more aggressive target of 80 buses per lakh of population in HAS scenario. The VKT shift approach used by *Sharma* et al. (2010 and 2014) is adopted to calculate the VKT shifted to buses and emission reductions achieved. Further, it is also assumed that only electric buses would be procured in the future years, considering the policy emphasis on E-mobility.

1 Sengupta J., PMPML's average daily ridership stagnant despite new buses: Survey, Nov 12, 2019, URL: https://timesofindia.indiatimes.com/city/pune/pmpmls-average-daily-ridership-stagnant-despite-new-buses-survey/articleshow/72013837.cms

Table 4: Summary of Assumptions in Shared Mobility Scenarios				
Scenario Year	Occupancy		Additional PKT on existing commercial cars	
	LAS	HAS	LAS	HAS
2025	3.5	3.5	50%	100%
2030	4.0	4.0	50%	100%

Shared Mobility

Pune is currently witnessing increasing ownership of private vehicles and limited use of public transport. Growth in vehicle ownership and demand for transportation has also led to higher congestion in core city areas. The shared mobility can offer a promising solution for sustainable transport by displacing private vehicle ownership (*NITI Aayog,* 2018). This could in turn provide a more affordable, reliable, clean, and efficient transportation in future years (*Arbeláez Vélez and Plepys,* 2021).

We have analyzed the impact of car sharing in Pune city in future years i.e. 2025 and 2030. The calculations were based on increasing the occupancy of cars (presently at 2.9) and introduction of new cars for shared mobility in future years. Table 4 shows the summary of assumptions made in shared mobility scenario.

High Capacity Mass Transit Corridor (HCMTR)

HCMTR is a 35.96 km elevated six-lane corridor passing over 34 junctions having 2 dedicated lanes for BRTS with 26 stations and 4 lanes for private vehicles with 17 up-ramps and 16 down ramps. The proposed HCMTR elevated corridor starts from Bopodi and ends at Vishrantwadi junction. HCMTR main corridor is designed for a minimum design speed of 50 kmph and ramps for 25 kmph (*PMC,* 2021c). The proposed corridor would facilitate congestion-free movement of vehicles by avoiding city traffic.

We have estimated the vehicle kilometres travelled (VKT) on HCMTR in future years using the projected traffic figures in the detailed project report. The VKT shifted to HCMTR would lead to emission reduction by avoiding frequent acceleration and deceleration conditions, due to congestion, in core city areas. Many researchers around the world have reported reduction in vehicular emissions with free flow of traffic. The emission reduction factors used in this study are provided in Annexure IV.

Key considerations and assumptions for each control intervention in NFC, LAS and HAS as explained above are summarised in tables 5-7.

Fig. 9: Key plan showing alignment of proposed HCMTR in Pune city (Source: HCMTR DPR)

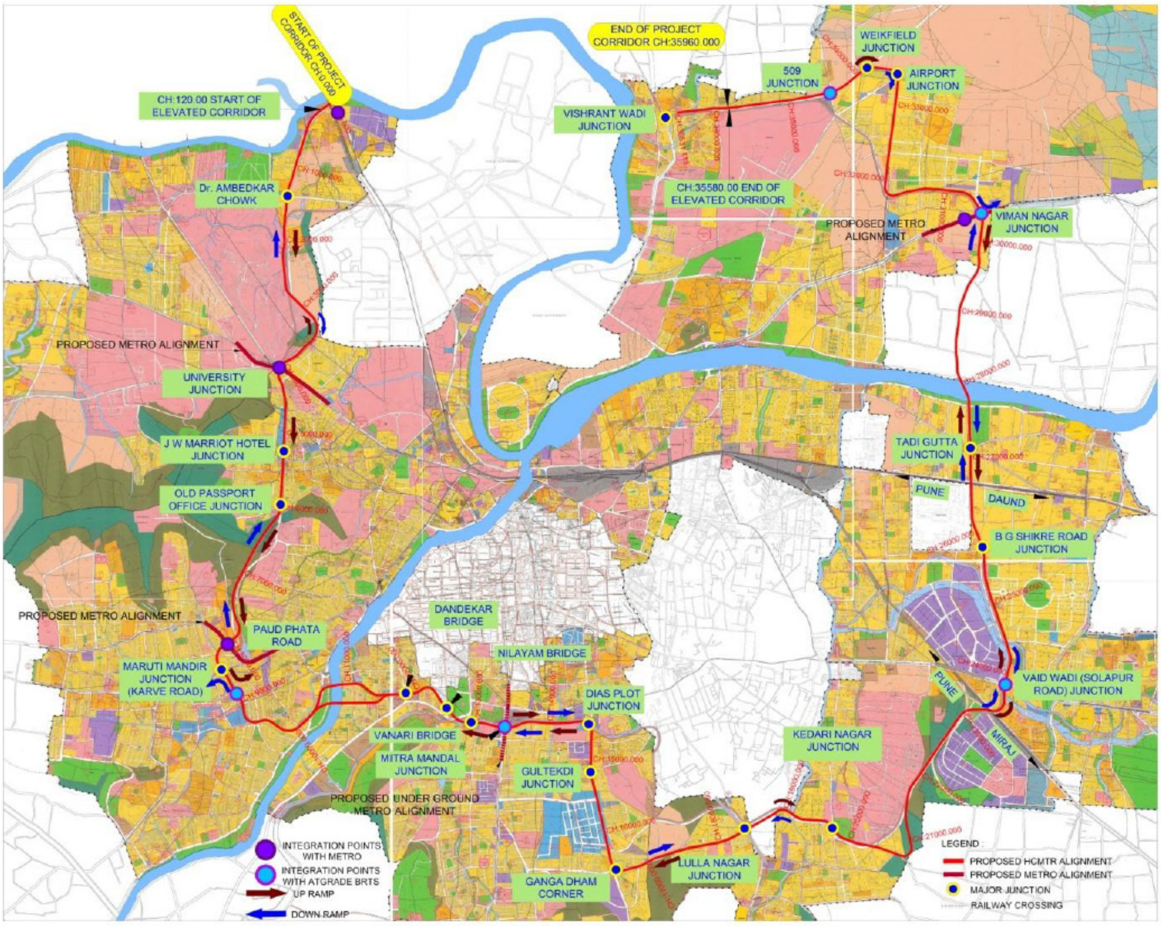


Table 5: Summary of Key Policies and Assumptions in the No Further Control (NFC) scenario						
Intervention	2W	Autos	Cars	LCV	HDV	Buses
Emission Standards	Implementation of BS-VI standards starting April, 2020					
Roll-out of E20 fuel	No E20 Introduction		No E20 Introduction	--	--	--
Increased EV Penetration	EV @1% in 2025 & @2% 2030	EV @1% in 2025 & @2% in 2030	EV @1% in 2025 & @2% in 2030	EV @3% in 2025 & @5% in 2030	--	EV@5% 2025 & @10% in 2030
NMT Share	NO VKT REDUCTION			--	--	NO VKT REDUCTION
Mass Rapid Transit System (MRTS)/ Metro	NO MRTS			--	--	NO MRTS
Improved Public Transport	NO VKT REDUCTION			--	--	NO VKT REDUCTION
Shared Mobility	NO SHARED MOBILITY		NO SHARED MOBILITY	--	--	--
HCMTR	NO HCMTR					

Table 6: Summary of Key Policies and Assumptions in the Low Ambition Scenario (LAS)						
Intervention	2W	Autos	Cars	LCV	HDV	Buses
Emission Standards	Implementation of BS-VI standards starting April, 2020					
Roll-out of E20 fuel	E20 @ 65% in 2030		E20 @ 45% in 2030	--	--	--
Increased EV Penetration	EV @10% in 2025 & @35% in 2030	EV @20% in 2025 & @35% in 2030	EV @5% in 2025 & @20% in 2030	EV @10% in 2025 & @20% in 2030	--	EV @10% in 2025 & @30% in 2030
NMT Share	VKT reduction @1% in 2025 & @2% in 2030	VKT reduction @1% in 2025 & @2% in 2030	VKT reduction @1% in 2025 & @2% in 2030	--	--	VKT reduction @1% in 2025 & @2% in 2030
Mass Rapid Transit System (MRTS)/ Metro	2025: 3 Metro lines in 2025 & 5 km ZIF around each metro line. 2030: 3 Metro lines in 2025 & 5 km ZIF around each metro line.			--	--	2025: 3 Metro lines in 2025 & 5 km ZIF around each metro line. 2030: 3 Metro lines in 2025 & 5 km ZIF around each metro line.
Improved Public Transport	VKT reduction due to shifting of passengers to buses	VKT reduction due to shifting of passengers to buses	VKT reduction due to shifting of passengers to buses	--	--	55 buses per lakh population
Shared Mobility	VKT reduction due to shifting of people to SHMO	--	2025: Occupancy @3.5 and 50% Additional PKT 2030: Occupancy @3.5 and 100% Additional PKT	--	--	--
HCMTR	--	--	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions

Table 7: Summary of Key Policies and Assumptions in the High Ambition Scenario (HAS)						
Intervention	2W	Autos	Cars	LCV	HDV	Buses
Emission Standards	Implementation of BS-VI standards starting April, 2020					
Roll-out of E20 fuel	E20 @ 50% in 2030	--	E20 @ 30% in 2030	--	--	--
Increased EV Penetration	EV @15% in 2025 & @50% in 2030	EV @30% in 2025 & @50% in 2030	EV @7.5% in 2025 & @30% in 2030	EV @15% in 2025 & @30% in 2030	--	EV @15% in 2025 & @45% in 2030
NMT Share	VKT reduction @2% in 2025 & @4% in 2030	VKT reduction @2% in 2025 & @4% in 2030	VKT reduction @2% in 2025 & @4% in 2030	--	--	VKT reduction @2% in 2025 & @4% in 2030
Mass Rapid Transit System (MRTS)/ Metro	2025: Start of 3 Metro lines in 2025 & 8 km ZIF around each metro line. 2030: 5 Metro lines will be operational in year 2030. 8 km ZIF for 3 metro lines and 5 km ZIF for 2 metro lines.			--	--	2025: Start of 3 Metro lines in 2025 & 8 km ZIF around each metro line. 2030: 5 Metro lines will be operational in year 2030. 8 km ZIF for 3 metro lines and 5 km ZIF for 2 metro lines.
Improved Public Transport/ VKT Reduction (%)	VKT reduction due to shifting of passengers to buses	VKT reduction due to shifting of passengers to buses	VKT reduction due to shifting of passengers to buses	--	--	80 buses per lakh population
Shared Mobility	VKT reduction due to shifting of people to SHMO	--	2025: Occupancy @4 and 50% Additional PKT 2030: Occupancy @4 and 100% Additional PKT	--	--	--
HCMTR	--	--	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions	VKT would be shifted to HCMTR with reduced emissions

RE-SUSPENDED ROAD DUST

Re-suspended road dust is introduced into the atmosphere due to vehicular movement on road surface. As four control interventions considered in this study result in reduction in vehicle kilometres travelled (VKT) on different roadways, it will in turn reduce the road dust re-suspension. Hence, we have also modelled the impact of VKT reduction on road dust re-suspension emissions. Emissions from paved road dust re-suspension due to movement of vehicles was calculated using US EPA (AP-42) method. These dust emissions due to movement of vehicles will vary with the silt loading on the road surface and also the average weight of the vehicles plying on the road. The term silt loading (sL) refers to the mass of the silt-size material (equal to or less than 75 µm in physical diameter) per unit area of the travel surface. In this study, silt loading values on different types of roads in Pune city, were finalised in consultation with expert team from The Energy and Resources Institute (TERI), New Delhi. Particulate matter emissions from re-suspension of road dust due to movement of vehicles on paved roads were calculated using Eq. 1:

$$\textbf{Emissions load} = \textbf{VKT x EF}_{RD} \dots\dots\dots\dots\dots\dots\dots (1)$$

where, VKT is Vehicle Kilometre Travelled (km/day) and EF is paved road dust emission factor and calculated using Eq. 2:

$$\textbf{EF}_{RD} = \textbf{k x w}^{1.02} \textbf{ x } (\textbf{sL})^{0.91} \textbf{x} \left(1 - \frac{P}{4N}\right) \dots\dots\dots (2)$$

Where, EF = particulate emission factor (having units matching the units of k)

k = constant (function of particle size) in g/VKT, value of k for PM_{10} and $PM_{2.5}$ is 0.62 and 0.15, respectively.

sL = road surface silt loading in g/m2

w = average weight of the vehicles (in tons) travelling on the road

P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period,

N = number of days in the averaging period (e.g., 365 for annual).

The gross vehicle weights for different classes are obtained from vehicle specification sheets through online surveys. Number of rainy days in a year were obtained from climatology data for 1991-2012 (IMD, 2015). The emission factors calculated using above methodology were then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions. Table 8 summarises the per cent reductions assumed in each scenario to calculate re-suspended road dust emissions.

Table 8: Per cent Reduction in Silt Loading assumed in calculation of Road Dust Emissions in Future Scenarios

Year	NFC	LAS	HAS
2025	0%	10%	15%
2030	0%	20%	30%

DISPERSION MODELLING

The final component of this study included modelling the ambient concentrations of pollutants including $PM_{2.5}$, PM_{10}, NO_2, CO and SO_2 over Pune city for three scenarios namely NFC, LAS and HAS for 2025 and 2030. Dispersion modelling of the emission scenarios is performed with the latest version of the AERMOD Modelling System; AERMOD Version 21112. AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. The details of dispersion model, source and receptor configurations, meteorology, and geophysical data used for dispersion modelling simulations are provided in Annexure IV.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EMISSION REDUCTIONS AND AIR QUALITY BENEFITS

4.1 VEHICLE PENETRATION IN FUTURE YEARS

As discussed in section 3.1.2, vehicle fleet characteristics are a crucial input for projecting the future vehicular emissions and evaluation of emission scenarios. Based on the various policies and initiatives taken and/or proposed by central, state, local governments and research groups, we have adopted the vehicle composition depicted in Fig. 10 and 11 in NFC, LAS and HAS for time periods 2021-2025 and 2026-2030.

During years 2021-2025, two wheelers will be primarily using gasoline fuel whereas during 2026-2030, they are assumed to shift to E20 and EVs with varying percentages in LAS and HAS. Similarly, about ~99 per cent of autos in Pune city, currently use CNG as a fuel, mainly due to lower prices of CNG compared to gasoline and diesel and fiscal incentives offered by urban local body. Considering current trend in the mobility sector and future policies, 30 per cent and 50 per cent autos are assumed to shift to EVs during 2021-25 and 2026-30, respectively.

Cars are the most complicated segment in terms of fuel share. Presently, about ~44 per cent of cars use gasoline as a fuel, followed by diesel (~30 per cent), and natural gas (~25 per cent). The electric cars presently contribute to only 1 per cent share the total cars, mainly due to high prices, technological barriers, and limited availability of models. With various driving forces, cars are assumed to shift to E20, NG and EVs with varying percentages in future scenario years.

The commercial vehicles i.e. LCVs and HDVs, are conventionally dependent on diesel as a fuel. With advancement in engine technologies, more number of LCVs are assumed to use natural gas (NG) and/or electric powertrain instead of diesel (Fig. 10 and 11) in future years. But due to present technological challenges HDVs are assumed to rely primarily on diesel as a fuel in future scenarios. Similar to HDVs, buses also use diesel as a fuel in the present scenario and are assumed to gradually shift to NG and EVs with policies and technological advancements.

Fig. 10: The vehicle fuel-mix adopted in years 2021-2025, for projecting the vehicular emissions in future scenarios

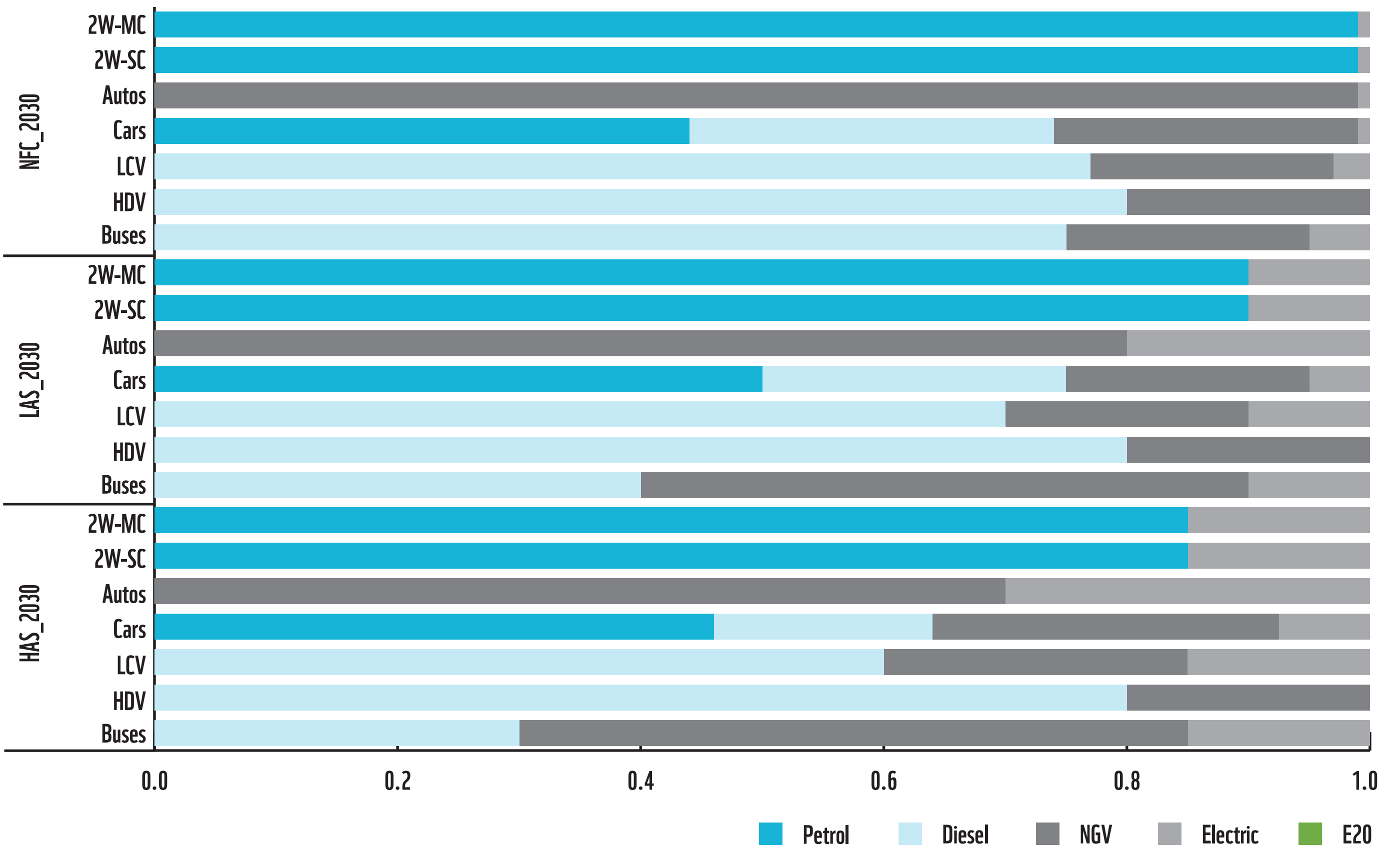
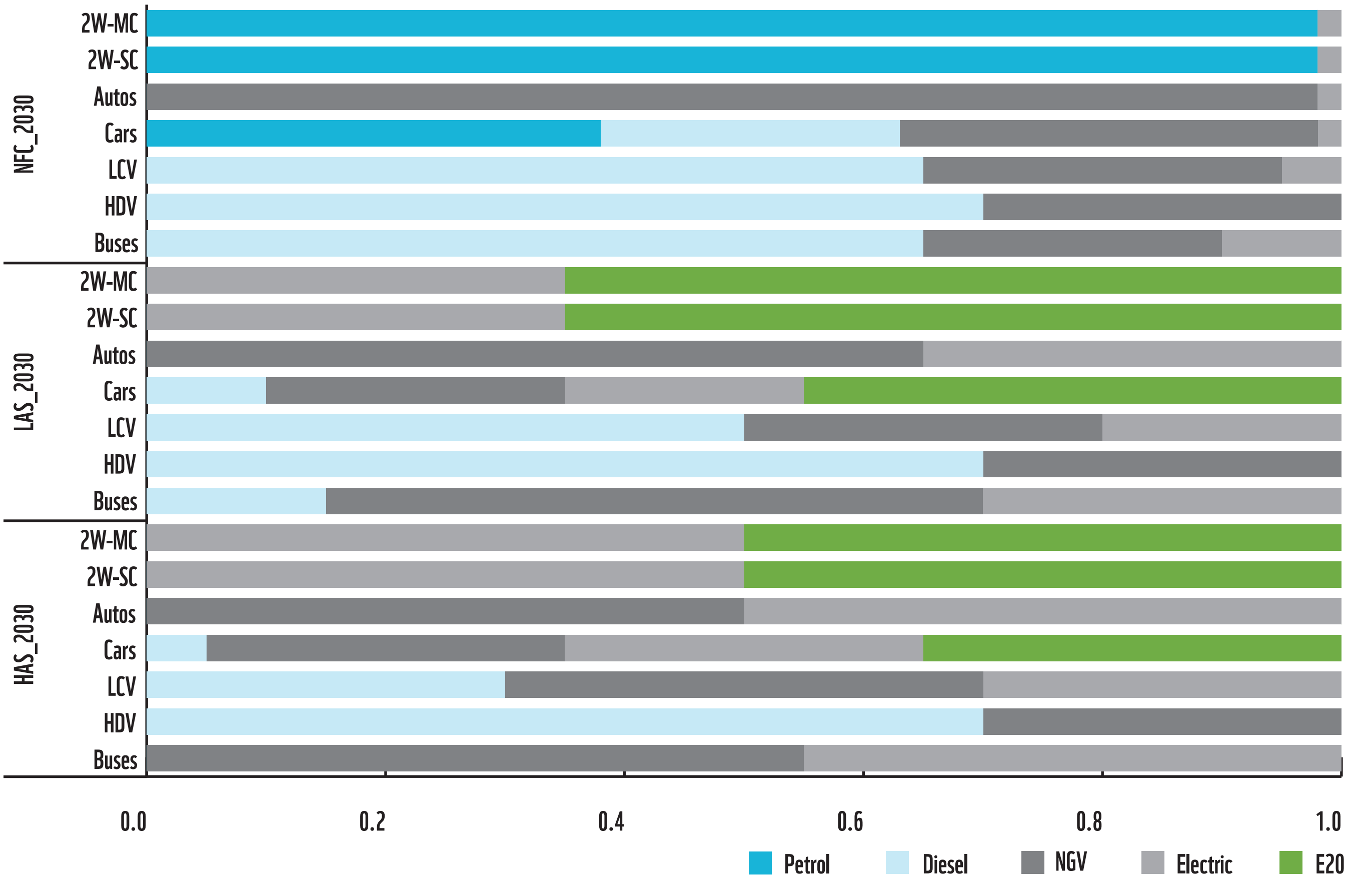


Fig. 11: The vehicle fuel-mix adopted in years 2026-2030, for projecting the vehicular emissions in future scenarios



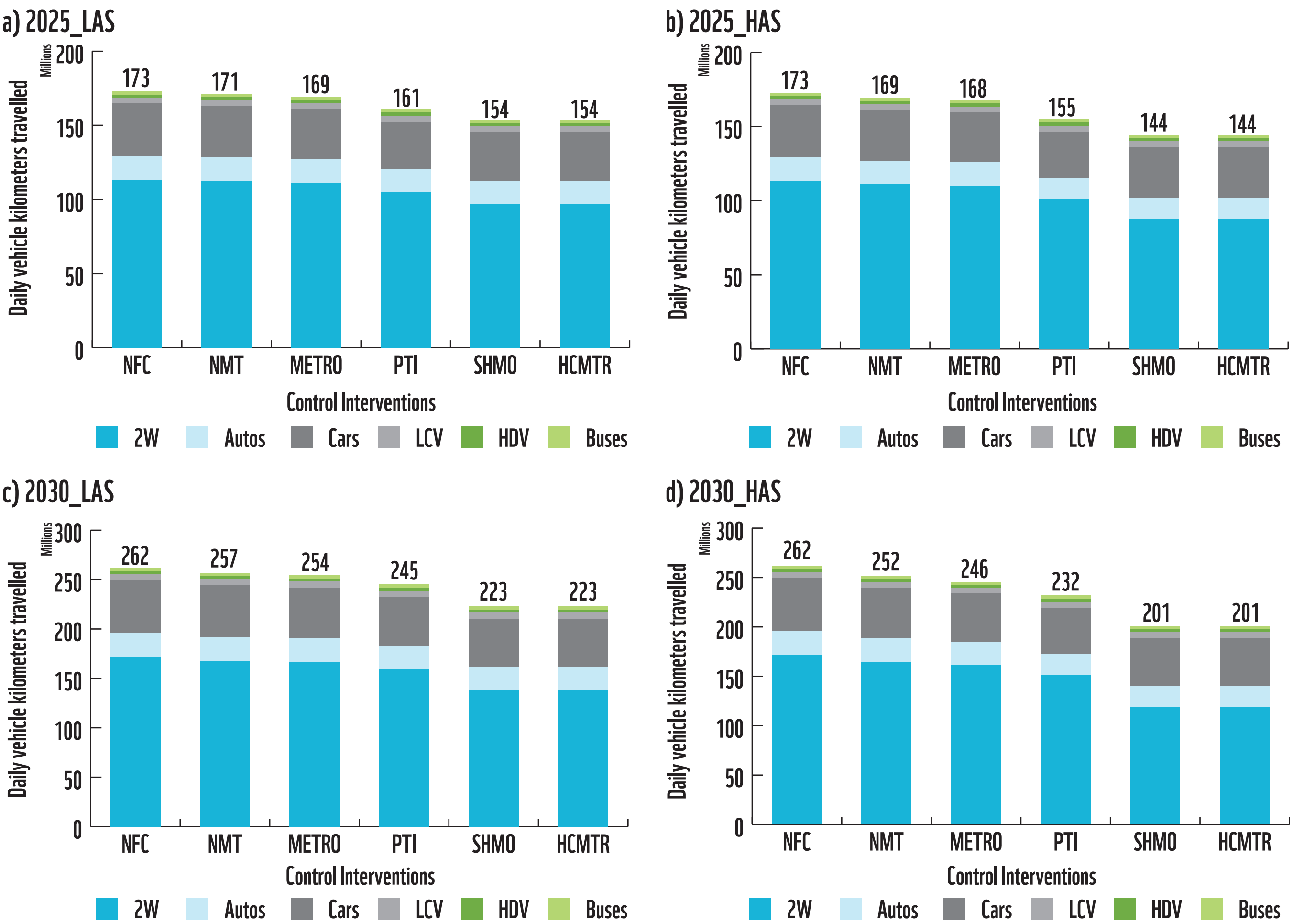
4.2 VEHICLE-KILOMETRES TRAVELLED

The four control interventions proposed in this study i.e. NMT, METRO, PTI, and SHMO leads to significant changes in vehicular kilometres travelled in Pune city for scenario years 2025 and 2030. Figure 12 presents the projected change in daily vehicle kilometres travelled by vehicle type and control interventions considered for four cases i.e. LAS_2025, HAS_2025, LAS_2030 and HAS_2030. It is important to note that there is no VKT reduction due to HCMTR, because it will only lead to shift of selected categories of vehicles to a new route within study area.

The VKT is observed to decrease in both the scenarios compared to NFC during years 2025 and 2030. Overall, the LAS has a potential to achieve a decrease of 11.1 per cent and 14.9 per cent daily VKT in years 2025 and 2030, respectively whereas HAS with more aggressive measures can achieve 16.6 per cent and 23.2 per cent VKT reduction in 2025 and 2030, respectively. Control intervention-wise comparison of VKT reduction suggests that maximum reduction can be obtained through shared mobility HAS for 2025 and 2030 while minimum VKT reduction is observed through MRTS. This reduction is obvious because VKT reduction in case of MRTS occurs only in the zone of influence around the MRTS lines whereas shared mobility option will be practised throughout the city area.

Vehicle category-wise comparison of VKT reduction suggests highest reduction in VKT of two wheelers (14.3-30.8 per cent), followed by buses (6.9- 16.2 per cent), autos (6.8- 12.1 per cent), and cars (2.7 – 8.5 per cent) w.r.t. corresponding NFCs whereas no VKT reduction is expected in case of LCVs and HDVs. It is important to note that two wheelers and cars constitute maximum percentage of total VKT and four control interventions i.e. NMT, METRO, PTI, and SHMO, are targeted to reduce VKT of private vehicles i.e. two wheelers and cars. On the other hand, none of the interventions considered in this study are likely to reduce the VKT of LCVs and HDVs. In case of PTI, an increase in VKT of buses is observed due to shifting of passengers to buses, who were earlier using other modes of transport such as two wheelers, autos and cars.

Fig. 12: Daily vehicle kilometres travelled by vehicle category and control intervention, in Pune city for a) LAS_2025, b) HAS_2025, c) LAS_2030 and d) HAS_2030.



4.3 VEHICULAR EXHAUST EMISSIONS

VEHICULAR EMISSIONS PROJECTIONS WITH NFC

The emission projections for 2025 and 2030 were based on increased vehicular population and activity, and no new policies are assumed to be implemented. In the absence of new policies, the traditional fuels will remain a key energy source in the vehicular sector (refer Fig. 10 and 11). We used NFC as a reference, for evaluation of control interventions and/or scenarios selected in this study. Fig. 13-17 show projected vehicular exhaust emissions of air pollutants in Pune city by vehicle category in NFC scenario for years 2021, 2025 and 2030.

Vehicular exhaust PM emissions predominantly consist of fine particles i.e. particles having aerodynamic diameter less than or equal to 2.5 µm. Therefore, vehicular exhaust emission factors available for Indian vehicles are considered same for $PM_{2.5}$ and PM_{10}. Hence, in this study a common term, particulate matter (PM) is used to describe the particulates originating from vehicle exhaust.

Based on assumptions that no new policies will be implemented, vehicular exhaust PM emissions are projected to decrease, leading to 21.8 per cent and 12.0 per cent decrease in 2025 and 2030, respectively relative to 2021 (Fig. 13). Similarly, vehicular emissions of NO_x are also declining by 13.5 per cent and 5.2 per cent in 2025 and 2030, respectively. However, CO emissions are projected to decline by 14.5 per cent in 2025 and increase by 9.2 per cent in 2030, relative to 2021. Although the vehicle numbers (Fig. 7) and activity (Fig. 12) are increasing, the exhaust emissions are either decreasing (PM and NO_x) or increasing at a slower rate (CO) in future years. This is mainly due to the effect of fleet modernisation. Already adopted policies such as BS-VI, will result in slower growth of exhaust emissions in future. Additionally, an increase in CO emissions in 2030 can be partially explained by the comparatively higher CO emission factors (based on BS-VI emission limits) adopted for BS-VI fleet.

The carbon dioxide emissions are projected to increase from 7.6 million tonnes in 2025 to 11.4 million tonnes in 2030 i.e. one-and-a-half times, in NFC scenario. Similar to carbon dioxide, exhaust sulphur dioxide emissions are also projected to increase by 1.3 and 1.8 times in 2025 and 2030, respectively, relative to 2021. Although sulphur content in fuel is reduced to 10 ppm in BS-VI standards, the increasing number of vehicles and on-road activity is responsible for increase in SO_2 emissions in future years.

Fig. 13: Exhaust PM emissions by vehicle category in 2021, 2025, and 2030 in NFC scenario

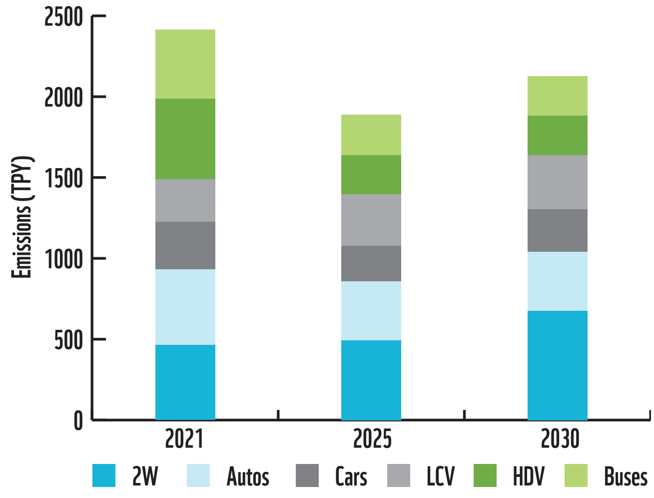


Fig. 14: Exhaust NO_x Emissions by Vehicle Category in 2021, 2025, and 2030 in NFC Scenario

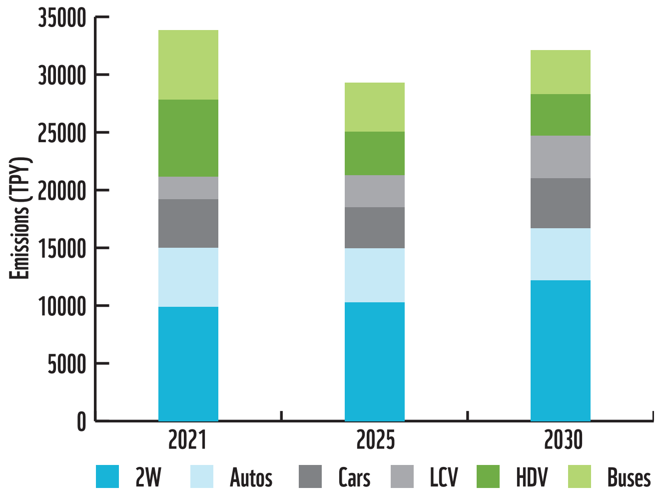


Fig. 15: Exhaust CO Emissions by Vehicle Category in 2021, 2025, and 2030 in NFC Scenario

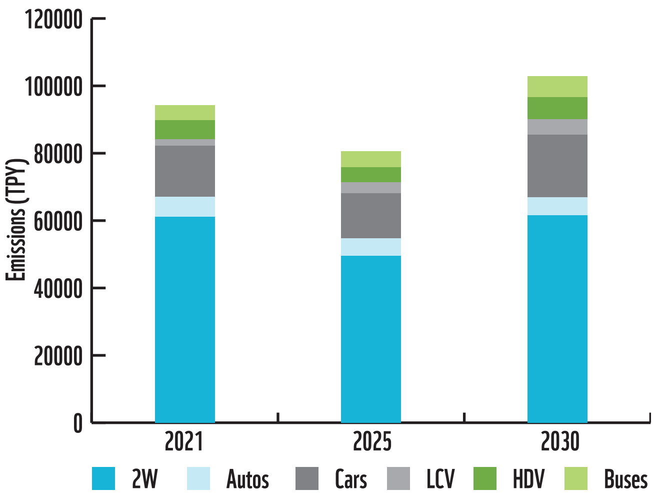


Fig. 16: Exhaust CO_2 Emissions by Vehicle Category in 2021, 2025, and 2030 in NFC Scenario

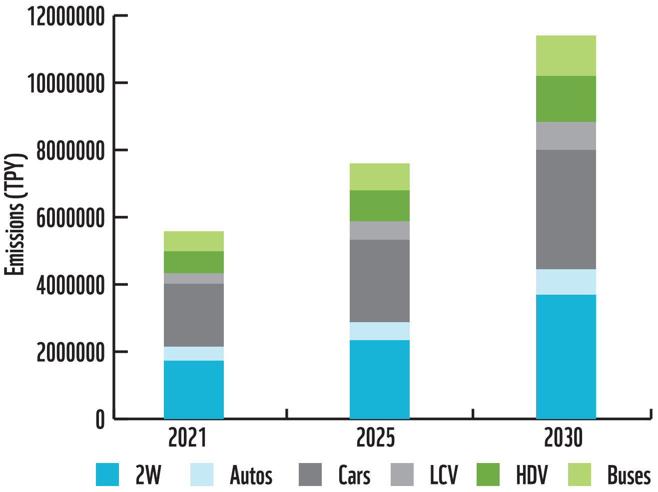
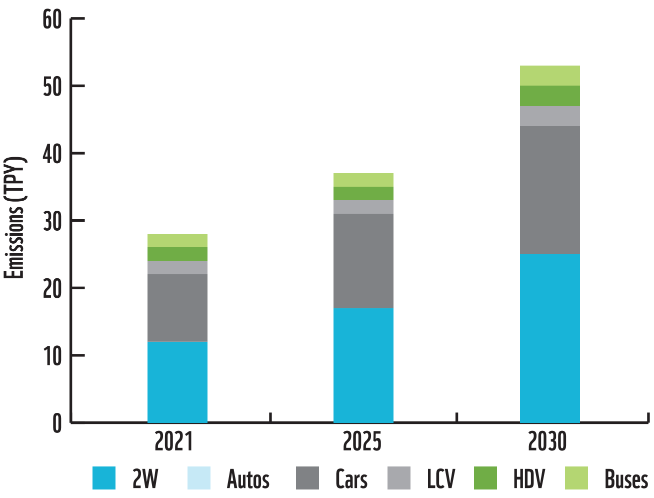


Fig. 17: Exhaust SO_2 Emissions by Vehicle Category in 2021, 2025, and 2030 in NFC Scenario



VEHICULAR EMISSIONS FROM THE LOW AND HIGH AMBITION SCENARIOS

This section discusses the projected emissions of pollutants under consideration with implementation of LAS and HAS in 2025 and 2030. As discussed earlier, these scenarios consider implementation of Bharat Stage (BS)- VI Emission Standards, Ethanol blended Gasoline (E20), Electric Vehicle (EV) penetration, Non-Motorized Transport (NMT), Mass Rapid Transit System (MRTS) or METRO, Public transport improvement (PTI), Shared Mobility (SHMO) and High Capacity Mass Transit Corridor (HCMTR) in Pune city with varying factors for 2025 and 2030. Figure 18 presents vehicle category-wise projected emissions of air pollutants a) PM, b) NO_x and c) CO, d) SO_2, and e) CO_2 with NFC, LAS and HAS in 2025 and 2030.

The LAS projections for Pune city indicate a potential decrease of exhaust PM emissions to 1739 TPY in 2025 i.e. a decrease of 7.9 per cent w.r.t. NFC_2025 and to 1675 TPY in 2030 i.e. a decrease of 21.2 per cent w.r.t. NFC_2030. Similarly, projected exhaust emissions of NO_x indicate a potential reduction to 29293 TPY in 2025 i.e. a decrease of 8.9 per cent w.r.t. NFC_2025 and to 26580 TPY in 2030 i.e. a decrease of 17.2 per cent w.r.t. NFC_2030. The CO emissions are expected to decrease to 80647 TPY in 2025 i.e. a decrease of 11.7 per cent w.r.t. NFC_2025 and 74162 TPY in 2030 i.e. a decrease of 27.9 per cent w.r.t. NFC_2030. Sulphur dioxide emissions are projected to decline by 23.6 per cent (28.78 TPY) and 34.6 per cent (34.8 TPY) in 2025 and 2030, respectively while carbon dioxide emissions are projected to decline by 9.6 per cent (6.88 million tonnes per year) and 23.2 per cent (8.75 million tonnes per year) in 2025 and 2030, respectively relative to their respective NFC scenarios.

The HAS projections for Pune city indicate a potential decrease of exhaust PM emissions to 1655 TPY in 2025 i.e. a decrease of 12.3 per cent w.r.t. NFC_2025 and to 1484 TPY in 2030 i.e. a decrease of 30.2 per cent w.r.t. NFC_2030. Similarly, projected exhaust emissions of NO_x indicate a potential reduction to 24758 TPY in 2025 i.e. a decrease of 15.5 per cent w.r.t. NFC_2025 and to 23568 TPY in 2030 i.e. a decrease of 26.6 per cent w.r.t. NFC_2030. The CO emissions are expected to decrease to 63242 TPY in 2025 i.e. a decrease of 21.6 per cent w.r.t. NFC_2025 and 64258 TPY in 2030 i.e. a decrease of 37.6 per cent w.r.t. NFC_2030. Sulphur dioxide emissions are projected to decline by 27.5 per cent (27.33 TPY) and 45.9 per cent (28.77 TPY) in 2025 and 2030, respectively while carbon dioxide emissions are projected to decline by 16.9 per cent (6.32 million tonnes per year) and 32.3 per cent (7.72 million tonnes per year) in 2025 and 2030, respectively, relative to their respective NFC scenarios.

Fig. 18: Vehicle category-wise projected emissions of air pollutants a) PM, b) NO_x and c) CO with NFC, LAS and HAS in 2025 and 2030

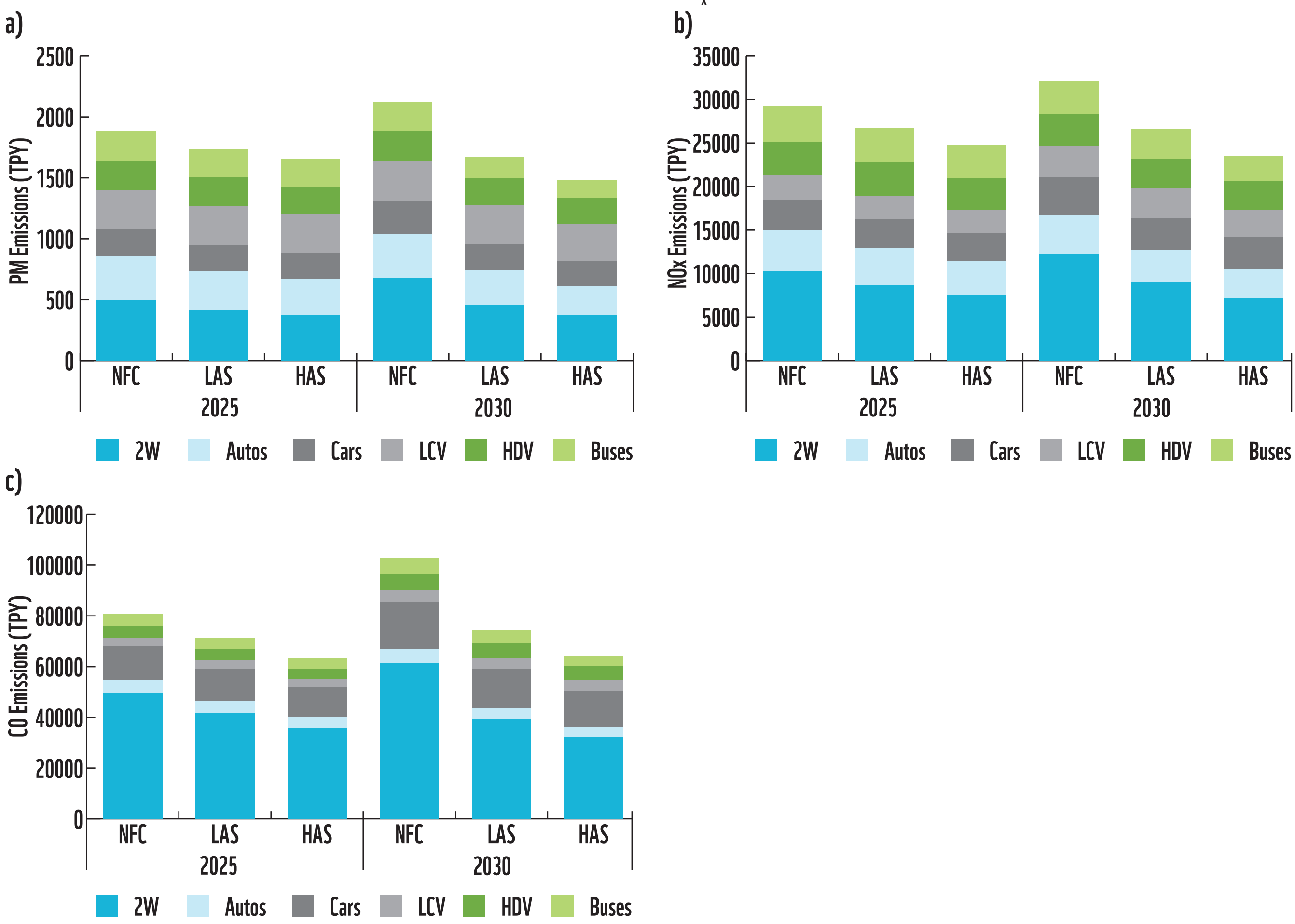
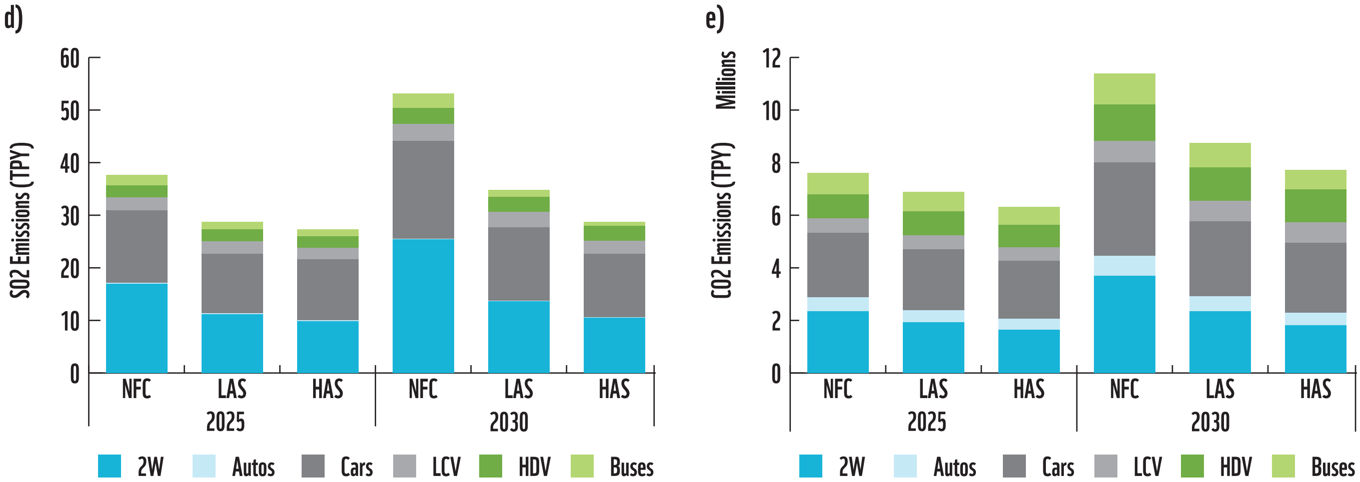
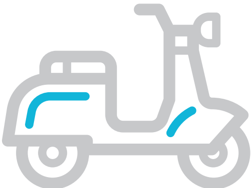


Fig. 18: Vehicle category-wise projected emissions of air pollutants d) SO_2, e) CO_2 with NFC, LAS and HAS in 2025 and 2030





THE VEHICLE CATEGORY-WISE COMPARISON OF PM EMISSION REDUCTIONS SUGGESTS THAT MAXIMUM POTENTIAL REDUCTION CAN BE OBTAINED FOR TWO WHEELERS

The vehicle category-wise comparison of PM emission reductions suggests that maximum potential reduction can be obtained for two wheelers (15.9 to 45.3 per cent) followed by autos (11.2 to 33.1 per cent), buses (7.0 to 38.2 per cent) and cars (4 to 23.4 per cent) compared to respective NFCs. On the other hand, LCVs (0.1 to 8.2 per cent) and HDVs (0.0 to 13.3 per cent) showed a minimal decrease in PM emissions in future scenarios relative to corresponding NFCs. This can be explained by the fact that emission decline in private vehicles and buses is a combined effect of fleet modernisation and VKT reduction whereas in case of LCVs and HDVs the emissions reduction is solely an effect of fleet modernisation. A similar trend is observed in other pollutants also (Refer to Fig. 18).

CONTROL INTERVENTION-WISE EMISSION BENEFITS

This section discusses the impact of selected control interventions on vehicular exhaust emissions in 2025 and 2030 w.r.t. corresponding NFC scenarios. Figure 19 and 20 highlights projected control intervention-wise PM exhaust emissions for LAS and HAS in 2025 and 2030, respectively. In general, the control interventions in HAS showed higher PM reductions (12.3 per cent in 2025 and 30.2 per cent in 2030) than LAS (7.9 per cent in 2025 and 21.2 per cent in 2030), relative to corresponding NFCs. This is obvious because more stringent and aggressive controls are assumed in HAS compared to LAS.

In 2025, the increased penetration of EVs and NGVs could reduce the PM emissions to 1862 TPY (i.e. 1.4 per cent) and 1847 TPY (i.e. 2.1 per) in LAS and HAS, respectively. There is no introduction of E20 till 2025, hence this effect can be directly attributed to EVs and NGVs. Implementation of NMT in Pune city is projected to offer an additional reduction of 0.7 per cent (1849 TPY) and 1.4 per cent (1822 TPY) in LAS and HAS, respectively. Commencement of MRTS/METRO and public transport improvement are projected to decrease the city level PM emissions to 1822 TPY (i.e. reduction of 3.5 per cent relative to NFC_2025) and 1766 TPY (i.e. reduction of 6.4 per cent relative to NFC_2025) in LAS, respectively. With more aggressive implementation of MRTS/METRO and PTI in HAS, the reductions can be further decreased to 1795 (i.e. decrease of 4.9% relative to NFC_2025) and 1714 TPY (i.e. decrease of 9.2 per cent relative to NFC_2025). Implementation of shared mobility in Pune city, can reduce the PM emissions further to 1739 TPY (i.e. reduction of 7.9 per cent relative to NFC_2025) and 1676 TPY (i.e. reduction of 11.2 per cent relative to NFC_2025) in LAS and HAS, respectively. As HCMTR is assumed to be operational in HAS_2025, the PM emissions in LAS are same as SHMO i.e. 1739 TPY. Operational HCMTR in HAS_2025 can offer an additional reduction of 1.1 per cent over SHMO and will lead to cumulative PM reduction of 12.3 per cent relative to NFC i.e.1655 TPY.

In 2030, there will be more advancements on the technology and alternative fuels front. E20 fuelled vehicles will be running on roads, along with further increase in EVs. The combined effect could result in a significant decrease in PM emissions, lowering them to 1872 TPY (i.e. decrease of 11.9 per cent relative to NFC_2030) and 1774 TPY (i.e. decrease of 16.5 per cent relative to NFC_2030) in LAS and HAS, respectively. With assumption of more NMT friendly environment in Pune city by 2030, PM emissions are set to decrease further by 1.2 per cent (1846 TPY) and 2.3 per cent (1725 TPY) in LAS and HAS, respectively. A fully operational MRTS/METRO with five proposed lines along with more improved public transport are projected to decrease the city level PM emissions to 1826 TPY (i.e. reduction of 14.1 per cent relative to NFC_2030) and 1783 TPY (i.e. reduction of 16.1 per cent relative to NFC_2030) in LAS. With more aggressive implementation of MRTS/METRO and PTI in HAS_2030, the reductions can be further decreased to 1679 (i.e. decrease of 21.0 per cent relative to NFC_2030) and 1618 TPY (i.e. decrease of 23.8 per cent relative to NFC_2030). Implementation of shared mobility in Pune city, can reduce the PM emissions further to 1711 TPY (i.e. reduction of 19.5 per cent relative to NFC_2030) and 1528 TPY (i.e. reduction of 28.1 per cent relative to NFC_2025) in LAS and HAS, respectively. As HCMTR is assumed to achieve its full capacity by 2030, the PM emissions are projected to decrease upto 1675 TPY and 1484 TPY in LAS and HAS, respectively thereby offering a total reduction of 21.2 per cent in LAS_2030 and 30.2 per cent in HAS_2030, relative to NFC_2030.

Similar trends are observed in all other pollutants also and hence are not discussed here. Please refer to Annexure V for graphs showing projected exhaust emissions by control intervention for remaining pollutants with LAS and HAS in 2025 and 2030.

Fig. 19: Projected control intervention wise exhaust PM emissions (vertical bars) for LAS and HAS in 2025. The lines with markers show control intervention wise percent change (secondary y-axis) w.r.t. NFC_2025.

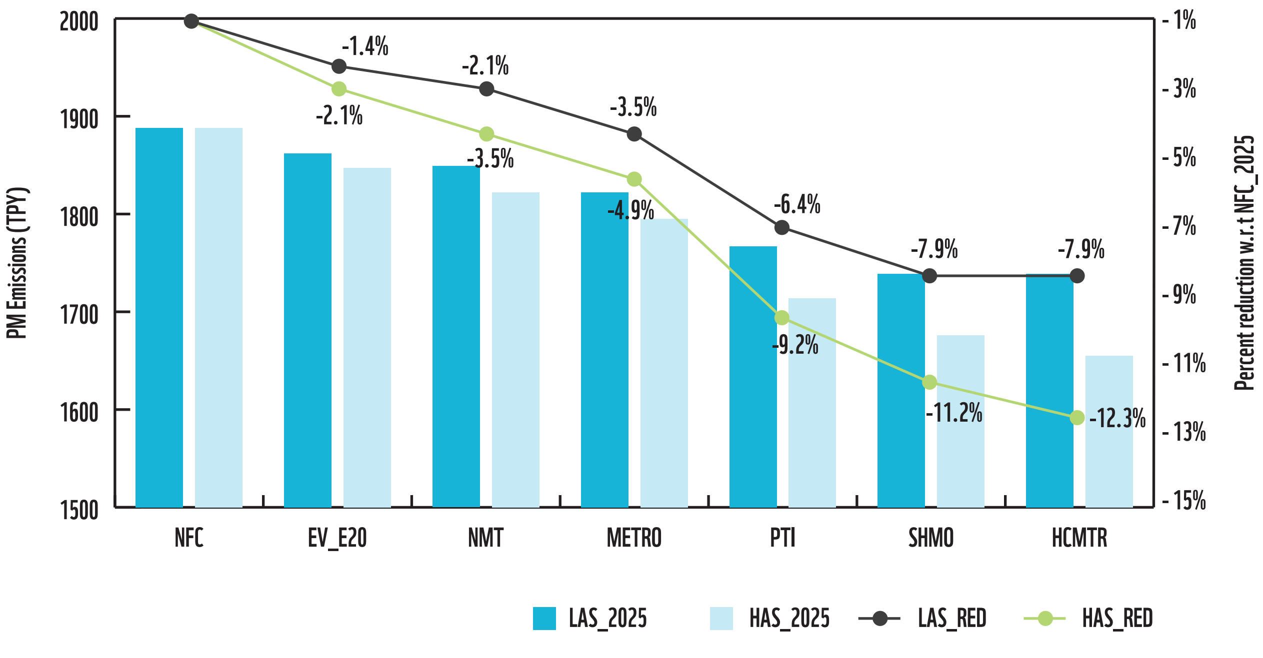
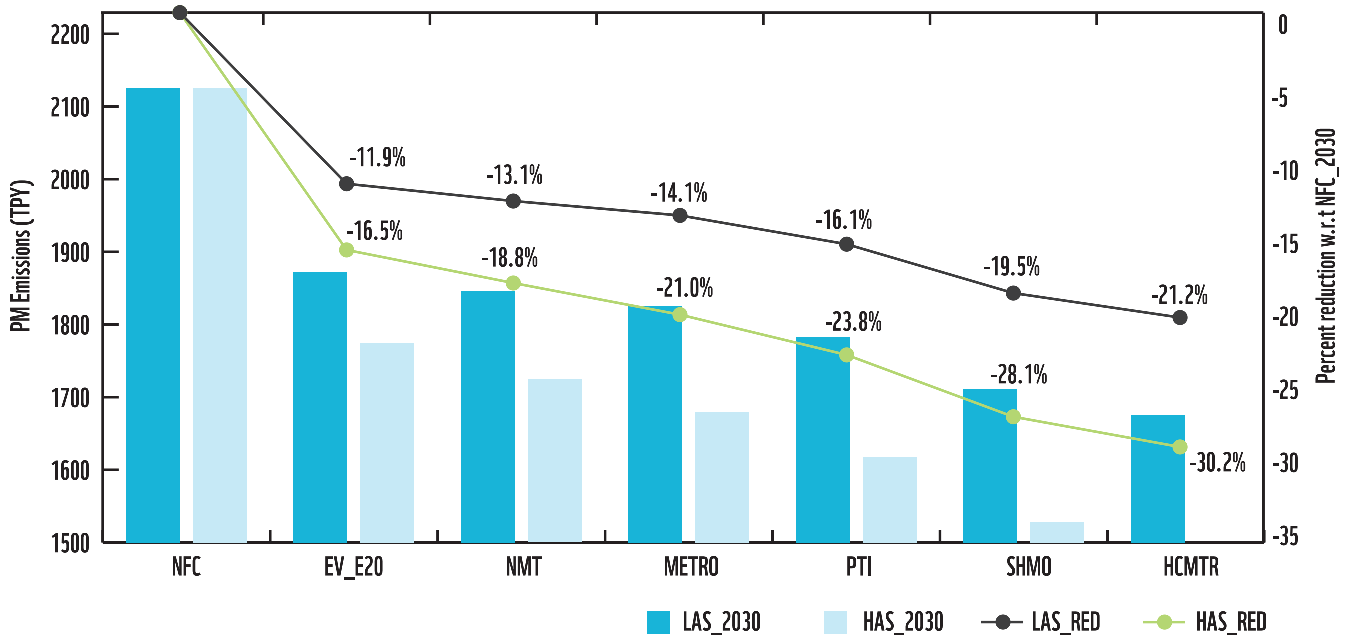


Fig. 20: Projected control intervention wise exhaust PM emissions (vertical bars) for LAS and HAS in 2030. The lines with markers show control intervention wise percent change (secondary y-axis) w.r.t. NFC_2030.



4.4 IMPACT ON RE-SUSPENDED ROAD DUST EMISSIONS

As discussed earlier, the re-suspended road dust is a major contributor to particulate matter emissions in year 2021 in Pune, accounting for about 28 per cent and 57 per cent of total $PM_{2.5}$ and PM_{10} emissions, respectively. As these emissions are directly related to on-road vehicle activity, a reduction in VKT due to implementation of various control interventions, would ultimately result in reduction of re-suspended road dust in Pune city. In addition to VKT reduction, it is also assumed that silt loading on different types of roads would also decrease in 2025 and 2030 as result of adoption of better cleaning technology and practices in years to come (refer Section 3.1.6 for details).

We assessed the combined effect of reduction in VKT and silt loading, on subsequent reduction of PM emissions in Pune city. Fig. 21 depicts the changes in $PM_{2.5}$ and PM_{10} emissions from re-suspended road dust with NFC, LAS and HAS in 2025 and 2030. As shown in the figure, the PM emissions with assumption of no further controls i.e. NFC, are projected to increase by ~1.5 times in 2030 (i.e. $PM_{2.5}$: 3383 TPY and PM_{10}: 13981 TPY), compared to 2025 (i.e. $PM_{2.5}$: 2231 TPY and PM_{10}: 9222 TPY). The measures assumed in LAS would bring down the PM emissions by 19.2 per cent (i.e. $PM_{2.5}$: 1802 TPY and PM_{10}: 7450 TPY) and 30.5 per cent (i.e. $PM_{2.5}$: 2351 TPY and PM_{10}: 9717 TPY) in 2025 and 2030, respectively, relative to corresponding NFCs. Similarly, adoption of more stringent controls proposed in HAS would result in a decrease of PM emissions by 28.0 per cent (i.e. $PM_{2.5}$: 1607 TPY and PM_{10}: 6641 TPY) and 44.4% (i.e. $PM_{2.5}$: 1880 TPY and PM_{10}: 7769 TPY) in 2025 and 2030, respectively.

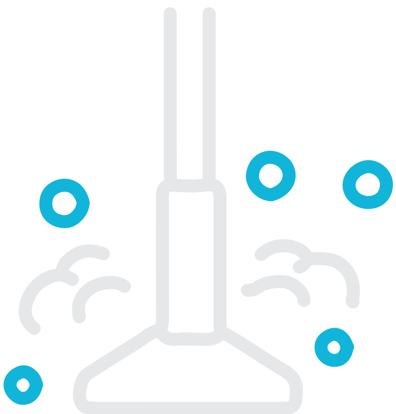
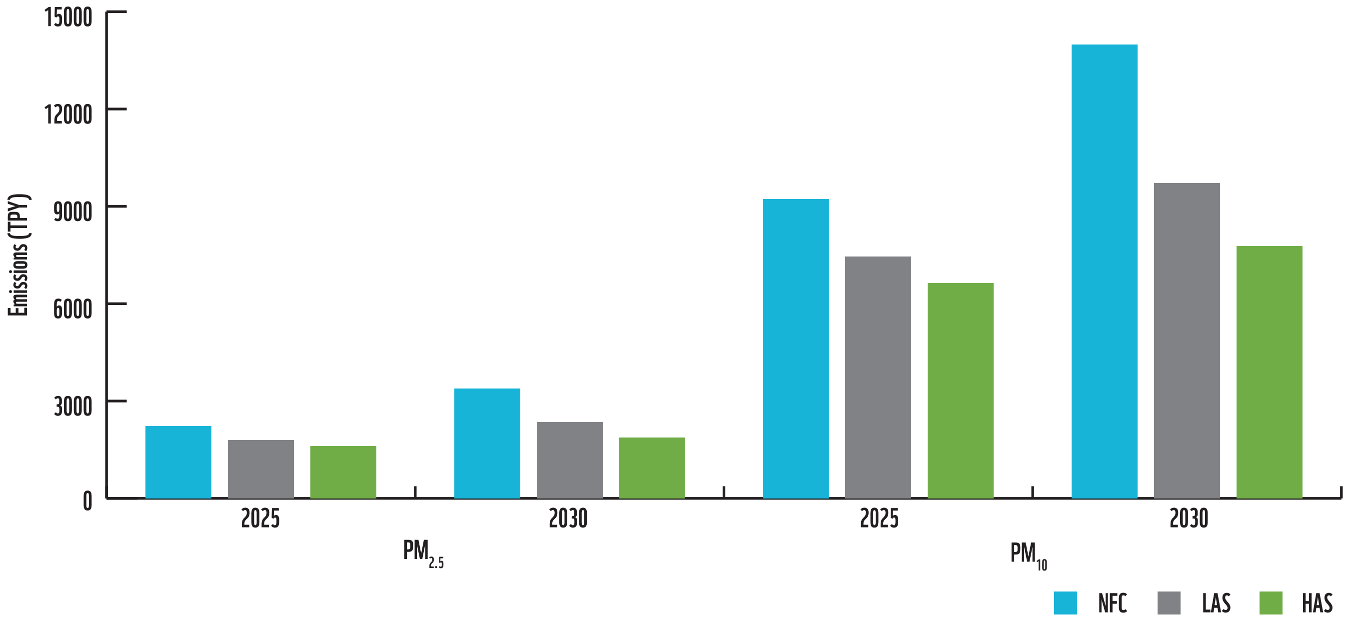
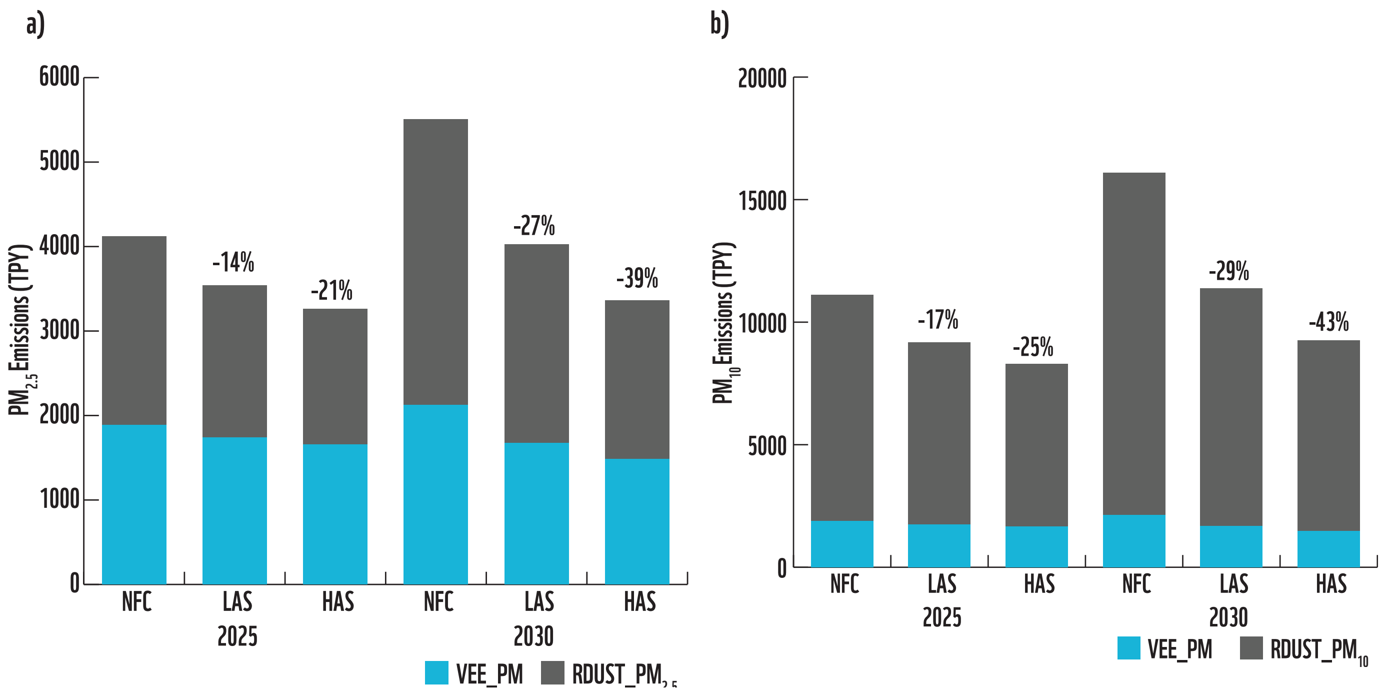


Fig. 21: Changes in $PM_{2.5}$ and PM_{10} emissions from re-suspended road dust with NFC, LAS and HAS in 2025 and 2030



Figures 22 (A) and (B) show the combined effect of control measures on vehicular (VEE) and re-suspended road dust (RDUST) on $PM_{2.5}$ and PM_{10} emissions (TPY) in Pune city, respectively. In 2025 the $PM_{2.5}$ emissions are projected to reduce by 14 and 21 per cent in LAS and HAS, respectively whereas in 2030, the $PM_{2.5}$ emissions are expected to decrease by 27 and 39 per cent in LAS and HAS, respectively compared to respective NFCs. The PM_{10} emissions are also expected to decline significantly in 2025 (17 per cent in LAS and 25 per cent HAS) and 2030 (29% in LAS and 43% in HAS). More details are provided in Annexure VI.

Fig. 22: Changes in $PM_{2.5}$ (a) and PM_{10} (b) emissions from vehicular exhaust and re-suspended road dust with NFC, LAS and HAS in 2025 and 2030. The numbers on top of bars indicate potential percent reduction compared to respective NFC scenarios.



4.5 AIR QUALITY BENEFITS

Air quality benefits of LAS and HAS were assessed for years 2025 and 2030 using AERMOD modelled annual average concentrations pollutants at three selected locations in Pune city. The locations of three NAMP stations i.e. Karve Road, Nal stop and Swargate, were selected to assess the impact of proposed emission scenarios on air quality. Table 10 and 11 present AERMOD predicted air pollutant concentrations at selected locations for NFC, LAS and HAS scenarios in 2025 and 2030, respectively.

An examination of Tables 10 and 11 suggest that maximum reduction could be achieved in PM_{10} concentrations, followed by CO, $PM_{2.5}$, and NO_2 while minimal (greater than 2 per cent) reductions are observed in sulphur dioxide concentrations at three selected locations, compared to respective NFC scenarios. In case of particulates the reduced concentrations are combined effect of both lowered exhaust emissions and road dust re-suspension (due to decrease in VKT as well as silt loading), while in case of gaseous pollutants the change is attributable to exhaust emissions only. It is interesting to note percent reductions in nitrogen dioxide concentrations are not as high as other pollutants such as PM and/or carbon monoxide in both LAS and HAS. This can be mainly attributed to increased emissions per unit distance of NO_x in E20 fuelled vehicles and higher penetration of NGV fuelled LCVs and HDVs. Ambient sulphur dioxide concentrations at three locations are predicted to change marginally (-0.4 to -1.1 per cent) in different scenarios, mainly due to lower share of vehicular sulphur dioxide in total sulphur dioxide emissions.

Table 9: AERMOD predicted air pollutant concentrations (in µg/m³) at selected locations for NFC, LAS and HAS scenarios in 2025. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)

Location	Scenario	$PM_{2.5}$	PM_{10}	NO_2	CO	SO_2
Karve Road	NFC	32.8	86.5	34.3	333.3	11.8
	LAS	29.1 (-11.2%)	73.1 (-15.6%)	31.7 (-7.4%)	298.2 (-10.5%)	11.8 (-0.4%)
	HAS	28.5 (-13%)	69.9 (-19.3%)	30.6 (-10.8%)	280 (-16%)	11.8 (-0.4%)
Nal Stop	NFC	32.9	86.8	35.4	335.8	11.5
	LAS	29.2 (-11.3%)	73.1 (-15.8%)	32.9 (-7.2%)	300 (-10.6%)	11.5 (-0.4%)
	HAS	28.8 (-12.4%)	70.3 (-19%)	31.3 (-11.6%)	282.6 (-15.9%)	11.5 (-0.4%)
Swargate	NFC	40.7	106.8	43.7	420.3	13.9
	LAS	36.1 (-11.3%)	90.1 (-15.7%)	40.6 (-7.2%)	376.2 (-10.5%)	13.9 (-0.4%)
	HAS	34.6 (-15%)	84.7 (-20.7%)	39.1 (-10.7%)	344.8 (-18%)	13.9 (-0.5%)

Table 10: AERMOD predicted air pollutant concentrations (in µg/m³) at selected locations for NFC, LAS and HAS scenarios in 2030. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)

Location	Scenario	$PM_{2.5}$	PM_{10}	NO_2	CO	SO_2
Karve Rd	NFC	40.8	116.8	35.9	396.0	12.7
	LAS	29.8 (-26.9%)	83.8 (-28.2%)	31.6 (-11.8%)	286.1 (-27.8%)	12.6 (-0.7%)
	HAS	29.1 (-28.6%)	74.3 (-36.4%)	30.5 (-15.1%)	272.2 (-31.3%)	12.6 (-0.9%)
Nal Stop	NFC	40.9	117.0	37.1	397.7	12.2
	LAS	29.8 (-27.1%)	83.9 (-28.3%)	33.5 (-9.9%)	287.7 (-27.7%)	12.1 (-0.7%)
	HAS	29.4 (-28.2%)	74.7 (-36.2%)	32.5 (-12.5%)	275.1 (-30.8%)	12.1 (-0.9%)
Swargate	NFC	50.1	143.5	45.5	497.0	14.4
	LAS	35.5 (-29.2%)	100.6 (-29.9%)	38.4 (-15.5%)	345.2 (-30.6%)	14.3 (-0.8%)
	HAS	34.7 (-30.7%)	88.8 (-38.1%)	36.6 (-19.5%)	325.8 (-34.5%)	14.3 (-1.1%)

The AERMOD predicted annual average concentrations of $PM_{2.5}$ at three selected locations ranged from 28.5 to 40.7 µg/m^3 during 2025 and from 29.1 to 50.1 µg/m^3 during 2030. The predicted annual average $PM_{2.5}$ concentrations are projected to exceed the air quality standard (i.e. 40 µg/m^3) prescribed by NAAQS in NFC_2030 scenario. The implementation of control measures considered in LAS and HAS can reduce $PM_{2.5}$ by 11.2 to 11.3 per cent and 13.0 to 15.0 per cent at selected locations in the Pune city. Similarly, in 2030, the $PM_{2.5}$ concentrations at three selected locations in Pune city could be lowered by 26.9 to 29.2 per cent and 28.2 to 30.7 per cent compared to NFC, during LAS and HAS, respectively.

As discussed previously, PM_{10} is the main reason for non-attainment of NAAQS in Pune city. The PM_{10} concentrations at three selected locations in city are predicted to range from 69.9 to 106.8 µg/m^3 in 2025 and from 74.3 and 143.5 µg/m^3 in 2030. The introduction of control measures suggested in this study can achieve significant reductions in PM_{10} concentrations at selected locations (i.e. 15.6 to 20.7 per cent in 2025 and 28.2 to 38.1 per cent in 2030). It is important to note that, even the most aggressive vehicular control measures may not be able to meet the annual average air quality standard for PM_{10} i.e. 60 µg/m^3, at three locations in 2030. Which in turn imply that only vehicle related control measures may not be sufficient to improve the PM_{10} situation in Pune city. Several control actions/measures in other sectors such as construction, industries, residential, and open waste burning must also be introduced to reduce the PM_{10} concentrations.

Implementation of LAS and HAS will significantly reduce the ambient concentrations of gaseous pollutants such as NO_2 (7.2-19.5 per cent) and CO (10.5-34.4 per cent) in future years thereby improving air quality and public health. Ambient sulphur dioxide concentrations would not change (0.4-1.1 per cent) much in future years compared to NFC levels, because the vehicles are not a major source of sulphur dioxide emissions and contribute less than 4 per cent in total sulphur dioxide emissions.

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SUMMARY AND FINDINGS

Relevant recommendations, from the India roadmap on 'Low Carbon and Sustainable Mobility with thrust on decarbonisation of the Indian transport sector', for rapidly growing urban centres like Pune city were identified.

- A stakeholder consultation workshop was conducted during the initial phase, for dissemination of information on India road map and to get views/ opinions of stakeholders on the relevant transport sector emission control interventions for Pune.
- Eight control interventions for transport sector were evaluated, for Pune city, in short term (Year 2025) and Mid-term (Year 2030). These are:
   1. Impact of BS VI implementation (BS-VI)
   2. Roll-out of E20 fuel (E20)
   3. Increased penetration of Electric Vehicles (EV)
   4. Non-motorised transport (NMT)
   5. Use of Metro rail services for public transport (METRO-Mass rapid transit system)
   6. Improved public transport system (PTI)
   7. Increased Shared Mobility (SHMO)
   8. Implementation of HCMTR corridor (HCMTR)
- Three future scenarios (for Year 2025 and Year 2030), were designed with varying level of application -
   1. The No Further Control (NFC) scenario represents already adopted policy measures, would continue without any other controls.
   2. The Low Ambition Scenario (LAS) represents policies and technologies that are planned or in pipeline and could be implemented.
   3. The High Ambition Scenario (HAS) represents aggressive implementation of policy measures considered in LAS for additional emission reductions.
- Pollutant-wise per cent reduction in tail-pipe emissions (tonnes per year) is evaluated w ith respect to NFC scenario to represent impact of control interventions.

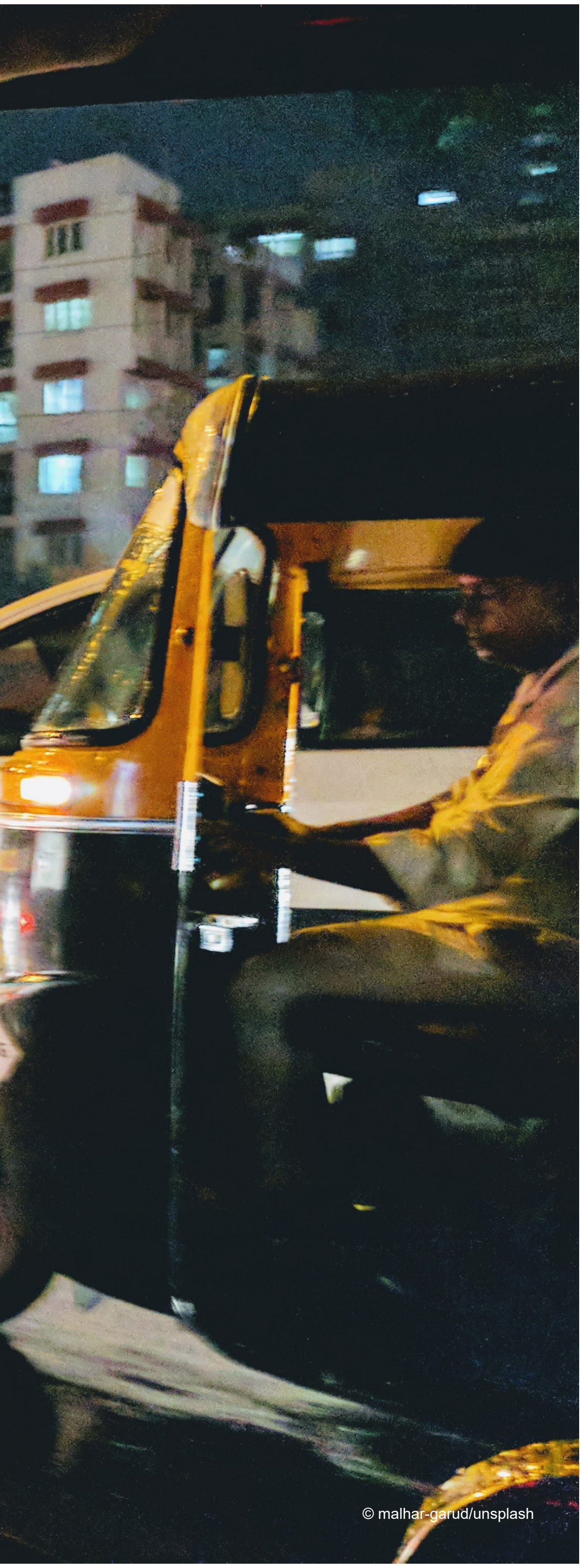


Fig. 23: Estimated potential changes (in percentage) in vehicular exhaust emissions of selected pollutants in years 2025 and 2030.

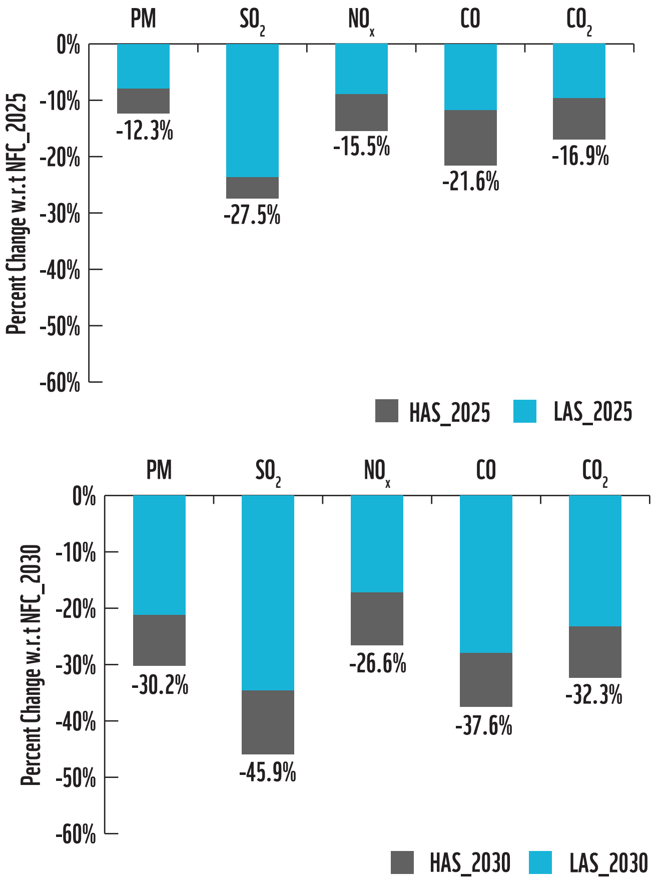
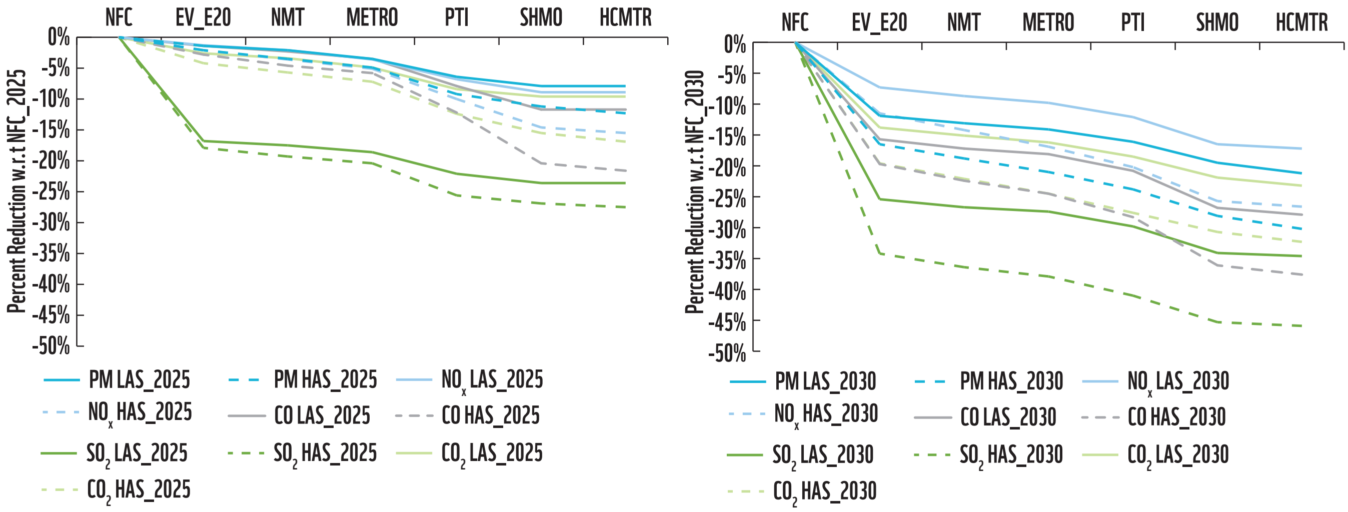


Fig. 24: The control-intervention-wise estimated potential percentage change in vehicular exhaust emissions for LAS and HAS in 2025 and 2030, respectively



- Impact of individual control interventions, from transport sector, in tail-pipe emissions (tonnes per year) of selected pollutants under different scenarios is presented above.
- Reduction in re-suspended dust due to reduction in VKT and reduction in silt-loading on roads was calculated for year 2025 and year 2030. This reduction was considered for evaluating total reduction in particulate matter emission load due to control interventions.
- Dispersion modelling was taken up using AERMOD system for assessing potential change in annual average concentrations of selected pollutants at city level. Gridded (2 km x 2 km) emission inventory with emission loads from all sources including transport, industry, residential, etc. was used as an input for dispersion modelling. Substantial reductions in ambient concentrations of pollutants at selected locations, as shown below, was observed as a result of cumulative impact of transport sector control interventions.

Table 11: AERMOD predicted air pollutant concentrations (µg/m³) at selected locations for NFC, LAS and HAS scenarios in 2025. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)

Location	Scenario	$PM_{2.5}$	PM_{10}	NO_2	CO	SO_2
Karve Road	**NFC**	32.8	86.5	34.3	333.3	11.8
	LAS	29.1 (-11.2%)	73.1 (-15.6%)	31.7 (-7.4%)	298.2 (-10.5%)	11.8 (-0.4%)
	HAS	28.5 (-13%)	69.9 (-19.3%)	30.6 (-10.8%)	280 (-16%)	11.8 (-0.4%)
Nal Stop	**NFC**	32.9	86.8	35.4	335.8	11.5
	LAS	29.2 (-11.3%)	73.1 (-15.8%)	32.9 (-7.2%)	300 (-10.6%)	11.5 (-0.4%)
	HAS	28.8 (-12.4%)	70.3 (-19%)	31.3 (-11.6%)	282.6 (-15.9%)	11.5 (-0.4%)
Swargate	**NFC**	40.7	106.8	43.7	420.3	13.9
	LAS	36.1 (-11.3%)	90.1 (-15.7%)	40.6 (-7.2%)	376.2 (-10.5%)	13.9 (-0.4%)
	HAS	34.6 (-15%)	84.7 (-20.7%)	39.1 (-10.7%)	344.8 (-18%)	13.9 (-0.5%)

Table 12: AERMOD predicted air pollutant concentrations (µg/m³) at selected locations for NFC, LAS and HAS scenarios in 2030. (Note: The numbers in the bracket indicate the percentage change w.r.t. NFC scenario)

Location	Scenario	$PM_{2.5}$	PM_{10}	NO_2	CO	SO_2
Karve Rd	**NFC**	40.8	116.8	35.9	396.0	12.7
	LAS	29.8 (-26.9%)	83.8 (-28.2%)	31.6 (-11.8%)	286.1 (-27.8%)	12.6 (-0.7%)
	HAS	29.1 (-28.6%)	74.3 (-36.4%)	30.5 (-15.1%)	272.2 (-31.3%)	12.6 (-0.9%)
Nal Stop	**NFC**	40.9	117.0	37.1	397.7	12.2
	LAS	29.8 (-27.1%)	83.9 (-28.3%)	33.5 (-9.9%)	287.7 (-27.7%)	12.1 (-0.7%)
	HAS	29.4 (-28.2%)	74.7 (-36.2%)	32.5 (-12.5%)	275.1 (-30.8%)	12.1 (-0.9%)
Swargate	**NFC**	50.1	143.5	45.5	497.0	14.4
	LAS	35.5 (-29.2%)	100.6 (-29.9%)	38.4 (-15.5%)	345.2 (-30.6%)	14.3 (-0.8%)
	HAS	34.7 (-30.7%)	88.8 (-38.1%)	36.6 (-19.5%)	325.8 (-34.5%)	14.3 (-1.1%)

- The dispersion modelling results suggest that even if stringent control interventions in vehicular sector are implemented in Pune city, it is difficult to achieve the NAAQS for pollutants such as PM_{10}. Several control actions/measures in other sectors such as construction, industries, residential, and open waste burning must also be introduced to reduce the PM_{10} concentrations at city level.

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ANNEXURE I

Extract of relevant City Level Recommendations from India Roadmap[1]

Sector / Brief Background	Recommendations		
	Short-term (2020-2022)	Mid-term (2020-2030)	Long-term (2030-2050)
Urban Transformation for Healthier, Inclusive Lifestyles and Efficient, Resilient, Prosperous Cities	• Formation of Unified Metropolitan Transport Authority (UMTA) and set up a task force. • Citizen Charter for Urban Mobility (CCUM) at Strategic, Tactical and Operational Level • Redefine RTO's role in qualifying bus operators for providing MAAS (Mobility as a Service) under direction of the UMTA	• Extend incentives for public transport, limit registration of private vehicles in large metros, enforce congestion charging and implement Scrap Policy rigorously • Set up Scheduled Services and app-based Services for Public Transport • Implement new technologies for last-mile connectivity, such as urban ropeways, shared mobility, and infrastructure and technologies for non-motorized transport • Increase utility of Bus Ports through allowing their use by private operators under PPP model. • Implement Transit Oriented Development (TOD) rigorously • Revisit the City Master Plans in line with current and future needs using technology and data analytics to simulate city mobility needs • Develop and implement Integrated Transport Mobility Plan	Invest in advanced technologies for electric mobility and intelligent transport systems.
Low-carbon energy supply strategy (Environment and Pollution)	• Build public awareness, campaigns, and participation about low carbon transportation • Sensitisation and capacity building initiatives with academic institutions and local communities. • Adopt effective pedagogy for triggering behavioral change towards sustainable, low carbon mobility options		
Low-carbon energy supply strategy (Renewable Energy)	• Bundle EVSE (Electric Vehicle Supply Equipment) as mandatory in new buildings through Building Codes • Ensure closer alignment of Energy and Transport Sector in policymaking to develop joint pathway for low carbon and sustainable mobility	• Develop framework for recycling and disposal of solar panels	100% EV stations powered from renewable energy

1 FICCI/WWF (2020), India Roadmap on Low Carbon and Sustainable Mobility (Decarbonisation of Indian Transport Sector)

Sector / Brief Background	Recommendations		
	Short-term (2020-2022)	Mid-term (2020-2030)	Long-term (2030-2050)
Low-carbon energy supply strategy (Petroleum and Biofuels)	• Develop and focus on the use of more carbon efficient modes of transport (Priority to Rail, Metro, LRT, Buses, Taxis, etc.) • Improve fuel efficiency of vehicle fleet by introducing labelling/ratings systems, minimum efficiency standard and corporate fleet efficiency standards	• To adopt a systems approach and reduce the need of transport through appropriate choices for locating industries and other businesses, and through better planning to minimize commuting needs. e.g. TOD • Monitor Implementation of goals of National Policy on Biofuels, 2018	
Low-carbon energy supply strategy (Deployment of EVs)	• Develop ecosystem to convert existing ICE Vehicles to EVs and encourage large volume manufacturing of EVs to control prices • Develop policy framework and guidelines for phasing out vintage petrol and diesel vehicles • Apply minimum renewable energy purchase obligations by EV charger installations • Provide tax incentives for EV charging from renewable energy sources	• Mandate for infrastructure development by City governments/ municipalities to allot space for EVSE networks on lease at concessional rates under OPEX model	
Improve Intermodal and Mode-Wise System Efficiencies	• Build clear governance structure at national, state and local level to implement transport and mobility directives including clearances, approvals, land and funds allocation, infrastructure and operation • Make it mandatory for ULBs to provide safe, smart, and sustainable public transport to all its citizens • Provide departure and arrival bus bays at the railway stations, air and seaports having enough parking space, connectivity of feeder buses with metro systems (following an integrated systems approach) • Permits should be clearly defined for the relevant type of services to being in clarity in the type of services it is expected to provide. Permits can be of three types: i) Scheduled—Vehicle that operates on a fixed route; ii) Schedule Metered—Vehicles that runs on time and km basis for the general public as per government approved rates, and iii) Chartered – Vehicle that is available for hire or reward for the general public. • Earmark substantial part of the road budget towards the development of public transport infrastructure, such as multi-modal terminals, surface ports, bus stations, highway amenity centres, rest areas, viewpoints, parking lots, multi-modal logistics parks, etc. • Decongesting traffic through inter-related steps- Sustainable solutions to traffic problems can be secured by combining public policy and private sector innovation, like improving public transport and discouraging private vehicles from using parking pricing and management.	• Set up fully functional Traffic Management Centres for coordinating the urban and regional ITS activities • Road safety and better traffic management can be done by integrating ITS (intelligent transport systems), optimising road networks, improving junction and roadway design, strengthening traffic management measures, segregating traffic and building ring roads and logistics parks around cities. • Public-Private Partnership: Private participation should be encouraged in developing better public transport facilities, development of infrastructures, such as bus and multimodal terminals.	

Sector / Brief Background	Recommendations		
	Short-term (2020-2022)	Mid-term (2020-2030)	Long-term (2030-2050)
Avoid Vehicle Kilometres for Commuting, Shopping and Accessing Services	• Notify a mandate to adopt sustainable transport models with focus on usage of public transport, shared mobility to reduce the numbers of private vehicles on road. • Introduce emission standards for polluting vehicles. Notify a mandate to scrap all commercial vehicles older than 15 years. • An integrated system approach using National Common Mobility Card should be adopted. Like airline miles, public transport miles should be introduced to avail discounts on usage of public transport. • ITS should be adopted for seamless travel in public transport. • Flexible working options will also help in reducing the need to travel.	• TOD plans including mixed land use, non-motorized infrastructure. • Revisiting the city master plans to revise them as per the current needs. • City wise targets to double the modal share of public transport. • City level electrification targets for buses, commercial fleets. and other public transport modes. • Adopting sustainable designs, policies, systems to promote compact city approach, integrated public transport development plans and clean fuel infrastructure plans	• Implementation and execution of master plan documents for planning, enforcement, awareness, and engagement strategies
Accelerate Action on Adaptation in the Transport Sector	• Apply TOD by promoting mixed land-use, NMT infrastructure, e-commerce for service at doorstep, encouraging work from home, ZEV like e-Autos for last mile mobility by connecting metro infrastructures, and creating porosity by ensuring all daily needs are within walking distance. • Promoting NMT components in transport master plans • Implement stringent SOP (standard operating procedure) for drainage system • Develop a climate risk evaluation tool to assess risks and build mitigation strategies • Designing of high-quality public transport services on dedicated infrastructure along major city corridors • Driver training on disaster management to help deal with post disaster management activities • Emergency/redundant route planning • Better weather/disaster forecasting tools to help predict imminent dangers, and preparing in advance	• Developing quality, reliable, sustainable and climate resilient infrastructure by integrating transport infrastructure into urban planning • Creating frameworks to evaluate the preparedness of transport infrastructure for climate change related disasters • Preparing strategy document on low carbon and climate-resilient mobility plan for cities integrating them to form the national low carbon mobility vision • Implement Master Plan for systemic improvement of all utilities in cities • 3D Mapping of all major cities • More resilient design standards for infrastructure, utilities and storm water drains • Ensure Build-Own-Operate-Maintain (BOOM) models are implemented • Building sufficient redundancy	

<table>
<tr><th rowspan="2">Sector / Brief Background</th><th colspan="3">Recommendations</th></tr>
<tr><th>Short-term (2020-2022)</th><th>Mid-term (2020-2030)</th><th>Long-term (2030-2050)</th></tr>
<tr><td>Large Scale Deployment of Economic Instruments and Leveraging Finance</td><td colspan="3">URBAN PLANNING AND INFRASTRUCTURE FOR SUSTAINABLE MOBILITY
Passenger Mobility (with holistic perspective)
(i) All cities to have a mandatory budget for providing better passenger mobility including pedestrian and NMT (non-motorized transport) infrastructure, Mass Transit Systems, Bus (where possible) Multi-mode Terminals, Technology Platform to monitor and integrate all services, and Common EV Charging Stations.
(ii) Cities should be funded for holistic, sustainable mobility programmes, rather than funding a specific project. Funds should be allocated for integrated transport systems.
(iii) Funds should be managed and disbursed only through single SPV (special purpose vehicle) which shall fund the projects on the basis of approved plan, with priority given to a plan which will carry more people per rupee spent.
(iv) Accelerate decarbonization of, current, city transport systems (through large-scale adoption of EVs and Bio-CNG/Advanced biofuels vehicles), with subsidy and viability gap funding schemes that facilitate scale-up, having defined duration and budgets for financial assistance.

INCENTIVISING AND ENHANCING PUBLIC TRANSPORT
Fiscal measures should be taken to enhance usage of public transport for daily work, thereby limiting use of private vehicle. This could be achieved through higher motor vehicle tax, fuel taxes, road user charges, on-street parking charges for private vehicles. The revenue gained to be used to fund public transport as well as pedestrian and NMT infrastructure.

ELECTRIC VEHICLES
(i) Electric utilities may be mandated to setup EVSE networks in strategic locations in their service area,
(ii) Bundle EVSE as mandatory in new buildings through building codes
(iii) EV manufacturers to contribute a certain percentage of the vehicle cost towards EVSE fund
(iv) EVSE infrastructure may be clubbed with highway construction cost,
(v) In commercial centres, tourist and religious places, large commercial establishments may be encouraged to invest in EVSE infrastructure
(vi) PSUs (public sector undertakings) and large private companies may be mandated to set up EVSE infrastructure, for their vehicles.
(vii) Oil distribution companies may be encouraged to create EVSE infrastructure
(ix) Fleet operators and car rental companies may be encouraged to set up EVSE networks.
(x) Fiscal incentives like tax concessions, free or concessional land on long-term lease at strategic locations, which will also have Cafes/ATMs, gyms, air/ tyre changing stations. Where such fiscal incentives are provided, the allocation should be through a transparent bidding and selection process. Where there are no fiscal incentives provided by the Government, growth should be through market-driven competitive forces, without any Government involvement, except for statutory clearances.</td></tr>
</table>

ANNEXURE II

Discussion Summary of Stakeholder's Workshop on "Low Carbon & Sustainable Mobility Roadmap for Pune City"

A.2.1: Governance:

Mr. Amarnath Karan, CEE	• Guidelines are prescribed by state government for UMTA Committee • Implementation of parking policy can constrain the use of private vehicles in Pune city • Promotion and increasing modal share of NMT is important • Government is planning for bus rejuvenation programme • Discourage use of private transport • Improvements in city bus infrastructure is required
Mr. Mahesh Harhare, GIZ	• Different studies were carried out by Indian government regarding UMTA • Hyderabad city passed resolution for setting up UMTA similarly, Pune has also setup PUMTA • State level public transport funds will be useful, which will reduce burden on State Transport Corporations. • For transit-oriented development (TOD) each city needs to carry out study for feasibility of TOD.
Mr. Mangesh Dighe, PMC	• Strengthening UMTA would be a very nice approach. It will benefit not only PMC, but also PCMC and the three cantonment boards. • For improving the mobility in a region, a dedicated organisation/institute would be very helpful.
Mr. Aniruddha Shahapure PSCDC	• Pune Smart City Development Corporation provided subsidy for 150 electric buses. • With implementation of Adaptive Traffic Management System, Pune city will have more optimized traffic signals
Dr. Utkarsh Mukkannawar, IITM	• Airport-like approach shall be followed in roadway maintenance work • UMTA authority shall also check road conditions. • EVs do not have direct emissions from tailpipe, however they may contribute at power plant locations.

A.2.2: Management:

Mr. Aniruddha Shahapure, PSCDC	• With current COVID-19 scenario, most of the IT professionals are working from home and this is likely to continue in future as well. • Planning of mass rapid transport shall consider future policies/practices and such as work from home scenarios as well. • Public Transport System shall be convenient for common people, in order to increase its modal share. • Feasibility assessment in different areas shall be carried out for NMT options such as pedestrian, cycling, etc.
Mr. Mangesh Dighe, PMC	• Pool of experts is required for course corrections/modifications in the existing plans. • There is a requirement of data for future projections for modelling and data-based decisions. • For real-time data collection technologies like google analytics may be utilised.
Dr. Sachin Ghude, IITM	• Flexible working hours can be adapted by organisations/institutions • Odd-Even formulas like Delhi, can be implemented for congestion management in Pune as well.
Dr. Gaurav Gowardhan, IITM	• Flexible working days can be adapted by organizations/companies in addition to flexible working hours
Mr. Amarnath Karan, CEE	• System level efficiencies shall be improved • Better public transport infrastructure shall be provided • Service and institution also needs to be strengthened for public city bus transport to enhance its modal share. • NMT approach at city level as well as zonal level shall be considered • Safe and convenient NMT infrastructure shall be developed specifically considering women, children and elderly people.

Ms. Ashwini Yadav, PMC	• Energy demand and consumption needs to be estimated, specifically for future EV scenarios • Cost effectiveness of EVs shall be assessed and use of solar power and renewables shall be promoted for charging EVs. • Affordability and range of EVs is currently concern for common people.
Dr. Utkarsh Mukkannawar, IITM	• Signal synchronising shall be improvised. • Signal waiting timings shall be optimized based the traffic flow conditions at a particular time.

A.2.3: Technology, Innovation, Research:

Dr. Nivedita Gogate, MIT	• There is need for Resilient Mobility Development Plan. • Entire city shall be divided into different smaller zones with zonal mobility plans.
Dr. Santosh Kulkarni, CDAC	• C-DAC is working on Urban Modelling Project for integrated forecasting system, which will be helpful for local bodies and disaster management authorities. • Unavailability of data for development tools is a major constraint.
Dr. Sachin Ghude, IITM	• Contribution from non-tail pipe emissions, especially from city buses is an important air pollution source • Electrification of buses and their share in transport sector needs to be improved.
Mr. Aniruddha Shahapure, PSCDC	• Certain forecasting tools are available with PSCDC, which can predict future climatic conditions • PSCDC is working closely with disaster management cell of PMC. • High end computing server is also available in command control center for simulations • Large number of data sets are available with PSCDC.
Dr. T.S. Panwar, WWF-India	• Many start-ups are working on development of new battery technologies. • Shared mobility i.e. sharing cabs and bikes, shall be encouraged in city
Dr. Utkarsh Mukkannawar, IITM	• The Environmental clearance committee shall promote charging infrastructure development in buildings in line with the promotion of solar panels.
Dr. Yogendra Kanitkar, MIT	• Retro-fitment of HCVs shall be explored and promoted, instead of phasing out. • Need for research on recycling of battery materials.

A.2.4: Public Awareness and Participation:

Dr. Gaurav Gowardhan, IITM	• Public Awareness is an important component • Early warnings can be provided to public for air quality • Advertisements shall be made to increase awareness • On traffic signals, display boards shall be used with awareness messages and positive impact of actions (for example, how much fuel is saved on signal by turning off the vehicle)
Mr. Amarnath Karan, CEE	• People shall be made aware about the importance of vehicle maintenance • Driving behaviour can play an important role in air pollution reduction • Students shall be made aware about the air quality, climate change and its impact • Several initiatives were already taken up for example: SAFAR app, awareness drives were initiated in PMC schools
Dr. Utkarsh Mukkannawar, IITM	• Different colour codes flags are displayed, according to the AQI during prayers in schools. • College students were involved in recent emission inventory study by IITM, which has resulted in increased awareness.
Mr. Mangesh Dighe, PMC	• Video conferencing facility at PMC can be used for awareness generation in schools.
Mr. Aniruddha Shahapure, PSCDC	• Display boards at strategic locations are available under smart city project. These can be utilized to spread the awareness.

ANNEXURE III

Table A.3.1: The summary of emission reduction fractions for E20 vehicles used in this study						
Vehicle category	**PM**	**CO**	**HC**	**NO_2**	**CO_2**	**Reference**
Motorcycle -E20	0.64[a]	0.50[b]	0.80[b]	1.10[b]	0.95[c]	[a]Storey et al., 2010 ; [b] NITI Aayog, 2021;
Scooters -E20	0.64[a]	0.50[b]	0.80[b]	1.10[b]	0.95[c]	[a]Storey et al., 2010 ; [b] NITI Aayog, 2021;
Cars -E20	0.64[a]	0.75[d-h]	0.85[d-h]	1.12[d-h]	0.64[d-h]	[a]Storey et al., 2010; [d]Koten et al., 2020; [e]Hilton and Duddy, 2009; [f]Karavalakis, 2012; [g]Knoll et al., 2009; [h]ORNL, 2012

Table A.3.2: Summary of daily ridership, average trip length, and zone of influence used in different scenarios of MRTS in Pune city						
Metro Lines	**LAS**			**HAS**		
	Daily Ridership	**Avg. Trip Length**	**Zone of Influence**	**Daily Ridership**	**Avg. Trip Length**	
Year 2025						
Line 1: Nigdi to Swargate	4,44,987	7.01	5 km ZIF	4,44,987	7.01	8 km ZIF
Line 2: Vanaz to Ramwadi	3,07,321	4.07		3,07,321	4.07	
Line 3: Hinjewadi to Civil Court	3,51,724	9.26		3,51,724	9.26	
Year 2030						
Line 1: Nigdi to Swargate	5,36,257	7.01	5 km ZIF	6,46,290	7.01	8 km ZIF
Line 2: Vanaz to Ramwadi	3,69,034	4.07		4,44,772	4.07	
Line 3: Hinjewadi to Civil Court	4,78,299	9.26		5,74,156	9.26	
Line 4: Civil Court to Hadapsar	-	-	-	4,08,217	6.37	5 km ZIF
Line 5: Swargate to Katraj	-	-		1,76,167	5.66	

Table A.3.3: Summary of emission reduction fractions used in this study for HCMTR		
Pollutant	Reduction Fraction	Reference
PM	0.44[i]	[i]Wang et al., 2020
CO	0.53[i-l]	[j]Sharma and Mathew, 2016; [k]Xue et al., 2013, [l]Nasir et al., 2014
NO_x	0.19[i-l]	[j]Sharma and Mathew, 2016; [k]Xue et al., 2013, [l]Nasir et al., 2014
CO_2	0.32[i-l]	[j]Sharma and Mathew, 2016; [k]Xue et al., 2013, [l]Nasir et al., 2014
SO_2	0.32[i-l]	[j]Sharma and Mathew, 2016; [k]Xue et al., 2013, [l]Nasir et al., 2014

ANNEXURE IV

This annexure provides the details of dispersion model, source and receptor configurations, meteorology and geophysical data used for dispersion modelling simulations. Dispersion modelling of the emission scenarios is performed with the latest version of the AERMOD Modelling System; AERMOD Version 21112. AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (PDF) (*EPA,* 2021a, 2021b, 2021c).

Figure A.4.1 shows the flow diagram of AERMOD modelling system. The modelling system consists of a dispersion model i.e. AERMOD and two pre-processors (AERMET and AERMAP). The major purpose of meteorological pre-processor i.e., AERMET, is to calculate boundary layer parameters for use by AERMOD. Surface characteristics in the form of albedo, surface roughness, and Bowen ratio, plus standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are input to AERMET. AERMET then calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (θ*), mixing height (zi), and surface heat flux (H). The terrain pre-processor i.e. AERMAP uses gridded terrain data to calculate a representative terrain-influence height (hc), also referred to as the terrain height scale. The terrain height scale hc, which is uniquely defined for each receptor location, is used to calculate the dividing streamline height. The gridded data needed by AERMAP is selected from Digital Elevation Model (DEM) data. AERMAP is also used to create receptor grids. The elevation for each specified receptor is automatically assigned through AERMAP. For each receptor, AERMAP passes the following information to AERMOD: the receptor's location (xr, yr), its height above mean sea level (zr), and the receptor specific terrain height scale (hc).

Fig. A.4.1: Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

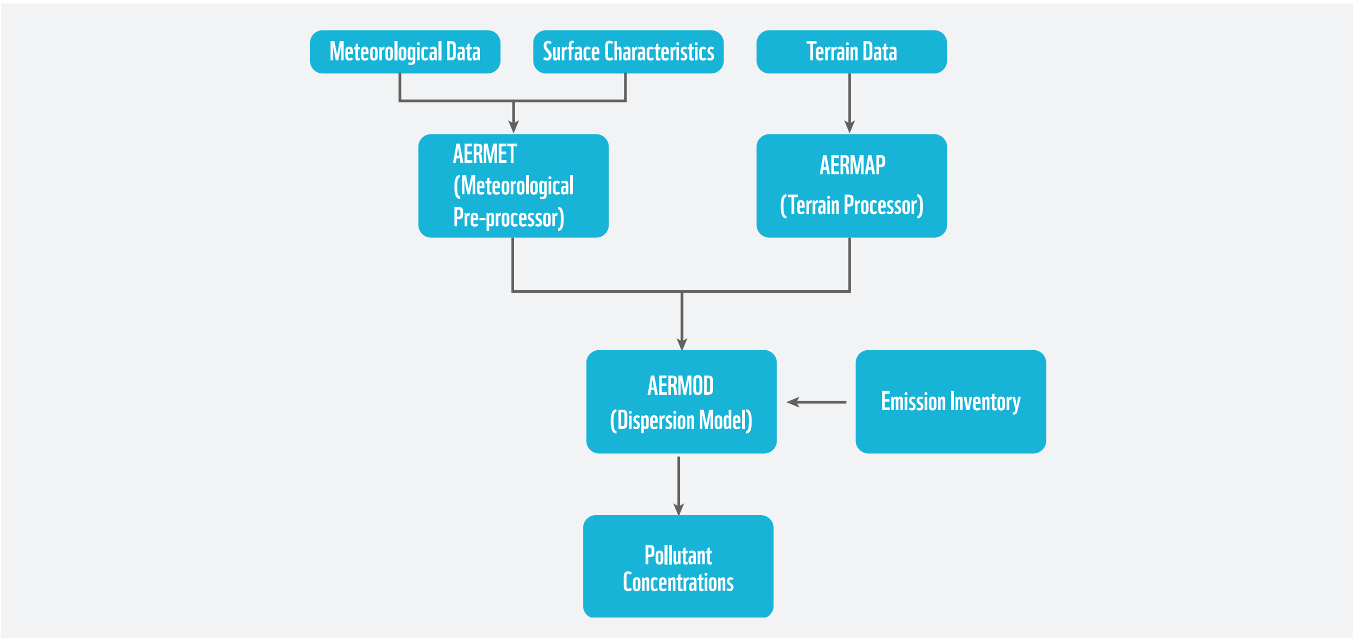


Table A.4.1: Summary of AERMOD dispersion modelling setup used in this study			
S. No.	**Description**	**Symbol**	**Details**
1.	Length of modelling domain in X-direction	X	32 km
2.	Length of modelling domain in Y-direction	Y	28 km
3.	X-direction receptor grid resolution	ΔX	1000 m
4.	Y-direction receptor grid resolution	ΔY	1000 m
5.	Receptor height	H_R	1.5 m
6.	Total number of gridded receptors		956
7.	Total number of discrete receptors		1
8.	Number of sources	Sn	224 x 9
9.	Source configuration in AERMOD		Area sources having L=2000 m and W= 2000 m
10.	Meteorology		ERA5 fifth generation ECMWF reanalysis • Meteorology data year: 2020 • Dry bulb temperature at 2 m • Wet bulb temperature at 2 m • Cloud cover • Wind speed at 10 m • Wind direction at 10 m
11.	Terrain data		NASA's Shuttle Radar Topography Mission (SRTM) global product having 30 arc second (~90 meter) spatial resolution

A.4.2: Dispersion Model Validation

As discussed in Section 3.1.7, we performed dispersion modelling simulations using AERMOD system with the meteorological, geophysical and emissions data. The AERMOD simulated monthly pollutant concentrations were compared against CPCB's online measurements for year 2021. The model performance is evaluated using three statistical measures such as correlation coefficient (R), Normalised Mean Bias (NMB) and Root mean squared error (RMSE).

Table A.4.2 presents the summary of statistical measures obtained by comparing AERMOD simulated monthly mean concentrations against the in-situ observations. AERMOD model is found to simulate the monthly mean concentrations with a good accuracy compared to observations for all the pollutants. Slightly negative values of NMB for pollutants such as $PM_{2.5}$ and SO_2 indicate slight under-estimation by AERMOD whereas slightly positive NMB values for PM_{10} and NO_2 indicates over-estimation of monthly mean values. Correlation coefficient (R) greater than 0.7 and lower RMSE values for all the pollutants indicate overall good model performance. CO is not included in the model performance evaluation, as some errors are suspected in the CO monitoring data at selected station.

Table A.4.2: Statistical Summary of Model Performance for Monthly Simulated AERMOD Concentrations					
Pollutant	Mean_Mod	Mean_Obs	R	NMB	RMSE
$PM_{2.5}$	24.16	26.85	0.81	-0.10	7.73
PM_{10}	59.95	47.2	0.80	0.14	17.9
SO_2	6.18	10.93	0.74	-0.43	6.74
NO_2	21.17	17.78	0.78	0.19	6.33

ANNEXURE V

Fig. A.5.1: Projected control intervention wise exhaust NO_x emissions (vertical bars) for LAS and HAS in 2025. The lines with markers show control intervention wise percent change (secondary y-axis) w.r.t. NFC_2025.

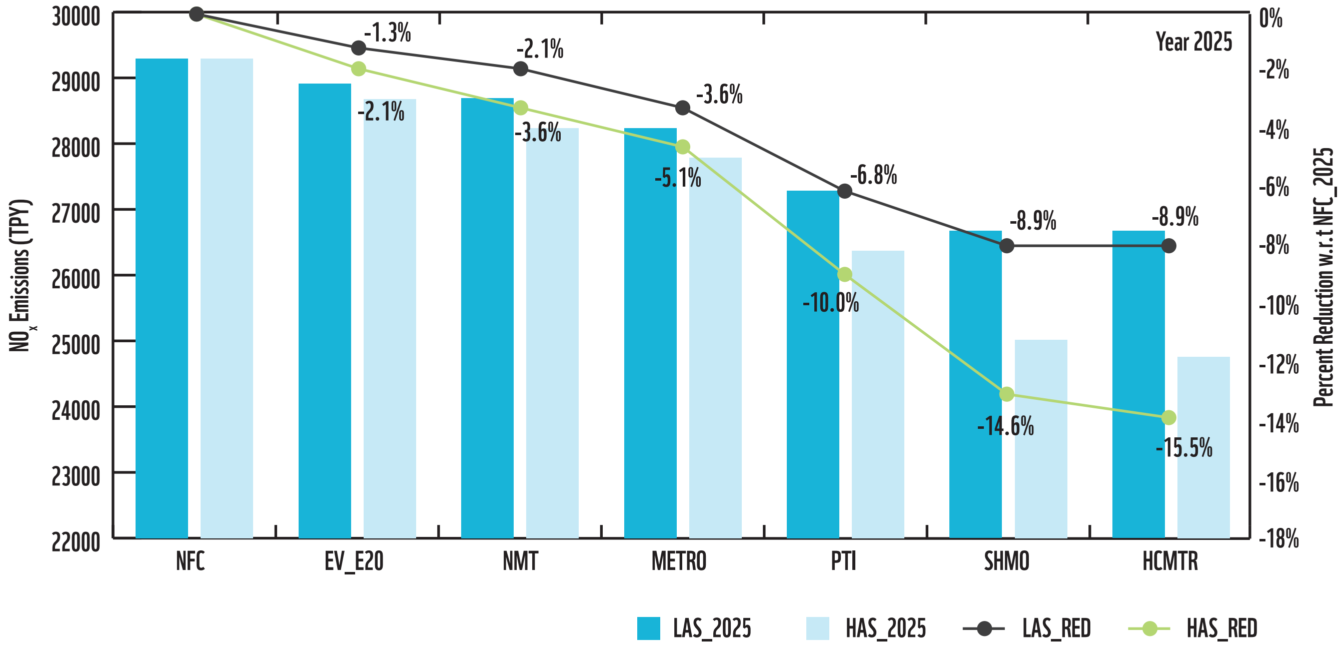


Fig. A.5.2: Projected control intervention wise exhaust NO_x emissions (vertical bars) for LAS and HAS in 2030. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2030.

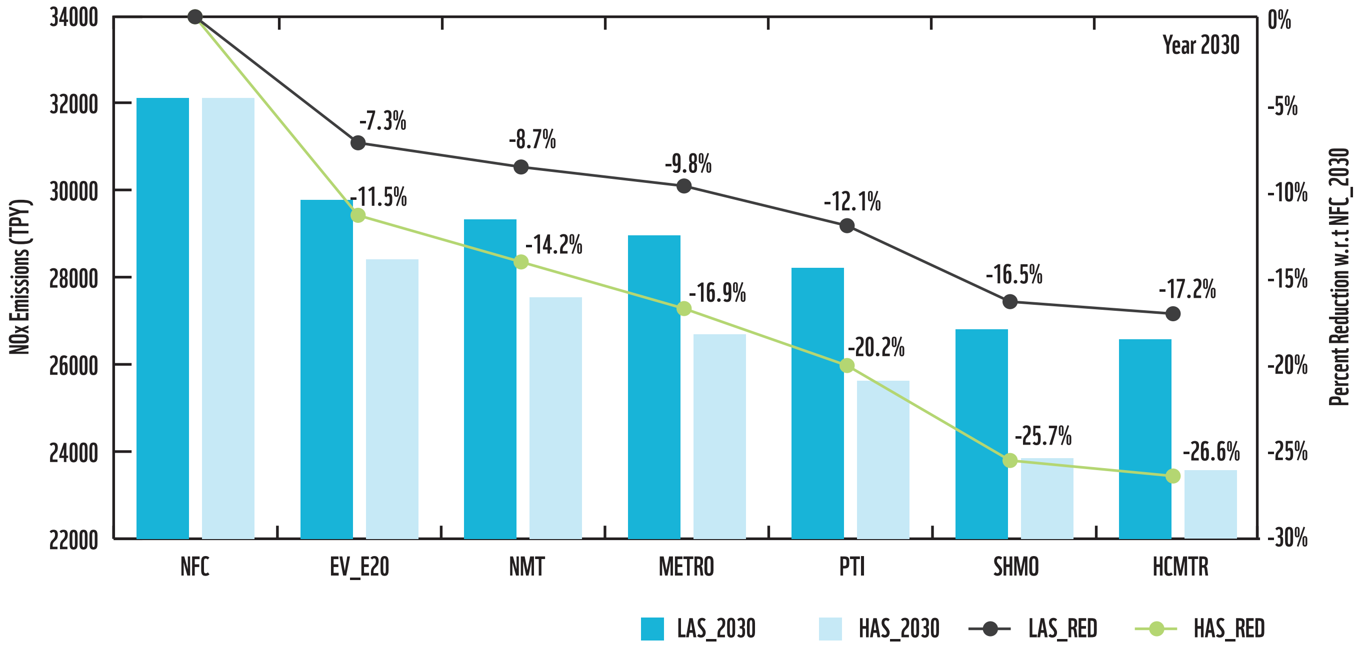


Fig. A.5.3: Projected control intervention wise exhaust CO emissions (vertical bars) for LAS and HAS in 2025. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2025.

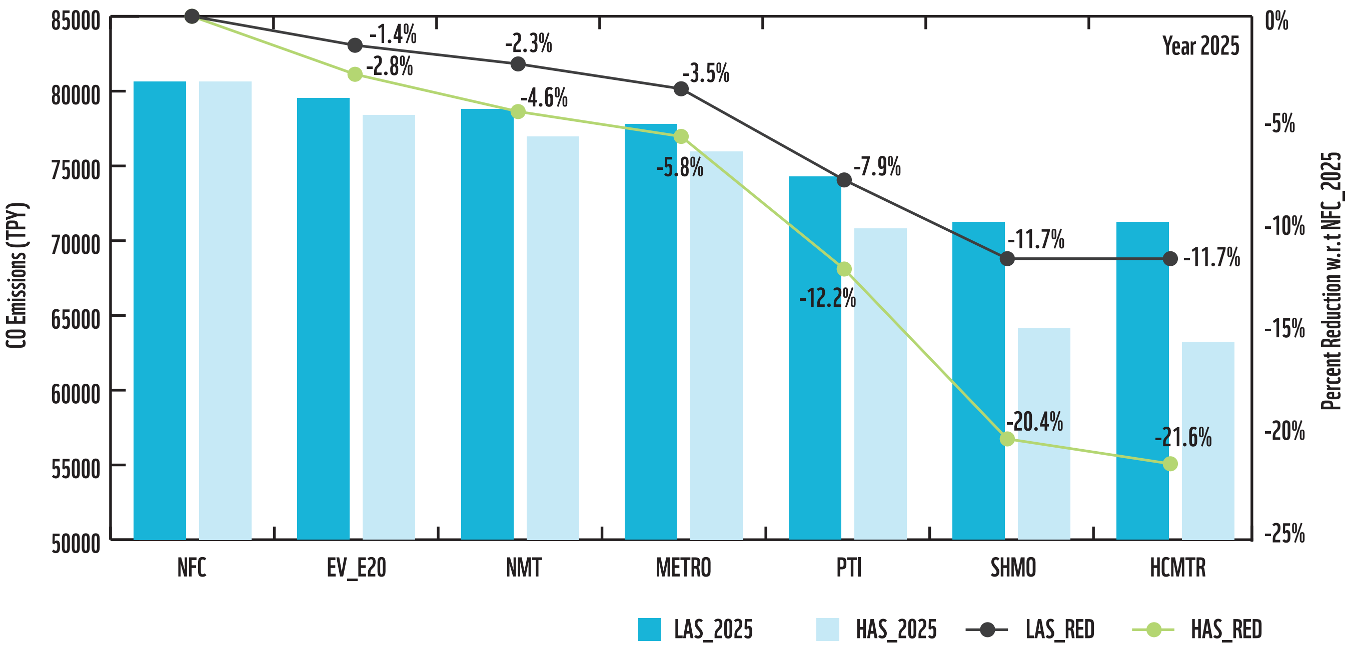


Fig. A.5.4: Projected control intervention wise exhaust CO emissions (vertical bars) for LAS and HAS in 2030. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2030.

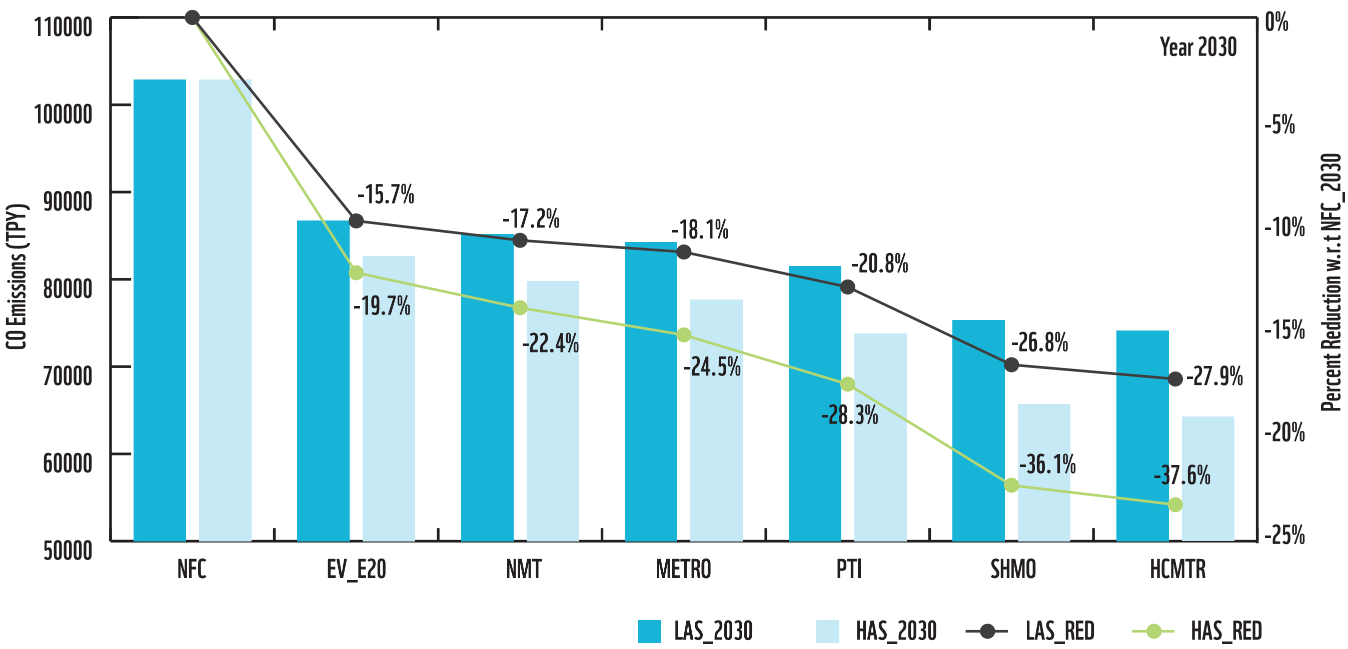


Fig. A.5.5: Projected control intervention wise exhaust SO_2 emissions (vertical bars) for LAS and HAS in 2025. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2025.

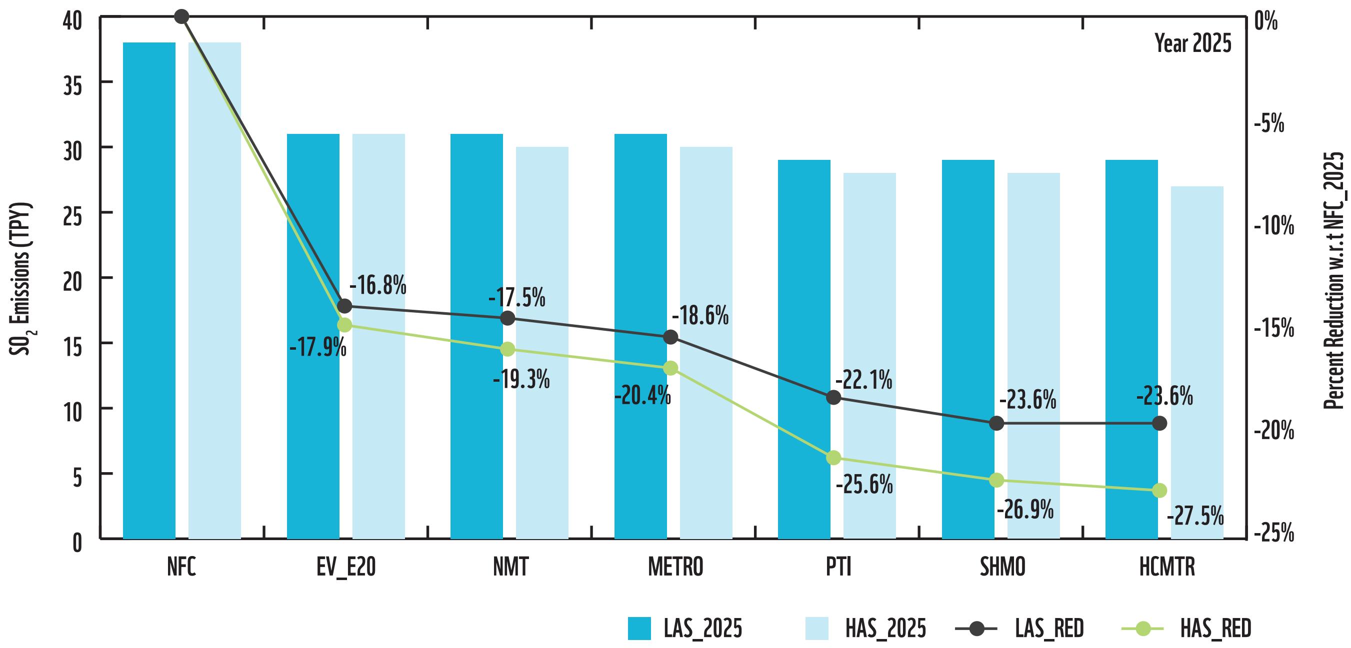


Fig. A.5.6: Projected control intervention wise exhaust SO_2 emissions (vertical bars) for LAS and HAS in 2030. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2030.

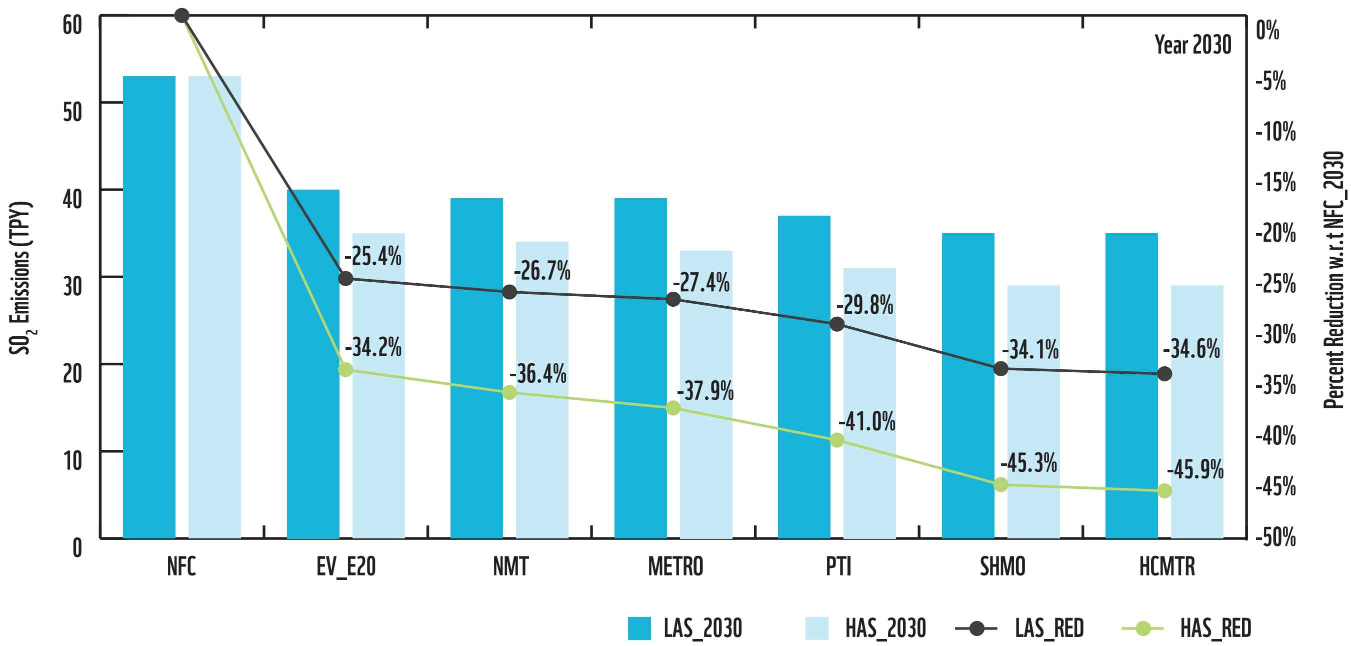


Fig. A.5.7: Projected control intervention wise exhaust CO_2 emissions (vertical bars) for LAS and HAS in 2025. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2025.

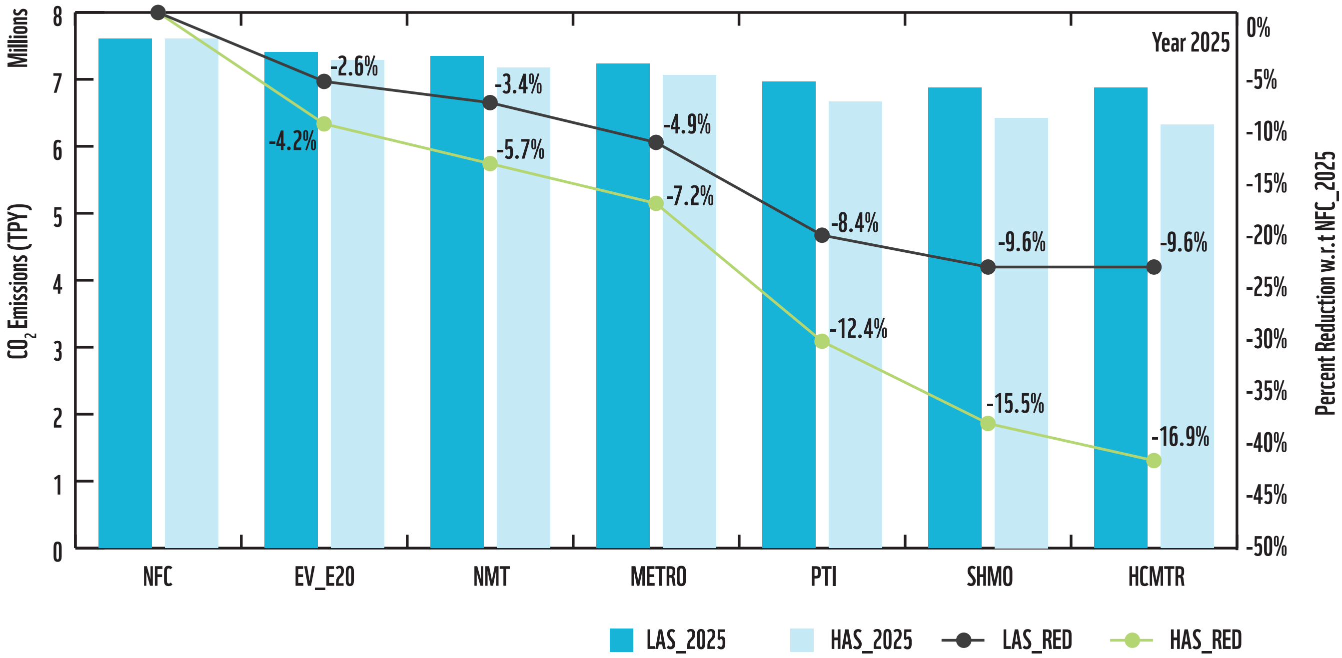
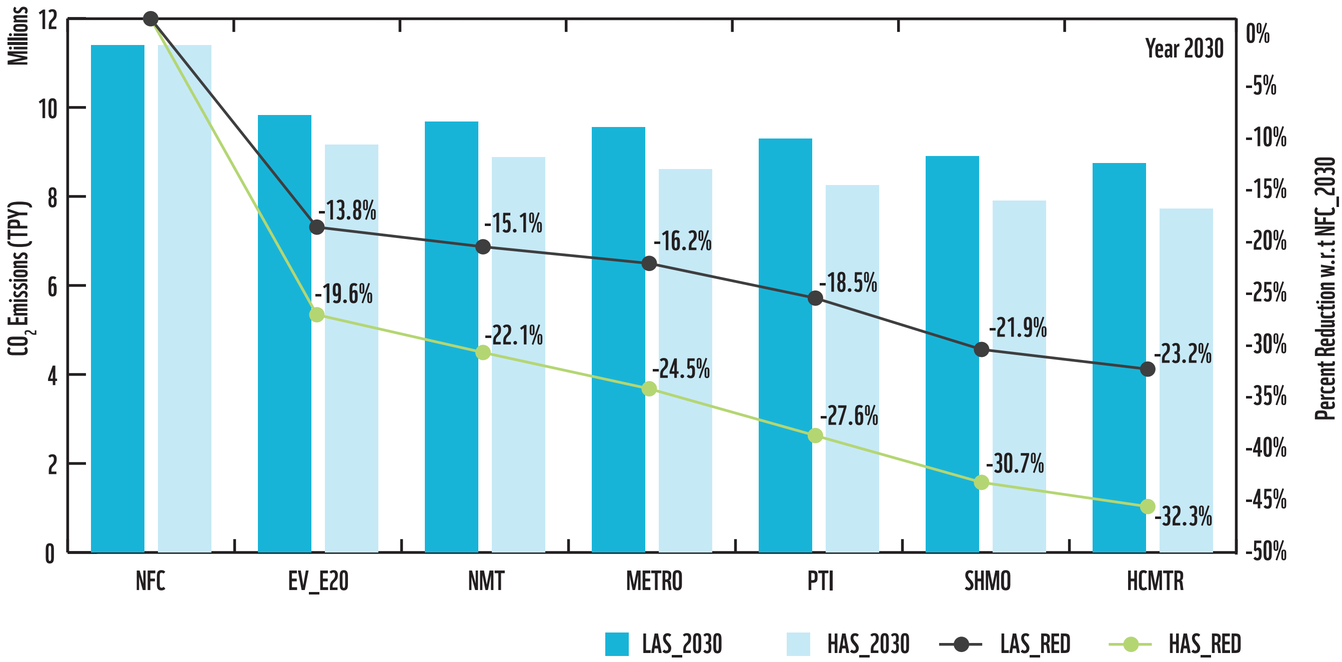


Fig. A.5.8: Projected control intervention wise exhaust CO_2 emissions (vertical bars) for LAS and HAS in 2030. The lines with markers show control intervention-wise per cent change (secondary y-axis) w.r.t. NFC_2030.



ANNEXURE VI

Table A.6.1: $PM_{2.5}$ emissions (TPY) in Different Scenarios in 2025 and 2030 as a Result of Combined Effect of Vehicular Exhaust and Road Dust Control Measures

Year	Scenario	VEE_PM	RDUST_$PM_{2.5}$	TOTAL $PM_{2.5}$ (VEE+RDUST)	Percentage Change in Total $PM_{2.5}$ w.r.t. NFC
2025	NFC	1888	2231	4119	-
	LAS	1739	1802	3541	-14%
	HAS	1655	1607	3262	-21%
2030	NFC	2125	3383	5508	-
	LAS	1675	2351	4026	-27%
	HAS	1484	1880	3364	-39%

Table A.6.2: PM_{10} emissions (TPY) in Different Scenarios in 2025 and 2030 as a result of Combined Effect of Vehicular Exhaust and Road Dust Control Measures

Year	Scenario	VEE_PM	RDUST_PM_{10}	TOTAL PM_{10} (VEE+RDUST)	Percentage Change in Total PM_{10} w.r.t. NFC
2025	NFC	1888	9222	11110	-
	LAS	1739	7450	9189	-17%
	HAS	1655	6641	8297	-25%
2030	NFC	2125	13981	16106	-
	LAS	1675	9717	11393	-29%
	HAS	1484	7769	9253	-43%