COMPREHENSIVE CLEAN AIR ACTION PLAN FOR THE CITY OF PATNA

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FOREWORD

Urban Patna has witnessed unprecedented degradation of air quality during the last decade.This has affectedthe overall quality of life in this region. Its impact on human health hasturned out to be very costly. In this view, the Government of Bihar, through Bihar State Pollution Control Board (BSPCB), has undertaken some serious action against the sectors responsible for this precarious situation. For instance, just last year, more than 400 units of brick kilns were asked to shut down their operations for violating the environmental protection laws. Further, many brick kilns were asked to upgrade to cleaner technologies. Most of the iron and steel manufacturing units have been asked to use induction-based processing. Similarly burning of waste and biomass in the open is being controlled through Patna Municipal Corporation. Some more serious steps are in the pipeline.

The major problemfor Patna's air quality is encounteredduring the winters when the level of Particulate Matters (PM) goes up significantly. Patna experiences a very poortosevere Air Quality Index (AQI) during most of the winter. This is mainly attributed to the burning of biomass and waste in the open. In spite of severalefforts, the air quality of Patna has remained bad. A major technological transformation and emission reduction in sectors like industries and transportmust be accomplished.

'Patna Clean Air Action Plan' (PCAAP) is a long-awaited report, as it can prove to be a key guide in implementing air pollution control measures. Apart from estimating emission from various sectors, this report provides for a cost-benefit assessment of the implementation process. The report will also be useful in forming a time-bound action plan and analyze the budget for the task.

I extend my heartiest congratulations to BSPCB and appreciate its efforts. The Centre for Environment, Energy and Climate Change (CEECC) at the Asian Development Research Institute (ADRI), Centre for Study of Science, Technology and Policy (CSTEP), Urban Emission; Shakti Sustainable Energy Foundation (SSEF), and Bloomberg Philanthropies for preparing this report.

(Sushil Kumar Modi)

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FOREWORD

India has been one of the countries with a very high growth rate in the last couple of decades. As a result, the country is experiencing the worst air quality status, especially in metro cities. Moreover, Patna has emerged as one of the cities with the worst air quality globally in the last decade. According to various quality assessments, it has been found that the problem of air quality in Patna agglomeration is mostly due to Particulate Matters 10 and 2.5 (PM 10 and 2.5). Other hazardous pollutants such as NOx, SOx, CO, etc. have been observed within standard limits most of time. The disease burden of the country has increased significantly due to poor air quality, which has propelled the government and policymakers to look closely into seasonal patterns of air quality and device some robust control measures.

It was a high time for us to formulate the strategies and contextual action plan in order to address the present scenarios of Patna air quality. The Patna Clean Air Action Plan (PCAAP) report is an outcome of the National Clean Air Program, initiated by the Ministry of Environment, Forest and Climate Change, Government of India. It has been found that major sources of PM in Patna are –Outside (neighborhood), where the contribution is largely unknown and natural, mostly dependent on the windrose pattern. Patna city is located on the bank of River Ganga which allows dust particles to be blown into the city from sandy river banks which adds up to the outside contribution. The second major source of emission is Domestic, where the burning of biomass for cooking, lighting, and heating contributes heavily. Nevertheless, according to Petroleum agencies, Government of India, the LPG penetration rate in more than 90% but 10% using biomass emits so much to make domestic sector the second major contributor. And the third major contributor is the Transport sector, which is inevitable due to a high number of vehicles on the roads, narrow roads with dusty pavements and a significant number of unfit vehicles plying in the city. Moreover, unmanaged traffic conditions leading to traffic jams also add up to the overall pollution load. The other contributors are road and construction dust, open waste burning, industries like brick kilns, and DG sets.

This report does not only estimates the emission load and source contribution but also provides the techno-economic analysis. It incorporates the budget to implement cleaner technologies in the various sectors and their pollution reduction potentials. This report offers a ready to use action plan with implementation strategies based on the cost-benefit analysis. It also provides a forecast of emission inventory up to 2030 based on the base year 2018-2019. The forecast includes the level of emission load by 2030 based on the level of compliance.

I would like to record the appreciation of work executed by technical partners of Bihar State Pollution Control Board -Centre for Environment, Energy and Climate Change (CEECC) at Asian Development Research Institute (ADRI), Centre for Study of Science, Technology and Policy (CSTEP) and Urban Emissions. I would also like to appreciate the Shakti Sustainable Energy Foundation (SSEF) and Bloomberg Philanthropies for supporting the study. I believe that this report will serve as a referral to Government agencies to implement the actionable points in order to combat the degrading air quality of Patna.

(Ashok Ghosh)

Acknowledgements

We are thankful to the Shakti Sustainable Energy Foundation and Bloomberg Philanthropies for providing support to conduct this study.

We acknowledge the following consortium partners for their timely contributions:

Dr Pratima Singh and her team, Anirban Banerjee and Udhaya Kumar V, from the Center for Study of Science, Technology and Policy (CSTEP): For coordinating the Patna Clean Air Action Plan (PCAAP) report by conducting various stakeholder discussions on the ground, identifying control measures, and assessing the control measures in terms of both technical and economic feasibility. They have also contributed towards writing Chapters 3, 4, 5, and 6 of the PCAAP report.

Dr Shaibal Gupta and Dr Prabhat P Ghosh from the Asian Development Research Institute (ADRI) for supporting the study on ground and coordinating with the stakeholder consultations. We also thank Dr Niladri Sekhar Dhar and his team, Aseem Kumar Anshu, Vivek Tejaswi, Ravi Ranjan Sinha, Prangya Paramita Gupta (ex employee), from the Centre for Environment, Energy and Climate Change (CEECC) at ADRI for coordinating the entire activity and their contribution towards writing Chapters 1 and 2 of the PCAAP report. We extend our sincere gratitude to Mr Abinash Mohanty (ex-employee) for his overall coordination in steering this study.

Dr Sarath Guttikunda and his team from Urban Emissions: For preparing the emission inventory for the city and their guidance in writing Chapter 2 of PCAAP report.

We thank Dr S S Krishnan and Anantha Lakshmi P from CSTEP for their critical review of the project. Moreover, we appreciate the inputs from Dr Sumit Sharma (TERI; India), Prof Frank Kelly (King's College London; UK), Dr Pallavi Pant (Health Effects Institute; US), and Dr Sumi Mehta (Vital Strategies, US), which made the report more robust.

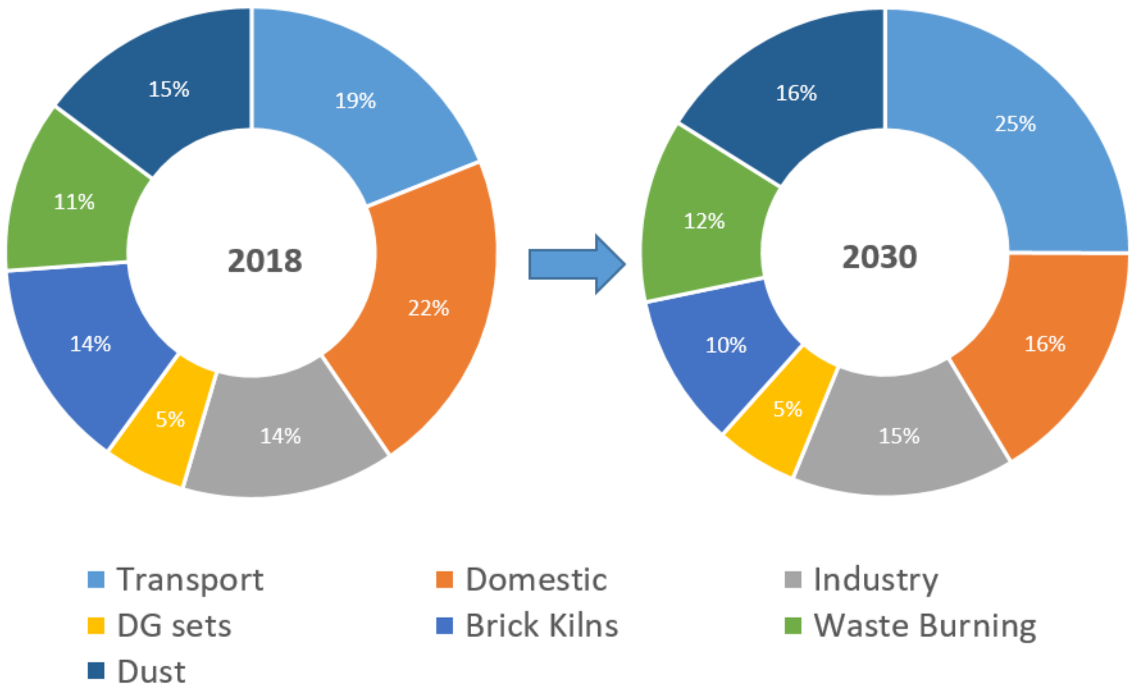
We would like to extend our sincere gratitude to the Communications and Policy Engagement team at CSTEP for editorial and design support.

We also acknowledge the inputs from various line departments without whose inputs the study would have been incomplete.

Executive Summary

The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, launched the National Clean Air Programme (NCAP), which proposes strategies to reduce air pollution. The NCAP identifies 122 non-attainment Indian cities [cities that violate the National Ambient Air Quality Standards (NAAQS)]. Patna, the state capital of Bihar, is among the five most polluted cities in the world (World Health Organization, 2016). The city has also been identified as one of the non-attainment cities in India. In this context, the Patna Clean Air Action Plan identified source-specific control measures (CMs) and performed a techno-economic assessment (TEA) on the CMs. This helped identify technically and economically feasible solutions/technologies to reduce pollution levels in Patna. An emission inventory was also developed for the city of Patna. Several focused group discussions with various stakeholders were carried out to understand the pollution landscape in the city and workshops were conducted as a part of the study, to discuss and validate the findings.

The emission inventory was developed to estimate the total emission load from various polluting sources of the city. The research team conducted dispersion modelling using the emission inventory, which was projected for the year 2030 using various scenarios. Surveys were conducted to collect data and to substantiate the emission load.



The study estimated that by 2030, under the business-as-usual (BAU) scenario, the total PM2.5 emission load will be approximately 28,000 tonnes/year (compared with 20,000 tonnes/year in the base year, 2018). The transportation, domestic, and industrial sectors were identified as major polluting sources contributing to the total PM2.5 emission load in 2030. Under the BAU scenario, the concentration level of PM2.5 is expected to increase by 28%, from 104.4 μg/m^3 in 2018 to 134.0 μg/m^3 by 2030.

In 2030, the highest pollution-concentration (annual average) contributors in Patna are estimated to be outside sources—23%, domestic (including cooking, heating, and lighting)—

21%, and transportation—19%. Apart from these sources, contributions are expected to be from the following sources: industries (12%), open waste burning (11%), dust (11%), and diesel generator (DG) sets (4%). The total concentration from the three major polluting sectors (domestic, transportation, and industries) will likely be around 52%.

In 2018, the transportation sector contributed 15%–38% (seasonal variation) of the total pollution concentration. The government must make a serious effort to improve the transportation sector infrastructure in Patna.

The concentration levels in Patna are estimated to peak during the winter season, between November and February. It was observed that biomass burning increases considerably during the winter season, to generate heat and light. Hence, domestic heating is a potential cause of this sudden peak in concentration. It is estimated to contribute 18%–30% of the total concentration levels during the winter months. However, the percentage share of concentration levels from domestic heating stays well below 10% during the rest of the year. Hence, there should be a significant focus towards domestic heating during the winter season.

To identify source-specific CMs, major determinants of pollution from various sectors such as transportation, domestic, industry, open waste burning, DG sets, construction, and road dust were identified. Existing policies along with these determinants were also considered while developing CMs.

Transportation:

In Patna, the mode share of public transportation is only around 21%. By 2030, at least 500 additional public buses need to ply in Patna to achieve the target mode share of 40% set under the city mobility plan. By introducing a mix of compressed natural gas (CNG) and electric buses (90% of the additional public buses), emissions from the transportation sector could be reduced by 11%. This control measure will cost the concerned department INR 321 crore (capital cost). The installation of diesel particulate filters in trucks, banning two-stroke autos, strict enforcement of Pollution Under Control (PUC) norms, and the promotion of CNG / electric vehicles (EV) could further reduce emissions from the transportation sector.

Other measures such as providing better parking policies, establishing demarcated lanes for cycle rickshaws, and banning carriage vehicles would likely help improve the existing transportation scenario and reduce pollution levels in Patna.

Industries:

The Bihar government has mandated the brick industry to adopt cleaner technologies. New technologies such as zigzag are considered to be less polluting than fixed-chimney kilns. Hence, the government has recommended that the brick industry shift to zigzag technology. Effective implementation of the zigzag technology would reduce the emission load from brick kilns by 34%. The government should also focus on shifting polluting industries outside the city (after taking into account the wind direction) and encourage factory owners to shift to advanced technologies that emit less pollutants.

Solid-waste management:

By ensuring effective waste collection and disposal strategies, 90% of the emissions from open waste burning could be reduced. Considering the waste-to-energy (WTE) plant (planning stage) and future projections of solid-waste generation, it was estimated that around 700 tonnes per day (TPD) of composting plants and 30 TPD dry-waste collection centres will be required for proper waste management by 2030. The Patna municipality would require at least INR 130 crore (capital cost) for installing these plants.

Domestic:

Although the liquefied petroleum gas (LPG) penetration in Patna is around 90%, it was observed a widespread use of biomass as cooking fuel. The emissions from the domestic sector will be reduced by around 81% by making LPG cylinders more affordable and accessible. The government would have to invest around INR 30 crore in the form of incentives as LPG subsidies. The introduction of smokeless chulhas / induction stoves can also help reduce the emission load from the domestic sector.

Construction dust:

The effective and efficient implementation of already existing rules and regulations by the government would help reduce the total emission load from dust by around 56%.

Capacity building:

To further strengthen the existing infrastructure in Patna, the state government should consider installing additional Continuous Ambient Air Quality Monitors (CAAQM) stations for the effective measurement and monitoring of pollution levels. This could help identify pollution hotspots and prepare appropriate strategies accordingly.

Three scenarios were created based on the CMs and their emission-reduction potential. These scenarios had varying levels of compliance vis-à-vis the suggested CMs. These scenarios focussed on high-, medium-, and low emission-reduction potential of CMs. The reduction in mortality rates for the different pollution-reduction scenarios were estimated on the basis of PM2.5 reduction between 2018 and 2030. The study estimated that the emission level will increase by 42% in 2030 without any interventions. The estimated mortality, due to air pollution under the BAU scenario, was estimated to be 4,900 deaths per year in 2030.

The study estimated that under high-, medium-, and low emission-reduction scenarios, the PM2.5 emission level can be reduced by 69%, 48%, and 30% respectively with reference to the BAU scenario, as described in Figure 1. Under the high emission-reduction scenario, the city would save at least 15,000 lives by 2030.

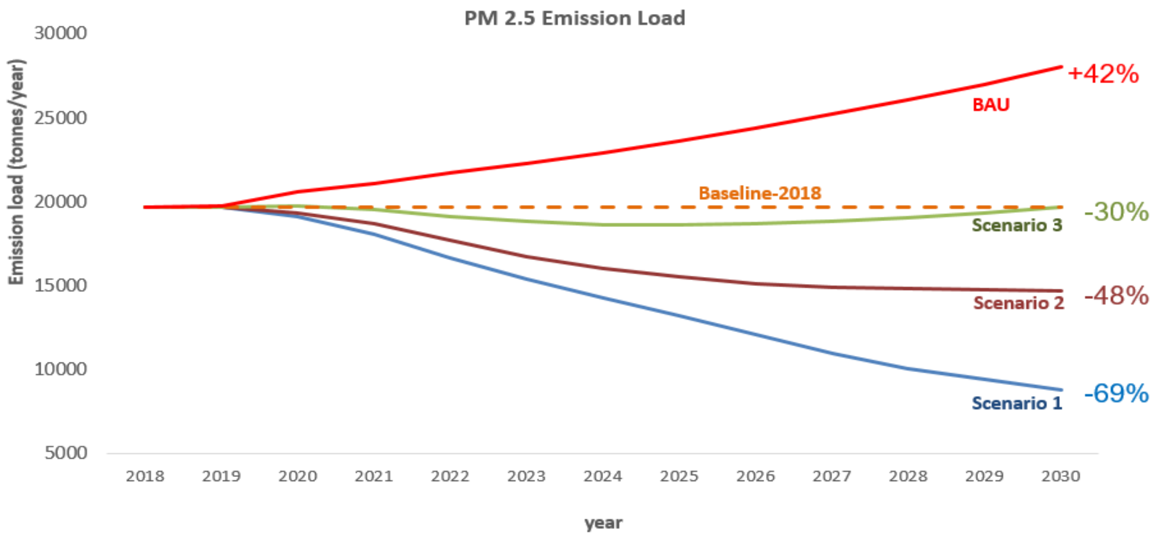


Figure 1: Scenarios: emission-reduction potential

Based on the study conducted by the consortium partners, the Bihar State Pollution Control Board (BSPCB) suggests that the state government and concerned line departments should implement the following CMs, which would result in maximum pollution reduction:

- Introduce EVs / CNG vehicles in the city
- Increase the public mode of transportation
- Implement efficient solid-waste management strategies
- Decrease the use of solid fuel by increasing the penetration and refuelling rate of LPGs
- Promote advanced technologies in industries
- Enforce rules for construction and demolition waste management

It is necessary for the government to work closely with citizen groups to sensitise them about the effects of air pollution. Existing policies like traffic regulations, construction-and-demolition waste management rules, and construction of road pavements are a few of the measures that could be implemented with immediate effect by the line departments.

Environmental consequences of air pollution—which is of great concern not only to the present generation but also to future generations—need to be considered strongly. The social well-being of people can be secured only when the suggested measures (to help curb air pollution in an effective and timely manner) are implemented. The suggested short-term CMs need to be implemented immediately. The medium-term measures, on the other hand, should be implemented within a 3-year period. Meanwhile, long-term measures should be implemented in the coming 5 years. Moreover, it is essential that project management and audit units are established for effective implementation of the policies. This will help ensure the timely implementation of the suggested policies based on the provided roadmap and time frame.

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Abbreviations

AAQ	Ambient Air Quality
AQI	Air Quality Index
As	Arsenic
BaP	Benzo(a)pyrene
BAU	Business as Usual
BC	Black Carbon
BSPCB	Bihar State Pollution Control Board
BSRTC	Bihar State Road Transport Corporation
C_6H_6	Benzene
CAAP	Clean Air Action Plan
CBA	Cost Benefit Analysis
CMVA	Central Motor Vehicles Act
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
CRF	Concentration Response Function
D.O.T	Department of Transport
DALYs	Disability Adjusted Life-Years
DG Sets	Diesel Generator Sets
DPF	Diesel Particulate Filter
EI	Emission Inventory
ER	Excess Risk
EF	Emission Factor
EV	Electric Vehicle
FAME	The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FCK	Fixed Chimney Kiln
GBD	Global Burden of Disease
GDP	Gross Domestic Product
HHK	Hybrid Hoffman Kiln
IGSC	Indira Gandhi Science Complex
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LPG	Liquefied Petroleum Gas
LULC	Land Use and Land Cover
MLH	Mixing Layer Height
MoEF&CC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
MSME	Ministry of Micro, Small and Medium Enterprises
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NAMP	National Air Quality Monitoring Programme
NCAP	National Clean Air Programme
NGT	National Green Tribunal
NH_3	Ammonia
Ni	Nickel
NMVOCs	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
O&M	Operation & Maintenance
O_3	Ozone
OC	Organic Carbon

Pb	Lead
P-CAAP	Patna Clean Air Action Plan
PM	Particulate Matter
PMC	Patna Municipal Corporation
PMUY	Pradhan Mantri Ujjwala Yojana
PUC	Pollution Under Control
PV	Photovoltaic
RSPM	Respirable Suspended Particulate Matter
SBPDCL	South Bihar Power Distribution Company Limited
SIAM	Society of Indian Automobile Manufactures
SO_2	Sulphur Dioxide
SPCB	State Pollution Control Board
SWM	Solid Waste Management
TCO	Total Cost of Ownership
TEA	Techno-Economic Assessment
TPD	Tonnes Per Day
VOC	Volatile Organic Compounds
VSBK	Vertical Shaft Brick Kiln
WHO	World Health Organization
WTE/W2E	Waste to Energy

1. Background and Approach

1.1 Introduction

The emerging risks associated with air pollution in India have become a major concern for the environment and human health. This is evinced by the fact that 15 of the 20 most polluted cities in the world are in India (World Health Organization, 2018). Exposure to air pollution has resulted in approximately 2,802 disability adjusted life-years (DALYs) per 1,00,000 people and 1.24 million premature deaths in India in 2017, based on statistical study (Dandona et al., 2017).

Although the issue of air pollution is pan-Indian, it is more prevalent in the Indo-Gangetic plains. The activities in this area such as brick manufacturing, crop burning, and mining, as well as thermal inversion during the winter season contribute to severe levels of ambient air pollution in the region.

Patna, the capital city of Bihar, experiences some of the highest levels of air pollution in India. For instance, the National Air Quality Monitoring Programme (NAMP) states that Patna has experienced (annually) PM2.5 levels of 117.48 µg/m^3 in 2018 (CPCB, 2018). Moreover, the city was ranked the 5th most polluted city in terms of particulate matter, globally, in 2016 (WHO, 2016). Rapid urbanisation and industrialisation have greatly contributed to the rising levels of air pollution in the city. The major contributors to Patna's deteriorating air quality are the transportation sector, industries, brick kilns, and biomass burning (Guttikunda et al., 2019).

Notably, the Ministry of Environment, Forest and Climate Change (MoEFCC) has recognised the scale and severity of the issue when it launched the National Clean Air Programme (NCAP) in January 2019. The MoEFCC also provided a five-year roadmap, a "time-bound national level strategy" to tackle deteriorating air quality in several Indian cities. Section 7.1.2 of the NCAP mandates a Clean Air Action Plan (CAAP) for all 122 non-attainment cities, including Patna. In this regard, the Bihar State Pollution Control Board (BSPCB), with technical assistance from the consortium (Centre for Environment, Energy and Climate Change at Asian Development Research Institute (CEECC-ADRI); the Center for Study of Science, Technology and Policy (CSTEP); and Urban Emissions), has developed an evidence-based Clean Air Action Plan for the city of Patna. The action plan defines a comprehensive set of policy measures and programmes that the state government and city administration will implement over an agreed-upon timeline to reduce ambient air-pollution levels.

1.2 Approach

For the development of the Clean Air Action Plan for Patna, a state-level committee (SLC) was constituted under the chairmanship of Chairman, BSPCB. Representations from the various line departments included Urban Development; Road Construction; Transport; Bihar State Disaster Management Authority; Environment, Forest and Climate Change; Industries; Building Construction; Urban Development; and Health. Representatives of the identified departments (not lower than the rank of Joint Secretary) were nominated as SLC members for their assistance in obtaining the required data to formulate the Patna Clean Air Action Plan. Furthermore, several trainings at CEECC-ADRI with Urban Emissions and CSTEP helped provide capacity building for local institutions.

CEECC-ADRI collected primary data from 10,000 vehicles to develop an emission inventory, with the support of Urban Emissions. Based on the collected data and identified sources, Urban Emissions developed a baseline emission inventory for Patna, covering the targeted pollutants (PM, SO_x, and NO_x) and all the primary sources of emission.

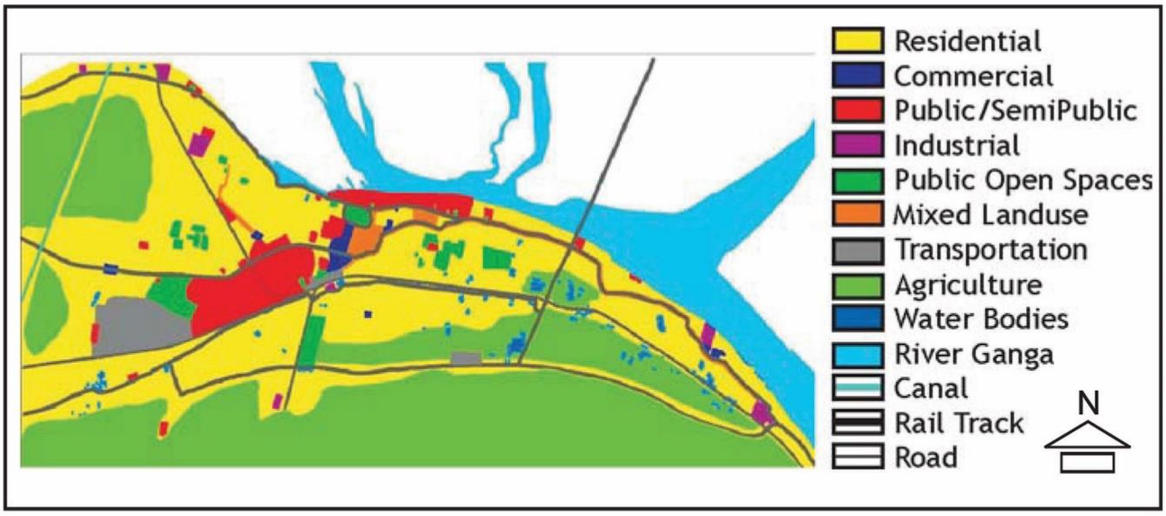
CSTEP developed a comprehensive set of CMs based on the existing pollution landscape for the city. The CMs considered source-specific determinants alongside existing and upcoming policies at central and state levels. Focussed group discussions with the line departments helped understand the existing institutional arrangements, as well as the availability of financial resources and capacity. These discussions helped shortlist and evaluate the CMs based on the emission-reduction potential and implementation on ground. Moreover, CSTEP performed a techno-economic assessment of the shortlisted CMs and provided a detailed strategic roadmap defining the short-, medium-, and long-term implementation plans for all the CMs till 2030. A broad set of feasible targets and anticipated outcomes to be achieved in the agreed-upon timelines has been defined. These targets and timelines have been developed keeping in mind the various national and sub-national policies and standards, state-level committees, and comprehensive assessments.

2. Patna: Current Pollution Landscape

2.1 Overview of Patna city

The state of Bihar has a population of 104 million. 11% of the population dwells in urban areas, which makes Bihar one of the least urbanised states of India (Census 2011). Patna, which is the capital of Bihar, faces an unprecedented pressure of urban agglomeration. Because Patna is a growing city in terms of infrastructure, transportation, industrialisation, and urbanisation, land use and land cover (LULC) pattern is a crucial aspect in identifying the sources of air pollution.

Brick kilns are mostly located along the river Ganga, industries are located in north and central Patna, and major commercial sectors are located in central Patna. The residential area of Patna doubled while the area of agricultural land decreased from 53.7 km^2 to 19 km^2 over the past two decades (Mishra and Rai, 2016). As per the Census 2011, the total built-up area of the city is 86 km^2. The number of water bodies has also significantly shrunk (Figure 2).



Source: (Mandal & Dutta, 2009)

Figure 2: Land use land cover of Patna w.r.t different sectors

2.2 Socio-economic profile of Patna

The 2011 Census states that the population of Patna was 5.8 million, with a density of 1,823 inhabitants per square kilometre. Patna has seen a 30% population growth between 2001 and 2011. The city's sex ratio was 897 females per 1,000 males[1]. The overall literacy rate of Patna was 70.68%, with the male literacy rate at 78.48% and the female literacy rate at 61.96%.

Patna boasts of 14% of the total urban population of Bihar (Bihar Economic Survey, 2019). The urbanisation rate in Patna is 43%, which was higher than any other city in Bihar in 2011[1]. The work participation rate in Patna was 32.2%, of which about 73% were main workers and 27% were marginal workers in 2011[1]. Additionally, 37% of the workers were engaged in the primary sector (agriculture, forestry, fishing, mining, etc.). The remaining 63% were engaged in the secondary and tertiary sectors, which include food manufacturing, textile manufacturing, industries, sales, repair services, and banking (*Master Plan for Patna - 2031*, 2014). The per capita gross domestic product (GDP) (base year 2004–2005) of Patna was estimated to be INR 6,303, with a GDP rate of 7.29% in 2011–2012. Moreover, Patna has been ranked as the 21st fastest-growing city in the world and 5th fastest-growing city in India, with an annual growth rate of 3.72%.

Patna has long been considered as the one of the major hubs for agricultural trade. The common agricultural products in Patna are cereals (rice, wheat, and maize) and pulses (arhar, urad, moong, gram, pea, lentils, and khesari). The most commonly exported agricultural products are sugarcane, sesame, and rice.

In 2018, Patna (Urban) had 174 industries, 22 of which were red category industries[1]. The predominant types of industries in Patna are leather, handicraft, and agro processing. Most of the industries are agglomerated at four industrial areas in and around Patna—Patliputra, Fatuha, MIP Bihta, and Bihta. The state government has taken several initiatives to increase the investment opportunities in medium- and large-scale industries. An Industrial Investment Promotion Policy was introduced in 2016 to address key issues like development of secondary infrastructure, adoption of state-of-the-art technology, development of domestic supply chain, and skill development.

2.3 Existing policies/interventions in the state of Bihar

Air-pollution exposure to humans has a spatial dimension because both the population density and the resulting pollutant concentrations vary over space. This creates a role for effective local policies that aim at reducing pollution levels in highly populated areas (OECD 2012). To improve air quality in Patna, BSPCB has implemented several policies suggested by the Central Pollution Control Board (CPCB).

The existing policies implemented in different cities of India, including Patna, are as follows:

- **National Air Quality Monitoring Programme (NAMP):** The government is executing a nation-wide air quality monitoring programme called the National Air Quality Monitoring Programme (NAMP). In this regard, the BSPCB has set up an online air quality monitoring system at IGSC Planetarium, Patna. Patna also has two manual stations reporting data on PM10, SO_2, and NO_2.

- **Forty-two action points:** A comprehensive set of directions under section 18 (1) (b) of the Air (Prevention and Control of Pollution) Act, 1986 has been issued by the CPCB to ensure the implementation of 42 measures (action points) that aim to mitigate air pollution in major cities. This includes control and mitigation measures relating to vehicular emissions, resuspended particles of road dust, and other fugitive emissions, biomass and municipal solid waste burning, industrial emissions, construction and demolition activities, and other general steps contributing to air pollution. The directions containing 42 action points were issued initially for implementation in Delhi-NCR but were subsequently extended to State Boards for implementation in other non-attainment cities, including Patna.

- **Impetus on vehicular pollution:** Bharat Stage IV (BS-IV) norms have been launched for mandatory implementation since 1 April 2017. The government has also proposed leapfrogging to BS-VI by 1 April 2020. Bharat Stage Emission Standards (BSES) are emission standards issued by the Government of India to regulate the output of air

[1] Red category industries - industrial sectors having pollution index score of 60 and above

pollutants from internal combustion engines and spark-ignition engine equipment, including motor vehicles.

- **Cleaner technologies in brick kilns:** The BSPCB has notified all brick kilns of Bihar to convert to cleaner technologies by 31 August 2019, in accordance with the High Court directive (CWJC no: 15962/2018). In this regard, BSPCB has issued the closure of 23% of total brick kilns in Patna, which were found violating the environmental protection rules (BSPCB, 2018).

- **Central Motor Vehicles Act (CMVA):** As per CMVA, electric rickshaws have been permitted in Patna in an effort to curb air pollution.

2.4 Emission inventory

An emission inventory (EI) accounts for the total emission load from various polluting sources in a given geographical area, within a particular time frame. An EI helps identify the most polluting sources in a city/state/region. It is also used to estimate and project future emissions for various pollution control/reduction scenarios (ACAP, 2017).

There is very limited information that can be accessed to conduct EI studies in Indian cities. This is also true for big cities like Delhi and Mumbai. Guttikunda et al. (2019) detail the architecture for conducting such studies in various cities of India and the resources accessed for various sectors. There are studies (such as Guttikunda et al., 2014) that discuss the uncertainties, gaps, and pathways for various sectors.

2.4.1 Methodology

The EI for the Greater Patna Region (GPR) was developed for an area of 60 km X 30 km for the year 2018. Various pollutants such as PM2.5, PM10, NO_x, CO, SO_2, CO_2, and non-methane volatile organic compounds (NMVOCs) were considered in the EI. Although an inventory of NH_3 emissions was not prepared, the NH_3 emission data was extracted from the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) (http://www.htap.org/) 2012 and the data was used after linear extrapolation. The EI was developed to estimate emissions from the transport sector, domestic and commercial cooking, space heating, diesel generator (DG) sets, solid waste burning, industries, aviation, and dust from different activities (construction and road). The developed EI was also projected for the year 2030 under the business-as-usual (BAU) scenario.

The EI was prepared by considering the various activities (A) in a sector that contributes to the total pollution load in a city/state/region. Activities (A), when multiplied by the respective Emission Factors (EF), provides an estimate of the emission load of any particular activity. This emission load is distributed in a 1 km X 1 km unit of area in GPR. The sector-specific methodology for estimating the emission has been provided in the following sections. The model details and the architecture are detailed in Guttikunda et al., 2019.

EI looks at pollutants at the source and does not include remote effects of pollutants or the effects of meteorology on pollutant concentration. Dispersion modelling has been used to address this gap.

Emission from transportation: For the *transportation sector*, the ASIF (Schipper L, Marie-Lilliu, c., 2000) principle were used to estimate the emissions.

$$E_T = A \times S_i \times I_i \times F_{ij} \qquad \textbf{(2.1)}$$

Where,
E_T - Emissions from transportation
A - Total travel activity,
S_i - Vector of modal share[2],
I_i - Energy intensity of each mode (i),
F_{ij} - Sum of each fuel (j) in mode (i); the emission factors[3] mentioned below are used to convert fuel used into emissions.

The steps mentioned above have been repeated for all modes of transportation. The vehicle exhaust emissions factors are adjusted by vehicle type, deterioration of vehicle engine with age (corroborated with the PUC data from the city), and fuel type, along with local congestion levels. A database of average emissions factors for fleets is available in Goel & Guttikunda (2015) and also can be accessed at Urban Emissions (http://www.urbanemissions.info/publications).

The emissions estimated from the transportation sector have been adjusted for traffic congestion, which tends to increase emissions from vehicles. The methodology for estimating congestion rates in the city has been based on extracts from the Google Maps Direction API. For the city, 100,000 requests were made per day for 15 days to build the spatial and temporal speed maps, which were integrated into the emission calculations.

To substantiate the methodology, a transportation survey was conducted at various petrol pumps in Patna in 2018, which helped us understand the vehicle characteristics (mode share, age, and fuel use).There are evaporative emissions also at the fuel stations, which adds to the VOC totals. Fuel sales information was also gathered as a part of this exercise. Table 1 presents the key results of the survey, and Annexure A contains the detailed results from the survey.

Table 1: Key results - fuel transportation survey - Patna

Vehicle type	Vehicles surveyed (no.)	Fleet average age (Years)	% of vehicle older than 10 years
Cars	2,832	5.9	16.1
SUVs	1,603	4.5	5.9
Motorcycles	4,038	4.9	11.2
Autos / Tempos	1,265	5.3	6.7

According to the data provided by the Bihar government's transport department, the in-use vehicular population in Patna is around 1,437,562 as of 2018. Of the total registered fleet, two-wheelers (70%) and passenger four-wheelers (13%) are the dominant ones. While projecting emissions for future years, the vehicle growth rate was obtained from the national road

[2] Modal Share – Percentage of travellers using a particular mode of transportation
[3] Emission Factor – Mass emitted for vehicle km travelled

transport emission study, based on the sales projection numbers from the Society of Indian Automobile Manufactures (SIAM), New Delhi India.

Table 2: Patna mode share

Mode of journey	Percentage (%)
Walk	6
Bicycle	22
Motorcycle	21
Car	4
Auto	22
Bus	21
Cycle-rickshaw	4

Source: (National Institute of Technology Patna, 2018)

The aviation industry also contributes to the total emission load of the city. The emissions from this sector is considered to fall under the transportation sector's emissions. Aeroplanes emit pollutants throughout their flight path. However, most flight paths are around 30,000 feet above the sea level and the dispersion occurs more quickly in high altitudes. Effective pollution occurs only during the LTO (landing and take-off) cycle, and hence, the emission from the aviation industry is estimated using the LTO cycle.

Emission from road dust resuspension

Vehicular movement on the road triggers resuspension of dust. The dust portion includes on-road resuspension of dust, which is also classified as non-exhaust PM emissions. The dust emissions are also linked to the local meteorology in the chemical transport model, to suppress any overestimation of resuspension during the rains.

The resuspension of dust is dependent on the weight of the vehicle, silt load[4], road surface type, and average rainfall. Data from street maps helped us to understand and identify the types of road (paved/unpaved) present in Patna.

Emissions from industry

Primary information pertaining to industries were extracted from the annual survey of industries, while the information on industries' emissions was estimated based on fuel consumption (Ministry of Statistics and Programme Implementation[5]). This has been corroborated with the information provided by line departments. Google Earth imagery for every grid in air shed area was used as a reference to locate the industries.

Major industries in Patna constitute the metal-fabrication industry, brick kilns, and the textile industry. While most of the industries rely on grid electricity for their energy needs, a few are forced to use in-situ DG sets because of frequent power outages. Information on various technologies implemented in industries was obtained from reports and literature review. This data on technologies used has been incorporated while estimating emissions for future scenarios.

[4] Silt load – Amount of dust present per unit area on the road
[5] Ministry of Statistics and Programme Implementation, Government of India, at http://mospi.nic.in/Mospi_new/site/India_statistics.aspx?status=1&menu_id=43

Besides the traditional manufacturing industries, Patna has brick kiln clusters around the city. Brick manufacturing includes land clearing[6] for sand and clay, combustion of fuel for baking bricks, operation of diesel engines on-site, and transport of the end product to various parts of the city. The conventional technology used by brick manufacturers is a fixed chimney kiln (FCK). The fuel used in FCKs varies from agricultural waste and biofuels (cow dung and wood) to fossil fuels like coal and heavy fuel oil[7].

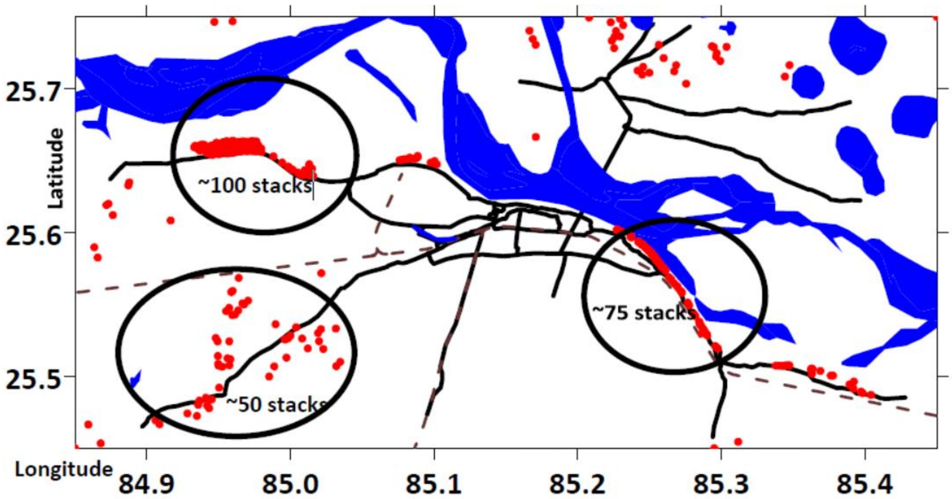


Figure 3: Brick kiln clusters in and around the greater Patna region

Source: (Guttikunda and Jawahar, 2014)

These FCKs are known for their low capital cost (land cost, cost incurred to set up the kiln, chimney cost, etc.), lower fuel consumption, and a production capacity of 20,000 to 40,000 bricks per day. Figure 3 highlights the location of various brick kiln clusters that were considered when estimating the pollution load in the emission inventory (Guttikunda and Jawahar, 2014). Industries were clubbed into 16 major categories[8] (Annexure A) to further assist in the calculation of emission/pollution analysis.

Emissions from domestic sector

Domestic-sector emissions are based on fuel consumption (coal, wood, kerosene, and LPG) estimates for cooking, heating, and lighting. Grid-level fuel usage in households was estimated based on census statistics[9]. According to Census 2011, 29% of households use non-LPG stove for cooking and heating. The dominant fuel in the city is LPG. Apart from LPG, fuels such as coal, biomass, and agricultural waste are used in slum areas, restaurants, and areas outside the municipal boundary. Gridded population data was obtained from the Gridded Population of the World and Global Rural and Urban Mapping Project (2010)[10]. It is assumed that while high-density areas (highly urban areas) most likely utilise LPG, low-density areas utilise a mix of fuels. The 2011 LPG consumption rates in the domestic sector were adjusted based on

[6] Land clearing: The process of removing trees, stumps, brush, stones and other obstacles
[7] Heavy fuel oil: It is the remnant from the crude oil refining process.
[8] Industry types from ASI database was used to club the industries into 16 major categories.
[9] Household energy usage in India, Database maintained by the Institute for Financial Management and Research, Chennai, India @ http://www.househol denergy.in
[10] GRUMP (2010) - Gridded Population of the World and Global Rural and Urban Mapping Project. Center for International Earth Science Information Network (CIESIN) of the Earth Institute, Columbia University, New York, USA @ http://sedac.ciesin.columbia.edu

surveys (Jain et al., 2018; Jain et al., 2015) and monthly reports on new LPG connections provided by Bihar state (MoPNG & www.data.gov.in).

Emissions from waste burning

Garbage burning in residential areas emits a substantial amount of pollutants and toxins (Guttikunda and Jawahar, 2014). Waste burning is the most challenging source and also the most uncertain for estimating the emission load. Despite government authorities having banned solid-waste burning, citizens continue to violate the regulation. According to the city development plan submitted to the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), Patna's metropolitan area generates around 800 to 900 tonnes of solid waste per day. This generated waste is transported to collection centres, and from there the waste is taken to a landfill facility. Total solid waste collected and treated in Patna is 770 tonnes per day. The estimation of emissions from waste burning was conducted by multiplying the quantity of waste burned with its emission factor.

Emissions from power sector

There are no power plants in the immediate vicinity of the GPR. The nearest power plant is 60 km east of Patna city. While most of the city's electricity needs are met by the coal- and gas-fired power plants situated to the south of the city (closer to the coal mines), a large proportion of mobile phone towers, hotels, hospitals, malls, markets, large institutions, apartment complexes, and cinemas supplement their electricity needs with in-situ DG sets. The total diesel consumption in the in-situ generator sets is estimated at 7 Petajoule (PJ), approximately 10%–15% of the total energy consumption in the transportation sector (Guttikunda and Jawahar, 2014).

Anthropogenic activities increase with an increase in population. Hence, population growth rate (census data) was considered while estimating emissions from the domestic sector, construction activities, brick demand, diesel usage in the generator sets, and open waste burning.

Dispersion modelling

Dispersion modelling is performed to understand the physical and chemical transformation of air pollutants over a geographical area. Advection of the pollutant refers to a kind of physical transformation that depends on the topography of the area, meteorological conditions, and the pollutant's wet and dry deposition. Area-specific meteorology plays an important role as it influences the transport and vertical mixing of pollutants. There are different types of dispersion models available, based on complexity and computational needs. Comprehensive Air Quality Model with Extensions (CAMx) was used to analyse the air quality of Patna.

The 3D meteorological parameters from Weather Research and Forecasting (WRF), along with the estimated emissions load of each of the grid points, have been included as inputs to the model. Pollutant concentration is the model output. Concentration is the amount of pollutant matter present in a unit volume of ambient air. It is generally expressed in microgram per cubic meter ($\mu g/m^3$) or part per million (ppm). Concentration values are important as they help identify changes in air pollutant concentrations over time. These values are also the basis for evaluating the effectiveness of existing controls and a way of identifying the sources of possible problems for the future (P. Brimblecombe, 2011). The detailed model formulation and meteorological parameters considered in the study can be accessed from Guttikunda et al. (2019).

Model validation

The model was validated using monitoring data from BSPCB monitoring stations in Patna for the year 2017-2018. This was carried out for the hindcast results as well as the forecast mode

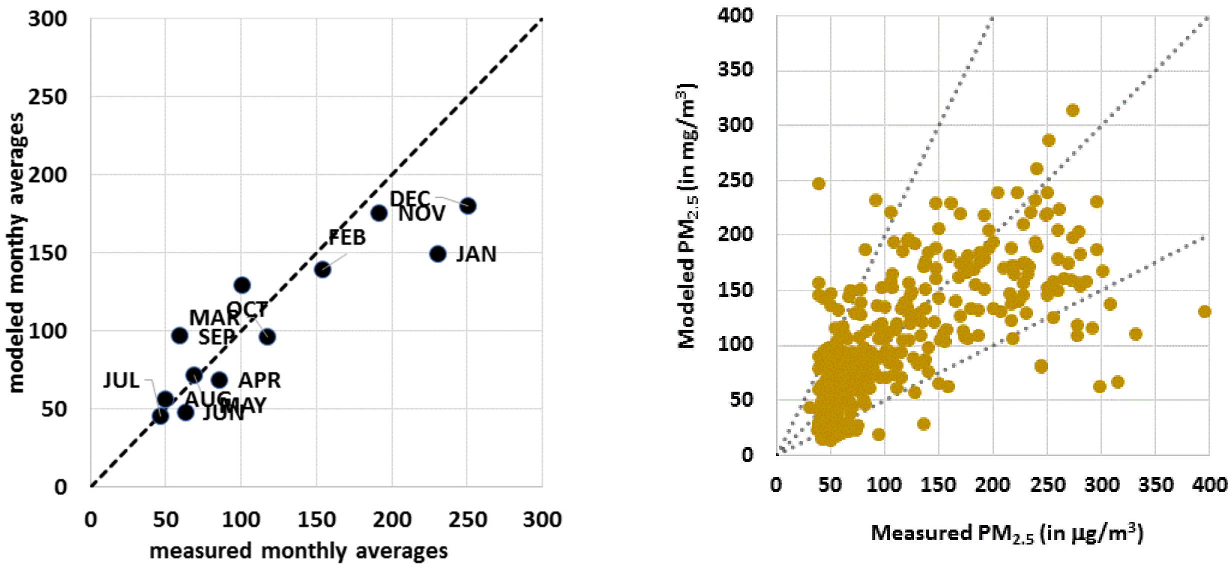


Figure 4: Modelled vs measured PM2.5

(updated every 30 minutes). Figure 4 presents the modelled and measured values of PM2.5.

2.4.2 Results

It was found that sectors like transport, domestic fuel consumption, open garbage burning, road and construction dust, industries, DG sets, and aviation are contributing to the total pollution load in Patna. The contribution of these sectors varies drastically—from 4% to 32%. Black carbon, NO_x, CO, SO_2, CO_2, PM2.5, PM10, and non-methane volatile organic compound (NMVOCs) emissions were estimated for all the sectors contributing to pollution in the city (See Annexure C).

The PM10 and PM2.5 sectoral emission loads were estimated for 2018, based on the primary and secondary data collected for different sectors. The sectoral emission loads were also projected until 2030, based on the growth rates of different sectors.

Figure 5 presents PM2.5 emissions projected for the period between 2018 and 2030 (under the BAU scenario) from various sectors contributing to pollution in the city. The year 2018 is considered as the base year for the emissions estimation. The total PM2.5 emission load for 2018 is estimated to be 20,000 tonnes. The major contributors of pollution in Patna are transportation, domestic, and industry, with a share of 19%, 22% (including cooking, heating, and lighting), and 28% (including brick kilns and industries) respectively. The total contribution from these sectors amount to around 69% of the total emissions. Open waste burning and dust account for 11% and 15% of the emissions, respectively.

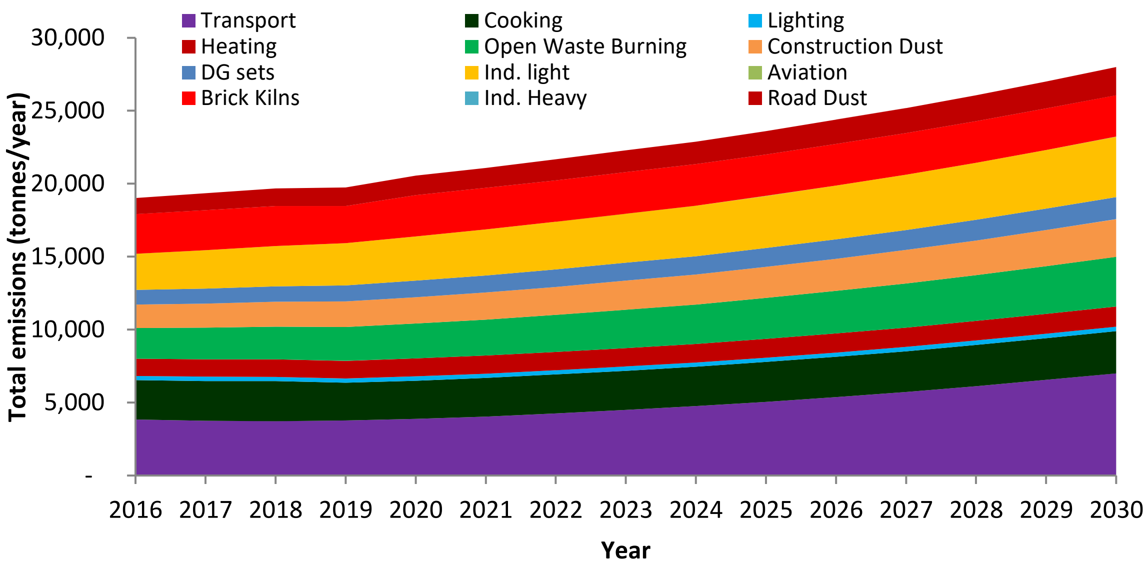


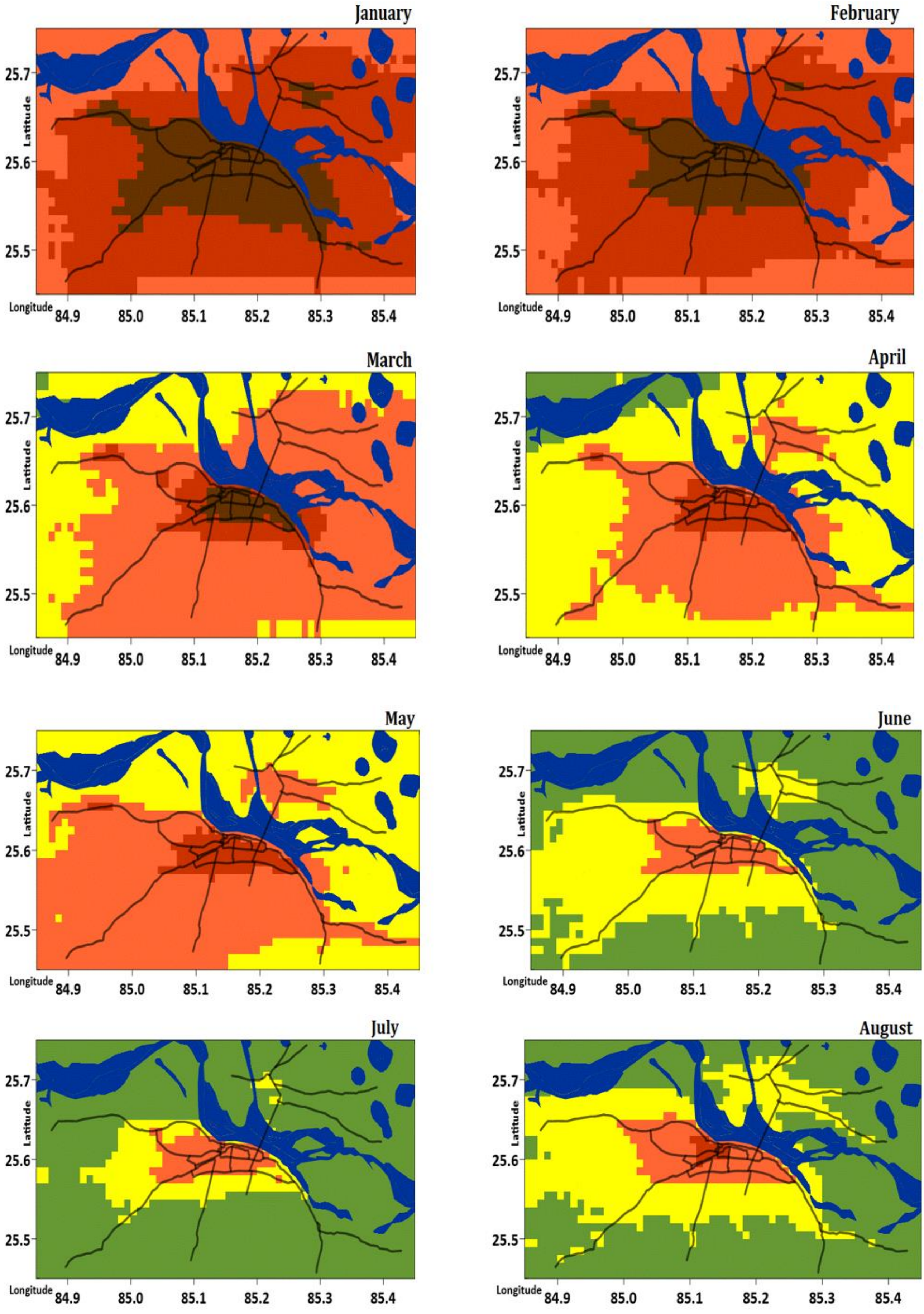
Figure 5: PM2.5 emissions (BAU)

The total PM2.5 emission load estimated for 2030 is around 28,000 tonnes/year (around 40% increase from the base year 2018) (The various scenarios are explained in Section 5). The major contribution of emissions in Patna for 2030 is estimated to come from the transportation sector (25%) and industries sector (25%), followed by the domestic sector (16%) (includes cooking, heating, and lighting), dust (16%), open waste burning (12%), and DG sets (5%). Based on our estimates, PM2.5 emissions from the transportation sector will likely increase by 88% in 2030, in comparison with the 2018 levels.

The increase in emission load from the transportation sector is mainly attributed to vehicular and economic growth, estimated to increase by 88% in 2030 under the BAU scenario. Similarly, the increase in emission load from the domestic sector is attributed to solid fuel burning, which is estimated to increase by 5% in 2030 from the baseline (2018). The domestic survey revealed that people still use traditional chulhas for cooking in a few parts of the city, because of inadequate refilling stations nearby and the ease of freely available solid fuel. The number of households using solid fuel for cooking remains almost constant till 2030, and hence the percentage increase in emissions from the domestic sector is relatively low (CEED, 2016).

The emission load for the city does not include PM2.5 emitted outside the boundary, the influence of weather parameters (rainfall, wind speed, atmospheric mixing height, etc.), and the generation of secondary PM by atmospheric chemistry. In order to incorporate such factors, dispersion modelling is used to determine the concentration levels in the city.

Concentration levels in the city were estimated for 2018–2030 using the emission inventory prepared for Patna city. Figure 6 presents monthly estimates of PM2.5 concentration levels in Patna for 2018 (BAU). It is observed that the concentration levels are high (above 150 $\mu g/m^3$) during the winter months (November, December, January, and February). The months of June, July, and August are relatively clean (compared with the winter months) with concentrations in the range of 20 to 100 $\mu g/m^3$.


January
February
March
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Latitude
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25.7
25.6
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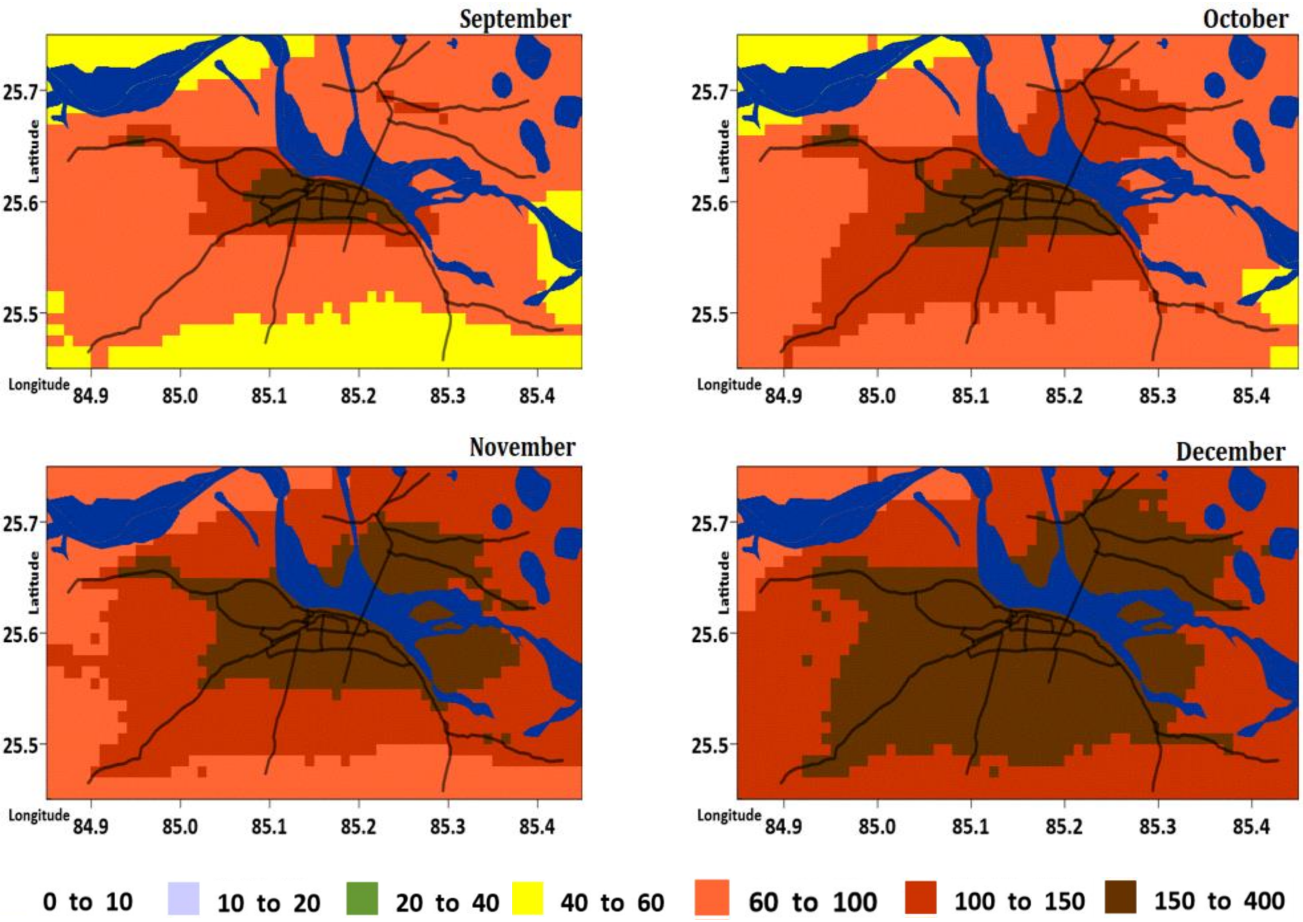
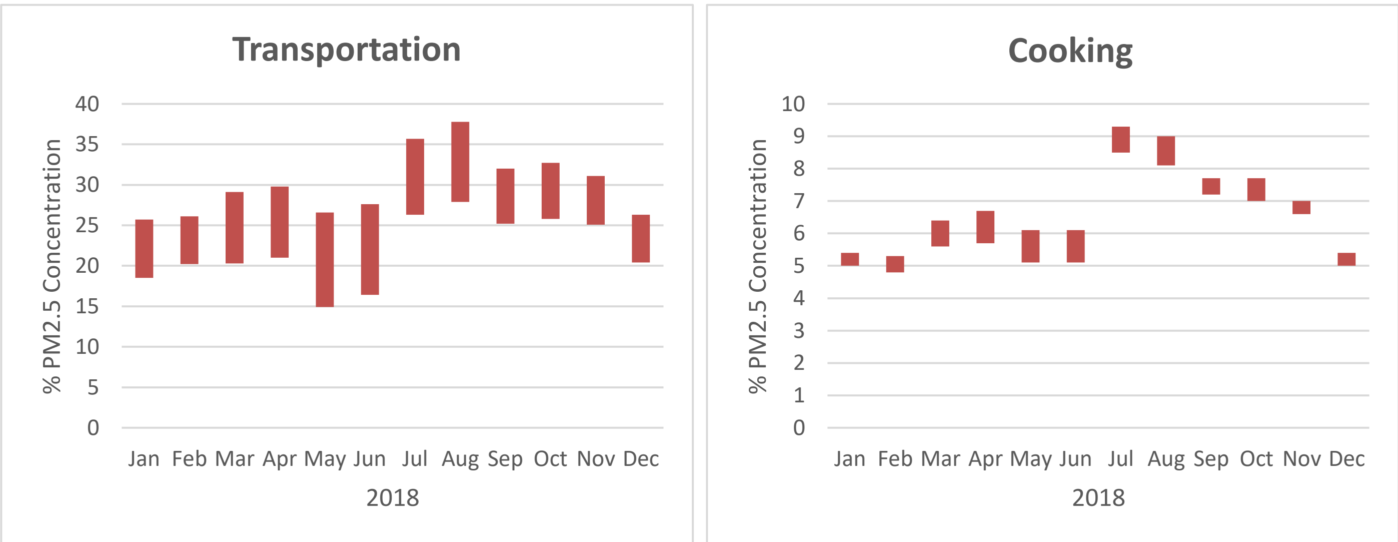
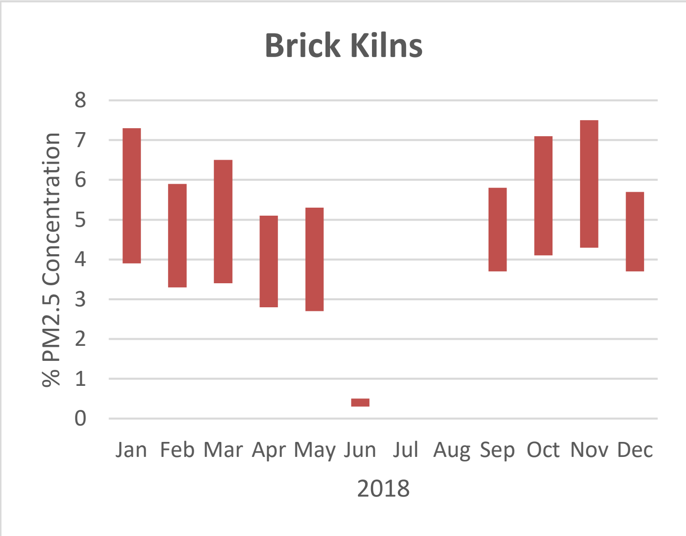
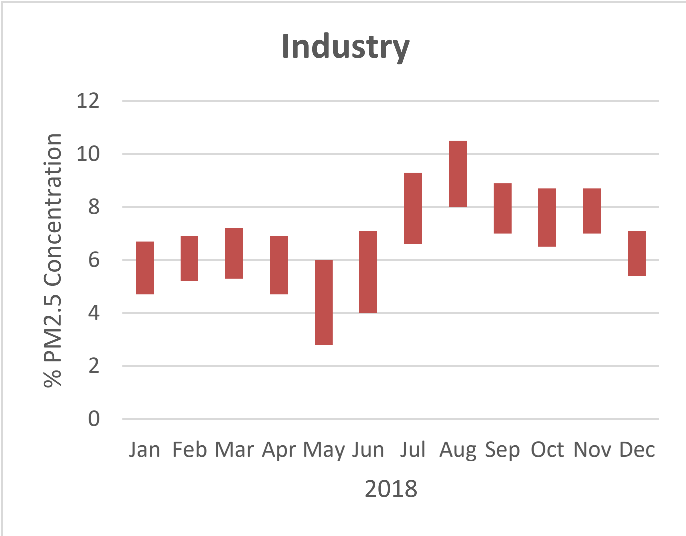


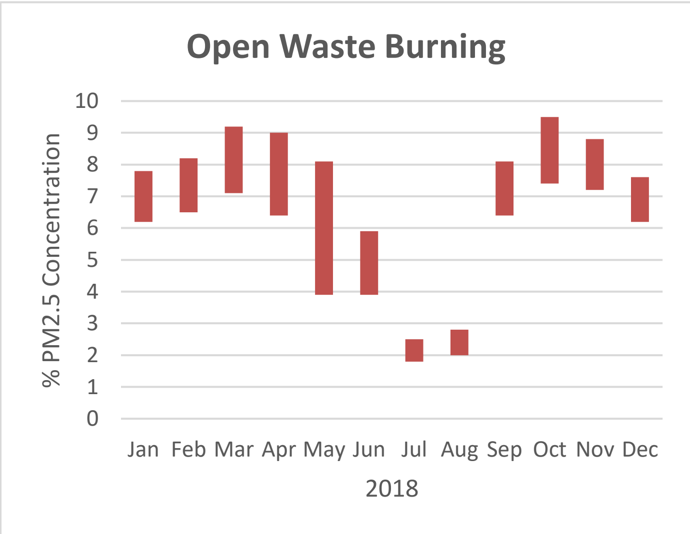
Figure 6: PM2.5 concentration levels (μg/m³) (BAU-2018)

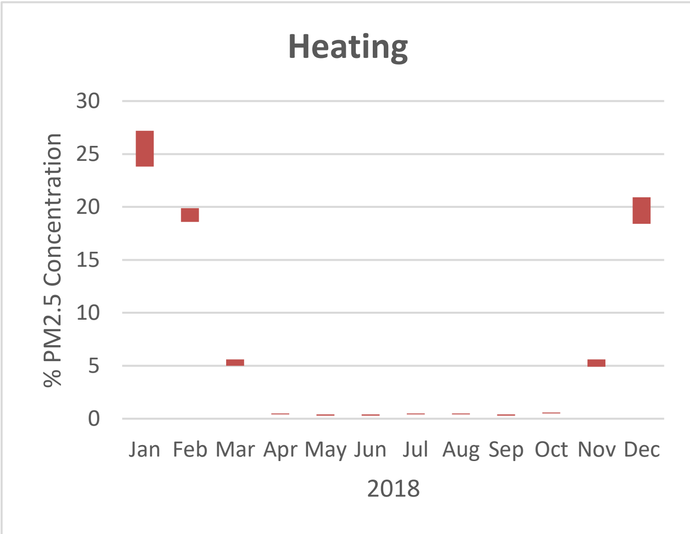
Figure 7 presents the sectoral contribution (in range) of PM2.5 concentration levels for 2018. The transportation sector's share in pollution concentration levels ranges from 23% to 39%, whereas the contribution from heating ranges from 0% to 25% (maximum of 25% during the winter season). Contribution from other sectors such as open waste burning and cooking is minimal (<10%) throughout the year. The contribution of construction and demolition dust is also significant, with a range of 7% to 12% across the year.

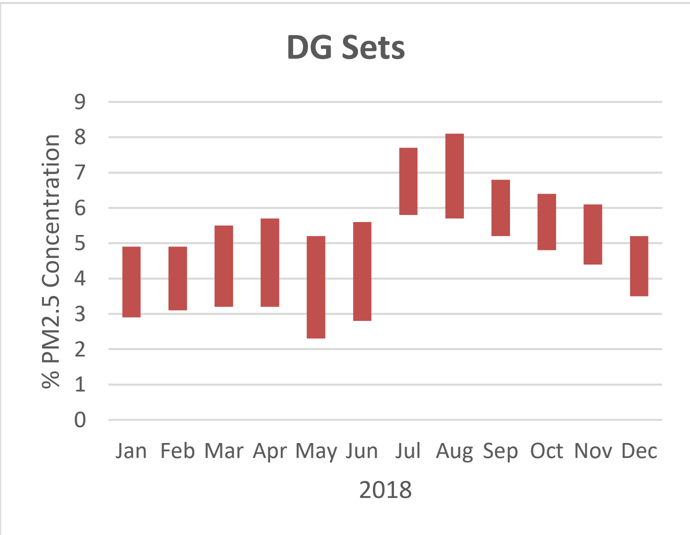


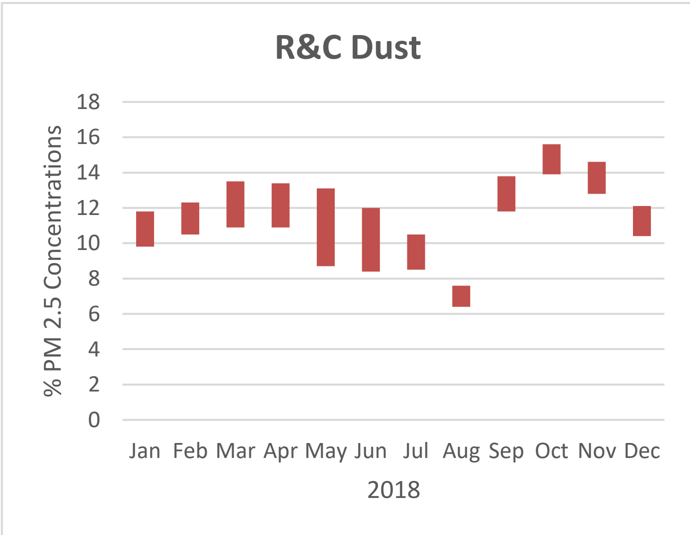

Brick Kilns
% PM2.5 Concentration
0 1 2 3 4 5 6 7 8
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018


Industry
% PM2.5 Concentration
0 2 4 6 8 10 12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018


Open Waste Burning
% PM2.5 Concentration
0 1 2 3 4 5 6 7 8 9 10
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018


Heating
% PM2.5 Concentration
0 5 10 15 20 25 30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018


DG Sets
% PM2.5 Concentration
0 1 2 3 4 5 6 7 8 9
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018


R&C Dust
% PM 2.5 Concentrations
0 2 4 6 8 10 12 14 16 18
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2018

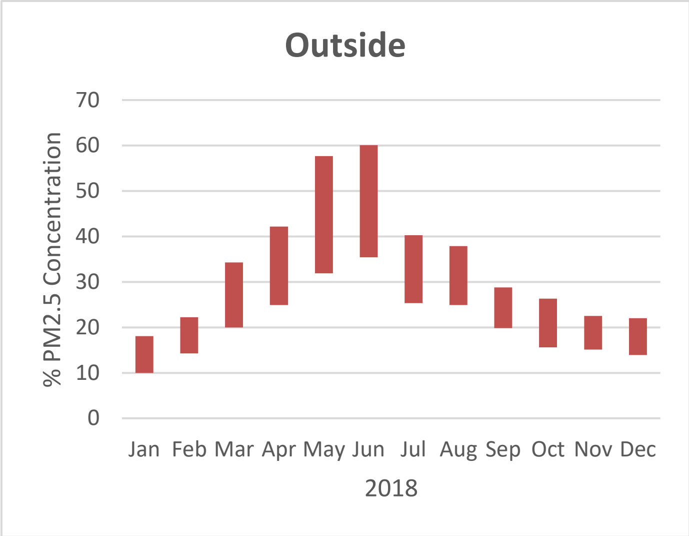


Figure 7: Sectoral share of PM2.5 concentration levels (%) (2018)

Patna's PM2.5 concentration levels are expected to reach an annual average of 134 µg/m³ by 2030, which is 235% higher than the current NAAQS level. Figure 8 presents the sectoral share of concentrations for the years 2018 and 2030 under the BAU scenario. By 2030, outside contribution will likely be the predominant contributing factor to the city's total pollution, with a 23% contribution share. This will likely be followed by the domestic fuel consumption and transportation sectors, contributing 21% and 19% respectively to the total pollution concentration of the city.

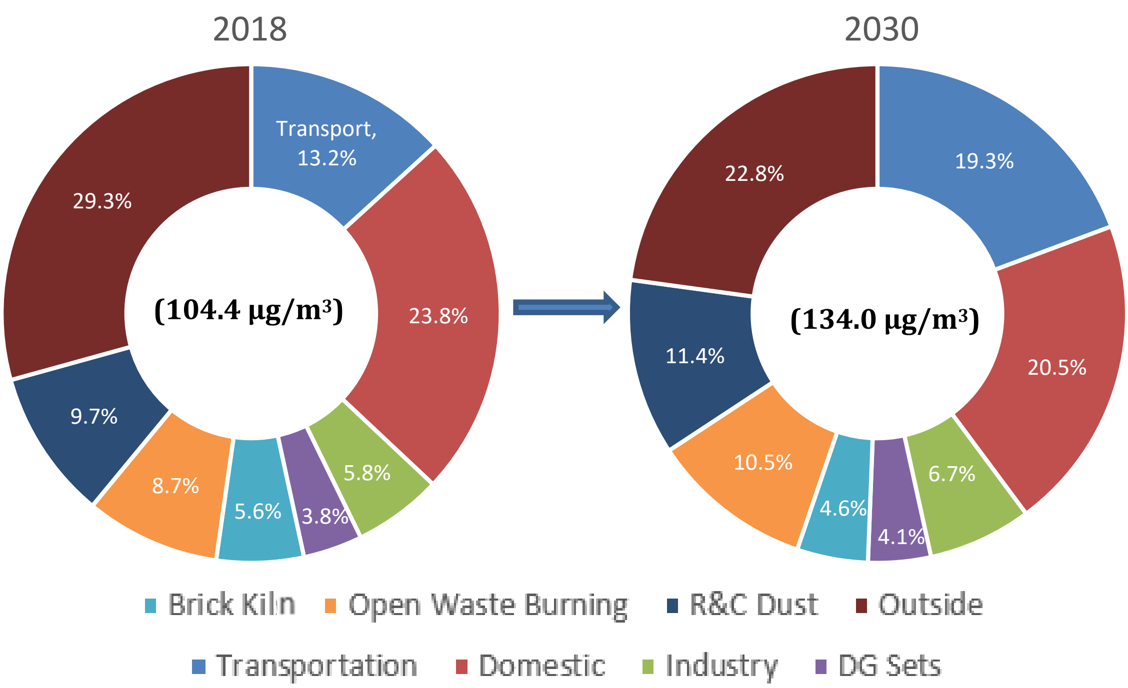


Figure 8: PM2.5 concentration levels (BAU) 2018 vs 2030

This rise in pollution levels is attributed to anthropogenic activities and economic growth. Road dust and open waste burning are likely to be responsible for 11% of the total pollution concentration levels, while the share of DG sets and brick kilns is estimated to be 4% and 5% respectively. The lack of proper solid waste management is the primary cause for emissions from waste burning. Complete elimination of emissions from brick kilns can be a challenging task because even with technology upgradation, emissions from brick kilns would still exist.

Under the BAU scenario, emissions from transportation and domestic fuel use (solid fuel) are estimated to increase. Therefore, serious interventions, in terms of policies and mitigation measures to reduce pollution levels, are the need of the hour.

3. Sector-Specific Control Measures

The pollution in Patna city is predominantly anthropogenic in nature. Tailpipe emissions from the transportation sector, industrial emissions (brick kilns, manufacturing, and fabrication industries), dust from construction and demolition activities, and household emissions (cooking and heating) mainly contribute to the city's pollution load. Reducing the pollution load of the city will require reducing emissions from these sectors. A list of sector-specific control measures (CMs) was identified to reduce emission from these sectors.

3.1 Comprehensive list of control measures

A comprehensive list of sector-specific CMs was prepared for an effective action plan for Patna. Figure 9 presents the various sector-specific determinants that were selected to identify the CMs. The determinants were selected based on the present and existing scenarios of the various sectors in Patna.

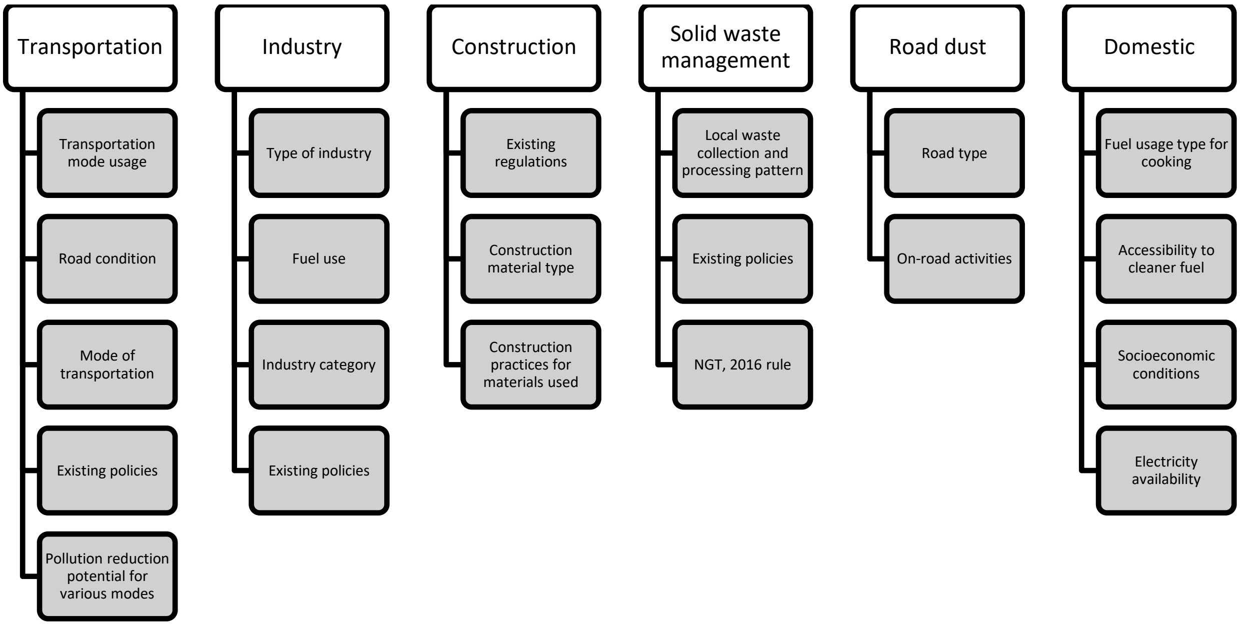


Figure 9: Determinants for source-specific CMs

Transportation sector: To identify CMs for the transportation sector, determinants such as the existing mode of transportation (i.e., bus, car, auto rickshaw, 2-wheelers, and non-motorised transport) and modes of transportation used by the public were considered. Moreover, factors such as road condition (road width, paved/unpaved roads) and the pollution-reduction potential of various modes of transportation were considered while determining the CMs. Existing and upcoming emission-reduction policies were also examined to identify CMs.

Industrial sector: Various determinants were considered for suggesting the CMs, such as type of industries (brick kiln, metal fabrication, smelting, and others), fuel use (biomass, coal, CNG, and diesel), and categorisation (red, orange, green, and white). Apart from the abovementioned determinants, the existing and upcoming policies relating to air pollution were considered while selecting the CMs.

Construction sector: CMs were selected based on the central and state governments' existing rules and regulations on pollution reduction. The construction practices (transportation and storage of material) exercised in the city also helped define the CMs.

Solid waste management (SWM): The sector is governed by various factors such as:-

- Door-to-door waste collection / Collection from local dumping place
- Frequency of collection
- Waste segregation
- Types and quantity of waste processing (if any)

When attempting to determine CMs for solid waste, the aforementioned factors along with central and state policies of waste management and National Green Tribunal (NGT) rules–2016 (ban on any type of waste burning) were taken into account.

Road dust: Determinants such as types of road (paved or unpaved), on-road activities (number and type of vehicles plying), and construction activities near the roads, plantation around the roads, and potholes were considered while determining the CMs.

Domestic sector: This sector is considered to be one of the highest contributors to pollution. It, therefore, has many determinants to consider when identifying CMs. Determinants such as fuel use for cooking/heating (LPG and wood), availability and accessibility to cleaner fuel, socio-economic conditions, and fuel for lighting purpose (because of non-availability of electricity) were taken into account.

The determinants helped us identify CMs for various sectors contributing to pollution. The policies introduced by the state and central governments—such as the metro rail (by the Bihar government), introduction of BS-VI vehicles and fuel (by the central government), and the introduction of increased LPG use for cooking under the Pradhan Mantri Ujjawala Yojana (PMUY)—were taken into account for determining the CMs.

It was important to understand the various line departments' capability to implement the identified CMs. For this, multiple focussed group discussions were conducted with the line departments and collected the necessary data (Annexure E).

A comprehensive list of CMs was proposed based on the polluting sectors and their contributions. Implementation timelines for the CMs (short-, medium-, and long-term) were also suggested based on the availability of infrastructure and the existing policy framework of the various line departments. A benefit-cost ratio of the CMs was estimated to help line departments prioritise implementation strategies. Benefit-cost ratios were estimated by performing a techno-economic assessment (TEA) for each CM. The CMs were shortlisted by BSPCB, after deliberations with various line departments, based on the benefit-cost ratio and the implementation time.

The short-listed CMs for TEA have been listed in Table 3. A detailed list of CMs adopted for Patna city has been attached in Annexure B. It has also been sent to NGT to check for compliance.

Table 3: Shortlisted CMs for TEA

City name: Patna						
Sl. No.	**Sectors**	**Action Points**	**Technology/Infrastructure Requirement (TR/IR)/ Methods (M) / Outcome (OC)**	**Benefit-Cost Ratio[11]**	**Implementation Period (short: 6 months, med: <2 years, long: >2 years)**	**Implementation Agency**
1	Transportation	Addition of new buses to the public transport system: electric buses, hybrid diesel buses, CNG buses	TR/IR—Introduction of electric buses with proper support infrastructure (charging stations) OC—Public transportation in play will reduce the number of private vehicles operating in the city. This will reduce the total emission load from tailpipe emissions	High	Long	Bihar State Road Transport Corporation (BSRTC) Private Bus Owners Transport Department Industry Department
			TR/IR—Introduction of CNG buses OC—Public transportation in play will reduce the number of private vehicles plying in the city. This will reduce the total emission load from tailpipe emissions	Medium	Long	
		Complete ban on 2-stroke autos and replacing them with CNG-based vehicle or EV	TR—E-rickshaws OC—Reduction of emission load from autos	High	Medium-Long	Transport Department, Government of Bihar
			TR—CNG-based autos OC—Reduction of emission load from autos	Medium		
		PUC check (every 6 months) and better PUC check infrastructure and management	OC—With better PUC infrastructure and strict pollution norms, emission from private and public vehicles will decrease.	Medium	Medium	

[11] Lives saved and cost incurred are the deciding factor for categorising CMs into high, medium, and low for BCR. The categorisation scale of BCR varies for all the CMs listed. The BCR listed in the table was estimated with the help of initial-level TEA.

		Incentivising the use of cleaner fuels: electric vehicles and CNG/LPG for private vehicles	TR—Proper infrastructure to increase the adoption rate of cleaner fuels OC—Reduction of emission load from private vehicles that switched to electric/CNG/LPG-based vehicles from petrol/diesel-based vehicles	Medium	Medium	
		Installation of diesel particulate filter (DPF) in all diesel vehicles	M—Installing DPF filters in existing diesel vehicles OC—Reduction of emission load from diesel vehicles	Medium	Medium	Transport Dept, Govt of Bihar
2	**Industry**	Adopting new technologies for brick kilns	Adapting zigzag technology	Low	Medium	Bihar State Pollution Control Board (BSPCB) Dept of Industries (Bihar)
			Adapting Hoffman technology	Medium	Long	
			Adapting vertical shaft brick kiln technology	Medium	Long	
		To mandate solar PV panels and green belt inside industry premises (large industries)	M—Installing solar panels inside industry premises OC—Reduced electricity demand	Medium	Medium	
		Introduction of and shifting towards cleaner fuels in induction and casting industries	TR—Feasible technologies that support cleaner fuel OC—Reduction in emission load from industries	Medium	Medium	
3	**Solid waste management**	Installing waste composting plants at city level	M—Composting plants OC—Composting waste/garbage will reduce the emission load from garbage burning	Medium	Medium	PMC
		Recycling centres for dry waste	M—Recycling centres for dry waste OC—Proper disposal of dry waste will reduce the emission load from garbage burning	Medium	Medium	

		Waste-To-Energy (WTE) plants	M—Incineration and Gasification OC—Controlled burning of garbage will reduce the emission load from uncontrolled burning	High	Long	PMC
4	**Domestic**	To mandate rooftop solar panels for power backup and solar water heating	TR—Solar panels and other technological requirements OC—Reduced electricity demand	Low/ Medium	Medium	BSPCB PMC
		Introduction of improved chulhas (low-emission chulhas)	Identifying areas for using chulhas; Procuring the chulhas OC—Reduction in indoor emission load	Medium	Medium	Food And Civil Supplies Department PMC
		Increasing the LPG connections in low-income strata	M—Increase in LPG connection OC—Reduction in emission load	High	Medium	Food And Civil Supplies Department
		Replacing kerosene with an alternative fuel	M—Procuring solar lanterns OC—Reduction in emission load	Medium	Medium	Bihar Renewable Energy Development Agency (BREDA) PMC
5	**Construction & Demolition**	Construction materials should be transported in covered vehicles	OC—Reduction in emission load from dust			Traffic Police
		To mandate facility of tar road inside construction sites for movement of vehicles carrying construction material	OC—Reduction in emission load from dust			PMC

<table>
<tr><td>6</td><td></td><td>Promotion of the use of prefabricated blocks for building construction</td><td>OC—Reduction in emission load from dust</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Road dust</td><td rowspan="2">To take appropriate action to remove road dust/silt regularly by using mechanical sweepers</td><td>Mechanical sweeping
Identifying the road stretch with high silt content
Procuring the mechanical sweepers
OC—Reduction in resuspension of dust</td><td>High</td><td>Medium</td><td rowspan="2">PMC</td></tr>
<tr><td>Manual sweeping
OC—Reduction in resuspension of dust</td><td>Low</td><td>Short</td></tr>
</table>

4. Methodology: Techno-Economic Assessment (TEA) of the Control Measures

4.1 Techno-economic assessment

Techno-economic assessment (TEA) is a framework used to analyse the economic and technical performance of a process, service, or product. Technical feasibility assessment analyses the effectiveness of a particular technology, whereas economic feasibility assessment analyses the cost incurred (capital, operational, maintenance, salvage value, etc.) and the benefits achieved in the form of lives saved by better air quality. A TEA was performed for the shortlisted CMs identified (Table 3) in each sector.

The following sections talk about the sector-specific TEA and the technologies considered for emission reduction and policy solutions.

4.1.1 Transportation

Studies (Ken et al., 2006) have highlighted the importance of public transportation in an urban setup in reducing air-pollution levels. If citizens shift from private modes of transportation to the public mode, will result in improvement in air-pollution levels. Improving public transportation will reduce air-pollution levels and result in positive externalities such as congestion reduction, reduction in average travel time, resource conservation, etc. (Dora, 2007). The Indian government is also pushing for an improved public transportation system through schemes such as the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and the Smart Cities Mission.

Cities like Delhi, Mumbai, Hyderabad, Kolkata, Chennai, and Bengaluru have an established public transportation system. However, Patna, unlike other cities, lacks a well-established public transportation system. There are around 330 minibuses in Patna, but they are privately-owned. These buses do not run on scheduled timings, which is one of the reasons why people do not prefer public transportation.

Key Facts[12]:

- Mode share of buses for the year 2018: 21%; target mode share of buses by 2030: 40%
- Number of buses operating in Patna: 330 minibuses (privately-owned)
- Constant investments are being made by the government to improve the transportation infrastructure (new CNG stations, EV charging stations, and introduction of metro)
- 15 PUC centres are currently functional in Patna. However, they have no efficient mechanism to calibrate the instruments present at these centres.

To reduce Patna's pollution levels, the following CMs were taken into account when looking at the transportation sector.

[12] City Mobility Plan Patna

Control measure 1: The addition of new buses to the public transport system (electric and CNG buses)

Proposed measure: "Addition of new electric and CNG buses to the public transportation system"

The *Need for Government Support for Public Bus Transport* (CSTEP, 2015) suggests that with an increase in the fleet of public buses, the mode share of public transportation will also likely increase. Feasible technologies were identified to boost public transportation, taking into consideration the existing modal share, road widths, and societal preference. The total cost of ownership (TCO) of these identified technologies was calculated using the formula (4.1). Cost-benefit analysis (CBA) was conducted by estimating the total cost incurred by the government and the potential lives saved (estimated using reduced emissions) to identify economically feasible technology. Table 4 lists the key parameters that were considered for each technology.

Table 4: Key parameters for technologies considered—addition of new buses

Parameters	Diesel Buses	CNG Buses	Electric Buses
Capital Cost (INR Lakh)	25	40	80
O&M Cost (INR/km)[13,14]	24–30	20–25	6–12
Fuel Efficiency	2.2–4.3 km/l	2–4 km/kg	1.5 kWh/km
Fuel Cost (INR/km)[15]	16–25	13–20	10
Salvage Value	10%	10%	1.5%
Battery Cost (INR Lakh)[16]	NA	NA	21
Revenue (INR/km)[17]	40	40	40
Seating Capacity	31	31	31
TCO (INR/km)	55	45	40

$$\text{TCO} = \frac{C + F * L * D + (O + M) * L * D - S}{L * D} \quad \textbf{(4.1)}$$

Where,

C – Initial capital cost;
F – Fuel cost (INR/km);
L – Lifetime (years);
D – Distance travelled by the vehicle in a year (km);
O & M – Operation and maintenance cost (INR/km);
S – Salvage value (estimated resale value of an asset at the end of its useful life)
Battery replacement costs are included in the O&M cost.

The total number of buses required to achieve the target mode share was estimated using equation (4.2). It is assumed that the introduction of buses will increase the mode share of public transportation.

$$\text{Total no. of buses required for year n} = \frac{T * \ Pn * Eb}{C * Pb} - D \quad \textbf{(4.2)}$$

Where,

13 Financial Analysis of Solar Electric Bus in India
14 Electric Buses in India: Technology, Policy and Benefits
15 Fuel cost is estimated using the fuel tariff and the fuel efficiency.
16 Lithium Ion battery market and costs - BNEF
17 State Road Transport Undertakings 2014 (CTU)

T – Target mode share;
Pn – Projected population at year n;
Eb – Total no. of buses present at the base year (2018);
C – Current mode share;
Pb – Population at the base year (2018);
D – Discarded buses

Control measure 2: Ban on registration of two-stroke autos

Proposed measure: "Registration of two-stroke autos to be banned and replacing two-stroke autos older than 12 years with either CNG-based autos or e-rickshaws"

A majority of Patna's citizens rely heavily on autos for daily commuting. This is mainly because the city does not have an efficient public transportation system. The existing mode share of autos is around 22%, which is greater than that of any other mode of transportation. Two-stroke autos, which are common in Patna, use a mixture of oil and gasoline that tends to emit more pollutants than four-stroke autos do. The proportion of toxic air pollutants emitted by two-stroke autos is more than twice that of four-stroke autos (Ghate et al., 2018).

Potential control technologies were identified that could replace the existing two-stroke autos, by looking at the ground-level scenario. Table 5 lists the technological options and key parameters that were considered when determining suggestions for the replacement of two-stroke autos. CBA was conducted on the shortlisted technologies using their TCO (estimated using equation 4.1). The potential benefits that these technologies could offer were also estimated in terms of pollution reduction and additional revenue. A major cost component in the TCO of an auto rickhsaw is the operation and maintenance cost.

Table 5: Key parameters for technologies considered: ban on two-stroke autos

Parameters	Two Stroke Autos	CNG	Electric
Capital Cost (INR Lakh)	1	1.5	2
Fuel Efficiency	18-20 km/l	20-22 km/kg	0.15 kWh/Km
Fuel Cost (INR/km)	4.2	2.6	1.0
TCO (INR/km)[18]	9.5	6	2.5

Control measure 3: PUC check (every 6/12 months) and better PUC check infrastructure and management

Proposed measure: "To open PUC centres at each petrol pump, and policies like 'No PUC No fuel' shall be enforced"

Studies suggest that with effective polices and efficient PUC centres, the level of emissions from automobiles will decrease (Rogers et al., 2002) & (TERI, 2017). The total number of PUC centres that need to be installed in the city has been estimated considering (a) the cost to install (equipment cost and the registration fee) and operate (salary and other recurring costs) a PUC centre, (b) number of vehicles operating, (c) average cost to get a PUC certificate, and (d) percentage of vehicles to receive a PUC certificate.

[18] Estimated from Center for infrastructure, sustainable Transportation and Urban planning (CiSTUP), Indian Institute of Science (2012)

CBA was performed by estimating the total costs (capital and O&M cost) incurred and the benefits (based on emission reduction) achieved.

The equipment required for a PUC centre includes smoke meter, 4-gas analyser, and a computer. In addition to this, training of staff will be a requirement.

Key Facts:

- Total number of PUC centres in Patna – 12 (operational)
- Monitoring mechanism – None; total number of petrol pumps – 52

Control measure 4: Incentivising the use of cleaner fuels (CNG/LPG) and electric vehicles for private use

Proposed measure: "Provide incentives to people to buy CNG/LPG/electric vehicles"

Policies that promote the use of electric vehicles, such as the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) and the National Electric Mobility Mission Plan (NEMMP), already exist in India. However, unlike other Indian cities, very few people have benefited from the FAME scheme in Patna—only 1.3% of the total vehicles have been sold under the FAME[19] scheme in Bihar. It is anticipated that the transportation sector's emission levels could be reduced by increasing the proportion of vehicles that operate on clean fuels. Under this control measure, it is assumed that at least 5% of cars registered every year would be EV-based and at least 10%–20% of the cars will be retrofitted with CNG/LPG kit.

The cost incurred for implementation of this CM considered the incentives for the consumers. The government should also bear the cost of promotional activities focused towards increasing the adoption rate of CNG/LPG/electricity-based vehicles. Such fuels, as a replacement of diesel, could lead to reduced emissions. The benefits achieved by implementing the CMs, in terms of potential lives saved (using the difference in emission load), has been estimated.

Control measure 5: Installation of diesel particulate filter (DPF) in diesel vehicles

Proposed measure: "Create mandates and provide subsidies to diesel vehicles (trucks) to install DPF"

Patna is currently undergoing rapid urbanisation, which has kick-started a lot of construction activity in and around the city. This has increased the number of trucks currently operating in the region. Moreover, as the river Ganga flows near Patna, a lot of sand mining activities take place on the banks of the river. Trucks/Trailers, which run on diesel fuel, are used to carry sand within the city. Emissions from these heavy goods vehicles are relatively high, compared with any other mode of transportation.

The installation of DPF filters will help reduce emissions from these vehicles by at least 70% (Tsai et al., 2011) & (CARB-USEPA, 2015). Pollution caused by diesel vehicles can be curbed using the available filters (Preble et al., 2015). The kind of filters that could be installed in vehicles were identified by taking into account the availability of filters, the vehicle type, and the efficiency of the filters. The capital cost of the filter, the recurring maintenance cost and

[19] As per data accessed from https://www.fame-india.gov.in/

the pollution-reduction factor of the filter were used to determine an efficient option. Installing a DPF in a truck is expensive, and it does not provide any additional benefit to the driver. It was assumed that at least 15%–30% of the trucks that ply in Patna will be incentivised to install DPF filters by 2023. The major focus will be on trucks that are older than 10 years.

4.1.2 Industry

The economy of Patna is heavily dependent on the agriculture and service industries (MSME, 2011). Patna is also an important industrial hub, home to several brick kilns, as well as medium- and small-scale industrial units.

Key Facts[20]:

- Brick kilns in Patna: Total – 300; Operational – 122
- Agro-based, garments, wood/chemical/leather-based, metal fabrication, and brick kilns are some of the types of industries located in Patna
- More than 80% of the brick kilns use Fixed Chimney Kiln (FCK) technology ("Status of Brick Sector In The State of Bihar," 2012)
- The Bihar government's notification mandates the conversion of FCKs to Zigzag kilns (BSPCB, 2016)

Considering the various types of industries present in Patna, the following CMs were proposed for reducing pollution levels.

Control measure 1: Adapting efficient technologies for brick kilns

Proposed measure: "Convert all existing brick kilns to zigzag technology"

Despite legal mandates from the Bihar government to adopt zigzag technology in kilns, several brick kilns still use FCK. Shifting to zigzag technology could improve the city's air-quality levels. The cost of converting from FCK to zigzag kilns was estimated by considering the capital cost and opportunity cost (based on productivity loss during the days spent on shifting). Meanwhile, the benefits were estimated in terms of the additional revenue generated (based on improvements in product output), savings in fuel (based on fuel efficiency), and lives saved (based on emission-reduction potential). Table 6 presents a list of parameters (Iqbal, 2016) considered for adopting the improved technology for emission reduction in brick kilns.

Table 6: Key Parameters for technologies considered: brick kilns

Retrofitting Parameters	Induced Zigzag Kiln	Natural Zigzag Kiln
Capital required (INR lakh)	25	27
Days required to shift technologies	60	90
Coal consumed (tonnes)/lakh bricks	12	12
Product output	70-80%	70-80%
Total annual savings (INR lakhs)	44	44
Additional requirements	Draught fan	Chimney
Emission (PM) reduction potential in comparison with FCKs	40%	40%

[20] Data from Industries Department - Patna

Control measure 2: To mandate solar photovoltaic (PV) panels and green belt inside industry premises (large industries)

Proposed measure: "To increase the solar power generation capacity at industry premises"

The industrial sector tends to consume more electricity than the domestic sector (EIA, 2017). Policies/Mandates promoting renewable energy (the percentage of conventional energy forms currently used must be replaced by renewable energy) will encourage industry owners to install solar PV capacities within their premises. This, in turn, will help decrease industries' dependence on thermal power plants, resulting in the reduction of emissions.

Control measure 3: Introduction of and shifting towards cleaner fuels in metal-fabrication industries

Proposed measure: "To promote the use of technologies that use clean fuel"

Over the past decade, around 100 metal-fabrication industries have cropped up in Patna. There is uncertainty in the technology and fuel use in these industries. Therefore, industries that have upgraded to the latest technology/fuel use could not be identified. Shifting these industries to the latest furnace technologies such as induction or electric furnace will help reduce coal usage (Sodhganga, 2009).

In this case, the implementation of CMs requires investment from industry owners. To understand the cost of installing these clean technologies and the benefits of doing so, the relevant costs and benefits were calculated. The implementation cost of the CMs for the industries was estimated by accounting for only the capital cost. The benefits were estimated using the savings (in fuel consumed), additional revenue (calculated based on the change in product output), and lives saved (estimated using the emission-reduction potential).

4.1.3 Solid Waste Management

The Patna Municipal Corporation (PMC) is working towards creating an efficient solid-waste management plan for the city. To improve the current scenario, the PMC has initiated serious efforts to ban solid-waste burning in the city. Moreover, the PMC plans to build a waste-to-energy (W2E) plant to handle 1,000 Tonnes of waste per day (TPD). The waste generated from 75 wards in the city is neither segregated nor treated, and hence, it gets dumped in a landfill at the outskirts of the city. Therefore, after taking into account all the existing determinants in the city, the following control measures were suggested, to help reduce Patna's emission load. The amount of waste generated every year has been estimated using equation (3.1)

$$S_n = G \times P_n \quad \textbf{(3.1)}$$

Where,

S_n – Solid waste generated for year n
G – Per capita waste generated
P_n – Projected population at year n

Key Facts:

- Total municipal waste generated: 800–900 TPD
- Installed solid waste treatment capacity: 0 TPD
- No. of wards in Patna: 75; Segregation level: 0%
- Waste composition: Compostable: 52%; Recyclable: 12%; Non-Compostable: 36%

Control measure: Installation of composting plants at the city level, recycling centres for dry waste and waste-to-energy plants

Proposed measure: "To increase the treatment capacity of solid waste at the city level"

There are several efficient solid-waste composting methods, such as vermicomposting, windrow composting, anaerobic digestion, and stack pile composting (MouD, 2011). The windrow composting technique is economically attractive and technically simple. This technology can be operated at a centralised level and is likely the most suitable composting technology that could be implemented in Patna.

Around 36% of the waste generated in Patna is non-compostable. This is why the establishment of dry-waste collection centres are necessary.

Various composting methods were shortlisted for implementation in Patna. While selecting the composting method, a few variables were taken into consideration, such as (a) land-use pattern, (b) solid-waste composition, (c) use of compost, and (d) cost required to install composting plants for the waste generated in Patna.

The capacity of composting plants and dry-waste collection centres that need to be installed each year was estimated by projecting the solid waste generated, taking into account the population growth and the segregation level.

Cost of implementing this control measure was estimated by taking into account the capital cost (land cost, machineries, etc.), O&M (salary, maintenance of machineries, etc.), awareness activities, and more.

Studies suggest that a proper solid-waste management plan could reduce the amount of waste being burnt, which in turn may lead to improved air quality in the city (Guttikunda and Jawahar, 2014). In other words, the benefits of these control measures are directly linked to the potential emission reduction from waste burning. The overall benefits of implementation was estimated keeping in mind the revenue generated (sale of fertilisers and recyclable materials), along with the potential lives saved as a result of emission reduction. Table 7 presents the key parameters for the technologies that were considered.

Table 7: Key parameters for the methods considered: installation of waste treatment plants

Parameters	**Windrow composting** (CEDINDIA, 2011)	**Dry-waste collection centres** (Chandran et al., 2016)
Segregation Required	Yes	Yes
Implementation Time	< 1 year	1–2 year
Capital required (INR, per tonne)	9 lakh	15 lakh
O&M cost (INR, per tonne)	2.3 lakh	9 lakh

4.1.4 Domestic

In 2015, across India, residential biomass burning was the largest individual contributor (24%) to the deaths attributable to PM2.5 (GBD MAPS Working Group, 2018). Solid fuels that are burned for cooking purposes are also a major contributor to indoor air pollution. Evidence suggests that there is a strong link between indoor air pollution and asthma, tuberculosis, cancer etc. (Kurmi et al., 2012). Infants and children are more vulnerable because of their immature respiratory defence mechanisms. In Patna alone, there are around 1.5 lakh households that use traditional chulhas to fulfil their cooking needs (CEED, 2016). This number is expected to double by the end of 2050 (CEED, 2016) .

Key Facts:
- People use chulhas even if they have LPG connection (fuel used in chulhas is free/cheap)
- Solar rooftop potential: 759 MW (Loond & Ravi, 2014)

Control measure 1: To mandate rooftop solar panels for power backup and solar water heating

Proposed measure: "Focus on incentivising the installation of solar panels in rooftops"

Patna's total solar rooftop potential is 759 MW (Loond & Ravi, 2014). Industries and local shops often switch to DG sets during power outage. With the introduction of solar panels (assumed to achieve atleast 10%–30% of the total solar rooftop potential), the installed power generation capacity of Patna will increase and this will help reduce the use of DG sets.

Cost incurred by the Bihar government to implement this control measure will mostly be in the form to incentives that will be provided to the general public for the installation of solar PVs on their rooftops.

Control measures 2, 3, and 4: Introduction of improved chulhas (low-emission chulhas) / induction stoves, increasing LPG connections in the low-income strata, and ban on use of kerosene (use of solar lanterns)

Proposed measure: "Focus on subsidising the cost of smokeless chulhas / induction stove and the cost to get a new LPG connection, and promote solar lanterns within the economically lower strata of society"

By increasing the number of LPG connections and refuelling rate of LPG cylinders, and using smokeless chulhas or induction stoves, it is assumed that the dependency on solid fuels like wood and biomass will decrease. The emissions level from these solid fuels is higher than that of the emissions from LPG or smokeless chulhas (Singh, 2009). The cost for implementing this control measure was estimated by taking into account the incentives (Annexure D) provided for people. This will motivate people to switch to smokeless chulhas / induction stoves or to adopt LPG connections. The benefits of implementation were estimated by taking into consideration the percentage of emission reduction caused by the implementation of these CMs.

The electrification level in Patna is around 100%; however, there are non-notified slums in the city that are still dependent on kerosene as a fuel for lighting purposes. By promoting the use of solar lanterns in these slums, it is assumed that kerosene usage will decrease.

4.1.5 Road dust

Traditionally, all of the city's roads and sidewalks are swept manually. This method, however, is considered highly inefficient as dust swept from the roads is left on the roadside. This dust gets re-suspended once vehicle movement commences (Kuhns et al., 2008). One of the reasons of emissions from road dust is the lack of coordination between different governmental departments. The Bihar government must implement stringent norms to collect the dust lying on the roadside to curb the resuspension of dust. The installation of mechanical sweepers and end-to-end road pavement could help achieve the goal.

Control measure: Regular removal of road dust/silt using mechanical sweepers

Proposed measure: "Introduction of mechanical sweepers to control road dust emissions"

Roadside dust can be removed using mechanical sweepers currently available in the market. However, to select a suitable mechanical sweeper for Patna, various parameters were considered like (a) surface condition, (b) content of the debris, (c) area to be swept, and (d) frequency of sweeping. A CBA was performed to check the financial feasibility of the sweeper, considering the key parameters (Kueh et al., 2008) mentioned in Table 8.

Table 8: Key parameters considered - mechanical sweeper

Parameters	Mechanical Sweeper (MS)	Regenerative-Air Sweeper (RAS)	Vacuum-Assisted Sweeper (VAS)
Capital cost (INR lakh)	40	48	80
O & M cost per km (INR)	68	31	34
Life (Years)	10	12	14
Total Suspended particles reduction (%)	18	43	79

4.2 Health benefits

Long-term exposure to small particles [10 microns or less in diameter (PM2.5 & PM10)] has been associated with increased mortality and morbidity over time. When PM concentrations reduce, the related mortality and morbidity levels also go down. The reduced PM concentration helps project the associated health benefits in monetary terms. The Clean Air Action Plan's focus was to estimate the mortality avoided due to reduction in PM2.5 concentration levels.

The following method was adopted to estimate the mortality avoided annually (Pope et al., 2014)

$$M = \Delta PM2.5 \times E_p \times \Delta ER \times B_d \qquad \textbf{(3.2)}$$

Where,

- M – Mortality avoided annually
- $\Delta\ PM2.5$ – Change in PM2.5 concentration levels in 60 km X 30 km grid
- Ep - Exposed Population (Population of Patna)
- Bd - Baseline death rate (national mortality rate)
- ER (excess risk) – Supra-linear Concentration Response Function (CRF) considered on the basis of GBD assessments. $ER\ (excess\ risk) = 0.4\times \{1 - \exp\ [-0.03\ (PM2.5)^{0.9}]\}$

The method establishes a relationship between the changes in PM2.5 concentrations and the mortality avoided. According to a study by Pope, et al., 2014, the excess risk function can follow either a supra-linear form (rate of change of risk decreases with higher pollution concentration levels) or a linear form (risk increases at the same rate irrespective of pollution levels). However, recent studies consolidated that the ER or the CRF is more likely to be supra-linear at higher levels of exposure (Burnett et al., 2014) (Pope et al., 2014). This implies that the marginal benefits of pollution reduction at lower concertation levels are higher than the benefits in highly polluted areas. Figure 10 describes the difference between the supra-linear curve and the linear curve.

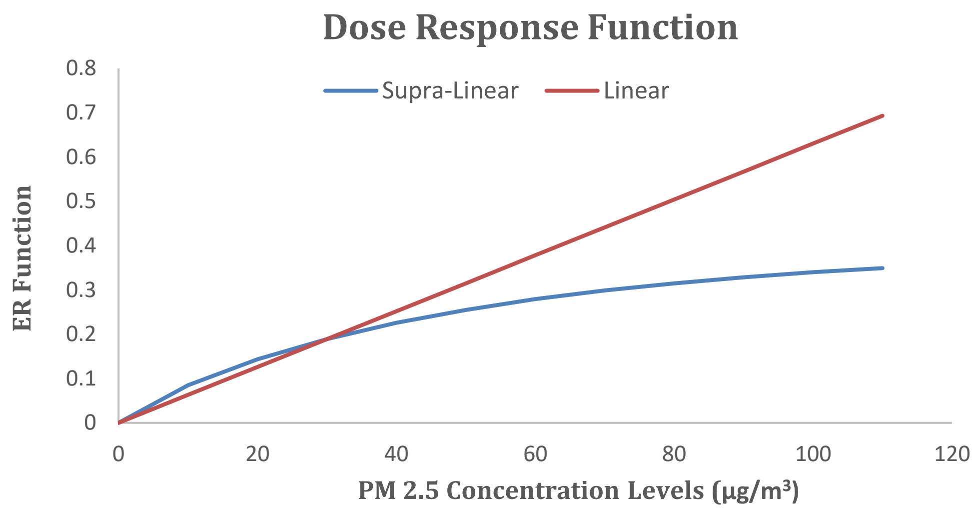


Figure 10: Supra-linear and linear form of ER function

5. Results and Discussion

As per the study estimate, the total emission load is increasing by a factor of 1.5 to 1.8 (Chapter 2.4.2) under the BAU scenario. Sectors such as transportation, waste burning, and industries are contributing to this increase in the emission load. Based on these emission concentrations, various scenarios (combination of CMs) were developed with varying levels of pollution reduction targets till 2030. Emission reduction scenarios for the sectors considered in the study have been described in detail below.

5.1 Sector: Transportation

Control measure 1: Addition of new buses to the public transport system (electric and CNG buses)

It was estimated that Patna will need at least 500 additional buses by the end of 2030 (Annexure D), considering the population growth and the target mode share set by the Patna transportation department.

Key Considerations:

- Mode share of public transportation: 40%
- Average distance travelled perday by a bus will remain constant: 154 Km/day[21]
- The battery of an electric bus needs to be changed every 6 years
- The rate of increase in Diesel/CNG price is comparatively higher than that of electricity cost[22]

Two scenarios were considered after taking into account (a) the country's preferences regarding EV adoption and (b) Bihar government's preference on adopting CNG buses.

Scenario 1: Preferred EV

The adoption rate of EV and its infrastructure is expected to grow at a rapid rate with the introduction of EV-promoting policies such as FAME. Hence, this scenario assumes that at least 50% of the buses will be electric, in the total number of buses added to the fleet by 2030.

Table 9 presents the estimated cost and benefits of this scenario. It is estimated that around 11% of the total emissions from the transportation sector (tailpipe emissions) can be reduced under this scenario. This reduction in emissions would help save at least 430 lives by 2030. Apart from the abovementioned benefits, the introduction of EV buses will also aid in revenue generation.

Table 9: Economic analysis - EV - preferred scenario

Year	2019-2022	2023-2025	2026-2030
Number of buses introduced	Electric – 50 CNG – 40 Diesel – 50	Electric – 80 CNG – 55 Diesel – 0	Electric – 135 CNG – 120 Diesel – 0
Capital cost (INR Cr.)	71	78	172
Operational cost (INR Cr.)	84	118	371
Revenue (INR Cr.)	105	188	704
Mortality saved (No.)	29	79	324

[21] City Mobility Plan
[22] Energy Information Administration (EIA). Annual Energy Outlook 2016.

Introducing electric buses to the fleet will be beneficial in (a) reducing pollution levels (health benefits), (b) increasing the mode share (direct savings in terms of spending money for transportation), and (c) reducing congestion levels (increase in average speed, reduced noise levels).

Scenario 2: Preferred CNG

The state is already procuring CNG for public use. Moreover, the Bihar government is inclined towards the use of CNG buses for public transportation. CNG buses are also the preferred mode of transportation to control air pollution in cities like Pune and Delhi. CNG buses emit less pollutants than diesel buses (Coroller & Plassat, 2003). Apart from this, the maintenance and fuel cost of CNG buses is considerably less than that of diesel buses.

For this scenario, 50% of buses were assumed to be CNG in Patna's public transportation fleet. It was estimated that around 9% of the total emissions from the transportation sector (tailpipe emissions) can be reduced under this scenario. This reduction in emissions would help save at least 400 lives by 2030. The cost incurred and the benefits that could be achieved in terms of revenue generated and mortality saved have been detailed in Table 10.

Table 10: Economic analysis – CNG - preferred scenario

Year	2019-2022	2023-2025	2026-2030
Number of buses introduced	Electric – 45 CNG – 50 Diesel – 80	Electric – 25 CNG – 80 Diesel – 20	Electric – 100 CNG – 110 Diesel – 0
Capital cost (INR Cr.)	79	68	139
Operational cost (INR Cr.)	102	169	482
Revenue (INR Cr.)	117	221	745
Mortality saved (No.)	26	71	292

Discussion: As presented in Table 9 and Table 10, the total capital cost required for Scenario 1 (EV preferred) is higher than that of Scenario 2 (CNG preferred). This is mainly because of the high initial capital cost incurred while purchasing an electric bus. However, looking at the other three criteria (operating cost, revenue, and mortality saved), Scenario 1 outperforms Scenario 2. It is expected that the cost of battery used in an electric bus will decrease exponentially (Curry, 2017), which will help reduce its capital cost. Hence, based on the study estimates, it is suggested that a preference for electric buses over CNG could be more efficient in reducing emissions from the sector.

Introducing electric and CNG buses in the city will definitely help curb pollution levels from the transportation sector. However, without proper infrastructure facilities, the associated technologies will become obsolete. Therefore, the government must simultaneously focus on infrastructure development alongside the introduction of additional buses to the public transportation system for an efficient public-transportation system.

Control measure 2: Ban on registration of two-stroke auto rickshaws

Registration of two-stroke auto rickshaws should be banned. Incentives should be given to two-stroke auto rickshaws that are older than 12 years to convert to either CNG or e-rickshaws.

Key Considerations:

- Total number of auto rickshaw permits given in the last 5 years: 13,018 (4-Seaters)[23]
- Incentive (estimated using the TCO difference) of INR 30,000–50,000 provided to auto rickshaw owners to shift to a cleaner technology

Scenario 1:

Under this scenario, the registration of new two-stroke auto rickshaws will be completely banned and vintage two-stroke auto rickshaws (12 years and above) will be replaced with e-rickshaws. The proposed CMs suggest that incentives be provided to auto rickshaw owners to convert two-stroke auto rickshaws to e-rickshaws, in a phased manner over a 5-year period.

Under the proposed control measure, subsidies should be provided to at least 10,000–13,000 auto rickshaws (4 - seaters plying in Patna) for encouraging conversion to e-rickshaws.

Scenario 2:

Under this scenario as well, banning the registration of new two-stroke auto rickshaws will be followed, along with replacing existing two-stroke auto rickshaws with CNG-based auto rickshaws.

Subsidy to be provided to at least 10,000–13,000 auto rickshaws (number of 4-seaters operating in Patna) for conversion to CNG-based auto rickshaws.

The cost incurred and the benefits achieved under Scenarios 1 and 2 are provided in Table 11. It was estimated that this control measure can reduce around 4% of the total emissions from the transportation sector. This reduction in emissions would help save at least 160 lives by 2030.

Table 11: Economic analysis - replacing two-stroke auto with CNG/EV-based autos

Cost and Benefits	**Till 2030**	
	Scenario 1	Scenario 2
Cost incurred (INR Cr.)	80	50
Mortality saved (No.)	160	112

The study estimates that the adoption of E-rickshaws will reduce the pollution levels. However, barriers such as technology, manufacturing capacity, affordability, and driver acceptance have a major impact on the adoption rate of E-Rickshaws (CapaCITIES, 2018). Additionally, the number of lives saved due to emission reduction in scenario 1 (electric autos) is 1.43 times higher than that of scenario 2. Therefore, considering the varied and substantial potential benefits offered by E-Rickshaws (emission reduction, cost involved, etc.), the government should focus on building new infrastructure and educating drivers to boost the adoption rate.

[23] Data provided by the Transportation department

Control measure 3: PUC check (every 6 months) and better PUC check infrastructure and management

At present, according to CPCB protocol, all vehicles must undergo a PUC check once a year. The existing PUC check system needs to be revised and the number of PUC centres and the infrastructure must be improved.

Under this control measure, it is proposed that 50 new PUC centres be set up with proper monitoring mechanisms and adherence to CPCB protocols. These PUC centres should also come with sufficient infrastructure and strict enforcement of laws. It is expected that the number of vehicles with valid PUC certificates will likely increase by at least 30% (based on the study (TERI, 2017)). Table 12 presents the total cost of setting up PUC centres, the operational cost (includes the manpower required, electricity charges, etc.), and the estimated lives saved under this scenario. Around 2% of the total emissions from the transportation sector could be reduced under this control measure. This reduction in emissions would help save at least 88 lives by 2030.

Table 12: Economic analysis: PUC scenario

Cost and Benefits	2019-2022	2023-2025	2026-2030
Capital cost (INR Cr.)	2	0	0
Operational cost (INR Cr.)	2.8	2.4	4.8
Mortality saved (No.)	12	20	56

The mere introduction of new PUC centres will not help/encourage vehicle owners to ensure that their vehicles are in a good condition. Initiatives like "*No PUC, No fuel*" must be introduced and public awareness about the impact of air pollution must also be escalated.

Delhi serves as a very good example for the implementation of a good PUC infrastructure; the city also has proper regulations in place. However, studies indicate (TERI, 2017) that fewer than 30% of vehicles in Delhi have a valid PUC certificate. Therefore, it is important for various government departments to create public awareness about the importance of vehicle maintenance.

Control measure 4: Incentivising the use of cleaner fuels (CNG/LPG) and electric vehicles for private vehicles

To bring about any kind of policy change and implement any regulation on ground, people must be provided with regulations that incentivise them to adopt the suggested change. Hence, for people to use clean fuel and electric vehicles, a proper incentive-provision channel must be created.

Under this scenario, incentives will be given to:

- Private vehicle owners who are motivated to retrofit their vehicles with CNG/LPG kit
- Owners purchasing new vehicles that use clean fuel

India already operates schemes that provide incentives to vehicle owners who purchase electric vehicles. Unfortunately though, limited knowledge about these scheme is available with the beneficiaries in Patna.

The burden of cost for implementing this control measure falls on the government. Under this control measure, individuals will be provided incentives only till 2022. This measure could reduce around 3% of the total emissions from the transportation sector. The estimated cost and benefits have been listed in Table 13.

Table 13: Economic analysis - incentivising private vehicles

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.)	127	0	0
Mortality saved (No.)	13	33	105

Control measure 5: Installation of DPF in diesel vehicles

Diesel vehicles emit pollutants that are harmful to human health (New Hampshire Department of Environmental Services, 2014). These emissions can be reduced by retrofitting diesel vehicles with DPF (CARB-USEPA, 2015). Technological upgrades to BS6 will likely propel all registered vehicles to come with pre-installed particulate filters. This control measure also suggests that trucks older than 10 years should have DPF installed.

It was estimated that this scenario would reduce the transportation sector's emissions by around 16%, which would help the government save around 650 lives by 2030. Table 14 presents the total cost incurred (incentives) and the lives saved.

Table 14: Economic analysis - installation of DPF

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.)	50	0	0
Mortality saved (No.)	50	105	499

Technologies like (a) selective catalytic reduction (SCR) for NOx emission reduction, (b) DPFs for PM reduction, and (c) diesel oxidation catalyst (DOC) for CO & hydrocarbon (HC) reduction (Preble et al., 2015) already exist in the market.

5.2 Sector: Industry

Control measure 1: Adapting new technologies for brick kilns

This control measure recommends the conversion of all the existing FCKs to Zig-Zag technology. Most importantly, the capital cost required to retrofit FCKs to zigzag technologies is much lower than other advanced technologies like Vertical Shaft Brick Kilns (VSBK) and Hybrid Hoffman Kilns (HHK). This control measure will help to reduce 34% of emissions from the brick kilns sector, saving around 1,242 lives by 2030.

Table 15 presents the cost of retrofitting all brick kilns from FCK to zig-zag technology in Patna.

Table 15: Economic analysis - brick kilns

Method	Induced Natural Zigzag kiln	Natural Zigzag kiln
Additional cost incurred (INR Cr.)	31	32
Additional maintenance cost /yr (INR Cr.)	3	-
Savings /yr (INR Cr.)	50	53
Mortality saved (no.)	1242	1242

Control measure 2: Introduction of technologies that use cleaner fuel

Industries using traditional/old technology are urged to switch to the latest technology, as per the government regulations. At present, 22 industries in Patna fall under the red category (CPCB, 2016). The furnace used by the metal fabrication industry uses coal as the primary fuel. Shifting from coal-based furnaces to electric or gas-based furnaces will help reduce emissions. Therefore, it is recommend that the industries switch to cleaner fuels.

Gas-fired cupola furnaces, induction furnaces, and rotary furnaces cost around INR 46 lakh, INR 30 lakh, and INR 10 lakh respectively (Sodhganga, 2009). The casting cost per kg of each furnace technology is around INR 30. Industry owners can switch to any of the abovementioned furnace technologies to reduce coal use. The cost of conversion to advanced furnaces should be borne by industry owners. If all the industries in Patna shift to either CNG or electric, 1,125 and 1,389 lives will be saved respectively.

5.3 Sector: Solid waste management

Control measure: Installation of composting plants at city level, recycling centres for dry waste & waste to energy (W2E) plants

Patna produced around 900 tonnes of solid waste per day in 2018. Considering the population growth and per capita waste generation, the city will produce around 2,000 TPD of waste by 2030.

Key Considerations:

- Per capita waste generation and waste composition to remain constant
- Patna's segregation levels to reach 70% by 2030
- A W2E plant of 1,000 TPD capacity to be operational by 2021
- It is assumed that setting up a proper solid waste management plan will reduce the solid-waste burning practices in Patna
- A composting plant of 200 TPD capacity will be installed every fourth year and an additional capacity of 100 TPD will be installed in 2027
- Dry waste collection centres of 10 TPD capacity will be installed every fourth year

Campaigns detailing on the benefits of waste segregation at household level along with financial incentives and strict regulation could result in 35% of households segregating their waste.

Capacities of composting plants and dry waste collection centres required were determined by considering the waste segregation level, the collection efficiency, and the projected waste generated per year.

Several composting technologies like vermicomposting, aerated stack-pile composting, and in-vessel composting aa re currently available in the market. However, considering the amount of waste generated in Patna, the most efficient composting technology to adopt would be windrow. Around 10% of the waste generated is dry waste, which makes the introduction of dry waste collection centres vital. Table 16 presents the total cost incurred under this scenario.

Table 16: Economic analysis - SWM

Cost		2019-2022	2023-2025	2026-2030
Composting plants	Capital cost (INR Cr.)	29	34	60
	Operational cost (INR Cr.)	30	52	168
Dry waste collection centres	Capital cost (INR Cr.)	1.5	1.9	2.2
	Operational cost (INR Cr.)	3	7	19
Mortality saved (No.)		111	345	1555

70% waste segregation would result in reducing 90% of emissions from waste burning. This could save around 2,000 lives. This scenario would also generate a revenue of around INR 160 crore through the sale of fertilisers and recyclable materials.

Household-level waste segregation and waste collection are key to developing an efficient solid-waste management system (Garcia, 2014). A proper waste-collection mechanism ensures safe transportation and treatment of the generated waste. Therefore, 100% waste collection needs to be ensured alongside boosting the installation and capacities of solid-waste treatment facilities.

The Patna Municipal Corporation (PMC) is in the process of installing a waste-to-energy treatment plant of 1,000 TPD capacity. It also plans to collect waste at the household level. This will ensure the implementation of the suggested CMs and achieve desired results.

5.4 Sector: Domestic

Control measure: Reducing the use of solid fuels

This measure is expected to reduce solid fuel burning with the increase of LPG connections and replacements of traditional chulhas with advanced chulhas and induction stoves. This, in turn, will result in reducing the domestic sector's emissions.

Scenario creation:

Two scenarios were analysed taking into consideration the percentage of people (Abhishek, 2017) willing to switch to LPG and the cost of solid fuel.

Scenario 1: Around 50 to 70% of households upgraded from traditional chulhas to smokeless chulhas.

Shifting from traditional to smokeless chulhas/induction stoves will help reduce emissions by 35%. It also benefits women who usually spend their time mostly in kitchen.

Table 17 presents the costs and benefits of using smokeless chulhas/induction stoves. Smokeless chulhas cost around INR 750-2,000. To ensure the desired reduction in pollution, the government should provide incentives ranging between INR 750-2,000. Patna has around 440,000 households (2018), of which, 30% still use traditional chulhas.

Our study suggests that 25% of households still using traditional chulhas, should be incentivised to switch to smokeless chulhas/induction stoves. The incentives are highly focussed during the year 2019 – 2022 and hence, the government's investment for this scheme is likely to be high during the initial years. However, the resultant emissions reduction will save many lives by 2030.

Table 17: Economic analysis - domestic sector

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.)	18	5	7
Mortality saved (No.)	302	698	1525

Scenario 2: Solar PV on government buildings, institutions, industries, and households

Patna's solar rooftop potential is around 759 MW (Loond & Ravi, 2014). Our estimates indicate that emissions from DG sets contribute to around 5% of the total PM2.5 emissions. DG sets are widely used by industries, hospitals, institutions, local vendors, and mobile towers. An increase in solar rooftop installation will increase the power generation and is expected to decrease the use of DG sets. The expected costs and potential lives saved under this scenario are presented in Table 18 .

Table 18: Economic analysis - solar PV

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.)	400	101	50
Mortality saved (No.)	55	212	728

5.5 Sector: road dust

This measure proposes end-to-end road pavement, strict compliance of existing policies and the introduction of mechanical sweepers. This can help reduce suspended road dust particles.

Key Considerations:

- Total road length of Patna: 3,000 km
- Total road length of major roads in Patna: 180 km
- Number of mechanical sweepers employed only on major roads : 10 by 2020

Patna requires at least 10 mechanical sweepers to cover 180 km of Patna's major roads. This will cost around INR 5 crore. Additional measures such as strict implementation of construction regulations and end-to-end road pavement could help the government save 1,200 lives in 12 years.

5.6 Scenario analysis

The previous section discussed individual interventions and the associated costs and benefits of various CMs. The study also looked into three combination scenario analysis for emission reduction. These scenarios were considered by clubbing various CMs in three buckets of high-emission reduction, medium-emission reduction, and low-emission reduction potentials. The section below details 1) the assumptions considered, 2) the estimated change in pollution levels, and 3) the costs and the benefits.

Scenario combination 1: High-pollution reduction combination

This scenario is designed to achieve maximum emission reduction by 2030. All the high emission reduction CMs/technologies from various sectors were clubbed. The interventions under each scenario have predefined targets, described in chapter 6.

The major interventions in this scenario are

1. Increase percentage share of electric transportation
2. Conversion of all the brick kilns and other industries to clean-fuel technology
3. Complete elimination of DG sets
4. Maximising the use of LPG for cooking

Scenario combination 1 - assumptions
• 60% electric, 30% CNG, and 10% diesel buses to be added to the public transportation fleet • Complete ban on two-stroke auto rickshaw registration and replacement of existing two-stroke auto rickshaws with E-rickshaws • At least 30% operating vehicles to have valid pollution under control (PUC) certificates • Up to 30% of trucks to have diesel particulate filter (DPF) installations • Brick kilns to adopt induced zigzag kiln technology by 2023 and promotion of prefabricated bricks • Installed solar rooftop capacity – 280 MW • At least 70% of traditional chulhas replaced by smokeless chulhas/induction stoves • LPG penetration rate – 95% • Electrification level – 100% • Number of mechanical road sweepers -10

It is estimated that the total emission load (PM2.5) will reduce by 69% by 2030 with respect to the BAU scenario (Figure 14). A major reduction in PM2.5 emissions in sectors like DG sets (91%) and open waste burning (90%), followed by the transport sector (75%) and brick kilns (74%), is expected by 2030 under this scenario. Figure 11 presents the estimated emissions for Scenario 1.

Introduction of solar PV and improvement in the existing power sector infrastructure will decrease pollution from DG sets. Patna would also have enough installed solid-waste-treatment capacity to treat all of the waste generated, essentially curtailing the burning of open waste.

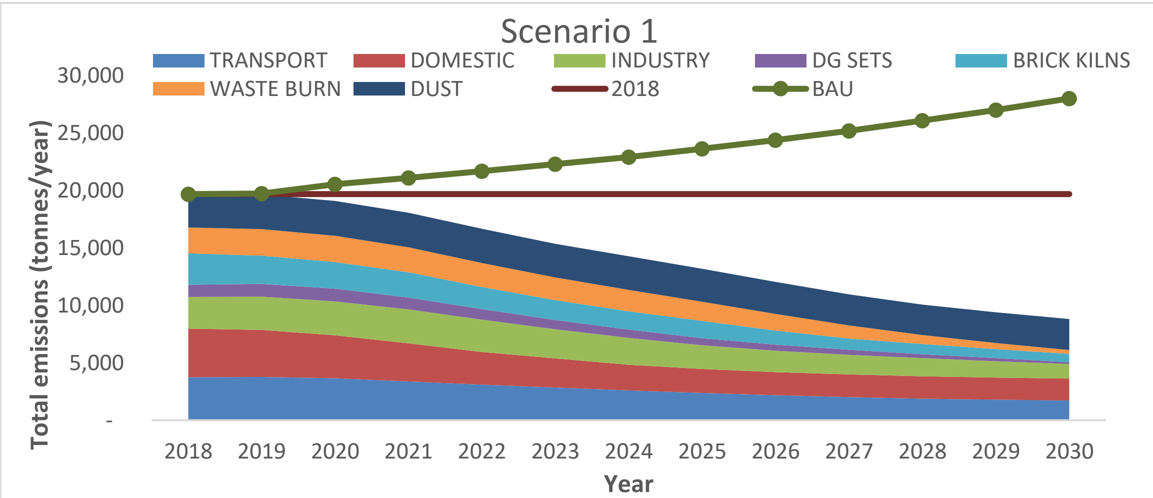


Figure 11: PM2.5 emissions scenario 1

Though all the brick kilns are expected to shift to advanced technologies, they are likely to continue contributing to the total emission load, given that they are located within the city. Hence, expecting 100% pollution reduction from the brick kilns sector is unrealistic.

The implementation of all the high-emission reduction CMs will help reduce pollution levels by 28% in 2024. NCAP has set a target of 20-30% pollution reduction by 2024 for all Indian cities. Therefore, our study estimates are in line with NCAP targets.

Scenario combination 2: Medium-pollution reduction combination

CMs/technologies with medium-level pollution reduction potential have been grouped under this scenario, which mainly focuses on CNG technology replacing EV. This scenario has the potential to reduce the PM2.5 emissions load by 48% by 2030 with respect to the BAU scenario (Figure 14).

Scenario combination 2 - assumptions

- Proportions of buses to be added to the public transportation fleet: CNG - 60%; Electric: 30%; Diesel- 10%
- Registration of two-stroke autos will be banned, and existing two stroke autos will be replaced with CNG-based autos
- Vehicles with valid PUC certificate - at least 30%
- Trucks with DPF installed: 20%
- Brick kilns in Patna to be shifted to natural zigzag kiln
- Installed solar rooftop capacity – 200 MW
- At least 50% of the traditional chulhas are replaced by smokeless chulhas
- LPG penetration rate – 90%
- Electrification level – 90%
- No of mechanical road sweepers -10

Under this scenario the total emission load (PM2.5) will reduce by 48% by 2030. The contributors of this PM2.5 emission reduction are expected to come from sectors like DG sets (75%), transport sector (71%) followed by brick kilns (51%). Figure 12 presents the estimated emissions for scenario 2.

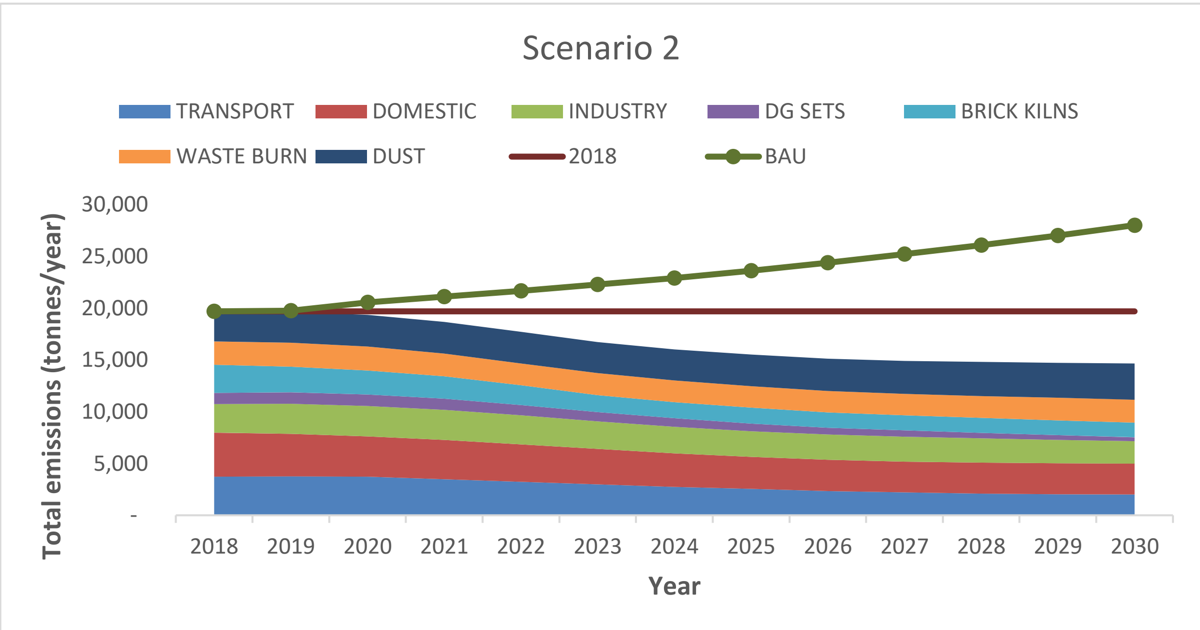


Figure 12: PM2.5 emissions scenario 2

Although scenario 2 is similar to scenario 1, it has slightly relaxed targets under each sector. As a result, emissions reduction from each sector is relatively less compared to the scenario. However, the transportation sector's emission reduction in both scenarios is nearly the same. This is mainly because, in both the scenarios, the number of vehicles (for public transportation) released remains almost the same; only the type of technology used varies.

Scenario combination 3: Low-pollution reduction combination

This scenario groups all the CMs that can be implemented immediately, without any major investment or technology change. Measures such as the introduction of buses - with the majority of new buses being diesel, the implementation of existing rules such as the banning of two-stroke auto-rickshaws, the shifting to zigzag kilns that use clean technology, etc., will help reduce pollution immediately. This scenario has the potential to reduce PM2.5 emissions load by 30% by 2030 with respect to the BAU scenario (Figure 14).

Scenario combination 3 - assumptions

- Proportions of buses to added to the public transportation fleet: CNG - 10%; Electric: 30%; Diesel- 60%
- Complete ban on registration of two-stroke auto-rickshaws
- Vehicles with valid PUC certificate - at least 10%
- All brick kilns must shift to natural zigzag kiln
- Installed solar rooftop capacity – 50 MW
- At least 30% of traditional chulhas must be replaced by smokeless chulhas
- LPG penetration rate – 90%
- Electrification level – 80%
- No of mechanical road sweepers – 5

Transport (69%) and brick kilns (31%) primarily contributed to this emission reduction, while other sectors contributed to less than 25% reduction. Figure 13 presents the estimated emissions for scenario 3.

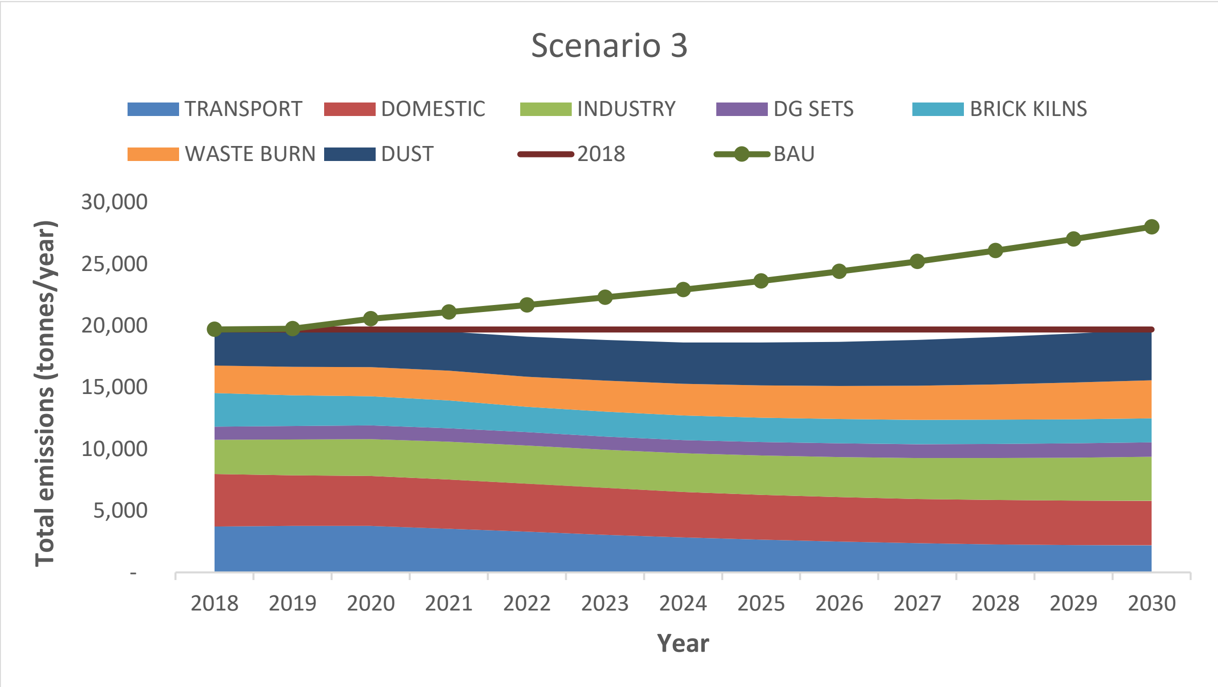


Figure 13: PM2.5 emissions scenario 3

A comparison: Scenario combination 1 vs scenario combination 2 vs scenario combination 3

Figure 14 presents the total PM2.5 emission load for high, low and medium-pollution reduction scenarios with respect to baseline (2018) and the BAU scenario. High-pollution reduction scenario would result in pollution reduction of 69%. The medium and low-pollution reduction scenarios would result in pollution reduction by 48% and 30% respectively.

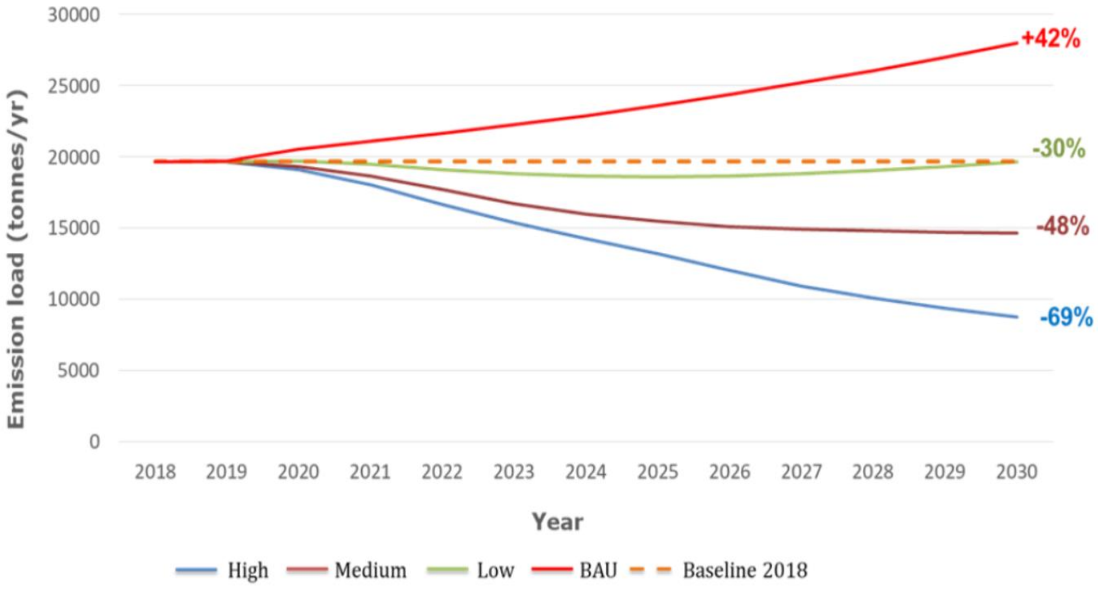


Figure 14: Pollution reduction potential scenarios

Table 19 presents the estimated cost incurred and the potential lives saved under each scenario. The transportation and solid waste management sectors require a larger budget allocation. It is because these sectors need additional machines, vehicles, and new infrastructure to improve the existing practices. However, for other sectors, the cost is either in the form of incentives and implementation cost or is borne by the private players. Hence, the government's cost burden is reduced.

The cost incurred (3813cr.) and the lives saved (15286) for scenario 1 is high in comparison to the other two scenarios as described in Table 19.

The cost incurred by the transportation sector is almost around INR 1,000 crore in all the three scenarios. This is because the current public infrastructure is not efficient and Patna would need to earmark more funds to improve its infrastructure.

The PMC has plans to install W2E of capacity 1,000 TPD, which would improve the existing infrastructure significantly. The investments for the three different scenarios vary considerably.

Table 19 presents the costs and benefits of implementing the suggested scenario combinations for the various line departments. The costs and benefits have been estimated over a period of 11 years (2019 – 2030).

Table 19: Economic analysis (scenario 1 vs scenario 2 vs scenario 3)

Sectors	Private Owners	Departments	Cost Incurred (INR Cr.)		
			Scenario Combo 1	Scenario Combo 2	Scenario Combo 3
Transport		Traffic Police	0.57	0.57	0.57
	Private		36	33	30
		D.O.T	225	154	94
		BSRTC	900	1039	1000
Industry	Metal Fabrication		20	20	20
	Brick kilns		66	66	66
SWM		PMC	428	214	60
Domestic		SBPDCL	15	13	13
		FCS	45	27	17
DG SETS	Private		1406	1163	960
		BREDA	511	422	350
Road Dust		UD	70	24	10.5
		BSPCB	0.4	0.4	0.4
		PMC	90	44	26.5
Lives Saved (No.)[24]			15286	11345	7014
Total			3813	3220	2648

[24] Lives saved is estimated till 2030, however the benefits will be accrued beyond 2030.

6. Recommendations, Implementation Strategy, and Target Setting

Air-pollution management needs a collaborative approach from all concerned departments across Patna. Various measures suggested in the study and existing policies must be implemented for effective reduction of the city's pollution levels. The formation of a project management and audit unit is also vital in ensuring the time-bound implementation of policies and control measures (CMs). Appropriate indicators to measure the effective implementation of the CMs and progress of the implementation strategy need to be devised.

Based on the techno-economic assessment of the shortlisted CMs for the city of Patna, the following policies are recommended:

1. Patna should introduce green public transport (EVs/CNG): As of now, diesel auto rickshaws and minibuses are the only public transportation modes available in Patna. These modes of travel are highly unreliable[25] as they are run by private players. Even though the Patna government plans to establish a metro rail service, the city still needs a functional bus transportation system that incorporates CNG/EV buses. Old two-stroke auto rickshaws should be phased out and replaced with electric auto rickshaws. Such measures will help reduce tailpipe exhaust to a major extent.

2. Vehicle fitness certificates and PUC certificates should be made mandatory for fuel refilling: Tailpipe emission from poorly maintained vehicles is much higher than that from vehicles that are well-maintained and serviced on a regular basis. By introducing policies like "No PUC, No Fuel", vehicle owners will be more inclined to get their vehicle serviced.

3. Trucks (diesel) and buses (diesel) plying in Patna must be retrofitted with diesel particulate filters (DPF). This will cut down tailpipe emission loads by around 60% to 80%.

4. Mandate citywide cap on coal and diesel (industrial) use, and revise/reduce the cap every four years: Industrial pollution is one of the major contributors to air pollution in Patna. The city must set a cap on coal and diesel usage for industrial use. This will encourage industry owners to adopt clean fuels (CNG/electric). A review/reduction of the cap every five years will help reduce industrial pollution to a greater extent.

5. Open dumping of solid waste should be penalised and the municipality should not collect waste if it has not been segregated at the household level. PMC should ensure 100% door–to-door collection of municipal solid waste. PMC should also develop a mechanism to penalise people who dump their solid waste in open sites. These steps will ensure that waste is collected and treated properly. PMC also needs to develop measures and campaigns to encourage segregation of waste.

6. Financial incentives (as reduced electricity unit cost) should be provided for houses with grid-connected rooftop photovoltaic systems (RTPV): Patna's residents should be encouraged and rewarded for setting up grid-connected RTPV. Unit price of electricity

[25] Schedule of private run buses are not regulated.

consumption can be reduced, based on the solar power generation capacity and household consumption patterns.

7. LPG distributors should be encouraged to provide 100% door-to-door LPG distribution service. A robust supply infrastructure (or more LPG distributors) must be set up to ensure door-to-door supply. Increasing the number of LPG distributing centres and workforce will ensure proper door-to-door supply and reduce the use of solid fuel.

8. Patna's city civic body should ensure end-to-end paving of the city's roads based on the examination of local ecological conditions. Dust on roads must also be removed to ensure road-dust suppression. The abovementioned measures and a green belt along the road will prevent, to a large extent, dust collection on roads.

9. Lack of monitoring acts as a hindrance towards enforcing regulations. The Patna administration should also focus on installing advanced monitors that track source contributions effectively. Such monitors can assist policymakers with the necessary data to take source-specific actions.

10. A health study should be commissioned to fill the gaps on details about air-pollution–related illness. This would help the health sector strengthen its public communications on air pollution and health.

6.1 Roadmap, Time Frame and Essential Levers of the Plan

This section describes the recommendations, targets, and strategies that should be adopted to ensure effective implementation of the suggested CMs. This section also discusses the various existing schemes in accordance with the suggested CMs. These schemes could be a potential source to financially support the related CMs.

Sector: Transportation

Transportation is one of the major contributors to pollution, contributing 20%–32% to the total pollution concentration in Patna. Reducing transportation sector emissions can be a complex process. It is recommended that new electric/CNG buses be introduced to the current public-transportation fleet. Table 20 presents the specific targets and strategies that need to be followed to introduce electric/CNG buses.

Table 20: Strategic roadmap: transportation sector

Sl No	Strategy	Similar Funding Schemes	Targets			Implementing Agency
			2022 (short term)	2025 (medium term)	2030 (long term)	
CM 1	Addition of new buses to the public transport system – electric buses, hybrid diesel buses, CNG buses					
1.1	Building a Depot (No.)	Smart Cities Mission, JNNRUM	2	3	3	BSRTC, Transport Department
1.2	Building EV Charging Station (No.)		20	50	150	
1.3	Building CNG Stations (No.)		3	5	7	
1.4	Introduction of CNG and EV buses (No.)		200	300	500	

The other CMs suggested for the transportation sector focusses on private vehicles. Table 21 details the strategies to be followed for implementing CMs focussing on private vehicles.

Table 21: Strategic roadmap: transportation sector

Sl No	Strategy	Similar Funding Schemes	Targets			Implementing Agency
			2022 (short term)	2025 (medium term)	2030 (long term)	
CM 2	Complete ban on 2-stroke auto rickshaws and replacing them with CNG-based vehicles or EV					
2.1	Ban on 2-stroke auto rickshaws	-	Complete Ban			Transport Department
2.2	Replacing existing 2-stroke auto rickshaws with CNG/EV-based autos	-	30%	70%	100%	
2.3	Setting up scrapping centres for old auto rickshaws (incentives need to be processed at the scrapping centre itself) (No.)	-	10	15	0	
2.4	Building necessary infrastructure	-	Build required scrapping centres			
CM 3	PUC check (every 6 months) and better PUC check infrastructure and management					
3.1	Setting up PUC centres (No.)	-	50			Private owners
3.2	Spreading awareness	-	Awareness programmes			
CM 4	Incentivising the use of cleaner fuels (CNG/LPG) and EVs for private use					
4.1	Setting up of incentives for different types of vehicles	FAME scheme	Incentive mechanism already in place			Transport Department
CM 5	Installation of DPF in diesel vehicles					
5.1	Installation share of DPFs (in trucks)	-	15%–30%	+0%	+0%	

Awareness programmes with a wide public outreach need to be created for promoting acceptance of new modes of transportation.

Sector: Industry

Unlike the transportation sector, emission reduction from the industry sector is directly associated with the kind of technology this sector uses. Policies that enable industries to adopt advanced technologies and fuel need to be enforced. Audit systems need to be set up to monitor the emission from industries. Table 22 lists the strategies that should be followed to ensure implementation of the CMs mentioned above.

Table 22: Strategic road map: industries

Sl No	Strategy	Targets			Implementing Agency
		2022 (short term)	2025 (medium term)	2030 (long term)	
CM 1	**Adopting new technologies for brick kilns**				
1.1	Conversion of FCKs to zigzag technology	100%			BSPCB
CM 2	**Introduction of technologies that use cleaner fuel**				
2.1	Setting up of infrastructure to monitor technology upgradation at each industrial unit	Immediate implementation of suggested CMs			Dept of Industries (Bihar)

Sector: Solid Waste Management

Open waste burning contributes to around 10% of the total emissions in Patna. Studies suggest that an efficient solid-waste management system can reduce the amount of waste burnt. Table 23 presents the targets and strategies that should be followed to achieve maximum pollution reduction from the solid-waste sector.

Table 23: Strategic road map: solid waste management

Sl No	Strategy	Targets			Implementing Agency
		2022 (short term)	2025 (medium term)	2030 (long term)	
CM1	**Introduction of composting plants and dry waste collection centre**				
1.1	Setting up laws / incentivising mechanisms to improve segregation at household level	Awareness programmes and policy initiatives to increase the segregation level			PMC
1.2	Level of segregation	50%	65%	70%	
1.3	Setting up composting plants (TPD)	200	400	700	
1.4	Setting up dry waste collection centres (TPD)	10	20	30	

The government should establish stringent regulations to control waste burning during the winter. It is observed that roadside dwellers burn leaves and dry waste in order to dispose of them and generate heat to shield themselves from the cold in winter. Therefore, alternative solutions for roadside dwellers need to be provided to discourage them from burning waste

Sector: Domestic

Wood and biomass (solid fuel) usage for cooking is a major contributor to domestic sector emissions, which can be reduced either by increasing LPG connections or by introducing smokeless chulhas / induction stoves. Table 24 details the various targets and strategies that can help ensure the highest levels of pollution reduction from the domestic sector.

Table 24: Strategic roadmap: domestic sector

Sl No	Strategy	Similar Funding Schemes	Targets 2022 (short term)	2025 (medium term)	2030 (long term)	Implementing Agency
CM 1	**Introduction of improved chulhas (smokeless chulhas)**					
1.1	Setting up incentivising mechanism	Unnatt Chulha Abhiyan (UCA)	-			Food And Civil Supplies Department, PMC
1.2	Awareness		-			
1.3	Replacement of traditional chulhas		50%	+15%	+15%	
CM 2	**Increasing LPG connections in the low-income strata**					
2.1	Setting up new LPG refuelling centres (No.)	PAHAL, Ujjwala Yojana	20	+5	+5	Food And Civil Supplies Department
2.2	Increase the LPG penetration rate		90%	+2%	+2%	
CM 3	**Replacing kerosene with an alternative fuel**					
3.1	Increase electricity connectivity	Saubhagya	90%	+6%	+4%	BREDA PMC
CM 4	**Solar Rooftops**					
4.1	Increasing the solar rooftop capacity	Solar Energy Subsidy Scheme	200 MW	+50 MW	+30 MW	BSPCB, PMC

Sector: Road Dust

Dust contributes around 30% of the total PM10 emissions in Patna. Construction activities, resuspension of dust, unpaved roads, transportation of uncovered material, and uncoordinated roadworks are some of the activities that result in the increase of suspended particles in the atmosphere. Because the sources of road dust are linked to activities of various departments, it is important to have a coordinated approach among various departments to reduce the emission from suspended particles.

Mechanical sweepers need to be adopted and end-to-end road pavements should be constructed to control the resuspension of dust. The strategy that should be followed, under this sector, is described in Table 25.

Table 25: Strategic roadmap: dust

Sl No	Strategy	Targets 2022 (short term)	2025 (medium term)	2030 (long term)	Implementing Agency
CM 1	**To take appropriate action to remove road dust / silt regularly by using either mechanical sweepers or road paving**				
1.1	Road paving (by laying roads / green cover) – major roads	80%	90%	100%	PMC
1.2	Addition of new mechanical sweepers of capacity 10–16 tonnes (No.)	10	12	14	
1.3	Addition of new mechanical sweepers of capacity 5–8 tonnes (No.)	5	6	7	

Communication and Implementation Strategy

A task force committee with representation from various line departments should be formed, to monitor and implement the CMs. The air-quality monitoring committee should keep a check on the functioning of the task force committee. The task force committee should be headed by the Chief Secretary of the state. The main objective of the committee will be "to reduce the emissions levels in Patna region to the target set by NCAP".

The committee should meet every quarter to discuss the (a) implementation status of the CMs, (b) new policy changes, and (c) required future steps. The respective representative from line departments should coordinate the implementation strategies within their departments within the stipulated time.

Alongside other stakeholders and funders, various available schemes at the central level need to be considered for creating the corpus needed to implement the action plan.

6.2 Emergency response actions

Despite our best efforts, there may be episodes where pollution levels may increase drastically due to anthropogenic and natural phenomena.

To control this unexpected increase in pollution levels, CMs are suggested in Table 26. These measures, if implemented on an emergency basis, could safeguard our environment.

Table 26: Emergency response action plan

Severe Pollution (ambient PM2.5 concentration values of 250 µg/m^3 and above)	**Agency Responsible / Implementation Agency**
Temporarily stop all construction activities	Bihar State Pollution Control Board (BSPCB)
Temporarily shut down brick kilns and hot mix plants	BSPCB
Temporarily shut down schools and colleges	
Very Poor Pollution (ambient PM2.5 concentration values of 121–250 µg/m^3)	**Agency Responsible / Implementation Agency**
Increase frequency of mechanised cleaning of roads and sprinkling of water on unpaved sections of roads	Patna Municipal Corporation (PMC)
Increase public transport frequency and restrict operation of diesel auto rickshaws	Department of Transport, Govt of Bihar
Increase parking fee to 3–4 times the current value	PMC
Strict vigilance and no tolerance for visible emissions—stop operations of visibly polluting vehicles by imposing heavy fines	Traffic police
Stringently enforce all pollution-control regulations in brick kilns and industries	BSPCB
Moderate to poor (ambient PM2.5 concentration values of 61–120 µg/m^3)	**Agency Responsible / Implementation Agency**
Stop burning of solid waste	PMC and BSPCB
Periodic mechanised sweeping and water sprinkling on unpaved roads	PMC

6.3 Way Forward

Development plays an important role in shaping a city's economy. Although Patna has developed at a rapid rate, this development has come at the cost of its air quality. Unfortunately, the resultant increase in air pollution has had tremendous health impacts and it is not sustainable for the future. Patna's rising air-pollution levels require immediate adoption and implementation of relevant mitigation measures. Various environmental consequences and the social well-being of people have to be considered while implementing the mitigation measures. Apart from this, future infrastructural development and growth for the city should be planned only after evaluating the impacts and consequences of the potential environmental damage.

Our study indicates that the mortality benefits [value of a human life—around INR 2.8 crore (Madheswaran, 2007)] of implementing CMs that focus on improving environmental quality far outweigh the costs. Such measures could end up saving hundreds of lives and prevent insurmountable environmental damage.

The effective implementation of pollution-mitigation policies hinges on various considerations, such as various government departments coming to a consensus and adopting a solution-driven approach.

Curbing pollution requires a combined effort from government bodies, local community groups, and citizens. Policies such as increasing waste-segregation levels, increasing the mode share of public transportation, and switching to cleaner fuels will be effective only if the community actively participates in adoption and implementation of these measures. Moreover, a project management and audit unit is to be set up to ensure that the abovementioned strategies are effectively implemented as per the provided roadmap and time frame.

Patna administration has already initiated actions on creating green buffer zones in various parts of the city. Steps such as end-to-end paving of roads and putting mechanical sweepers on roads have been initiated to reduce the resuspension of dust. Construction of a metro rail system is planned, which will help increase the mode share of public transport. Also, the government has initiated steps to build a waste-to-energy plant. Proactive action from the state government in implementing the suggested CMs will help improve the quality of air in the city.

To make any plan effective on the ground, it is important to make citizens and communities part of the plan. By creating awareness and advocacy plans, the understanding and knowledge of the subject will increase among the masses, creating an ecosystem that will help implement the strategies in a time-bound manner. Additionally, it is of the utmost importance to build capacity of the line departments and make citizens the champions of the cause—to ensure a good quality of life for the future.

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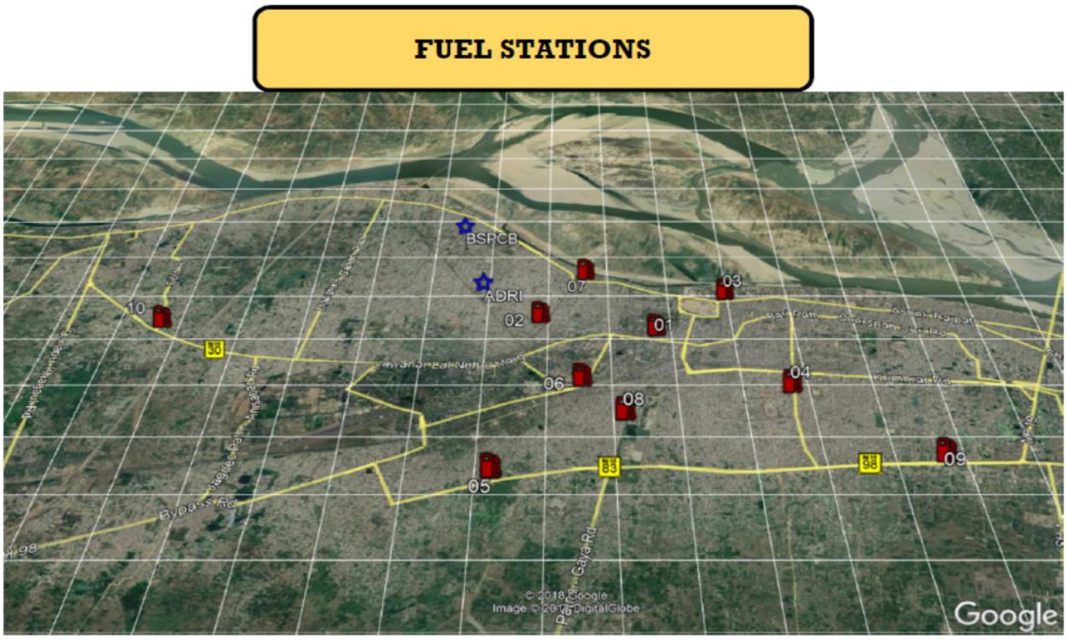
Appendix

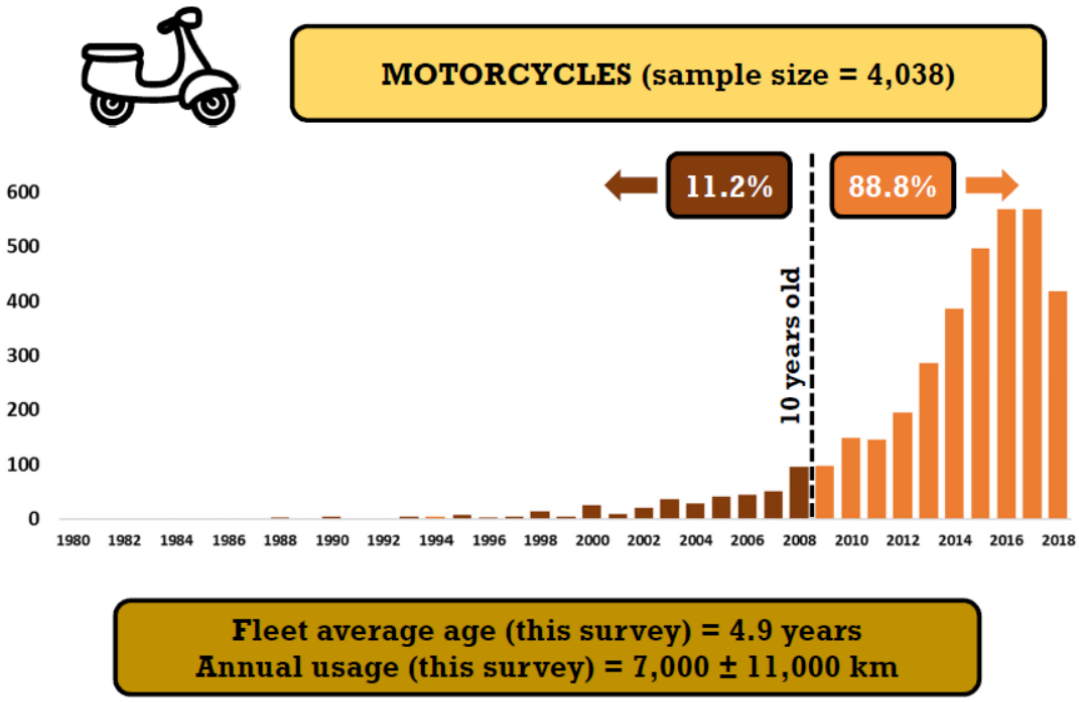
Annexure A:

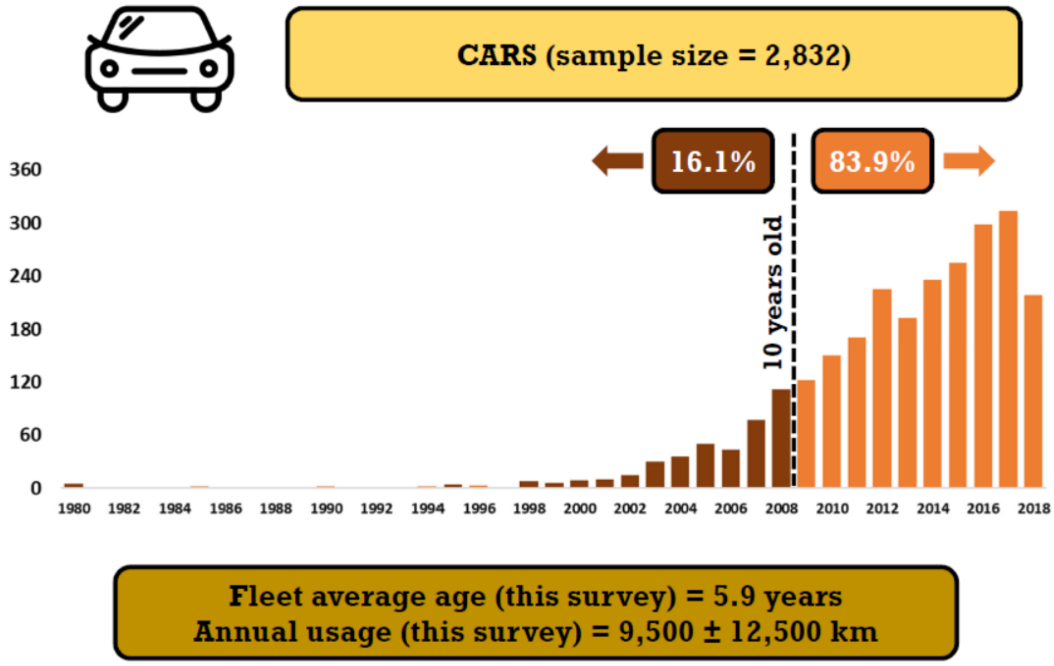
FUEL STATION SURVEYS (FuSS): PATNA

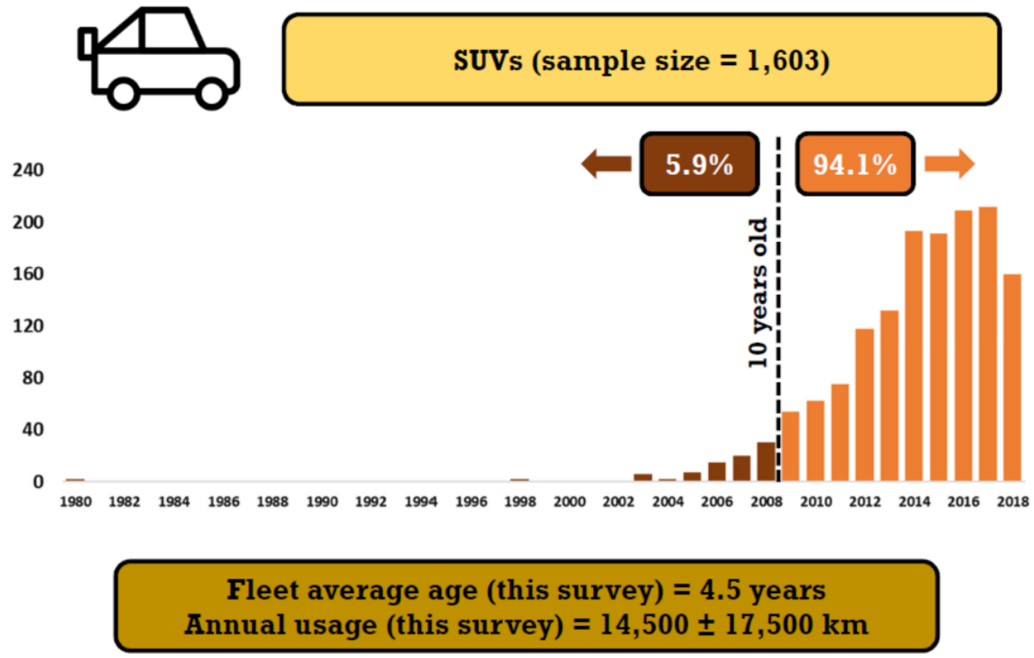
Survey location

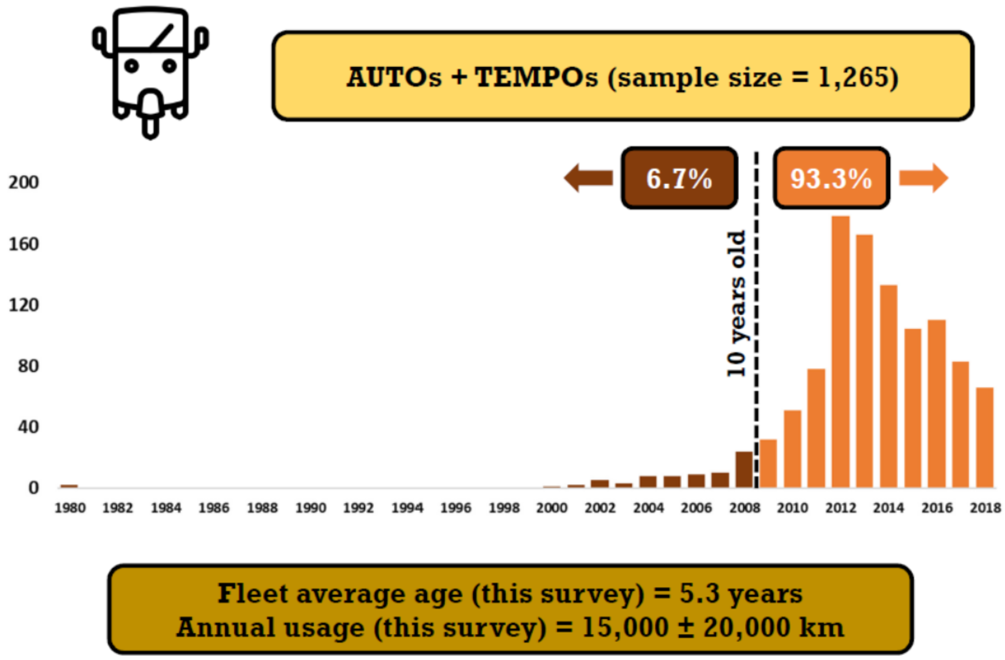


Key Results




CARS (sample size = 2,832)
16.1%
83.9%
10 years old
360
300
240
180
120
60
0
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
Fleet average age (this survey) = 5.9 years
Annual usage (this survey) = 9,500 ± 12,500 km


SUVs (sample size = 1,603)
5.9%
94.1%
10 years old
240
200
160
120
80
40
0
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
Fleet average age (this survey) = 4.5 years
Annual usage (this survey) = 14,500 ± 17,500 km



Industry classification

New Code	Description
1	Food processing
2	Textile works
3	Leather works
4	Wood processing
5	Paper and ink
6	Coke products
7	Refineries
8	Fertilisers & chemicals
9	Pharmaceuticals
10	Rubber, plastic and glass
11	Non-Ferrous processing
12	Iron & Steel processing
13	Other Metal processing
14	Manufacturing & repairs
15	Power generation
16	Waste & water treatment

Annexure B:

Clean Air Action Plan submitted to NGT

Sl. No	Sector	Action Points	Technology/Infrastructure requirement (TR/IR)/ Methods (M)/ Outcome (OC)	Implementation period (short: 6 months, med: <2 years, long: >2 years)	Implementation Agency	Time Target for Implementation
1	Transportation	Addition of new buses to public transport system – electric buses, hybrid diesel buses, CNG buses	Introduction of electric buses with proper support infrastructure (charging stations) OC—Public transportation in play will reduce the number of private vehicles plying in the city. This will reduce the total emission load from tail-pipe emissions	Long	Bihar State Road Transport Corporation (BSRTC), Private Bus Owners Transport Department Industry Department	December-2024
			TR—Introduction of CNG buses OC—Public transportation in play will reduce the number of private vehicles plying in the city. This will reduce the total emission load from tail-pipe emissions	Long		
		Check on more than 15-year-old diesel commercial vehicles		Short		December 2018

		Restriction on plying and phasing out of 15-year-old commercial diesel driven vehicles[26]*	OC—Reduction In black carbon emissions M—Policy reforms	Long	Transport Dept, Govt of Bihar	December 2022
		Ban on registration of diesel-driven auto rickshaws and tempo.	OC—Reduction In black carbon emissions M—Policy reforms	Long		December 2022
		Complete ban on 2-stroke autos and replacing them with CNG based vehicle or EV[27]	TR—E-rickshaws OC—Reduction of emission load from autos	Long		December-2022
			TR—CNG based autos OC—Reduction of emission load from autos			
		PUC check (every 6 months) and Better PUC check infrastructure and management (Hon'ble Supreme court of India in W.P.(C) no 13029/1985 said that pollution testing centres should be set up within premises of all petrol pumps)	OC—With better PUC infrastructure and strict pollution norms emission from private and public vehicles will decrease	Medium		December-2020
		Incentivising the use of cleaner fuels - electric	TR—Proper infrastructure to increase the adoption rate of cleaner fuels	Long		December-2022

[26] Subject to clearance from the High court
[27] Ibid

		vehicle and (CNG/LPG) for private vehicles	OC—Reduction of emission load from private vehicles which switched to Electric/CNG/LPG based vehicle from Petrol/Diesel based vehicles			
		Installation of Diesel Particulate Filter (DPF) in all the diesel vehicles[28]	M—Installing DPF filters to existing diesel vehicles OC—Reduction of emission load from diesel vehicles	Long	Transport Dept. Govt. of Bihar	December-2022
		Good traffic management including re-direction of traffic movement to avoid congestion.	OC- Reduction in emission due to non-congestion TR- Policy intervention	Medium	Traffic police	December 2020
		Demarcated lanes for E rickshaw's plying for public commuting	OC- Reduction in emission due to non-congestion TR- Policy Intervention	Short	Traffic police	Immediate
		Development of Multi level parking	OC- Traffic congestion & road encroachment reduction, emission reduction M- Land space demarcation around public transportation hotspots	Long	PMC	December 2023
		Monitoring of Vehicle fitness	OC- Reduction in emission M- Audit systems	Short-Medium	Transport & Traffic dept.	December 2019
		Checking on fuel adulteration	OC- Reduction in emission M- Audit systems	Short	District Administration & Oil companies	April 2019

[28] Policy decision – MV Act doesn't have provision for installing DPF.

		Periodic calibration test of vehicular emission monitoring instrument.	OC- Reduction in emission M- Audit systems	Short	BSPCB & Transport	April 2019
		Complete ban of carriage transport, heavy vehicles, during peak hours (8:00 - 11:00 am & 5:00 - 8 pm). (Arranging alternate routes to all carriage transports between)	OC—Reduction in peak hour traffic will facilitate faster vehicle movement and reduce tail- pipe emission	Short	Traffic police	April 2019
		Launch drive against any vehicle with visible smoke coming out of it and ensure strict compliances		Short	Traffic police	April 2019
2	**Industry**	Adapting new technologies for Brick kilns	Adapting Cleaner technology	Medium	Bihar State Pollution Control Board (BSPCB) Dept. of Industries (Bihar)	December 2019
		Random auditing for air pollution measures Online reporting systems in the industries	Setting up of policies and institutions that conduct random auditing for air pollution CMs Prevents opening up of new industries that fall under Red Category and Orange Category.	Medium		December 2019
		Introduction and shifting towards cleaner fuels in induction and casting industries	M- Regulatory requirements	Medium		December 2019

		Shifting of Polluting Industries	M- Regulatory requirements	Long		December 2021
		Ban on Polluting Industries	M- Regulatory requirements	Short		June 2019
3	**Biomass & Garbage Burning**	Check Stubble burning	OC- Reduction in emission from stubble burnings M- Regulatory as well as awareness sensitisation	Medium	Dept. Of Agriculture	December 2020
		Identify garbage burning locations and strict enforcement of NGT (2016) rules regarding prohibition of garbage burning.	OC—Reduction in emission load from garbage burning	Short	PMC	Immediate
		Promoting waste composting plants at city level				
		Recycling plants for dry waste.				
		Establishing waste to energy plants (WTE)				
4	**Domestic**	Increasing the LPG connections in low income strata. To mandate LPG/Bio gas in commercial eateries.	M—Increase in LPG connection OC—Reduction in emission load	Medium	Food And Civil Supplies Department	December 2020

		Ensuring uninterrupted electric supply within the city.	OC—Reduction in total emission load from kerosene lamps (as power cut backup will not be required)	Medium	South Bihar Power Distribution Company Limited	December 2019
		Ensure easy availability of affordable cleaner cooking fuels (LPG in urban areas & biogas in rural areas)	M—Improvement in LPG/Bio gas infrastructure	Medium	Food & Civil supplies Dept.	December 2020
5	**Construction & Demolition**	Construction materials should be transported in covered vehicles	OC—Reduction in emission load from dust	Short	Traffic Police	Immediate
		To mandate facility of tar road inside the construction site for movement of vehicles carrying construction material	OC—Reduction in emission load from dust	Medium	PMC	December 2019
		Promotion of the use of prefabricated blocks for building construction	OC—Reduction in emission load from dust	Long		December 2020
		Strict enforcement of CPCB guidelines for construction (use of green screens, side covering of digging sites, etc.)	OC—Reduction in emission load from dust	Short	BSPCB	Immediate
		Demolition & construction Sites should be covered from all sides	OC- Reduction in Road dust	Short	PMC	Immediate

		Restriction on storage of construction materials along the road.	OC- Reduction in road dust	Short	PMC	Immediate
6	**Road Dust**	To take appropriate action to remove road dust/silt regularly by using mechanical sweepers	Mechanical sweeping Identifying the road stretch with high silt content Procuring the mechanical sweepers	Medium	PMC & Urban Development Dept.	December 2019
		End to end road pavement	OC—Reduction in resuspension of dust M—Improvement in infrastructure	Medium	PMC & Urban Development Dept.	
		Creating green buffer along the roads.				
		Urban Greening including vertical garden				
7	**Strengthening of AAQ monitoring**	Installation of four CAAQMS at Patna. Two CAAQM stations under CSR funds of CPSU through CPCB at Eco-Park. Two CAAQM stations under State Govt. financial assistance.	OC- Proper evidence on sectorial contributions with primary baseline surveys to update the emissions inventory. OC- Efficient Monitoring	Short	BSPCB	June 2019

		Source apportionment study (Dispersion +Receptor) Modelling	OC- identification of pollutants	Medium	BSPCB	December 2019
8	**Public Awareness**	Issue of advisory to public for prevention and control of air pollution	OC- Awareness and better implementation of policy	Short	BSPCB & Dept. of Environment, forest & Climate Change	Immediate
		Launch public awareness programme campaign to control air pollution	OC—Through awareness, public participation for air pollution reduction will increase	Short	BSPCB PMC & Dept. of Environment, forest & Climate Change	Immediate
9	**Others**	Compliance of guidelines on DG sets and action against violation	OC- Reduction in black carbon TR- DPF (Diesel Particulate Filters installation)	Short	BSPCB & PMC	Immediate
		Help line to oversee non compliances on aforesaid issues.	OC- Awareness and better implementation of policy	Short	BSPCB & PMC	Immediate
		Hospital incinerators for bio-medical incineration	OC—Reduction in bio-hazardous materials being dumped in to the landfill	Short	BSPCB GMC Dept. of Health (Govt. of Bihar)	Immediate

		City wise cap on coal use	OC—Reduction in coal consumption will reduce the emission load	Medium	BSPCB Food And Civil Supplies Department	December 2019
		Polluter pay principle	OC—Will act as a deterrent against polluters	Medium	BSPCB	December 2019
		Transportation of municipal solid wastes, construction materials and debris in covered system.	OC- Minimization in road dust M- Monitoring of Implementation	Short	PMC	Immediate
		Immediate lifting of solid wastes generated from de-silting and cleaning of municipal drains for its disposal.	OC- Minimisation of road dust M- Monitoring of Implementation	Short	PMC	April 2019

Annexure C:

Total emissions for the Greater Patna Region for the base year 2018 (Tonnes)

	PM2.5	PM10	BC	OC	NOx	CO	VOC	SO_2	CO_2
Transport	3,721	3,917	1,456	1,206	4,434	49,005	11,046	91	13,21,573
Cooking	2,748	2,893	258	1,165	270	29,820	3,379	631	4,80,504
Lighting	296	312	269	1	0	39	3	29	9,008
Heating	1,199	1,262	157	656	131	12,531	2,042	83	45,231
Open Waste Burning	2,241	2,359	167	1,351	54	10,769	2,169	58	14,359
Construction Dust	1,698	9,621	-	-	-	-	-	-	-
DG sets	1,070	1,126	628	200	10,025	2,663	256	101	4,55,425
Ind. Light	2,762	2,790	978	542	2,234	4,202	386	754	2,50,921
Aviation	5.7	6.7	1.5	2.7	607.8	752.4	248.4	41.8	1,34,331
Brick Kilns	2,729	2,756	703	1,007	1,555	36,236	3,309	1,694	3,43,723
Ind. Heavy	-	-	-	-	-	-	-	-	-
Road Dust	1,212	8,078	-	-	-	-	-	-	-
Total	19,681	35,121	4,617	6,130	19,311	1,46,018	22,839	3,482	30,55,073

Total emissions for the Greater Patna Region for 2030 (Tonnes)

	PM2.5	PM10	BC	OC	NOx	CO	VOC	SO_2	CO_2
Transport	7,004	7,373	2,383	2,350	6,852	95,877	24,315	25	24,85,729
Cooking	2,893	3,045	279	1,228	285	31,955	3,571	707	5,68,628
Lighting	310	326	280	1	0	41	3	30	9,345
Heating	1,376	1,448	180	753	150	14,352	2,333	95	51,072
Open Waste Burning	3,410	3,590	254	2,056	82	16,389	3,301	88	21,852
Construction Dust	2,572	14,574	-	-	-	-	-	-	-
DG sets	1,518	1,598	892	284	14,233	3,781	363	143	6,46,590
Ind. light	4,132	4,174	1,464	810	3,342	6,286	578	1,129	3,75,417
Aviation	10.6	12.5	2.6	5.2	1,185.9	1,454.1	474.6	81.8	2,62,732
Brick Kilns	2,842	2,870	732	1,048	1,619	37,736	3,445	1,765	3,58,105
Ind. Heavy	-	-	-	-	-	-	-	-	-
Road Dust	1931	12,872	-	-	-	-	-	-	-
Total	27,999	51,883	6,465	8,536	27,750	2,07,872	38,385	4,064	47,79,470

Sector-wise formulas, data considered, and assumptions

Key macro-economic variables

Variable	Value
Inflation Rate (CPI)	4.30%
Average Person per household	5.984621
Population (2018) (mn.)	2.73
Population (2030) (mn.)	4.44

Annexure D:

Target mode share public transportation

Mode Share	Existing	Target
Bus	21%	40%

Source: City mobility plan Patna

Vehicle Characteristics in Patna (2018)

Vehicle type	% share
Truck	3%
Bus	1%
Car	13%
Taxi	1%
Jeep	3%
Three-wheelers	5%
Two-wheelers	70%
Tractor	2%
Trailer	1%

Source: Data from Transportation Department

Distance travelled by a bus

Distance travelled by a bus	
Average travel distance round trip (km)	11
Average trips per day	14
Average distance travelled by bus in a day (km)	154

Source: City mobility plan Patna

Projected buses required

Year	Projected Population (mn.)	Existing Buses	No. of buses required to achieve the target	
2018	2.73	174	-	
2019	2.84		344	
2020	2.96		359	
2021	3.08		373	
2022	3.20		388	
2023	3.34		405	
2024	3.48		422	
2025	3.63		440	
2026	3.78		458	
2027	3.93		476	
2028	4.09		496	
2029	4.27		518	
2030	4.44		538	±50

Charging station considered

Approx. Cost of Charging Station (EV) / Refuelling station Considered (INR Lakh)	
Level 1 (EV)	0.3
Level 2 (EV)	3.0
DC fast (EV)	15
CNG Refuelling station (CNG)	50

Incentives provided to autos

Autos	CNG	EV
Incentives	30000	50000

Incentives provided to buy CNG/LPG/Electric vehicles (FAME scheme)

Type	Incentive (INR)
Electric Vehicles	As per the FAME scheme
CNG retrofitting	30,000

Sector: Industry

Brick kilns in Patna

Brick Kilns in Patna	
Total	218
Operational	122
Demolished	12
Illegal Brick Kilns	17
Closed	67

Casting technologies considered for metal fabrication industries.

Furnace technology	Fuel used	Cost (INR)
Gas-fired cupola	Gas	Total operating Cost/Metric tonne of molten metal : 30.7K Capital Cost: 46L
Induction	Electricity	Total operating Cost/Metric tonne of molten metal : 34.8K Capital Cost: 30L
Rotary	Light Diesel Oil (L.D.O)	Total operating Cost/Metric tonne of molten metal : 33.6K Capital Cost: 10L

Source: Sodhganga, Economic Analysis of Melting Techniques

Sector: Solid waste management

Waste composition

Compostable	Recyclable	Non-compostable
51.96%	12.57%	35.47%

Projected Solid waste generation

Year	Projected population (mn)	Solid waste projection (TPD)
2018	2.73	800
2019	2.84	832
2020	2.96	867
2021	3.08	903
2022	3.2	938
2023	3.34	979
2024	3.48	1020
2025	3.63	1064
2026	3.78	1108
2027	3.93	1152
2028	4.09	1199
2029	4.27	1251
2030	4.44	1301

Assumptions considered—waste segregation level

Year	Segregation level	Segregated compostable waste (TPD)	Segregated recyclable waste (TPD)	Rest (TPD)
2018	0	0	0	800
2019	0%	0	0	832
2020	35%	158	38	671
2021	45%	211	51	640
2022	50%	244	59	635
2023	55%	280	68	631
2024	60%	318	77	625
2025	65%	359	87	618
2026	65%	374	91	643
2027	70%	419	101	631
2028	70%	436	105	657
2029	70%	455	110	686
2030	70%	473	114	713

Assumed plant capacity

Capacity in TPD			
Year	**Composting plant capacity**	**Dry waste collection centre**	**W2E plant**
2018	0	0	0
2019	200	10	0
2020	200	10	0
2021	200	10	1000
2022	200	10	1000
2023	400	20	1000
2024	400	20	1000
2025	400	20	1000
2026	400	20	1000
2027	700	30	1000
2028	700	30	1000
2029	700	30	1000
2030	700	30	1000

Sector: Domestic

Incentives provided

CMs	Incentives Provided (INR)
New LPG connection	1600
Smokeless Chulha	750 - 2500
Purchasing a cylinder	300

Sector: Road dust

$$\text{Total no. of mechanical sweepers required} = \frac{Total\ length\ of\ the\ roads\ considered}{Avg.\ speed\ of\ the\ mechanical\ sweeper * avg.\ running\ time} \quad \textbf{(5.1)}$$

Annexure E: Data required from line departments

Sl. no	Sector	Concerned Departments	Data Required
1	Transportation	Transport Department, Govt. of Bihar	1) Number of vehicles (buses/ Autos (2 strokes, E-Rickshaw and 4 strokes)/ two wheelers/ Cars/taxis/Heavy vehicles) plying in Patna 2) Vehicles registration details for the past 15 years (Yearly data for all vehicles) 3) Number of new buses proposed for public transportation in the city (if any) and type of buses 4) Total number of existing and proposed charging infrastructure for EVs.
		Bihar State Pollution Control Board (BSPCB)	1) Number of Pollution Under Control (PUC) centres (Operational and Non-operational centres) 2) Year of calibration (last) for the PUC units
		Bihar State Food & Civil Supplies Corporation Ltd.	1) Total number of existing and proposed charging/ fuelling infrastructure for CNG/LPG 2) Number of parking facilities (Public/Private) that are available in the city and their vehicle parking capacity 3) Number of petrol stations carrying out fuel adulteration
		Patna Municipal Corporation (PMC)	1) Number of petrol pumps and the amount of fuel sold and types of fuel sold 2) Total road length in the city, types of road and road width
2	Industries	BSPCB, Bihar Industrial Area Development Authority (BIADA)	1) Total no. of Industries in Patna (Segregated based on Industry Type/ Fuel Used/ Location-inside city/ outside city, emission details if monitored by BSPCB) 2) Total number of brick kilns in Patna (Segregated based on technology used/ fuel they use/ location-inside city/outside city) 3) List of Metal fabrication industries that use clean technologies 4) Number of industries that meet the standards set by CPCB 5) List of industry with waste disposal facilities, their waste treatment technology and their treatment capacities 6) An estimate on the total number of DG sets (industrial) that are used in Patna 7) Average running hours
3	Diesel generator sets		1) Estimate of number of DG sets used for commercial and domestic purpose 2) Average running duration (hrs/day) 3) Capacity of the DG sets (KVA)
4	Health	Health Department, Govt. of Bihar	1) Total number of respiratory health diseases registered in various hospitals (details for at least one year)

			2) Average cost that is spent on one person on respiratory health diseases 3) Average number of days a person stays in a hospital for cases related to respiratory health diseases
		BSPCB	1) Total number of hospitals with incineration facility (Total/Operational) 2) Amount of medical waste that is generated in Patna hospitals (tonnes/day) 3) Number of medical waste processing units
5	Solid waste management	BSPCB, PMC	1) Total solid waste generated in the city (tonnes/day)-domestic 2) Total solid waste collected and treated per day 3) Total waste burned on daily basis 4) Total number of solid waste treatment plants (composting/ recycling/ waste to energy plants) in Patna and their treatment capacity. 5) Total amount of waste that is (generated by the industries (tonnes/day)/ treated by the industries (tonnes/day)/ disposed by the industries (tonnes/day))
6	Domestic, institution & commercial.	PMC, BSPCB	1) Total urban, rural and slum population in the city 2) Number of slums inside the city 3) Mode of cooking and fuel used by the slum people (biomass burning, chulhas, dung cakes etc.) 4) Total number of households that use chulhas. 5) Percentage of households that have access to electricity 6) Type of fuel used in households (cooking-LPG, kerosene, and lighting-electricity. Kerosene for lamps etc.)
7	Road side vendors/eateries		1) Total number of roadside vendors that use DG sets 2) Type and amount of fuel used for (Cooking / DG sets)
8	Others	Finance Department, Govt. of Bihar	Average income of a person in Patna
		PMC	Average land cost in Patna