Cost effectiveness of interventions for control of air pollution in Delhi

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MAJOR FINDINGS

- Air pollution levels are very high in Delhi and adjoining areas. $PM_{2.5}$ concentrations in Delhi during 2019 violated the annual average standards by about 3 times.
- Transport (23%), industries including power plants (23%), and biomass burning (14%) were the major contributors to prevailing winter time $PM_{2.5}$ concentrations in Delhi during 2019.
- In a BAU scenario with consideration of some existing emission control policies, the winter $PM_{2.5}$ concentrations are expected to reduce by 9-28% between 2019 to 2030, despite which these levels remain significantly above (129-164 $\mu g/m^3$) the prescribed daily standard of 60 $\mu g/m^3$.
- Evidently, more stringent controls will be required to reduce emissions in the whole NCR and also in the rest of airshed to bring Delhi's winter-time $PM_{2.5}$ levels down to the level of the national ambient air quality standard.
- This study shows that stringent NCR level and Airshed level controls (detailed out in the report) can bring winter season $PM_{2.5}$ concentrations in Delhi down to 103-119 $\mu g/m^3$ and about 83-88 $\mu g/m^3$, respectively between 2022-2030. This is will be a reduction of 20-27%, and 36-47% w.r.t BAU between 2022-2030.
- For further reduction, even more stringent measures like control of ammonia release in farms, region-wide shift from solid fuels to gas/electricity, full vacuum cleaning of all kinds of roads, widespread landscaping and strictest control on refuse burning and construction activities will be required. This can bring the winter $PM_{2.5}$ levels to 55 $\mu g/m^3$ adhering to the daily standards. Further reductions can also be achieved through international cooperation by reducing contributions from outside of Indian boundaries. There is a need for further study of additional measures and costs on how to get levels further down closer to interim targets of WHO.
- Contribution of regional scale pollution is substantial in Delhi's $PM_{2.5}$ concentrations in Delhi and hence, regional level air quality planning and implementation is recommended for effective control of pollution in the whole region."Based on cost-effectiveness analysis, some of the air pollution control interventions emerge out as net negative cost strategies as they generate economic benefits (on account of efficiency gains) over a period of time. These include strategies like LPG penetration, induction cook-stoves, zig-zag brick kilns, use of agriculture residue in power plants etc.
- High cost effectiveness has been observed for the control strategies for industrial and dust pollution with low costs per unit of $PM_{2.5}$ removal observed. These include electrification of 2w and 3w vehicles, gaseous pollutant controls in power plant, fuel switch from solid to gaseous fuels in industries, vacuum cleaning of roads, and control of dust from construction activities.
- High cost effectiveness was found for fleet modernization of heavy duty vehicles like trucks and buses and low cost effectiveness has been observed for fleet modernization of cars. With BS-VI emissions standards slowly penetrating in, the potential and cost-effectiveness of fleet modernization will fall. Modal shift to public transport and electrification of public transport comes out to be quite cost effective in comparison to many other strategies. In addition, public transportation system provides additional social and economic benefits (that include reduced congestion, time and exposures, less expenditure on infrastructure creation and traffic management), there is a definite need for gradual transition towards multi-modal public transport system in the region.

Despite reduction of 21% in $PM_{2.5}$ concentration in BAU scenario in the years 2022-2030, mortalities will increase by 7% i.e. 14,400 in 2022 to 15,500 in 2030 in Delhi due to ageing population. Out of total 45000 mortalities in Delhi NCR in BAU scenario, around 12,300 mortalities will be avoided in the year 2030 in Delhi NCR if control strategies are implemented at the airshed level over and above the BAU. This will result in additional economic benefits of around INR 430 billion. Further, benefits to cost ratio is estimated to be over 2 in alternative scenarios, indicating that the economic benefits of moving towards clean air will outweigh the costs of implementation.

1. INTRODUCTION

Deteriorating ambient air quality (AAQ) in Indian cities is a matter of great concern. Violation of annual average ambient air-quality standards in more than 70% of Indian cities presents a grim picture of prevalent air pollution across the country. This concern is even more serious in big cities like Delhi. Particulate matter is identified as the most critical pollutant, among other important pollutants like NOx- Oxides of nitrogen; CO- carbon monoxide; SO_2- sulphur dioxide; NMVOCs- non-methane volatile organic compounds and ammonia. Due to growth in population, transportation demands, and industrialisation, there is steady growth in energy consumption based air pollutant emissions. Other than these, non-energy sources like refuse burning, road dust, construction activities, and agricultural residue burning, also add to the inventory of emissions in India. Air pollution is linked to different types of impacts on human health, vegetation, ecology, buildings and climate.

Being the capital city, Delhi's worsening air quality has not only concerned the residents but also attracted significant regional and global attention. Over the last several years, PM_{10} and $PM_{2.5}$ concentrations in Delhi have remained well above the prescribed national standards. The annual average concentrations of particulate matter (PM) generally violate the standards by about 3-4 times in the city. In order to take focussed actions for control of air pollution, there is a need for scientific source apportionment studies. Several of these studies have been conducted in past (ESMAP, 2004; NEERI, 2010; IITK 2015, TERI&ARAI,2018) which over the last 15 years have provided significant inputs towards estimates of source contributions in ambient PM_{10} and $PM_{2.5}$ concentrations in the city. The source apportionment studies used both receptor and dispersion models to explain several features of the contributors (e.g. secondary particulate and geographical contributions). Initial studies focussed more on sources within the city limits, but lately the focus has also shifted towards regional sources of pollution, which now have significant shares in the pollution contributions in Delhi. There are a number of towns like Ghaziabad, Gurugram, Faridabad, and NOIDA, Sonipat etc. in the vicinity of Delhi, which have grown at a rapid pace and have also shown very high air pollutant levels. In addition, there are rural areas within and outside of National Capital Region (NCR) where biomass burning in rural kitchens is common, and industrial areas which also play a very important role in adding to emission loads in NCR. Finally, the long range transport of pollution- agricultural residue burning in specific seasons, dust from outside of India also creates background pollution over the whole NCR. There are thus several sources and geographical regions which contribute to pollution concentrations observed in the city of Delhi. The sources do not just pollute in their vicinities but also contribute to deterioration of regional scale air quality across the whole NCR. Hence, there is a need to inventorise the pollutants from sources not only within Delhi's limits, but also in the surrounding NCR and beyond.

The problem of deteriorating air quality in Delhi and several other neighbouring towns needs to be addressed through a comprehensive air-quality assessment carried out for a wider region than Delhi. TERI&ARAI (2018) have provided the latest (year 2016) source apportionment estimates for Delhi and its surrounding towns and also suggested an action plan based on assessment of potential of different strategies for control of pollution. While the report provides the $PM_{2.5}$ reduction potential of different strategies, cost-effectiveness of control interventions has not yet been evaluated which can help policy makers in choosing the optimal options for control of pollution. It is in this context that this study aims at assessing the cost-effectiveness of several intervention by taking into account both the $PM_{2.5}$ reduction potential and costs associated with their implementation. It is to be noted that since 2016, there are several changes which have happened in the NCR region. On the one hand, significant growth has been observed in emissions contributing sectors, and on the other, several interventions have been taken for control of pollution in Delhi and outside. In view of this, emission inventories prepared in TERI&ARAI (2018) for the year 2016 have been projected to 2019 and air quality simulations have been performed to derive the most recent estimates of source contributions. Finally, future projections have been made - for 2022 in the short term, 2025 in the medium term and 2030 in the long term for assessment of air quality and cost scenarios. Based on these estimations for current and future air quality, an updated list of interventions have been developed and proposed.

This study also assesses the costs of implementation of these interventions and evaluates the Cost-effectiveness per unit of $PM_{2.5}$ concentrations reduced in the city of Delhi. Finally, based on the air quality and cost analysis, interventions for regional scale air quality improvement have been suggested.

2. STUDY DOMAIN

This study focuses on the city of Delhi which is surrounded by the national capital region which includes districts in Uttar Pradesh, Haryana and Rajasthan. Air quality influences from outside of NCR have also taken into account using air quality simulations conducted at national scale in India.

2.1 Delhi City

New Delhi, the capital of India is one of the fastest growing cities in India. It is a dense metropolitan city and is spread over the west bank of the river Yamuna.

Geography: It is located between the latitudes of 28°-24′-17″ and 28°- 53′-00″ North and longitudes of 76°-50′-24″ and 77°-20′-37″ East. The maximum length of the city is 51.90 km and maximum width is 48.48 km. The city is located at an elevation of 216 m above mean sea level. It is bordered by Haryana state on three sides and by Uttar Pradesh on the east side.

Climate: Delhi faces high variation in temperature and precipitation between summer and winter seasons. This is due to overlap between monsoon-influenced humid subtropical and semi-arid climates. The summer season in Delhi is from April till June. The temperatures rise to 40–45 ˚C in the summer in the region. The monsoon season in Delhi is from July till September. Delhi receives an average annual rainfall of 790 mm during the monsoon season. Winters are cold with temperatures during December and January falling to 4–5 ˚C. February and March, and October and November are climatically the best months. A comparison of key meteorological factors e.g. wind speeds, temperatures and rainfall for the years 2016 and 2019 are provided in Table 1.

Table 1: Average wind speeds for the year 2016 and 2019.

Season	Factor	2016	2019
Summer	Wind Speed (Km/h)	10	10
Winter	Wind Speed (Km/h)	6	7

Source: https://www.weatheronline.in/

It is to be noted that the year 2019 had somewhat higher wind speeds which leads to higher dispersion of pollutants. This also means that in 2019 the contribution of sources outside of Delhi could be higher due to atmospheric transport.

2.1.1 Demographics

Delhi is the capital of India and is one of the most populated cities in India. The city and its surroundings have grown at a fast pace. As per the 2011 census, Delhi has a population of 16.8 million, an increase from 13.9 million as recorded in the 2001 census. The total population growth in this decade was 21.21% and hence the average annual growth rate of the city was 1.92% (Census, 2011). Delhi's population accounted for 1.39% of India's population in 2011. The majority of people in Delhi (97.50%) live in urban regions. The population of Delhi has been estimated to grow to 18.7 million by 2016 and to 20 million in 2019 by using the decadal population growth rate provided by Census, 2011. Delhi is surrounded by a large national capital region (NCR), which includes the neighbouring satellite cities of Faridabad, Gurgaon, Ghaziabad and Noida and several other districts. The National Capital Region (NCR) has an estimated population of over 65 million and 70 million in 2016 and 2019, respectively.

Delhi is well connected with the neighbouring regions and other major cities of India through all modes of transport such as airways, railways and roadways. Delhi relies heavily on its transport infrastructure. The city has developed a public transport system based on Delhi Metro and CNG fueled buses. There are 1,13,91,551 registered motor vehicles in Delhi in 2018-2019 out of which 66.33% are motor cycles/scooters, 28.53 % cars & jeeps and rest are commercial vehicles such as Auto Rickshaws, Taxis, buses and goods vehicles (DES, 2020). Five National Highways converge on Delhi, which bring an additional traffic load to the city. These highways also used to carry traffic which was not destined for Delhi but due to non-availability of by-pass, this traffic would pass through Delhi, but now with construction of new eastern and western peripheral highways this traffic is expected to reduce. In order to cater to the growing demands of mobility, Delhi metro has been introduced during the last two decades which is now the largest and busiest transit system in India. The Delhi Metro project became the first railway project in the world to be certified for carbon credits for reducing greenhouse gas emissions by the United Nations in 2011 (https://mea.gov.in). The Delhi Metro project proposes to cover the entire city of Delhi and the adjoining sub-cities (Gurgaon, Noida, Ghaziabad, etc.) with a network of 405 km, in four phases, by 2021.

According to the Delhi 2021 Master Plan, the state will be promoted as a hub of clean, high-technology and skilled economic activities. Initiatives would be taken for the modernisation of existing and inclusion of new industries (Ministry of Commerce & Industry, ibef.org).

With its growing population, annual LPG consumption in Delhi has increased from 7,09,000 tonnes in 2011 to 7,77,000 tonnes in 2016 and now in 2019 to 8,26,986 tonnes. Approximately 47,53,000 tonnes of LPG was consumed in the NCR in the year 2016, which shows an increase of 43% in LPG consumption from 2011. In addition, there are several types of industries operating in NCR towns including brick-making, sugar, paper, dyeing, rubber, chemicals, ceramics, iron & steel, textiles, fertilizers, stone crushers, and casting & forging, etc. (Sharma *et al.*, 2018), which add to the pollution load in the city.

2.2 General Description of the NCR

Delhi is located at the centre of National Capital region (NCR). NCR includes the entire NCT of Delhi and 19 surrounding districts in the states of Haryana, Uttar Pradesh, and Rajasthan (National Capital Regional Planning Board, ncrpb.nic.in). It covers the Haryana districts of Karnal, Panipat, Sonipat, Jind, Bhiwani, Rohtak, Jhajjar, Mahendragarh, Rewari, Gurugram, and Faridabad (eleven districts); and the Uttar Pradesh districts of Meerut, Bagpat, Ghaziabad, Bulandshahr, Gautam Budh Nagar, and Muzzaffar Nagar (six districts); and two districts of Rajasthan, namely, Alwar and Bharatpur (Figure 1). The NCR is geographically located between the coordinates 27.60 °N to 29.30 °N and 76.20 °E to 78.40 °E. The area of the NCT of Delhi is 1484 km^2 (5%), while the NCR extends over an area of 58,332 km^2. The districts of Haryana cover an area of 25,327 km^2 (44%), while NCR districts in Uttar Pradesh extend over an area of 14,826 km^2 (36%). In addition, NCR districts of Rajasthan extend over 13,447 km^2 (15%) (Census 2011, National Capital Region Planning Board). Along with cities and towns, the NCR also contains ecologically sensitive areas like the Aravalli ridge, forests, and wildlife and bird sanctuaries.

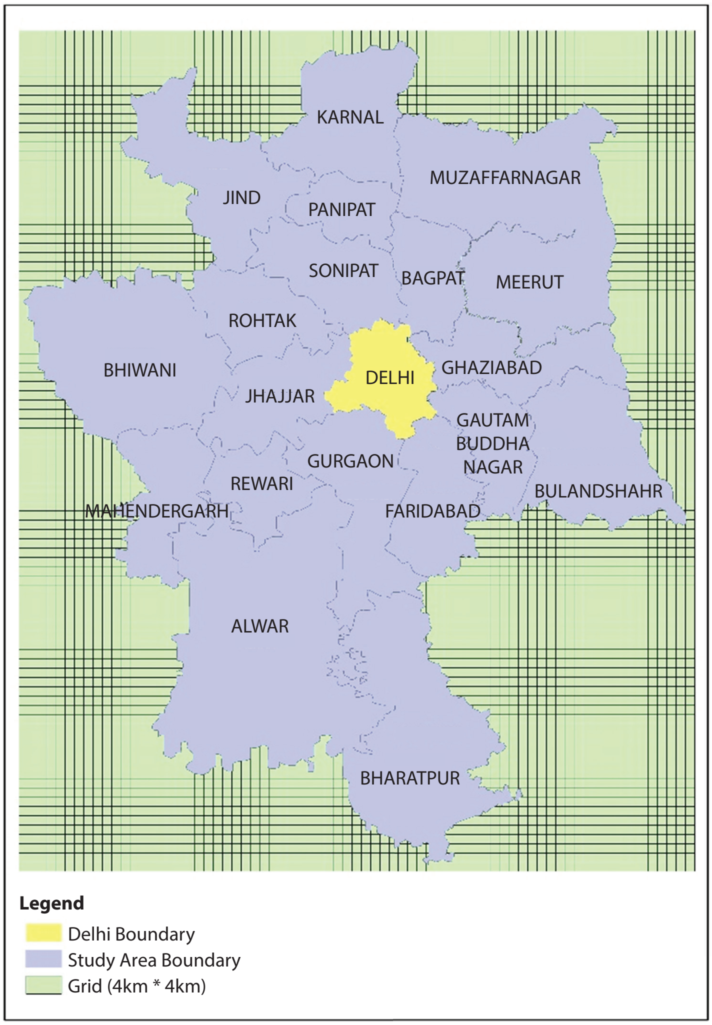

Figure 1: Study Domain: Delhi and NCR

The NCR is the largest urban agglomeration in India with a decadal population growth rate of more than 20% during 2001-2011. The NCR contains 7.6% of the total urban and 2.1% of the total rural population of India, of which about 4.4% of India's urban population resides in the NCT of Delhi.

3. AIR POLLUTION AND ITS SOURCES IN DELHI NCR

A variety of sources contribute to pollution in Delhi and NCR. Ghaziabad (a city in Uttar Pradesh state), Delhi (NCT), Noida (part of NCR), Gurugram (in Haryana), Bulandshahar (cin Uttar Pradesh), Jind (in Haryana), Faridabad (in Haryana) and Bhiwadi (in Rajasthan) were among the 10 most polluted urban centres in India in terms of $PM_{2.5}$ concentrations (CPCB, 2020).

Ambient Air Quality (AAQ) monitoring in Delhi is conducted under the National Ambient Air Quality Management Programme (NAMP) through various organizations, including the Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC), the National Environmental Engineering Research Institute (NEERI), and others. Under the NAMP, there are currently 10 manual monitoring and 38 continuous air quality monitoring stations in Delhi, of which 20 new continuous stations started operating from 2017. Figure 2 shows the daily average $PM_{2.5}$ concentrations in Delhi averaged for 29 stations for the years 2018, 2019, and 2020. It is seen from the Figure 2 that in all three years, peak $PM_{2.5}$ concentrations occurred during the post-monsoon and winter season. In November 2019, the government declared a public health emergency owing to the extremely unhealthy air in the city, temporarily ordering schools to close. Heavy smog has affected both air and road transport. On November 3, 2019, dozens of flights were cancelled due to poor visibility.

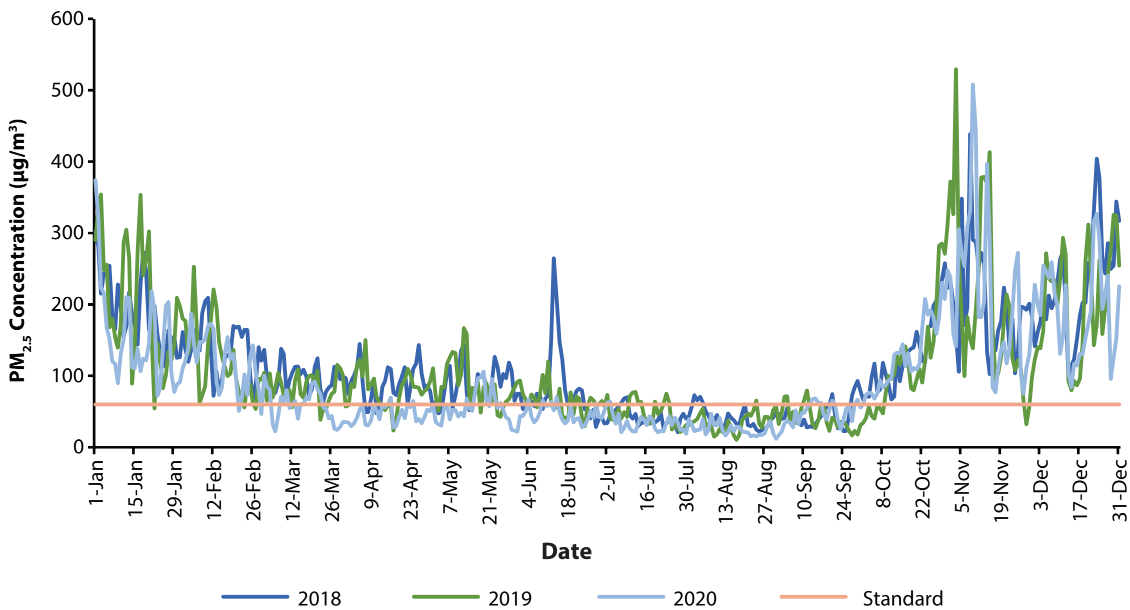

Figure 2: Daily $PM_{2.5}$ concentrations in Delhi (average of 29 stations) in 2018, 2019, and 2020

** Jan 2018 had 15 stations*

Figure 3, shows the annual average concentrations of SO_2, NO_2, PM_{10} in Delhi from the National Ambient Air Quality Monitoring Programme (NAMP) data for the year 2019. In Figure 4, $PM_{2.5}$ concentrations at different stations in Delhi are shown for the year 2019. At all the stations, the $PM_{2.5}$ concentrations were higher than the prescribed standard, that is 40 µg/m³. In Figure 5, data for NCR cities Ghaziabad, Greater Noida and Noida is shown for the year 2019. As seen in the Figure 4, the SO_2 and NO_x concentration is below the National Ambient Air Quality Standards (NAAQS) in all three cities, while PM_{10} and $PM_{2.5}$ concentrations are well above the NAAQS. Also, the $PM_{2.5}$ concentration in these three NCR cities are similar to the $PM_{2.5}$ concentration observed at different stations in Delhi (Figure 5), which is unsurprising since Delhi and these cities are broadly in the same airshed region.

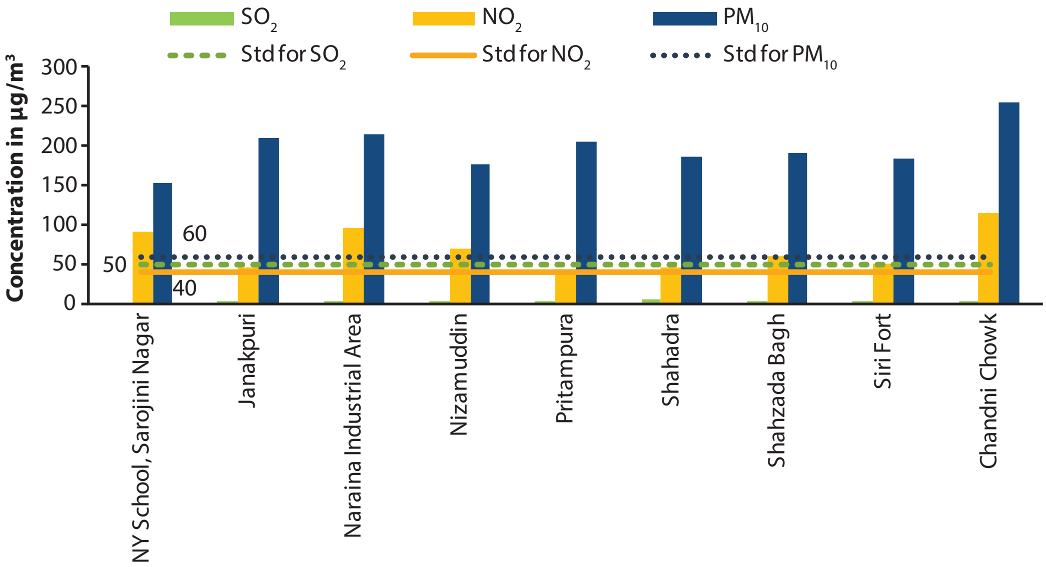

Figure 3: Annual average concentrations of PM_{10}, NOx and SO_2 at different manually operated stations in Delhi in 2019

Source: NAMP, 2019, http://www.cpcbenvis.nic.in/

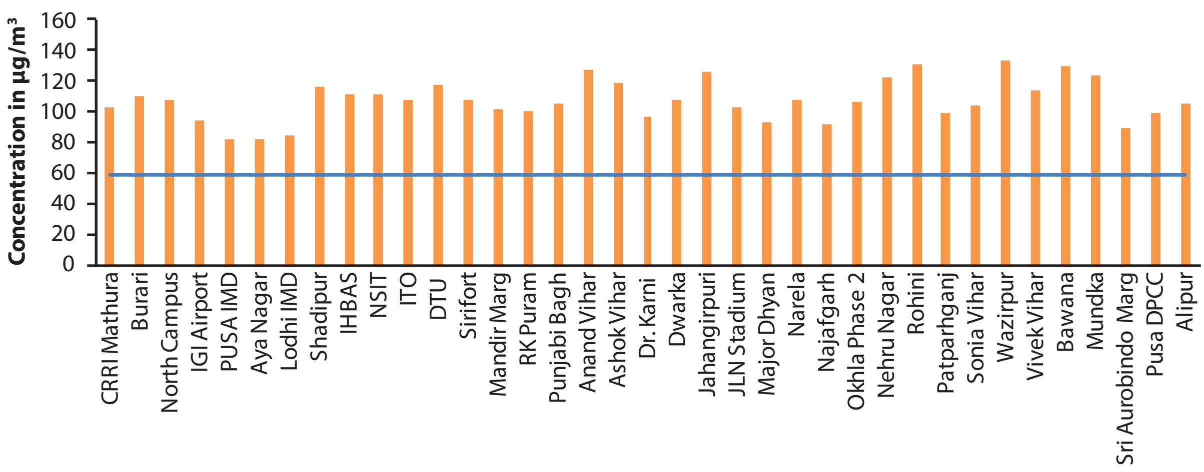

Figure 4: Annual average $PM_{2.5}$ concentration (µg/m³) at different stations in Delhi

Source: NAMP, http://www.cpcbenvis.nic.in/

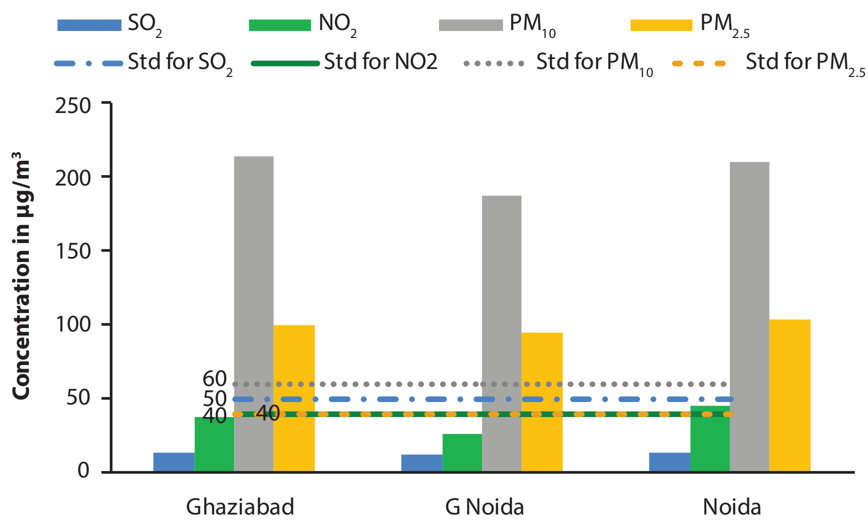

Figure 5: Annual average concentrations in 2019 in NCR cities

Source: NAMP, 2019, http://www.cpcbenvis.nic.in/

Over the last two decades (2000 to 2020), several policies have been implemented to tackle air pollution in Delhi, including shifting polluting factories outside the city, renewing the public transport system by introducing the Delhi Metro, reduction of sulphur content in diesel, introduction of vehicular emissions norms, and conversion of fleet transport vehicles to compressed natural gas (Hama et. al., 2020). Despite implementation of these policies in Delhi, ambient $PM_{2.5}$ concentrations in Delhi and its NCR region remain several-folds higher than annual National Ambient Air Quality Standards. The sources of the emissions are related to economic growth, such as those from coal-based power generation, industrial emissions, mobility demands and the corresponding vehicular emissions. There are also poverty-linked emissions from biomass-based cooking in the residential sector (mainly in regions in NCR outside Delhi), which contributes to both indoor and outdoor air pollution. In addition, dust emissions during the summer, pollution due to agricultural residue burning in upwind rural regions, and pollution from industries including brick kilns from surrounding regions of Delhi adversely impact air quality in NCR. A significant number of NCR households (Sharma et al., 2018) were estimated to use biomass for cooking using traditional cook stoves, which have low efficiencies of combustion and high pollutant emission rates. Major industries are generally equipped with air-pollution-control installations, but medium- and small-scale industries have limited controls.

Particulate matter (PM_{10} and $PM_{2.5}$) often exceeds the NAAQS (Figures 2, 3 and 4). Particulate matter is considered as the major air pollutant in recent studies. In addition to emissions, meteorological conditions, such as wind speed and direction, temperature, mixing height, humidity, and precipitation, also impact the levels of particulate matter and gaseous pollutants in ambient air quality. Higher levels of PM in the winter months are due to reduced wind speeds, and shallower mixing heights.

3.1 Source contributions to $PM_{2.5}$ pollution

There are several sources of pollution in the NCR region. They can be categorised into a) local, b) regional , and c) long range sources of pollution. Local sources of pollution in Delhi include different categories of vehicles, road dust, power plants, industries, construction activities, In 2016, Delhi had one coal-based and four natural gas-based power plants. The Badarpur thermal power station in Delhi, a coal-based plant, was closed on 15 October 2018.

Regional sources include many other sources of pollution which due to atmospheric transport contribute to poor air quality in Delhi city. As per the data collected from State Pollution Control Boards (SPCBs) in the NCR, there are 4149 air-polluting industries in the NCR. Additionally, there are about 5,000 brick kilns operating in the NCR. NCR including Delhi has four coal-based and five gas-based power plants. There are about 29 medium and small-scale industries and 5 factory complexes (metal processing, paint, dyeing, electroplating, alloy, leather, paper, chemicals, etc.) in different industrial areas in NCR, which significantly affect air quality (Rai et. Al, 2020). Furnace oil (FO) and petcoke are now banned for use as industrial fuel in NCR. Light diesel oil (LDO), low sulphur high speed diesel (LSHS), biomass, natural gas (NG), and coal are the major fuels presently used by industries in NCR. Other than industrial growth, several towns in NCR have grown at a fast rate in other sectors also. Residential apartments and shopping malls which came up in big numbers in the surrounding towns contributed to emissions not only during the construction phase but also on a continuing basis through the use of diesel generator (DG) sets to tackle the problem of frequent power cuts. With mobility demands, vehicular numbers have also grown in numbers in NCR considerably.

Due to the predominant North-West wind direction, Delhi is prone to long range transport from several upwind states and other countries lying in this direction. Burning of agricultural residues in farms located mianly in states of Punjab, and Haryana, and to some extent from Uttar Pradesh also contribute significantly to air pollution in certain seasons. In the post monsoon season, open biomass burning leads to increased $PM_{2.5}$ and PM_{10} concentrations in the NCR. Dust generated by natural phenomena and anthropogenic activities also add to the long-range transport of pollution from outside India's external boundaries to Delhi (TERI&ARAI,2018). Reactions between gases like ammonia, sulphur dioxide and oxides of nitrogen lead to formation of secondary particles which add to pollution loads.

The major sources responsible for the poor ambient air quality in Delhi have been assessed through various source apportionment studies. The 2016 source apportionment study conducted by TERI & ARAI, (2018) for the year 2016 reported that in winter season the three major sources of $PM_{2.5}$ were industry (30%), transport (28%) and dust (17%); while in summer, the major source was soil and road dust (38%), followed by industry (22%), and transport (17%).

The central and state governments have taken several steps to mitigate the rising air-pollution levels in NCR. One of them was the Graded Response Action plan which was prepared to take immediate control actions for control of pollution under different Air Quality Index categories in Delhi and NCR (CPCB, 2017). However, despite several efforts, pollutant levels have remained high in the region and well-above the prescribed standards. This calls for further investigation of changed contributions of sources and refinement of action plans. Moreover, proactive planning to draft cost effective strategies is required, taking account of future growth in different sectors contributing to poor air quality in Delhi.

4. OBJECTIVES

The broad objective of this study is to assess cost-effectiveness of various options to reduce air pollution in Delhi. This will require assessment of $PM_{2.5}$ source contributions in 2019, analysis of impact of different interventions on air quality, and estimation of cost effectiveness of different interventions.

5. METHODOLOGY

For development of an effective air-quality management plan, scientific apportionment of contributing sources is the essential step. Apart from source apportionment as at present, air quality projections for the future need to be made, in order to take into account sectoral growth patterns and control interventions. This is essential for evaluation of the effectiveness of control options planned for air quality management in the region. This requires an integrated approach towards air-quality management involving use of advanced air quality models which can take into account source emission inventories, atmospheric chemistry, long range pollution transport, and changing meteorological conditions for the region. A database should be built using the relevant scientific tools for designing an air-quality management plan for decision support to policy makers. Air quality models complement ground based observations by representing a wider area and provides a viable option for future scenario analysis. In addition to pollutant information, air-quality models give a deterministic, integrated analysis of emissions, meteorology, and the spatial and temporal variation of the current and controlled scenarios.

The overall approach followed in this study is shown in Figure 6. First the emission inventory of 2016 was projected to the year 2019 by accounting for the growth rates observed in different contributing sectors and interventions taken for control. Detailed information on sector-wise growth rates and interventions/control measures taken into account in this study are provided in Table 2. The detailed approach, activity data sources, and emission factors used for each of sectors inventorised for emissions of pollutants like $PM_{2.5}$, NO_x and SO_2 are given in TERI&ARAI (2018). Once inventorised, spatial, temporal and vertical allocations of the inventory were carried out to prepare emission files for carrying out air quality simulations for the year 2019.The modelling framework for this study consists of a meteorological model, an air quality model, and an emission inventory database which were integrated to simulate the local and regional atmospheric circulation, and predict the pollutant concentrations in the Delhi NCR region. CMAQv5.3.1 model has been used in the study to estimate chemical transport of pollutant species under prevailing meteorological conditions (Appel et al. (2017), USEPA (2020). The CMAQ system is used to assess air quality by following multi-pollutant and one atmosphere approach (Byun and Schere, 2006). The latest version of CMAQ 5.3.1 is now able to take into account the formation of secondary organic particulates which contribute significantly in $PM_{2.5}$ concentrations of Delhi. This is a significant model improvement over the last study, which improves estimates of organic matter contributions from sectors like biomass burning.

The NCR based emission inventory at a resolution of 4x4 km^2 was used to run the air quality simulations. In order to account for pollutants from outside the NCR, India scale simulations were performed using the 36x36 km resolution emission inventory prepared by TERI. In these national level simulations, atmospheric transport of pollutants from international boundaries were accounted for using global air quality products of National Centre for Atmospheric Research, U.S. (NCAR). The global product used in this study was generated from results of Community Atmosphere Model with Chemistry (CAM-chem) model. The pollutants entering from neighbouring countries like Pakistan, Nepal, Bangladesh etc., and fall within the national study domain were taken from ECLIPSE database of the International Institute of Applied Systems Analysis (IIASA, 2014).

The WRF model version 3.9.1 was used to generate 3-dimensinal meteorological fields over the NCR domain. The estimated emissions alongwith meteorological outputs from the WRF model were fed into the CMAQ model version 5.3.1 to estimate ambient $PM_{2.5}$ concentration in Delhi.

The model was used for simulations for the year 2019 from January to December. The simulated model $PM_{2.5}$ concentrations were validated with actual observations at 37 locations in Delhi. Finally the validated model was used for deriving source contributions of different sectors for 2019 using source-sensitivity approach. Seasonal estimates of source contributions were also derived using the validated CMAQ model.

Thereafter, sectoral emissions were projected for a business as usual (BAU) scenario for the years 2022, 2025, and 2030. The future growth rates and controls assumed in BAU scenario are given in the Table 3. These projected emissions were then fed into the air quality model and simulations were carried out to estimate source contributions in the year 2022, 2025 and 2030. Once the BAU scenario was established, a number of interventions for control of pollution in Delhi were tested and the most effective ones were identified on the basis of their $PM_{2.5}$ reduction potential. For specifically selected high potential interventions, cost effectiveness is estimated in terms of costs per $\mu g/m^3$ of $PM_{2.5}$ removed in Delhi. The list of interventions for which cost-effectiveness is assessed is provided in Table 4. Finally, a number of interventions were selected to formulate alternative scenarios to assess future air quality in Delhi in the short (2022), medium (2025), and long (2030) time frames.

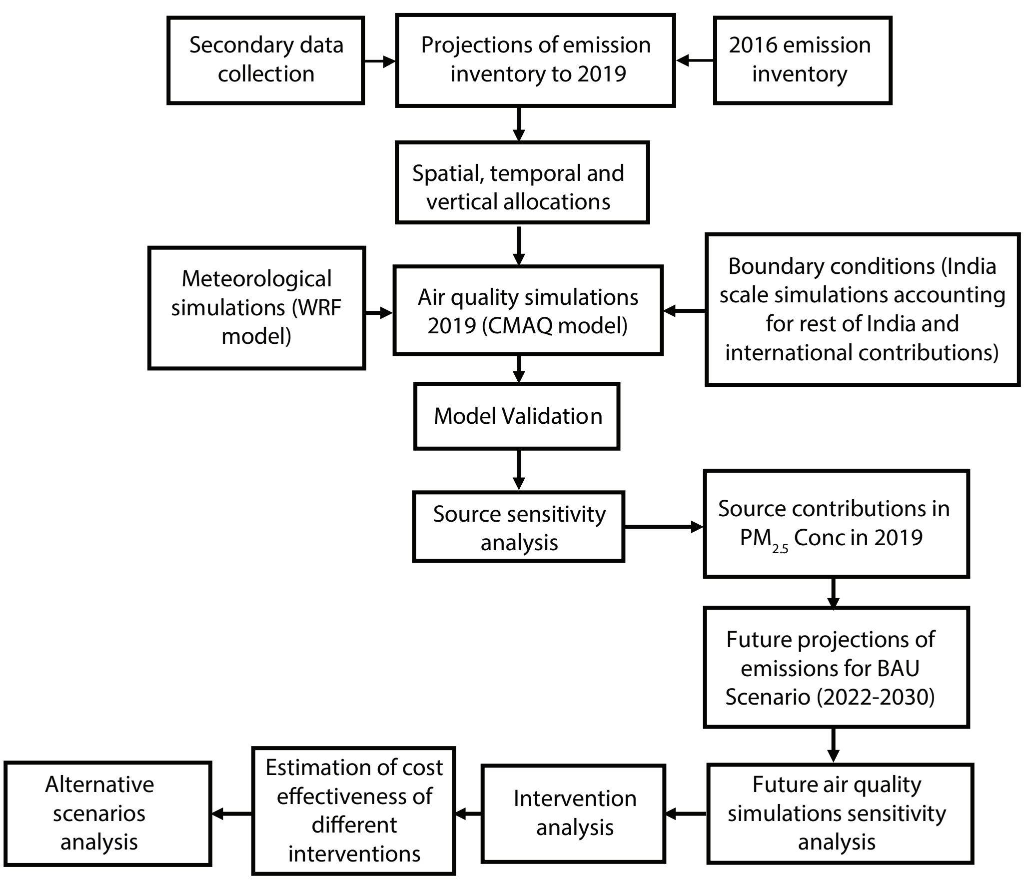

Figure 6: Overall approach for this study for Delhi NCR

Table 2: Growth rates and control measures considered for different sectors for emission projections for the year 2019:

Sector	Growth rate	Interventions and other assumptions	Source
Transport	7%	Ban on 10 year old diesel vehicles in Delhi-NCR Eastern and Western peripheral highways around Delhi. Penetration of BS-IV vehicles	GoD, 2020 NCRPD, 2015b:
Industries	-	Based on latest actual data of industry-wise fuel consumption received from CPCB.	Based on actual data provided by CPCB from SPCBs
Brick kiln	4%	46% of kilns converted to Zig-Zag.	Based on actual data provided by CPCB
Stone crushers	5%		Based on actual data provided by CPCB
Agriculture residue burning	-	38% reduction as compared to 2016 emission based on FRP values retrieved from VIIRS satellite data	VIIRS satellite data
Construction	5%	10% reduction due to adoption of construction guidelines.	NCRPD, 2015b
DG sets	-	Power supply situation remains same as of 2016 in Delhi and 58% reduction in demand supply deficit between 2016 and 2019 in NCR.	CEA, 2020a
Power plant	-	Badarpur power plant closure. Actual fuel consumption in 2019 from CEA.	CEA, 2020b
Refuse burning	-	Based on number of non-agricultural fires observed in VIIRS satellite database	VIIRS satellite database
Crematoria	Based on population growth rate (2.45%)	District wise crude death rate (CDR) is applied.	Census , 2011
Restaurant	Based on population growth rate (2.45%)	-	Census , 2011
Waste incinerator	No change	-	-
Airport	No change	-	-
Domestic	Population growth rate (2.45%)	Based on recent TERI estimates, 1.6 million households rely on biomass in Delhi NCR.	TERI's Assessment*
Road dust	7%	Reduction in silt content on arterial roads in Delhi.	Manuja et al. (2020)

** TERI's assessment was done to estimate number of households relying on biomass in NCR in 2019 using Census, 2011; PPAC, 2019 and SECC, 2011 data.*

Table 3: Growth rates and control measures in Delhi NCR considered for different sectors for future BAU scenario between 2019 to 2030

Sector	Growth rate	Intervention/assumption	Source
Transport	7% up to 2022 thereafter 4%	BSVI in 2020, ban on 10 year old diesel vehicles in Delhi-NCR.	NCRPD, 2010
Industries	7% up to 2030	For gaseous pollutant control, wet scrubber installed in 12%, 25% and 50% of units in NCR in 2022, 2025 and 2030, respectively. Also, 20%, 50% and 100% of industries in NCR on solid and liquid fuel will shift to gaseous fuel, in 2022, 2025 and 2030, respectively	NCRPD, 2015a Gas penetration in industries as observed in last few years.
Brick kiln	4% to 2021, thereafter 1.7%	100% switch to Zig-Zag technology on brick kilns in NCR by 2025	Growth rate of the construction sector is adopted after accounting for the use of alternative construction materials in future.
Stone crushers	5% up to 2021 thereafter 2%	Controls with removal efficiency of 40% and 20% for PM_{10} and $PM_{2.5}$, respectively.	NCRPD, 2015b
Agriculture residue burning	4.93% growth based on primary sector GDP growth rate	15%, 27% and 50% reduction due to extensive use of in-situ management in 2022, 2025 and 2030, respectively	NCRPD, 2015b
Construction	5% up to 2021 thereafter 2%	15%, 21%, and 30% reduction in 2022, 2025 and 2030, respectively due to stricter enforcement of construction guidelines	NCRPD, 2015b
DG sets	-	No demand supply gap in 2030	-
Power plant	No growth	20%, 50% and 80% of power plants will have SCR and FGD by 2022, 2025 and 2030, respectively.	
Refuse burning	Based on population growth rate (2.45%)	40% reduction due to stricter enforcement of ban on open burning in all three years 2022, 2025 and 2030.	-

contd...

Table 3 contd...

Sector	Growth rate	Intervention/assumption	Source
Crematoria	Based on population growth rate (2.45%)	-	-
Restaurant	Based on population growth rate (2.45%)	-	-
Waste incinerator	No change	-	-
Airport	No change	-	-
Domestic	Population growth rate (2.45%)	100% population will be on LPG in NCR by the year 2025/30.	Estimated on the basis of data on LPG penetration in NCR states before Pradhan Mantri Ujjwala Yojna.
Road dust	7%	99% coverage of arterial roads by vacuum cleaners in Delhi by 2030.	

Table 4: Description of alternative more stringent sectoral interventions for control of pollution in Delhi NCR (some of them have also been tested on airshed level, i.e. beyond NCR region also)

Sector	Intervention
Domestic	Increase in LPG penetration in residential sectors in households relying on biomass in NCR by 100% in 2022
	Supply improved induction cook-stoves 100% in 2022 to households using biomass
Agriculture residue and power plant	Use of 100% agricultural residues in power plants in 2022, 2025 and 2030
Transport	Enhanced Public transportation on electricity: 25% in 2022, 50% in 2025 and 100% in 2030
	Enhanced share of 2-wheeler electric vehicles- 20% in 2022 and 40% in 2025 and 100% in 2030 electric two-wheelers
	Enhanced share of electric three-wheelers- 100% three-wheelers in 2022
	Enhanced share of electric cars:- 10% in 2022, 20% in 2025 and 40% in 2030
	25% Modal shifts of cars and 2-wheelers to CNG buses in all three years i.e. 2022, 2025 and 2030
	100% fleet modernization of 2w, 4w, trucks and buses to BS-VI vehicles from 2022, 2025 and 2030
	100% Fleet Modernization of 2 & 4-wheelersto BS VI by 2022, 2025 and 2030
	100% Fleet Modernization of trucks and buses to BS VI by 2022, 2025 and 2030
	Increase penetration of biodiesel to 12% by 2025 and 20% by 2030
Power plant	Power plant controls : implement stricter NOx and SO_2 standards with continuous monitoring by 2022
Industries	Stricter enforcement using wet scrubbers and low NO_x burners in industries in 2022, 2025 and 2030
	100% fuel switch from solid and liquid to gaseous fuels in 2022, 2025 and 2030
	Stricter dust control on stone crushers by using wet scrubbers with double removal efficiency (i.e. 80% and 40% for PM_{10} and $PM_{2.5}$, respectively)
Brick kiln	100% Enforcement of Zig-Zag brick kiln technology in 2022, 2025 and 2030
Road dust	Vacuum cleaning of all arterial roads - in 2022, 2025 and 2030 in Delhi
	Wall to wall paving of arterial roads- in 2022, 2025 and 2030
Construction	Control of dust from construction activities- barriers and fogging based controls which control 60% of dust in 2022, 2025 and 2030

5.1 Economic Analysis

The aim of this explorative cost effectiveness exercise was to identify options that reduce the emission load cost-effectively. Figure 7 demonstrates the components that are considered for the analysis and the approach undertaken to arrive at the cost of interventions. Data to derive costs of implementation of proposed interventions were gathered after extensive literature review, consultation with sector experts, technology providers and government departments. The fixed capital costs are levelised for the duration of intervention i.e. up to 2022, 2025, and 2030 based on the full life of the project (i.e. if a vehicle life is 15 years, the costs are taken for the vehicle driven during the considered duration only). The operation and maintenance costs are estimated based on the level of activity, energy requirements and other operating cost heads involved. The transfer payments (i.e. taxes and subsidies) does not constitute resource cost and is excluded from the analysis. (squire et al, 1975).

The social discount rate of 10% is used to estimate the net present value of the proposed intervention. Wherein the net present value of investment expenditures is compared with net benefits generated by the investment, the process required estimation of economic costs and benefits at each stage of energy supply, distribution and use chain before arriving at the discounted numbers.

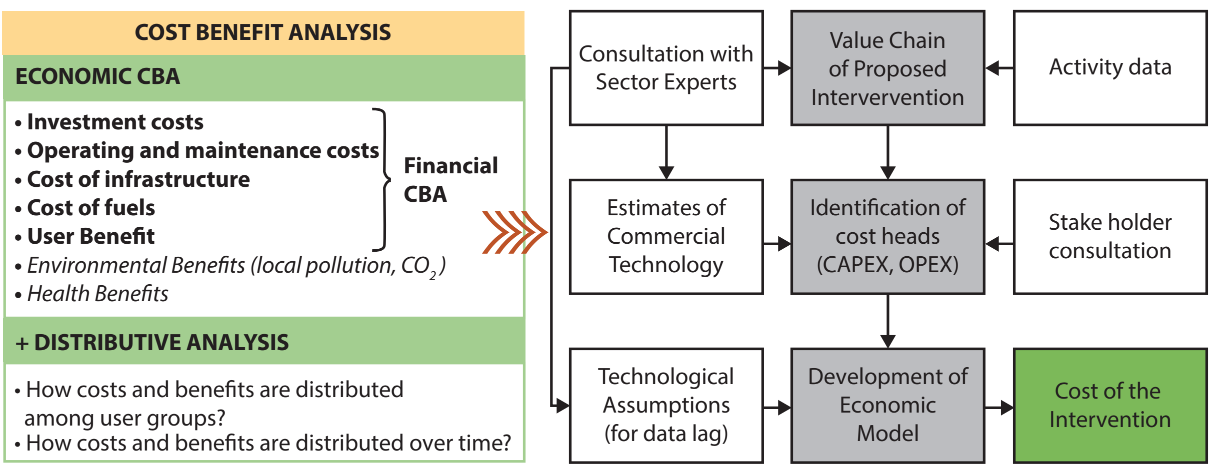

Figure 7: Components of CBA and Approach of CBA

The analysed costs and benefits are used to assess the net costs of different interventions using the above-mentioned approach which are further used to assess the cost-effectiveness. Ratio of cost to $PM_{2.5}$ concentrations reduction potential of selected strategies is compared. The interventions showing lower ratios are recommended (in terms of efficiency gains) for prioritisation and immediate action for control of pollution.

In addition, human health costs attributable to $PM_{2.5}$ pollution in Delhi and NCR have also been quantified in terms of disease-specific mortality. The study estimated the mortalities attributable to five diseases, cardiopulmonary diseases (COPD) (above 30), lung cancer (LC) (above 40), ischemic heart disease (IHD) (above 25), lower respiratory infections (LRI) (below 5) and stroke (all age groups) caused due to high ambient particulate matter concentrations. The health impact is estimated using the integrated exposure risk function (IER) developed by Burnett *et al.* (2014).

The mortalities attributable to $PM_{2.5}$ concentrations for different scenarios are also used to estimate the economic loss using the values of Disability Adjusted Life Years (DALY), value of DALY to GDP per capita and value of statistical life approach. Finally Benefit to cost ratios have been computed and assessed for different scenarios.

6. RESULTS AND DISCUSSIONS

6.1 Projected emissions inventory in 2019

Based on methodology described in previous section, sector-wise emission loads for $PM_{2.5}$, NO_x and SO_2 have been projected for 2019 and are presented in Table 5. Total $PM_{2.5}$ emission load estimated for Delhi was 25.4 and for NCR 516 kt/yr. Transport is found to be a major contributor (42%) of $PM_{2.5}$ in Delhi, followed by road dust (21%) and construction (11%). In case of NCR, industries excluding power stations are found to have a major share of 43%, followed by agriculture burning (15%), residential sector (14%), and transport (13%).

Table 5: Projected emission inventory (kt/yr) of Delhi and whole NCR for year 2019.

Sector	DELHI			NCR		
	$PM_{2.5}$	NO_x	SO_2	$PM_{2.5}$	NO_x	SO_2
Transport	10.8	146.4	1.2	65.0	565.9	4.6
Industries including power plants	0.3	0.4	0.0	259.0	182.5	360.3
Residential	2.1	4.0	0.2	71.8	23.9	6.3
Agricultural burning	0.2	0.0	0.0	79.5	10.2	15.1
Road dust	5.4	0.0	0.0	16.5	0.0	0.2
Construction	2.8	0.0	0.0	8.2	0.0	0.0
DG sets	0.0	0.7	0.0	1.5	22.3	1.5
Refuse burning	0.7	0.3	0.0	10.5	3.5	0.5
Crematoria	0.2	0.0	0.0	0.9	0.3	0.0
Restaurant	0.8	0.4	1.3	1.0	0.5	1.6
Airport	0.1	6.6	0.5	0.1	6.6	0.5
Waste incinerators	0.3	4.1	1.6	0.3	4.1	1.6
Landfill fires	1.5	0.6	0.1	1.6	0.6	0.1
Total	25.4	164.5	5.0	516.0	820.4	392.3

6.2 Comparison of emissions inventory in 2016 and 2019

The emission inventory of 2019 has been derived after taking into account the growth in different sectors and interventions taken for control e.g. banning of furnace oil and petcoke in NCR, closure of Badarpur power station, LPG penetration, reduction in kerosene use in lightening due to electrification, introduction of Euro-IV standards across India, construction of eastern and western peripheral highways, shift of industries to CNG (in Delhi and in some industries in NCR), reduced agricultural burning as detected through satellites, improved electricity supplies reducing DG set usage, vacuum cleaning and dust controls in Delhi roads, etc.

Despite the growth in contributing sectors, $PM_{2.5}$ emissions for Delhi have decreased by 22% in 2019 as compared to 2016. This can be attributed to closure of Badarpur station, introduction of Euro-IV standards across India, ban on 10-year old diesel vehicles, construction of eastern and western peripheral highways, and shift of industries to CNG. However, in NCR, $PM_{2.5}$ emissions have only increased by 3% as decrease in emissions from residential and agricultural burning sectors have been compensated by increased PM emissions in industrial sector (Figure 8). The shift from petcoke to coal has on the one hand reduced SO_2 emissions considerably, but has led to increased PM emissions due to use of coal, which is high in ash content. However, change in only $PM_{2.5}$ emissions cannot be directly linked to $PM_{2.5}$ concentrations, because of meteorology and also because of secondary particulate formations linked to SO_2 and NO_x emissions.

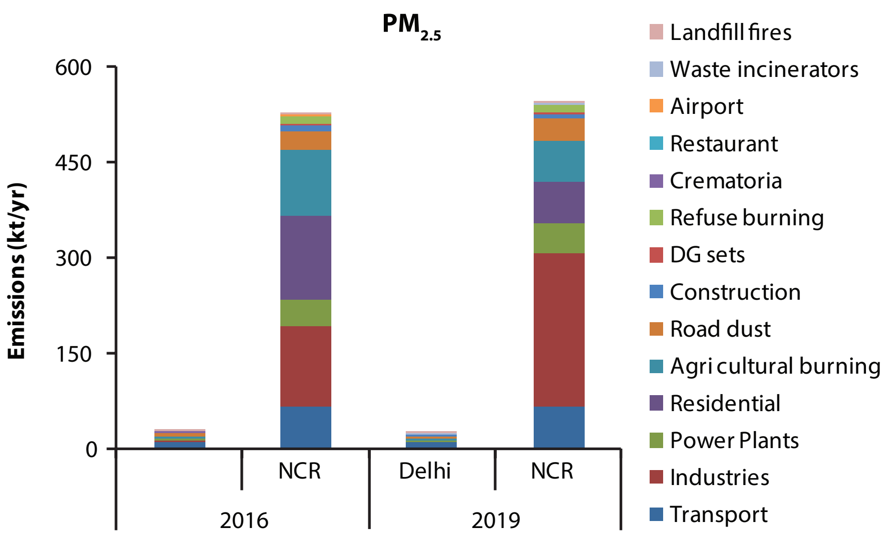

Figure 8: Comparison between $PM_{2.5}$ emissions of Delhi and NCR for the year 2016 and 2019

6.3 Air quality simulations for base year 2019

The projected emission inventory of 2019 has been fed into the air quality model (CMAQ) along with meteorological inputs from WRF model. Monthly $PM_{2.5}$ concentrations were derived for the whole NCR region including Delhi. The modelled yearly and seasonal averaged $PM_{2.5}$ concentrations in the study domain are depicted in the Figure 9 below.

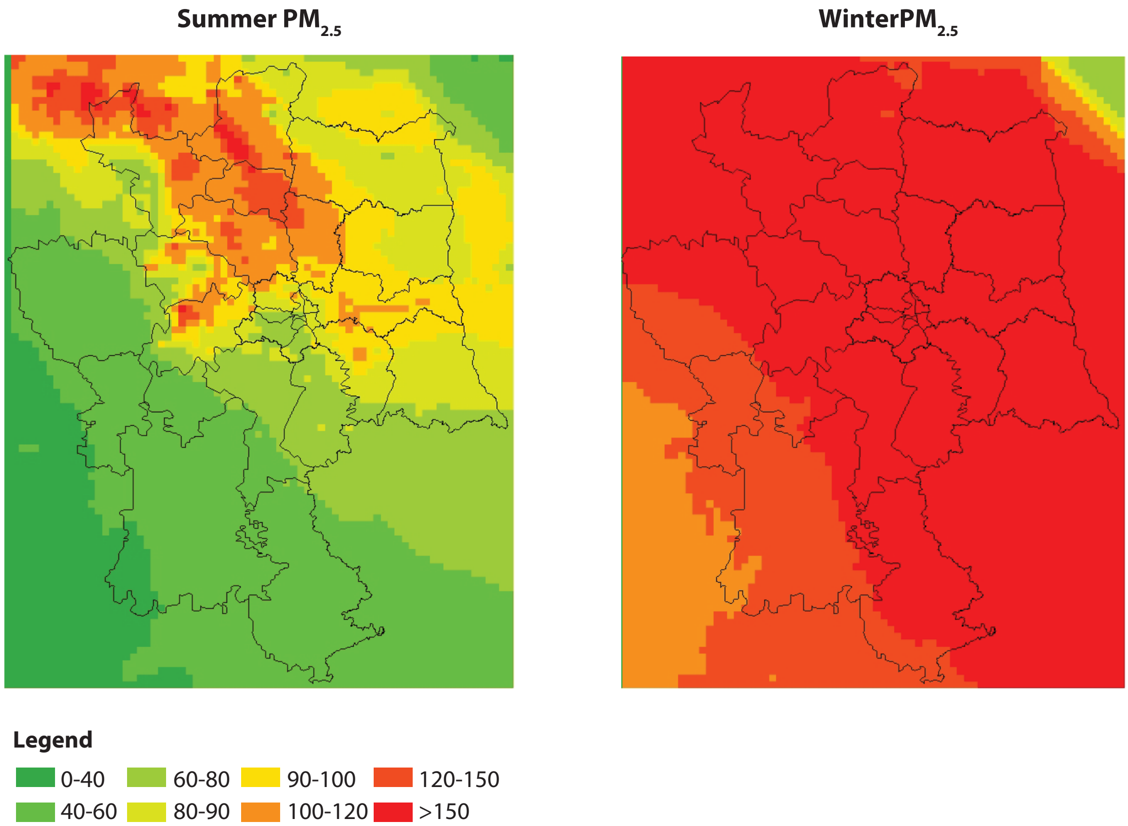

Figure 9: Modelled average ambient $PM_{2.5}$ concentration (µg/m^3) in the study domain (Delhi, NCR)

The model estimates higher concentrations in winter in comparison to summer season. This can be attributed to lower wind speed and shallower boundary layer height leading to reduction in dispersive capacity of the atmosphere resulting in higher concentration of ambient $PM_{2.5}$ concentrations. High levels of pollution during winters are evident in the entire NCR, pointing towards the fact that air pollution is a regional scale issue. Summers are relatively cleaner, but still show $PM_{2.5}$ concentrations above the standards in Delhi. Figure 9 also shows the effect of regional scale meteorological transport of $PM_{2.5}$ from north-west direction.

The modelled concentrations of $PM_{2.5}$ were month wise validated with data from 37 monitoring locations spread across the city. The modelled to observed $PM_{2.5}$ concentration ratio estimated in the study for summer (Apr, May & Jun) was found to be 1.06, for winter (Jan, Feb & Dec) it was 0.98, and the year's ratio was 1.04. This shows satisfactory model performance and confirms the ability of the model to reproduce seasonal variability in the concentrations. The comparison of modelled and observed monthly average concentrations for Delhi is shown in Figures 10(a) and 10(b). The r2 and index of agreement values between the monthly averaged $PM_{2.5}$ concentrations was found to be 0.82 and 0.95. The validated model was further used to study the source apportionment of Delhi using source sensitivity method.

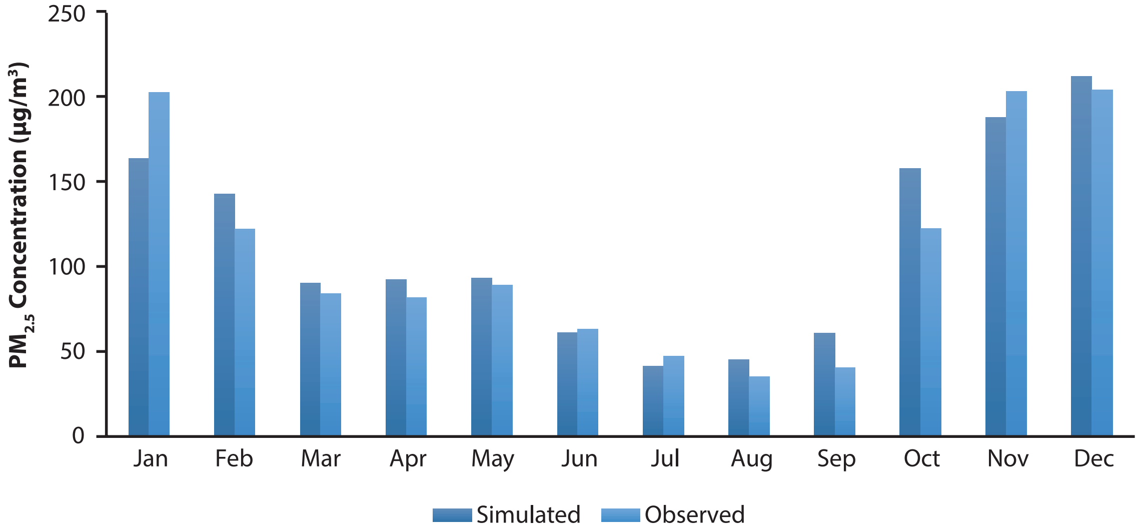

Figure 10(a): Monthly averaged modelled and observed $PM_{2.5}$ concentration (μg/m³) for Delhi (37 stations

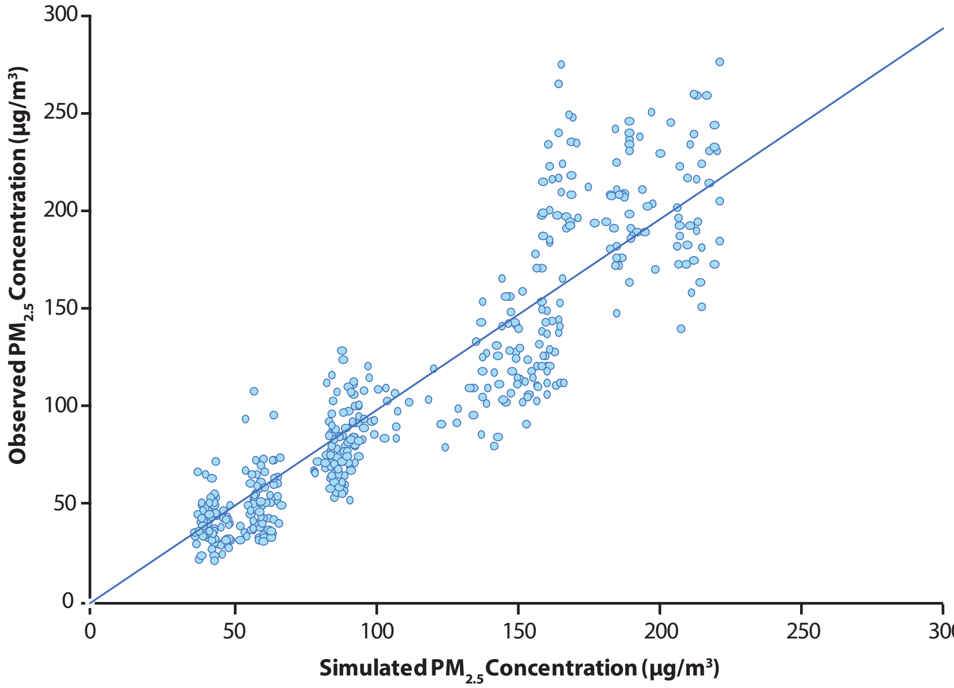

Figure 10(b): Scatter plot of monthly averaged modelled versus observed $PM_{2.5}$ concentration (μg/m³) for Delhi (37 stations).

6.3.1 Source Apportionment of $PM_{2.5}$ in Delhi (2019)

The validated model was used to carry out source sensitivities to derive relative source contributions. The seasonal $PM_{2.5}$ source contribution in Delhi estimated using air quality simulations are represented in Figure 11. The winter season comprises the months of December, January and February, summer includes the months of April, May and June, and post-monsoon includes the months of October and November.

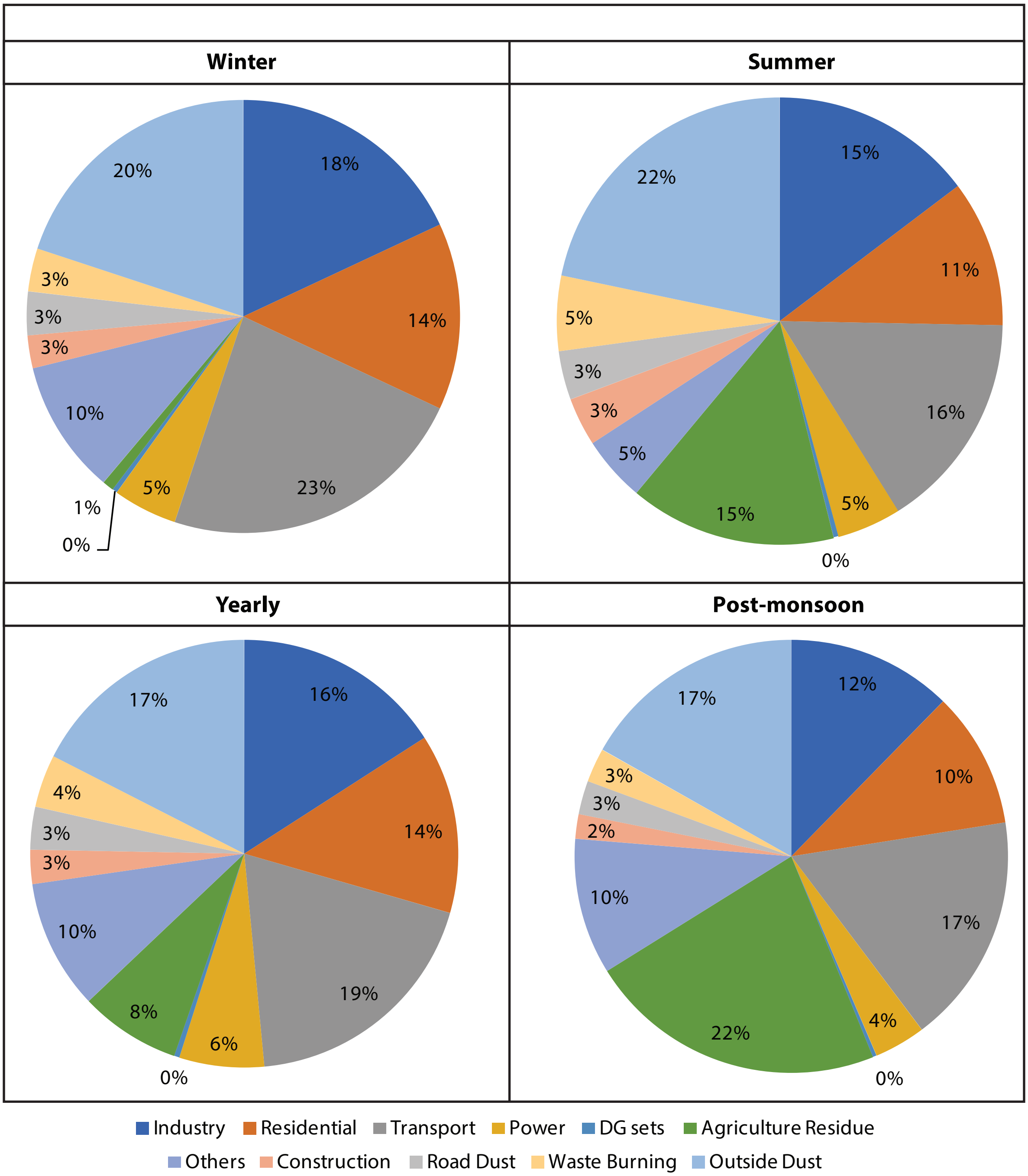

Figure 11: Yearly and seasonally averaged source contribution to prevailing $PM_{2.5}$ concentration (which includes both primary and secondary particulates) in Delhi in 2019

(Note: Others include contributions from crematoria, ammonia, biogenic, airport, restaurants and NMVOCs (which includes fugitive industrial process emissions from painting, adhesive use, edible oil production, solvent production, etc.)

The contributions shown above depict sectoral variations on seasonal basis. Agricultural contribution is found to be higher in post-monsoon and summer season due to burning of agriculture residue of paddy and wheat crop, respectively. However, due to dispersive atmospheric conditions in summers, the $PM_{2.5}$ concentrations are observed to be much less in summers than post-monsoon. Local sources have higher contribution in ambient $PM_{2.5}$ levels during winters as long-distance transport is relatively lower due to slower wind speeds. Hence, an increase in industrial contribution from 15% to 18%, residential shares from 11% to 14% and transport from 16% to 23%, can be observed between summers to winter $PM_{2.5}$ concentrations.

Assessment of yearly contribution of $PM_{2.5}$ shows that industries (including power plants) as major contributor (22%), followed by transport sector (19%) and residential sector (14%) in ambient $PM_{2.5}$ concentration in Delhi. Other sectors (crematoria, ammonia, biogenic, airport, restaurants and NMVOCs) together constitute 10% annually. Agricultural residue burning, which occurs only during a few months, contributes to about 7% in yearly averaged contribution, while it rises up to monthly averaged contribution of 24% in the post monsoon month of November. Road dust, and construction each contribute about 3%, while about 17% is contributed by dust from outside of India constitutes both secondary and primary particulates.

The increase in influence of local fossil fuel burning sources is quite evident in winter months where sectors like transport have 23% contributions in $PM_{2.5}$. The contributions from the transport sector is significant in winter time due to secondary particulate matter owing to higher nitrate formation in winter compared to summer. The sectors like construction and road dust that have large proportion of dust particles, have somewhat higher contribution in ambient $PM_{2.5}$ concentration in summers. This is understandable as dust suspension is higher in drier and windy conditions and less in the monsoon due to precipitation, and due to low wind speeds in winter. The comparison of sectoral contributions to more crucial winter-time $PM_{2.5}$ concentrations observed during 2016 (TERI & ARAI, 2018) and 2019 are presented in Table 6:

Table 6: Comparison of sectoral contributions to winter time $PM_{2.5}$ concentrations during 2016 and 2019

S.No	Sector	% share in 2016	% share in 2019
1	Transport	28%	23%
2	Industries incl. power plants	30%	23%
3	Biomass burning	15%	15%
4	Others	10%	13%
5	Dust incl. outside	17%	26%

**Others include DG sets, refuse burning, crematoria, airport, restaurants, incinerators, landfills, etc.*

6.3.2 Geographical contributions

The model has also been used to estimate geographical contributions to ambient $PM_{2.5}$ concentrations in Delhi. The geographical contributions vary as per prevailing meteorological conditions and source locations. The yearly averaged contribution in Delhi's ambient $PM_{2.5}$ concentration from Delhi's own emissions is estimated to be about 24%. Figure 12 shows the contributions of different regions in Delhi's $PM_{2.5}$ concentrations in different seasons. In comparison to 2016, Delhi's own sources contribute less in 2019. This is mainly due to controls on some sources (Badarpur power station closure, coal to gas shift in industries, peripheral expressways, road cleaning, etc), and also due to meteorological changes observed during 2019. The average wind speeds in 2019 were somewhat higher than in 2016, which means that long range atmospheric transport would be higher in 2019. This has been successfully reproduced by the model for the year 2019.

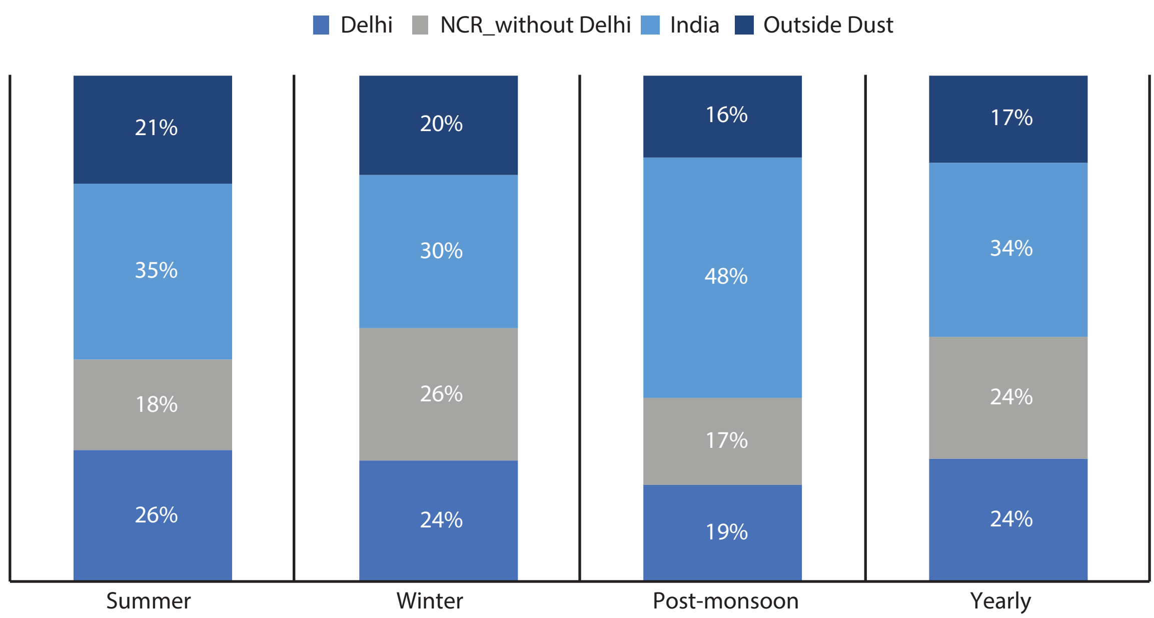

Figure 12: Geographical contribution towards $PM_{2.5}$ concentrations in Delhi

From Figure 12, it may be inferred that contribution from rest of India becomes more dominant during the post-monsoon months when open agriculture residue burning is prevalent in the upwind states of NCR.

6.4 Future projections of air quality in Delhi

6.4.1 BAU scenario

In order to understand the effect of growth in different sectors on air pollution in the region, analysis of future air scenarios was also carried out. In this regard, possible future growth scenarios were prepared for the years 2022 (short term), 2025 (medium term), and 2030 (long term). First, a Business as Usual (BAU) scenario was developed, which takes into account the growth trajectories in various sectors and also the policies and interventions, which have already been notified for control of air pollution. Table 3 shows the growth rates and control strategies assumed to assess future air quality scenarios for Delhi. The projected emission loads in BAU scenario for different pollutants like $PM_{2.5}$, NO_x and SO_2 in the years 2022, 2025 and 2030 are shown in the Figure 13,14 and 15.

From 2019 to 2030, the total $PM_{2.5}$, NO_x and SO_2 emissions for NCR are projected to decrease by 37%, 47% and 60% respectively (Figure 13). This is due to declining biomass use in rural kitchens, gradual shift to advanced BS-VI technology vehicles, reduced open agricultural burning, and enhanced CNG penetration in the industrial sector.

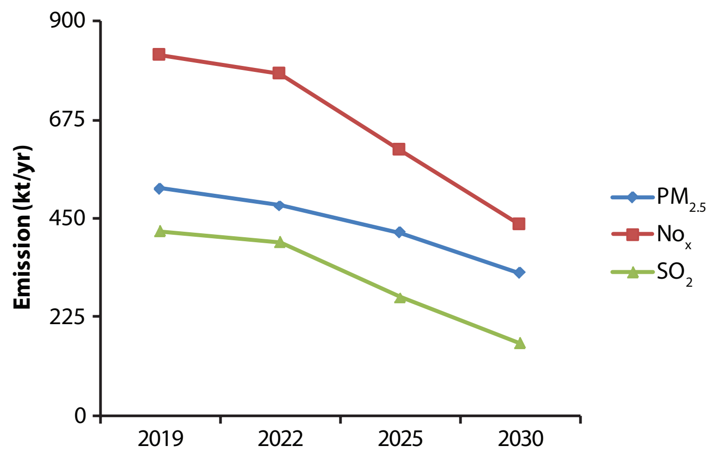

Figure 13: Estimated total $PM_{2.5}$, NOx and SO_2 emission load in NCR in the BAU scenario during 2019-2030

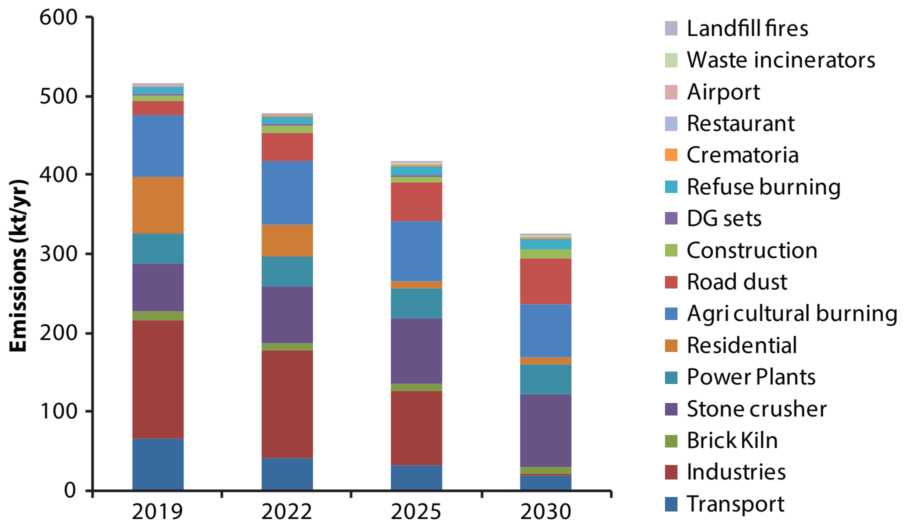

Figure 14: $PM_{2.5}$ emissions of different sources in NCR in BAU scenario for 2019, 2022, 2025 and 2030

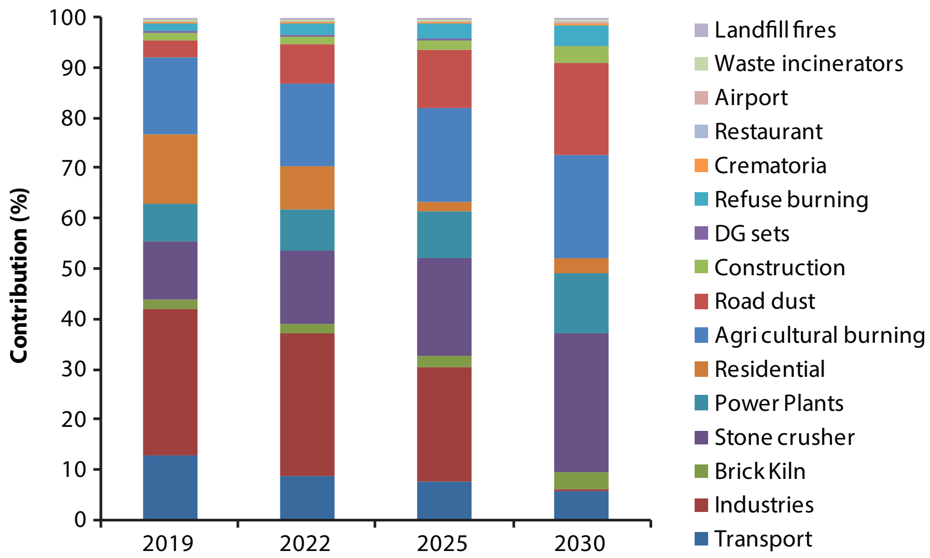

Figure 15: Percentage contribution of different sources in $PM_{2.5}$ emissions in NCR in BAU scenario for 2019, 2022, 2025 and 2030.

It is important to note that in the year 2030, emission from combustion sources are expected to reduce due to expected stringent controls, while the contribution of dusty sources such as road dust and stone crushers will increase (Figure 14, 15). The shares of some of the combustion sources such as power plant, agriculture residue burning is expected to stay with limited control expected. However, SO_2 and NO_x emissions from power plants are expected to reduce with introduction of new advanced emissions norms. This indicate that in order to maintain or improve air quality in future years, it is equally important to control these sources in addition to transport, industries and residential biomass burning,

After estimation of emissions for BAU scenario, air quality simulations were carried out for predicting winter-time $PM_{2.5}$ concentrations in Delhi and results are presented in the Figure 16. As seen in the Figure 16, despite 37% reduction in $PM_{2.5}$ emissions in NCR in the year 2030 w.r.t 2019, the winter time $PM_{2.5}$ concentrations in Delhi will go down by only 28%, and hence will remain well above the NAAQS. The strategies like BS-VI and ban on 10-yr old diesel vehicles will lead to 11% reduction, while 10% and 5% reductions are expected in residential and industrial sectors, respectively, due to penetration of gaseous fuels by 2030 in a BAU scenario. Some sectors like road dust, construction, and others are expected to show an increase in $PM_{2.5}$ concentrations.

This indicates that further reduction in Delhi's $PM_{2.5}$ concentrations will require airshed based controls, i.e. additional controls beyond NCR. This also points towards need for development of additional or alternative strategies for control of $PM_{2.5}$ concentrations in Delhi. In order to formulate an alternative scenario, which can help meeting NAAQS in future, a set of interventions is tested for their $PM_{2.5}$ reduction potential. Detailed description of these interventions is provided in the Table 4 and results are presented in the next section.

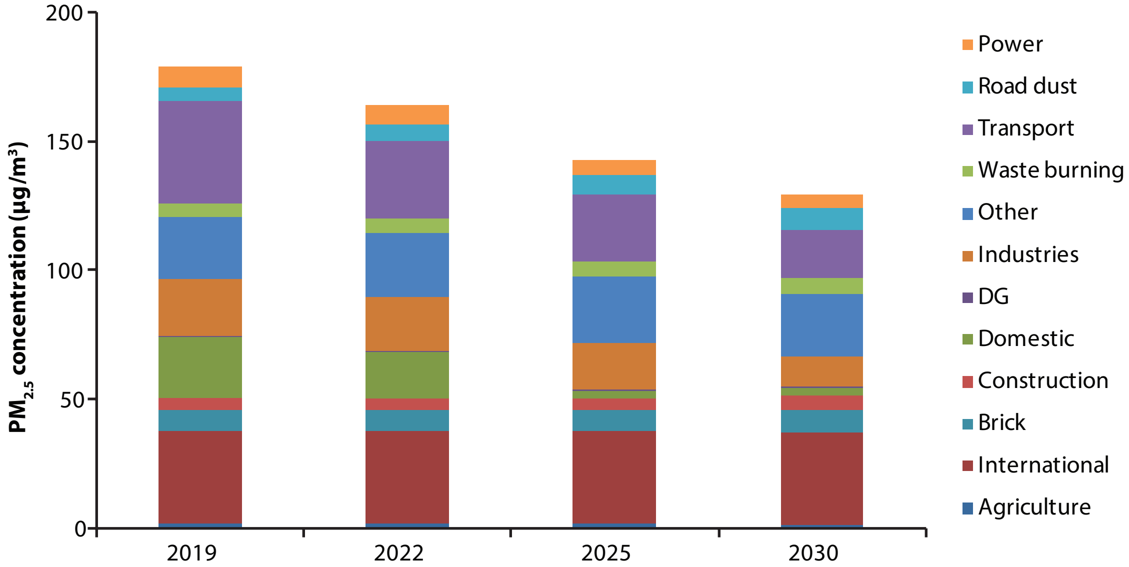

Figure 16: Winter-time $PM_{2.5}$ concentrations in BAU scenario in the year 2019, 2022, 2025 and 2030

6.4.2 Assessment of potential of alternative strategies for control

In order to select high impact strategies for control and construct the alternative air quality scenarios, an intervention analysis was performed to estimate the emission and concentration reduction potentials of different control strategies in transport, biomass, industries, and other sectors. The reduction potential was derived for different strategies based on their implementation in NCR and also in the whole airshed (NCR+ regions in India beyond NCR).

Biomass burning (Residential and agricultural residue)

Residential and agricultural residue sectors contributions to winter $PM_{2.5}$ concentrations were 13% and 1%, respectively in NCR in 2019. The share of agricultural residue burning increases to 22% in post-monsoon months, however this future air quality analysis was carried out for winter season only. In BAU scenario, the share of residential sector falls to 12%, 4%, and 4% in winter $PM_{2.5}$ concentrations during 2022, 2025, and 2030, respectively. This was due to the assumption of further LPG penetration in Delhi's airshed in the next 10 years. In BAU scenario, the winter season share of agricultural residue burning was expected to remain 1% in all three years i.e.2022, 2025, and 2030. A few strategies were analysed for assessment of reduction potential of $PM_{2.5}$emissions and concentrations in the two sectors. These included a) complete LPG penetration in households, b) supply of induction cook-stoves, and c) use of agricultural residues in power plants in NCR.

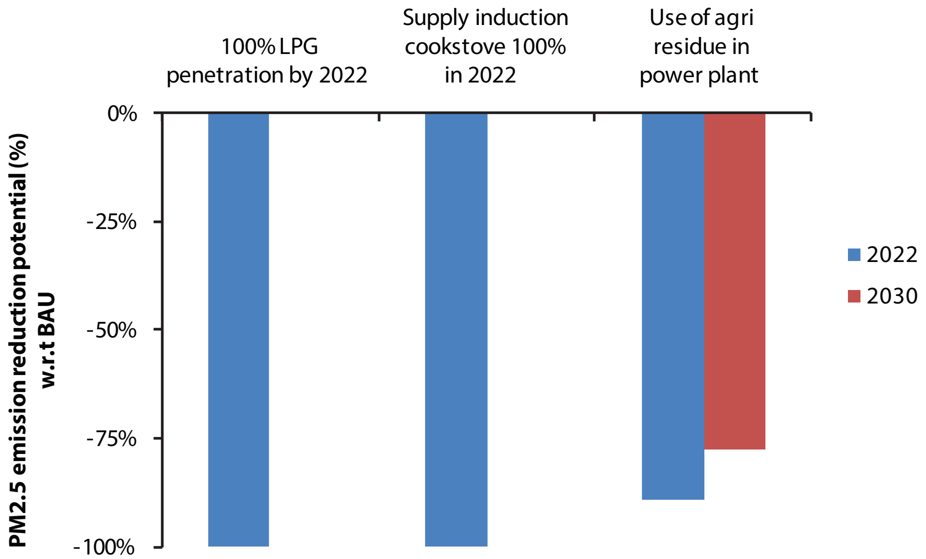

Figure 17: $PM_{2.5}$ emission reduction potential of various strategies with respect to residential sector emissions in controlling biomass burning in NCR in the year 2022 and 2030

* Reduction of potential for the agri burning strategy is with respect to sum of agri. burning and power sector emissions where agri residues are envisaged to be used with coal.

The strategies in the residential sector showed that enhanced LPG penetration can reduce total $PM_{2.5}$emissions from residential sector in NCR by about 99% in 2022, and similar emission reductions (100%) can be envisaged with provision of induction based cook-stoves. In addition to $PM_{2.5}$, the strategy of LPG penetration also shows significant reduction of 81% in NO_x emissions in 2022, while induction cook stoves would lead to reduction of 100% in NO_x emissions also. Strategies for agricultural residues aim at collection and full use of these residues for purposes like blending with coal in power plants, which can lead to a reduction of 89% in $PM_{2.5}$ emissions collectively from agri. residues burning and power sector in NCR by 2022, and 78% reduction by 2030 (Figure 17).

Emissions for different strategies are fed into the model to estimate the impact of these strategies on winter season $PM_{2.5}$ concentrations in Delhi. The concentration reduction potential of various strategies are not similar as emission reduction potential, as it also depends on to meteorological factors and location of sources. It was found that a maximum of 2-3% reduction in winter concentration of $PM_{2.5}$ by 2030 can be achieved by using agricultural residues in power plants (Table 7). Other strategies of LPG and induction cook stoves penetration in the whole airshed are expected to reduce about 9.5% in 2022 and 2% in 2030 with respect to BAU scenario. The lower reductions shown by the strategy in 2030 are because of 80% coverage of LPG already assumed in the BAU scenario by 2030.

Transport

Transport sector is one of the prominent contributors in $PM_{2.5}$ concentration in NCR. In 2019, the transport sector was found to contribute about 23% of $PM_{2.5}$ concentration in winter. However, in 2022, 2025 and 2030 its share is expected to decline to 19%, 18%, and 15%, respectively, mainly due to gradual introduction of BS-VI emissions norms. However, in order to further reduce its share, various strategies have been tested using the model. These strategies are provided in the Table 7 and the emission reduction potential of these strategies are presented in Figure 18.

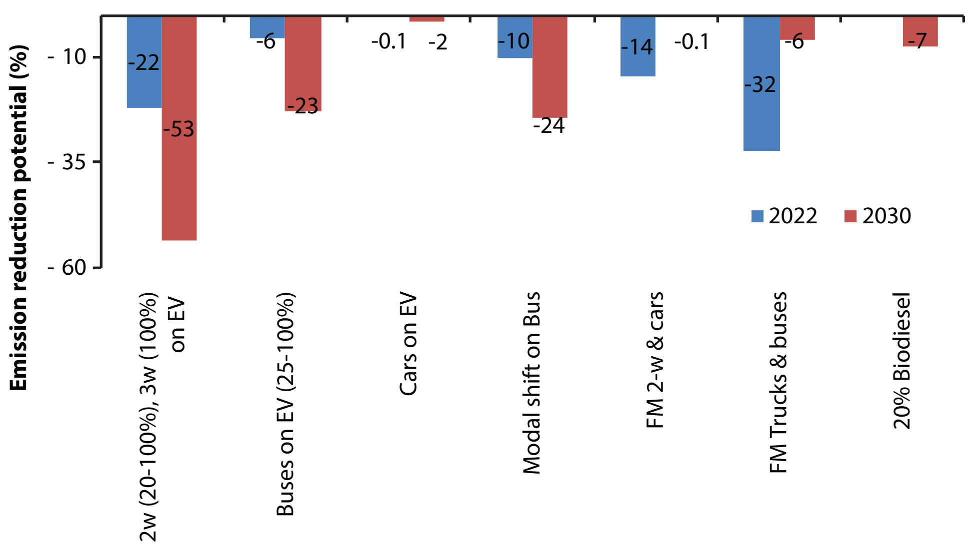

Figure 18: $PM_{2.5}$ emission reduction potential of various strategies with respect to total emissions in transport sector in the year 2022 and 2030

Since the share of transport is significant in total $PM_{2.5}$ emissions in NCR, substantial reductions were observed in $PM_{2.5}$ emissions due to interventions. Electrification of buses is expected to result in reduction of 6% and 23% in $PM_{2.5}$ emissions from transport sector in 2022 and 2030, respectively (Figure 18). Corresponding reductions in emissions due to shift of two and three wheelers on electric modes are 22%, and 53% respectively. Fleet modernization (replacing older vehicles with BS-VI) in trucks and buses leads to 32% and 6% reductions in $PM_{2.5}$ emissions in NCR in 2022 and 2030, respectively. Fleet modernization in two wheelers and cars leads to 14%, and 0.1% in $PM_{2.5}$ emissions, in 2022 and 2030, respectively. The reductions increase in case of greater penetration of electric vehicles in future, which is not assumed in BAU. However, in case of fleet modernisation, early turnover of the fleet will show higher reductions in 2022, but the reductions are smaller in 2030 as the fleet will gradually modernise to BS-VI norms in future in the BAU scenario.

The emissions estimated for different strategies are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ concentrations during winters in Delhi. Electrification (buses, autos, 2-wheelers and cars) of vehicular fleet shows reduction of 3.6%, 4.7% and 5.4% in $PM_{2.5}$ concentrations by 2022, 2025 and 2030, respectively in Delhi (Table 7). Fleet modernization leads to 7%, 5% and 0.2% reduction in $PM_{2.5}$concentrations by 2022, 2025 and 2030, respectively in Delhi. The strategy of increasing penetration of biodiesel shows slight reductions of 0.4% and 0.1% in $PM_{2.5}$ concentrations by 2025 and 2030, respectively in Delhi.

Industries

Industries contributed to about 18% in $PM_{2.5}$ concentrations in 2019. Power plants were found to contribute 4-5% to $PM_{2.5}$ concentrations in the years 2019-2030. Similar contributions were estimated for the years 2022, 2025, and 2030. Evidently this sector has high potential for control of emissions and $PM_{2.5}$ concentrations. The emission reduction potential of various strategies with respect to total emissions of respective sub-sectors e.g. power plants, bricks, stone crushers, and other industries were analysed and results are presented in Figure 19.

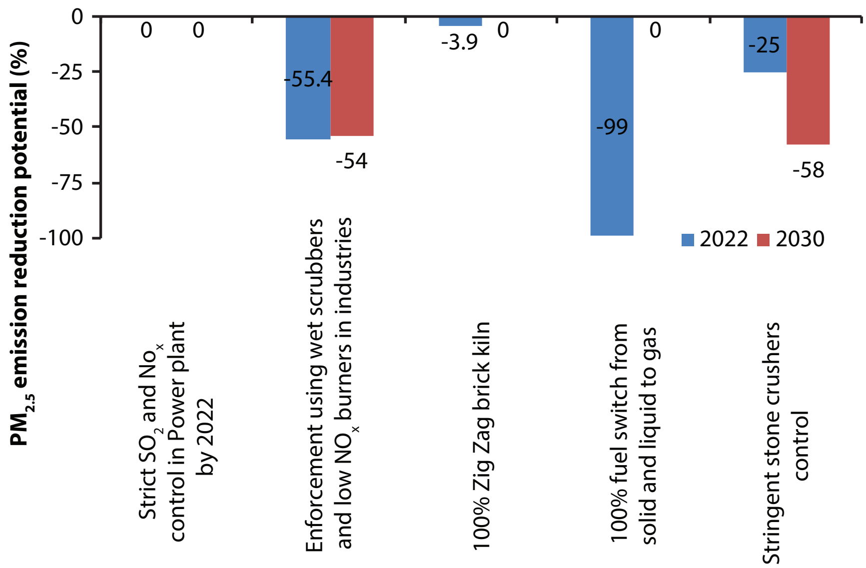

Figure 19: Emission reduction potential of various strategies in industrial sector in the year 2022 and 2030 w.r.t to sub-sectoral emissions (of power plants, bricks, stone crushers and other industries) in BAU scenario

It was realised that the maximum reduction in emissions of $PM_{2.5}$ can be achieved by completely switching solid and liquid fuel to gaseous fuel in industries in NCR, with reduction of 99% in $PM_{2.5}$ emissions by 2022 with respect to BAU. No further reductions are expected in 2030 as the BAU itself assumers 100% gas penetration in industrial sector in NCR. (Figure 19). Implementing stringent NO_x and SO_2 standards are not expected to reduce $PM_{2.5}$ emissions in NCR. However they will result in reducing secondary particulates in $PM_{2.5}$ concentrations in Delhi. 100% penetration of Zig-Zag technology in the brick kiln sector may lead to reduction of 4%, in $PM_{2.5}$ emissions in NCR in 2022 with respect to BAU, which itself includes a gradual penetration of zig-zag technology in the brick kiln sector by 2030. Strict PM control in stone crushers lead to 25% and 58% reduction in $PM_{2.5}$ emissions by 2022 and 2030, respectively in NCR.

The reduced emissions for different industrial emission control strategies were fed into the model to estimate the impact of these strategies on $PM_{2.5}$ concentrations. Fuel switch to gaseous fuels can lead to a reduction of 5.4% in $PM_{2.5}$ concentrations in 2022 and further reduction to 4% in 2025. (Table 7). If there is further penetration of CNG in the whole airshed, the reductions to $PM_{2.5}$ concentrations from this strategy would be 7% in 2022 and 13% in 2030. Stricter enforcement of use of wet scrubbers and low NO_x burners in industries leads to 3% reduction in $PM_{2.5}$ concentrations in 2022 to 4% in 2030 with respect to BAU. Enforcement of stringent NO_x and SO_2 standards in power plants would lead to approximately 1%-2% reduction in $PM_{2.5}$ concentrations by 2030.

Dust

Fugitive dust emissions from road and construction and demolition (C&D) activities contributed about 6% in $PM_{2.5}$concentrations in 2019. In 2022, the share of these two sectors was estimated to increase to 7%, and thereafter to 11% by 2030. Emission reduction potential of controls such as wall-to-wall paving, 100% vacuum cleaning on arterial roads, and strict norms for construction activities were assessed. The reduction potential of $PM_{2.5}$ emissions with respect to total emissions in these sectors are shown in Figure 20.

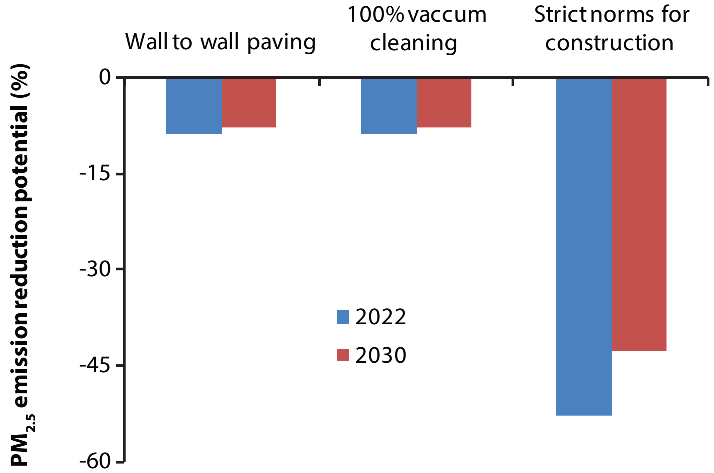

Figure 20: $PM_{2.5}$ emission reduction potential of various strategies (with respect to emissions of road dust and construction sector) to control dust in NCR in the year 2022 and 2030.

Wall-to-wall paving strategy is estimated to have a reduction of 9% in $PM_{2.5}$ emissions from road dust in short term by the year 2022 and similar reduction was estimated for 2030 in NCR. Silt removal using vacuum cleaning machines and strict norms for construction activities showed reduction of 8% and 53% in $PM_{2.5}$ emissions in the respective sectors by 2022, and reduction of 8% and 43% by 2030, respectively. The reduced emissions for different dust emission control strategies were fed into the model to estimate the impact of these strategies on $PM_{2.5}$ concentrations. Control of dust by wall-to-wall paving and vacuum cleaning of arterial roads is expected to reduce 0.3% of $PM_{2.5}$ concentrations in NCR by 2022. The low reductions are due to coverage of arterial roads only, and silt content is generally higher on sub-categories of the roads. Strict enforcement of norms for construction activities showed reduction of 1.3% in 2022 and 1.5% in in 2030 in $PM_{2.5}$ concentrations in Delhi with respect to BAU (Table 7). Considering, these sectors have higher shares in coarser fractions of PM, reduction potentials are expected to be higher for PM_{10} concentrations.

Table 7: Winter time $PM_{2.5}$ concentration reduction potential of various interventions if taken in NCR or in whole airshed

Sector	Intervention	$PM_{2.5}$ reduction (%)								
		BAU w.r.t 2019			ALT-NCR w.r.t BAU			ALT- air shed w.r.t BAU		
		2022	2025	2030	2022	2025	2030	2022	2025	2030
Domestic	Increase in LPG penetration in NCR by 80% in 2025/2030 in BAU and 100% in ALT	-2%	-10%	-10%	-4%	-1.1%	-1.4%	-9.5%	-1.4%	-2.0%
	Supply improved induction cook-stoves 100% in 2022 ,2025 and 2030 to households using biomass	-	-	-	-5%	-1.5%	-1.8%	-	-	-
Agriculture residue and power plant	In-situ management of 14%-50% residue in BAU (2022-2030) and in ALT 100% use of residues in power plants in 2022-2030	-0.4%	-1.1%	-0.8%	-	-	-	-3%	-2%	-2%

Table 7 *contd...*

Sector	Intervention	PM$_{2.5}$ reduction (%)								
		BAU w.r.t 2019			ALT-NCR w.r.t BAU			ALT- air shed w.r.t BAU		
		2022	2025	2030	2022	2025	2030	2022	2025	2030
Transport	BAU assumes BSVI implementation and ban on 10 year old diesel vehicles. ALT: Electrification of vehicular fleet (Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%)	-5%	-7%	-11%	-4%	-5%	-5%			
	Public transportation -25% in 2022, 50% in 2025 and 100% in 2030				-1.1%	-1.8%	-1.0%	NE	NE	NE
	Private electric vehicles- 20% in 2022 and 40% in 2025 and 100% in 2030 electric two-wheelers, and 100% three-wheelers in 2022				-3%	-3%	-4%	-3.5%	-4.0%	-5.8%
	Private electric vehicles- 10% in 2022, 20% in 2025 and 40% in 2030 electric cars				-0.1%	-0.3%	-0.3%	-0.1%	-0.4%	-0.4%
	25% Modal shifts of cars and 2-wheelers to CNG buses by 2022, 2025 and 2030				-0.6%	-0.6%	-0.3%	NE	NE	NE
	100% fleet modernization to BS-VI vehicles from 2022, 2025 and 2030				-7%	-5%	-0.3%	NE	NE	NE
	100% fleet Modernization of 2 & 4-wheelersto BS VI by 2022, 2025 and 2030				-1%	-1%	-0.1%	NE	NE	NE
	100% fleet Modernization of trucks and buses to BS VI by 2022, 2025 and 2030				-6%	-4%	-0.2%	-7.0%	-5.3%	-0.3%
	Increase penetration of biodiesel to12% by 2025 and 20% by 2030				0	0%	-0.1%	0.0%	0.0%	-0.1%

Sector	Intervention	$PM_{2.5}$ reduction (%)								
		BAU w.r.t 2019			ALT-NCR w.r.t BAU			ALT- air shed w.r.t BAU		
		2022	2025	2030	2022	2025	2030	2022	2025	2030
Power plant	Power plant controls – 20-80% in BAU between 2022-2030 and 100% implementation of stricter NO_x and SO_2 standards with continuous monitoring by 2022 in ALT	-0.4%	-1.0%	-0.6%	-1.7%	-0.6%	-0.2%	-2.3%	-1.0%	-0.4%
Industries	Enforcement of PM_{10}/ $PM_{2.5}$/SO_2/NO_x standards in industries by installing wet scrubbers and low NO_x burners: 12-50% in BAU and 100% ALT in 2022, 2025 and 2030	-0.4%	-1.8%	-5.0%	-3.6%	-2.9%	-0.4%	NE	NE	NE
	Fuel switch from solid to gaseous fuels: 20%-100% in BAU in NCR and 100% in 2022, 2025 and 2030 in NCR/ airshed.				-5.4%	-4%	-0%	-13%	-12.3%	-7.4%
	Stricter dust control on stone crushers				-0.2%	-1.2%	-1.4%	NE	NE	NE
Brick kiln	Enforcement (100%) of zig-zag brick kiln technology in 2022, 2025 and 2030	-0.1%	-0.1%	0.2%	-0.1%	0.0%	0.0%	-0.1%	0.0%	0.0%
Road dust	Vacuum cleaning of roads – 80% coverage of arterial in BAU and 100% coverage in ALT in 2022, 2025 and 2030	0.6%	1.1%	1.9%	-0.3%	-0.4%	-0.4%	NE	NE	NE
	Wall to wall paving- 100% coverage of arterial roads in 2022, 2025 and 2030				-0.3%	-0.4%	-0.4%	NE	NE	NE
Construction	Control of dust from construction activities- barriers and fogging based controls: 15%-30% in BAU and 60% in ALT in 2022, 2025 and 2030	0.2%	0.4%	0.8%	-1.3%	-1.4%	-1.5%	-1.3%	-1.4%	-1.5%

After estimating the air quality reduction potential of various interventions, the cost of implementation was estimated to analyse the different interventions in terms of their cost effectiveness i.e. cost per unit reduction in $PM_{2.5}$concentration.

ALT NCR w.r.t BAU is a scenario where the strategy is being implemented in NCR region only and ALT airshed w.r.t BAU represent a scenario where the strategy is implemented in the whole airshed region contributing to $PM_{2.5}$ pollution in the city of Delhi

**NE: Not estimated*

7. COST EFFECTIVENESS ANALYSIS OF CONTROL OPTIONS

A comprehensive economic assessment of selected interventions was undertaken to understand their cost effectiveness in reducing emissions and improving air quality in the region, thereby helping to take decisions for future investments in the air quality management action plan. Further to setting indicators to the targets for air pollution control, any strategic planning activity includes the evaluation of quantum of investments for the proposed intervention. The purpose of this exercise is to understand the cost implications of air pollution abatement interventions over next 10 years.

Decisions on air pollution reduction strategies are based on emission reduction potential, ease of implementation, investments, user's cost etc. The overall objective of the exercise is to estimate the economic costs and benefits of air pollution control interventions in selected sectors for improving ambient air quality in Delhi NCR.

7.1 Overall Approach for Economic Analysis

Economic analysis has been undertaken based on a stage-wise approach starting with the analysis of input and output parameters. These parameters have implications on unit level resource/fuel consumption, capital costs of proposed interventions and the consequent operational costs and benefits over a phased manner. The sector specific approach is discussed in the further sections while this section encompasses the broad overall approach undertaken. The input output profile of materials, energy and emissions has been created for each economic activity for which the intervention is proposed. The current level of activity has been analysed using the baseline information from primary and secondary sources and appropriate growth rates have been assumed for arriving future activity estimates and further costs and benefits. This is followed by identification of different cost heads of each intervention that include capital costs and/or costs associated with technology/ process upgradation or switching while benefits are those arising from improved efficiency. The fixed costs of the interventions are levelised for the period of intervention using the full life of the project. While transfer payments (i.e. taxes and subsidies) does not constitute resource cost and is excluded from the analysis. (squire *et al*, 1975). Discount factor of 10% have been used to estimate the present discounted net costs/benefits arising from the proposed interventions. Data related to activity, efficiency, capital costs and/or costs associated with technology/process upgradation or switching are based on information from literatures, consultation with sector experts, technology providers etc.

The economic analysis presented in the report can be divided in four broad sections:

1. ***Net Economic Cost Analysis:*** The section 7.2 below discusses the net economic cost of the interventions proposed for each sector. The analysis includes the estimation of costs as well as the direct benefits that will be accrued during operations. The NPV of estimated net costs of interventions for each sector is presented in table 35.
2. ***Cost Effectiveness analysis:*** The section 7.3 measures the cost effectiveness of the proposed intervention, analysis are undertaken by measuring the ratio of the net cost of the intervention to the outcome i.e. reduction in $PM_{2.5}$ (microgram per m3) from ambient air.
3. ***Social Cost/ Health Benefits:*** The cost analysis is also followed by a health impact assessment where the total mortality and the total economic loss from exposure to $PM_{2.5}$ pollution has been estimated. The benefits are than estimated for the avoided mortality in the proposed alternate scenario that are presented in chapter 8. The detailed methodology and results of the health impact assessment are given in the Annexure attached.

4. ***Benefit to Cost Ratio analysis:*** Based on the estimated net economic benefit from the health impact assessment and the net cost of the intervention, benefit to cost ratio is estimated and presented in annexure.

7.2 Economic Analysis

7.2.1 Biomass

There are quite a number of ways how the emissions from biomass (cooking/agri) residue can be controlled thereby reducing social costs while increasing efficiency of their utilization. However, the irresponsible usage of biomass can lead to no net benefit in terms of air pollution. It has been assumed that unused crop residue will be ploughed back to the soil at no additional cost. The proposed interventions to control the burning of biomass in region are listed as follows in Table 8:

Table 8: Biomass burning related Interventions

Sl. No	Interventions
1	*Enhanced use of LPG in residential sector*
2	*Supply of improved induction cook-stoves*
3	*Better utilization of crop residue using happy seeder*
4	*Use of Agri residue pellets in power plants*

The following section presents the method employed in the CBA, factors influencing the results and the cost estimates for each intervention to achieve the targets.

Enhanced use of LPG in residential sector

Shift from biomass to cleaner cooking fuels is a crucial step towards a high efficiency economy transition while improving ambient air quality. LPG based cook stoves is efficient alternative compared to conventional biomass based cook-stoves where large fraction of the fuel energy is lost because of low combustion efficiency. LPG cook stoves offer higher efficiency of around 45-50% compared to 8-10% in conventional biomass fired 'Angithi and Chulhas'. A transition will lead to better utilization due to efficiency of useful energy thereby reducing energy consumption and emissions.

An estimated 1.6 million households in 2019 were estimated to be dependent on biomass for cooking primarily using fire-wood, crop residue, and dung cakes as the fuel source in the NCR region. A gradual transition will lead to 0.9 million households using biomass by 2022 under the baseline scenario. In the accelerated intervention scenario, it is assumed that 100% of the households will switch to LPG for cooking by 2022. Only one LPG connection per household has been assumed for the intervention scenario. However these households will be eligible for subsidy of up to 12 cylinders per annum, beyond which the consumers may need to pay the full market price. The useful energy analysis has been undertaken followed by the economic analysis using the efficiencies of conventional and efficient LPG stoves. The consumption of biomass is converted to total energy content (in PJ) available in the fuel source and the useful energy has been estimated based on efficiency of conventional cook-stoves as well as LPG cook-stoves. There is no as such competitive market of biomass, and sold in a distorted market neglecting externalities cost. Thereby cost of biomass has been assumed based on the interactions which mainly includes harvesting, transportation and distribution costs. The calorific value and the cost of fuel which have been used are listed as follows in Table 9:

Table 9: Calorific Value and Cost of different fuels under scope

Fuel	Calorific Value (kcal/kg)	Cost/kg/kWh*
Fire-wood	3500	5
Crop residue	2500	4
Cow-dung cake	1672	2
Coal, Lignite, Charcoal	4166	6
Kerosene	10750	22#
LPG – 14.2 kg	9000	650

** based on stakeholder inputs*

 # Per litre

Tariff for new LPG connection and the subsidy amount are the key costs associated with a transition to LPG. The LPG connection cost is taken as INR 2300 rupees per connection. This includes security deposit for cylinder (14.2 kg), security deposit for pressure regulator, and other administrative, inspection, and installation charges.

The present discounted value of user cost of biomass for cooking has been estimated at INR 39.44 bn (billion) till 2022. On the other hand a transition to LPG will imply a total connection cost of INR 1.66 billion (borne by end users) and INR 0.36 bn as cost of LPG cookstoves). The user cost for LPG switch is INR 2.02 bn. This is presented in Table 10.

Table 10: Comparative cumulative discounted costs of biomass and LPG for 2022

Cost heads	NPV (in Billion rupees)
Cost of biomass in BAU	39.44
Cost of Connection (borne by end user)	1.66
Cost of LPG cookstoves	0.36
Cost of Energy from LPG	10.90
Net economic benefit	26.52

Supply of improved Induction Cook Stoves

Electric Induction stove is another efficient alternative to conventional biomass cook stoves. The efficiency of the electric stoves used in India is about 75%, with the significant improvement compared to currently used LPG and biomass cook stoves. Improving the cook-stove efficiency will reduce the total energy consumption and could also improve experience of cooking. Subsequently, induction stoves hardly cause any indoor or outdoor pollution. This intervention aims to supply improved cook-stoves in all the biomass using households of NCR by 2022.

Baseline data for households dependent on biomass remains the same as used for the above analysis for LPG usage. The major cost to be incurred includes that of a new induction cook-stove which is assumed to be INR 2000 per unit based on the market survey, and another 1000 rupees for induction friendly containers for cooking. It is assumed that one induction cook stove will be required per household. The useful energy analysis has been undertaken prior to estimation of cost of electricity. Useful energy requirement for cooking in NCR in 2019 is estimated in Table 11.

Table 11: Useful energy requirement for cooking in NCR in 2019

	stove effciency	Energy (PJ)
Energy Total of Biomass		66.44
Useful Heat from Biomass	8%	5.31
Electric energy required from Induction cook stoves	75%	7.08

The present value of the total cost of the intervention is estimated to be INR 15.99 billion . The cost comprises of 2 components: cost of induction cook-stove and related container, which is estimated at 0.54 billion rupees and associated cost of energy due to shift from biomass to electricity. The total discounted cost of electricity is estimated at INR 15.45 billion for 2022.Thus the total discounted cost is INR 15.99 billion and the net benefit is INR 23.45 billion (Table 12).

Table 12: Discounted costs of electricity and induction cook-stoves for cooking till 2022

Cost heads	NPV (in Billion rupees)
Cost of Induction cook-stoves	0.54
Cost of energy	15.45
Total cost	15.99
Cost of biomass in BAU scenario	39.44
Net Economic Benefit	23.45

Better utilization of crop residue using happy seeder machines

Since mid-1980s, the practice of manual harvesting has been replaced by automatic combined harvesters that leave behind a significant portion of the crop residue in the agricultural fields. Due to the lack of affordable crop residue removal mechanisms and relatively a very short time window for preparing the land for the next crop, the residue is subjected to burning in open fields.

The option of burning seems preferable to the farmers as it is a cheap process and quick and easy to execute. It does not require significant manpower and it enables timely sowing of the next crop. However, residue burning results in heavy air pollutant loading in the atmosphere.

While there are various technologies and processes that offer solutions to the current crop residue burning problem, in-situ utilization using machines e.g. happy seeders have been considered in this study to assess the costs involved. The intervention aims to use happy seeder machines for mulching the crop residue in the fields rather than burning the crop residue. The target years have been set as 2022 and 2025.

The area under farming for Delhi-NCR, Haryana and Punjab is assumed to remain constant for the intervention years. The total area and the average land size are presented in Table 13.

Table 13: Baseline data and assumptions regarding area under cultivation and average land size for selected crops

Region	Area (ha)	Average land size (ha)
NCR (excluding Haryana and Punjab)	1789	1.2
Haryana	28873	2.2
Punjab	196373	3.6

Source: Ministry of Agriculture

The happy seeder machine is needed to be attached to tractors for operation and it is assumed that the number of tractors required to pull the happy seeder machines already exist. Currently, government provides subsidies on happy seeder purchases for residue management. The subsidy is to the tune of 80% if a farmer group makes the purchases, and 50% if an individual farmer purchases the machine. However, no subsidy has been assumed for the analysis while it has been assumed that the purchases are made by farmer groups and the happy seeders are used optimally among these groups. The capital cost of a happy seeder machine is taken as INR 1, 75,000 which is levelised upto 2022, 2025 assuming 10 years of life of happy seeder. The fuel requirement of a happy seeder is 0.8 litres to cover a single hectare of farm area and the current fuel prices for the year 2020 have been considered for analysis.

The economic estimate reveals that if the intervention target is completed by 2022, the approx. cost incurred would be 0.19 billion rupees. However, if the target is achieved by 2025, the estimated present value of cost will be 0.35 billion rupees as presented in Table 14. The benefits of this strategy will be maximum during the post monsoon season when contributions of agri. residue burning are be highest.

Table 14: Cumulative discounted capital and fuel costs of using happy seeders for 2022 and 2025

Cost Heads	2022 - 100% coverage	2025 - 100% coverage
Capital Cost (NPV in billion INR)	0.19	0.33
Fuel Cost (NPV in Million INR)	0.23	0.50
Total (NPV in billion INR)	0.19	0.34

Use of Agri-Residue in Power Plants

Modern bioenergy is increasingly recognized as an important low carbon alternative to meet climate policy targets and air quality goals. The processed biomass pellets in its compact form has gained recognition for co-firing in coal based power plants for electricity generation. While agro-residue burning is a predominant issue in NCR, there is a huge scope of utilization of biomass pellets in power plants for energy generation. There will be two fold benefits of the biomass usage in power plants, one it will eliminate stubble burning in farms reducing emissions and secondly, it will reduce coal usage and associated emissions (flyash and sulphur related) in power plants.

Currently, coal has the largest share of utility power generation in the country, accounting for approximately 74% of all utility-produced electricity (CEA, 2019). Coal combustion in thermal power plants results in GHG emissions, air and water pollution which have detrimental effects on environment and public health. The key challenge faced by the thermal power plants in future would be to reduce the overall environmental footprint of electricity generated. The total surplus biomass availability in India stands at around 145 Million Tonne (MT) which can substitute part of the coal usage in power plants (MoP,2020). The use of torrified biomass pellets doesn't require any extra capital investment at the power plant.

There are several technology options available for large scale pelletization, which increases the specific density of biomass to more than 1000 kg m-3 which can be used as feed along with coal in thermal power plants. Recently, NTPC limited has decided to procure and use 6 million tonnes of agro residue-based pellets to co-fire its power plants, in its endeavour towards more sustainable power generation. This would help power plants to reduce their carbon footprint and also help overall power generation.

On the other hand, this would create a new value chain for aspiring entrepreneurs and an opportunity to farmers to channelize the agri-residue which is currently being burnt in fields. It would be a new income source for the farmers if they sell their agri-residue to the producers of biomass pellets, who in turn would sell the processed residue pellets to the power plant owners. Replacing coal with residue pellets would be a cheaper way of producing energy for the power plant owners, and the emission loads would be far lower than energy generation from coal. Also the secondary emissions related to transportation of coal from distant mines will be substantially reduced.

Therefore, the proposed intervention is a no regret option and win-win opportunity for all where farmers get a new income source; new manufacturers would enter the market, creating a new market for the entrepreneurs; and the power plant owners will be able to generate the energy they require at a cheaper cost with lower emission.

7.2.2 Transport

With rapid urbanization and a growing middle class population, there has been direct impact on living standards of people in terms of economic and social well-being. Delhi –NCR has seen a surge of vehicles on roads in past decade. The transport sector remains a consistent and significant contributor to the region's poor ambient air quality across all seasons. Absence of a long-term strategy will only complicate and make situations worse. On road vehicular traffic constitutes majorly petrol and diesel driven vehicles, while CNG fueled vehicles constitutes a share of 14%, 19%, 25%, and 12% among cars, buses, autos, and LCV segment respectively.

Exhaust emissions comprise of particulates and gases due to combustion in petrol and diesel vehicles, with substantial contributions from pre-BS VI compliant vehicles. Other than primary pollutants, gaseous pollutants (NO_x, SO_2, VOCs) released from transport sector are precursors of secondary particulates, and also ground level ozone, which is also known to cause several respiratory diseases (TERI, 2020). Knowing the significance of contribution of the sector in $PM_{2.5}$ concentrations, if emissions from this sector are controlled it can positively impact the air quality of NCR. The key challenges in the transport sector and the cost implications are discussed and selected interventions have been tested for their potential to curb air pollution at different costs (Table 15):

Table 15: Transport Sector Interventions

Electrification of vehicular fleet	
»	Public transportation -25% in 2022, 50% in 2025 and 100% in 2030
»	Private electric two-wheelers- 20% in 2022 and 40% in 2025 and 100% in 2030 and 100% three-wheelers in 2022
»	Private electric cars - 10% in 2022, 20% in 2025 and 40% in 2030
Fleet modernization to BS-VI vehicles	
»	100% Fleet Modernization of trucks and buses to BS VI by 2022, 2025 and 2030
»	100% Fleet Modernization of 2 & 4-wheelers to BS VI by 2022, 2025 and 2030
Modal shifts of cars and 2-wheelers to CNG buses	
Enhancing penetration of biodiesel	

The following section presents the cost-benefits analysis of transport sector interventions.

Electrification of Vehicular Fleet: Bus, 2-wheeler, 3-wheeler, and 4-wheeler

This intervention aims at increasing the penetration of electric vehicles across different vehicle segments. For each transition, analysis has been undertaken to project the net costs to the consumers and government, benefits in terms of fuel reduction, and finally net cost to the regional economy. The scrap value obtained after retirement of existing vehicle has been considered while evaluating costs and benefits.

In order to arrive at the cost of electrification of vehicular fleet, the current composition of vehicles and the annual vehicle kilometers travelled (VKTs) is analyzed for each segment proposed to be electrified. The number of vehicles sets the basis for estimating the cost of procurement of E-buses to achieve the identified targets in respective years. The existing share of vehicle stock comprises of CNG, gasoline, and diesel driven vehicles. The costs and operations are considered for each fuel category of vehicle. Annual vehicle kilometer travelled (VKTs) are used for estimating running and maintenance costs, and the associated charging infrastructure costs (Table 16).

Table 16: Number of vehicles and VKTs of baseline year, 2019

Vehicle Segment	Vehicular Fleet (No. of vehicles)	Annual VKTs (Million kilometers)
Buses	46031	3168
Mini Buses	36321	2937
2-wheeler	14556738	206937
3-wheeler	516126	19850
4-wheeler	5333303	139599

The key component in undertaking cost analysis for EV penetration is the charging infrastructure for adequate supply of electricity and vehicle costs. For charging infrastructure, it has been assumed that:

» *Charging infrastructure for public transportation i.e. E-bus to be developed in bus-depots, where civil work, new electricity connection cost is not considered.*

» *The three plug charger cost is in-built in the 2-wheeler cost, and hence infrastructure cost has not been included.*

» *For 4-wheelers, it is assumed that 50% of the electricity will be provided through fast charging public infrastructure, while the remaining 50% vehicle owners will be able to charge vehicles using in-house chargers.*

The assumptions related to EV and baseline gasoline and diesel vehicle characteristics are used based on the expert inputs and secondary review. These vehicle characteristics include vehicle type, purchase cost, maintenance cost, average energy usage and annual vehicle mileage.

Vehicle Purchase cost: Future vehicle purchase costs were modeled based on the current cost of vehicles, assuming the costs of EVs will fall over time @ 3% annually. Based on discussion with scrap dealers, the scrap value of the older vehicles obtained in the case where existing vehicles are needed to be retired for achieving the interventions target is considered.

Vehicle operations and maintenance costs: Vehicle maintenance costs are taken from secondary sources based on the manufacturer's recommended costs per unit kilometer travelled. While the actual current cost of staff per km has been taken while estimating the operations cost for buses. The marginal change in operations and maintenance including the fuel cost is then estimated. The average energy usage has been considered based on the current estimates for each type of fuel category vehicle.

Total cost of operation = Total km travelled (km) * cost of petrol/ diesel/ electricity (INR) * Fuel Efficiency (km/L)

Total cost of maintenance = Total km travelled (km) * cost of maintenance/km (INR/ km)

The cost and associated benefit analysis for the E-buses, 2 & 3-wheelers, and 4- wheeler segment to achieve the penetration targets in year 2022, 2025 and 2030 is presented in Table 17. The net present value of cumulative costs in year 2030 are 555, 63, and 520 billion INR for Buses, 2- wheelers and 3-wheelers, and 4-wheeler segment respectively. . The results are summarized in Table 17.

Table 17: Cost breakup of use of electric vehicle in Delhi NCR (Cumulative costs)

Cost Heads (NPV in Billion INR)	E-Buses (including mini buses)			2-wheelers and 3-wheelers			4-wheelers		
	2022	***2025 (CF)***	***2030 (CF)***	***2022***	***2025 (CF)***	***2030 (CF)***	***2022***	***2025 (CF)***	***2030 (CF)***
Cost of EVs	61	225	822	52	196	727	92	345	1313
Cost of Charging Infrastructure	7	13	23	-	-	-	5	10	19
Incremental change in operating cost	-22	-79	-290	-48	-179	-664	-57	-213	-812
Net cost of the Intervention	46	159	555	4	17	63	40	142	520

**CF- cumulative figure from 2019 up to specified year*

The above estimations shows the economic costs and benefits of the electrification of vehicular fleet. However, the benefit in terms of air pollution reduction might get nullified if the electricity for charging EVs is generated from conventional coal based power generation. This calls for further life cycle based detailed assessment of electricity sources of EV charging.

Fleet Modernization

Phasing out of older vehicles and replacing them with BS VI compliant vehicles is another intervention proposed for the transport sector to combat rising air pollution. In a move, that would take polluting commercial vehicles off road in a strategic transition plan, all pre BSVI vehicles are proposed to be replaced with BSVI compliant vehicles. In 2016, the Government of India had announced leapfrogging from BS-IV to BS-VI vehicle emissions standards for the whole country in the year 2020. The major difference between the existing BS-IV and forthcoming BS-VI fuel quality norms is the presence of sulphur in the fuel. While the BS-IV fuels contain 50 parts per million (ppm) sulphur, the BS-V/VI grade fuel only has 10 ppm sulphur content.

In this intervention, all pre-2020 vehicles have been considered for replacement with BS-VI vehicles in a phase wise manner. The price per unit of vehicle has been considered constant along the years till 2030. The cost of the interventions across four types of vehicle categories i.e. buses, trucks, 2-wheelers and 4-wheelers have been estimated. Benefits have also been considered that will arise from vehicle scrappage and improvement due to fuel efficiency which is assumed to increase by 5 per cent by 2030.

The cumulative cost of the intervention has been estimated for three different years, 2022, 2025 and 2030 (Table 18). The benefits have also been estimated that are from the fuel efficiency based on the CAFE norms as per the government standard and the benefits from scrapping older vehicles. Thus, the net cost of the intervention has been estimated taking in account all the associated costs and benefits in the intervention.

Table 18: Cumulative Cost estimates (billion INR) of fleet modernisation in Delhi-NCR to BS-VI levels

Cost Heads	Buses			2-wheelers and 3-wheelers			4-wheelers			Trucks		
	2022	2025	2030	2022	2025	2030	2022	2025	2030	2022	2025	2030
Cost of BS-VI vehicles	72	106	135	149	218	278	488	711	909	105	153	196
Benefits from fuel efficiency	31	26	17	43	35	23	93	76	51	20	16	11
Benefits from scrappage	7	6	5	62	55	44	133	116	94	16	14	11
Net cost of the Intervention	41	80	118	44	128	210	263	520	764	69	123	174

The total net present value of the net cost of the intervention across all the vehicle categories has been estimated to be INR. 417 billion in 2022, INR 851 billion in 2025 and INR 1265 billion in 2030.

Modal shift from personal to mass transport modes

One of the potential solutions to the problem pertaining to traffic congestion, parking woes, and the enormous amount of fuel consumption is a modal shift from private to public modes i.e. shifting 2-wheelers and 4-wheelers as private petrol and diesel vehicles to CNG buses. To reduce the commuter's overwhelming dependency on the private vehicles, modal shift from existing 2-wheeler and 4-wheeled vehicles to CNG buses is proposed to make urban transportation more sustainable. The reduction in fuel consumption will help improve the quality of air and the decrease in number of on road vehicles, would help control the congestion on roads.

The intervention proposes to shift 25 % of the two and four wheeler vehicles to CNG buses by 2022, 2025 and 2030. This would reduce the total vehicle kilometers travelled due to higher occupancy of buses as compared to private vehicles. Subsequently, there will be net reduction in fuel consumption and reduction in concentration of pollutants released by combustion of petrol and diesel. The modal shift will also lead to reduction in infrastructure (e.g. roads, flyovers etc) costs that will be required to accommodate fewer vehicles on road.

The number of vehicles on road in year 2019 is taken as the basis for achieving modal shift target in intervention years of 2022, 2025 and 2030. While the period of operations is taken up to 2030 i.e. the 25% vehicles if shifted in 2022 will operate till 2030. The average occupancy of vehicle segments (2W – 1, Car – 2, Bus – 47) have been used to obtain the vehicle kilometers that are needed to be covered through provision of CNG buses. The number of vehicles and the annual VKTs has been presented in Table 16.

The fuel required for the operations of 2-wheeler and 4-wheeler vis-à-vis CNG buses have been estimated using the average fuel efficiencies of diesel, petrol and CNG based 2-W, 4-W and buses and the net costs have been used to arrive at the incremental change in operating costs.

The number of additional buses required over and above the existing fleet to facilitate the modal shift is estimated using the average annual VKTs of buses in the region. The procurement costs are considered as per the current market rates for a CNG bus (AC variant), while other operating characteristics have been used for the same variant. The other operating expenditure apart from fuel cost, like staff cost and maintenance cost for the operations of buses has been considered for evaluating overall costs. The scrap value of private vehicles is also considered for estimations.

Cost of additional CNG buses includes the cost required to accommodate passengers who were earlier travelling by private 2-wheelers and 4-wheelers. With the bus occupancy being more than that of 2W and 4W, there have been benefits in terms of reduction in fuel usage due to VKT reduction. The total cost incurred if the modal shifts are made from 2-W and 4-Wheelers to CNG buses is presented in Table 19 below.

Table 19: Cost breakup of model shift from private vehicles to CNG buses in NCR (Cumulative costs)

Cost Heads (NPV in billion INR)	2022	2025	2030
Cost of additional CNG buses	164	266	407
Fuel Reduction Benefits	105	142	155
Net Cost	59	124	252

The NPV of cost of additional CNG buses in 2022, 2025, and 2030 is 164 billion rupees, 266 billion, and 407 billion rupees respectively. The benefits of fuel reduction is estimated at INR 105, 142, and 155 billion INR for years 2022, 2025 and 2030 respectively. The estimates show that the net cost of 25% modal shift is INR 59, 124 and 252 billion rupees respectively.

Enhanced penetration of biodiesel

Biodiesel is one of the important alternatives to diesel for fueling vehicles as it has net zero GHG emisisons and lower emission levels. This includes methyl or ethyl ester of fatty acids derived from non-edible vegetable oil, acid oil, used cooking oil, animal fat and bio-oil. It is biodegradable, nontoxic and produces fewer pollutants when burnt completely. It can be used in pure form (B100) or blended with diesel. Most of the common blend includes B2 (2% biodiesel, 98% diesel), B5 (5% biodiesel, 95% diesel) or B20 (20% biodiesel, 80% diesel). If compared with petroleum diesel, it is safer to handle and its quality is governed by ASTM D 6751 quality parameters (NEA, 2019).

Not only does it have environmental benefits but also economic benefits. Biodiesel is cheaper than petrol and diesel since waste materials such as used cooking oil are much cheaper than fossil fuel. Other advantages of biodiesel fuel are that it can also be blended with other energy resources and oil. Biodiesel fuel can also be used in existing oil heating systems and diesel engines without making any alterations. It can also be distributed through existing diesel fuel pumps, which is another biodiesel fuel advantage over other alternative fuels. Lack of sulfur in 100% biodiesel extends the life of catalytic converters and also the lubricating property of the biodiesel may lengthen the lifetime of engines.

Recognizing these benefits of biodiesel, the government adopted the National Policy on Biofuels in 2018. The policy is aimed at taking forward the indicative target of achieving 20% blending of biofuels with fossil-based fuels by 2030. Also, under this policy, MNRE has set an indicative target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel to be achieved by 2030 (TET, 2019). The government also has an administered price mechanism for the sale of biodiesel.

The proposed intervention of biodiesel penetration is the business proposition in which all stakeholders will get benefitted, and there will be no net costs in the system. Hence, the costs for this intervention is not estimated and proposed as a no regret option with a win-win proposition.

7.2.3 Industry

With increasing emphasis on urban air pollution prevention, the issue of pollution loads from the coal based thermal power plants, brick kilns, solid fuel usage in micro and small industries, and lack of monitoring system has come into focus in the NCR region. These issues have been partly addressed by the introduction of pollution control measures for the some industries but the progress made has not been really up to the expectations. The high upfront cost and subsequent operating cost involved with the reduction measures are perceived to be holding up implementation by the industries.

In order to move towards a cleaner industrial sector in terms of air pollution, interventions in Table 20 below are proposed as the control measures for air quality management in the NCR region.

Table 20: Industrial sector interventions proposed for NCR

Implementing stricter NO_x and SO_2 standards in Coal based Thermal Power Plants
Enforcement of Zig-Zag brick kiln technology
Fuel switch from solid to gaseous fuels in industries
Stricter enforcement of standards in industries through continuous monitoring equipment
Enforcement of PM_{10}/$PM_{2.5}$/SO_2/NO_x standards in industries through installation of wet scrubber

The following section presents the assessment of costs for control of industrial pollution. The detailed assessment has been undertaken including estimation of the upfront and operating costs involved in the selected interventions.

Implementing stricter NO_x and SO_2 standards in Coal based Thermal Power Plants

The proposed intervention advocates the abatement of NO_x and SO_2 emissions from coal based thermal power plants through introducing Pollution Control Equipments (PCEs) by 2022. Notably the norms are specified for SO_2, NO_x and PM emissions with the implementation of the specified techniques, i.e.

» Electrostatic Precipitator (ESP) for PM emissions control

» Flue Gas Desulfurization (FGD) for SO_2 emissions control

» Selective Catalytic Reduction (SCR) for NO_x emissions control

Though the Ministry of Environment, Forests & Climate Change (MoEF & CC) issued guidelines for control of NO_x and SO_2 emissions in December 2015, the norms are not being adhered to. The power plants in the region missed the deadline of December 2019 for emissions control compliance.

Although minimal, some progress has been made whereby primary studies have been conducted for many of the units, and tendering is ongoing for 4.9 GW of capacity.

The installed capacity of power plants that have impact on Delhi's ambient air concentrations stands at 12.6 GW including thermal power plants in Haryana, U.P, and Punjab. The preferred technologies are FGDs and SCR for SO_2 and NO_x control respectively.

The plant load factor (PLF)[1] of 2019 for these units have been assumed as the basis to calculate the operating costs of FGD and SCR technologies for future plant operations (Table 21).

Table 21: Operating cost components for FGD and SCR

	FGD	SCR
O&M cost (Million INR/ MW/ annum)	0.6	0.05
Reagent cost (INR/kWh)	0.09	0.04
Auxiliary Power Consumption	0.7%	0.6%

Source: Data for 2019 is taken from CEA

In order to comply with the emission standards specified by MoEF & CC, power producers will need to make significant investments in procurement of PCEs and their operations. From the literature survey and consultation with subject matter experts, we have identified the applicable cost heads for direct capital investments and associated operational expenditures. Cost heads involve capital cost of the specified technologies, operations and maintenance cost, reagent cost, auxiliary power consumption cost (Table 22). There will be an increase in fixed as well as variable cost of power generation, but as per Central Electricity Regulatory Authority (CERC) norms the increase in cost due to installation of PCEs will not be considered in Merit Order Dispatch, and the cost of pollution control will be passed on to end user.

Table 22: Cost breakup of introducing gaseous pollutant controls system in power plants

Cost heads (NPV in billion INR)	FGD (for SO_2 control)	SCR (for NO_x control)
Capital Cost[2]	8.05	4.83
Annual O&M cost	7.6	0.6
Annual Reagent Cost	6	2.6
Annual Auxiliary Power Consumption Cost	1.6	1.4
Total Cost of Intervention up to 2022	**41.5**	**12.8**

Total cumulative cost for enforcing SO_2 and NO_x standards in power plants affecting Delhi-NCR region by 2022 is estimated at NPV of 41.5 billion and 12.8 billion respectively.

1 PLF- It is the ratio of maximum power generated by the plant to the maximum power that could have been generated annually.

2 Levelised for period under scope

Enforcement of Zig-Zag Brick kiln technology

The benefit-cost assessment undertaken in this study looks at the option of improvement of existing clamp kilns and fixed chimney kilns (FCK) technology to the improved and cleaner Zig-Zag brick kiln technology. Clamp kilns and/or FCKs can be converted to improved Zig-Zag Kilns at low costs at the same site. The production capacity can be same or higher compared to the Clamp kilns and/or FCKs. The brick quality from Zig-Zag kiln is as good or better than FCK, with energy savings and PM emission reductions. Brick Kiln owners find this technology the most attractive because they neither need to relocate nor having to look for high cost land (Guttikunda and Khaliquzzaman, 2014), and large investment cost is not involved.

This intervention calls for the enforcement of Zig-Zag technology in brick industry, which consumes 25% less coal and emits 70% less suspended particulate matter (Bhattacharjya, 2017). The cost analysis is undertaken for 100% shift to zig-zag technology brick kilns by the year 2022, 2025 and 2030.

As of 2019, there are 4635 brick kilns operating in the Delhi National Capital Region, with 42% of them running on traditional and highly polluting technology (based on CPCB data). A comparative assessment of the key parameters of the existing and improved brick production technologies is presented in Table 23 below.

Table 23: Assumptions and parameters used for the analysis

Category	Unit	Fixed chimney bull's trench (FCBT) kiln	Zig-zag
Upgradation Cost/Kiln	Rs (in million)		1.75
Percentage of Class 1 bricks produced	Percent	60%	80%
Percentage of Class II and other bricks	Percent	40%	20%
Selling Price of Class 1 brick	Rs	4	4
Selling Price of Class II and other bricks produced	Rs	1.5	1.5
Operating Cost/Brick – INR	Rs	2.35	2.07

It may be noted from the above table, apart from the lower operating cost the biggest advantage is the increase in production of Class I bricks which will yield substantial increase in revenue.

The cumulative cost of intervention has been estimated for gradual shift to zig-zag technology by 2022, 2025 and 2030. The capital cost of technology conversion has been taken from secondary literature and consultation. While, the incremental benefits have been estimated for reduction in operational cost and increase in revenue from selling more Class I bricks. The total number of bricks produced per kiln has been estimated from the available brick production data of 2019.

The estimated costs of shifting from conventional to zig-zag technologies is presented in Table 24.

Table 24: Cost breakup of shifting from conventional to zig-zag technologies in brick kilns of NCR (cumulative costs)

Cost heads (NPV in billion INR)	2022	2025	2030
Capital Investment[3]	0.47	0.7	2.05
Incremental benefit in Operating Cost	5.4	4.7	3.8
Incremental Benefit in Revenue from Selling Bricks	9.5	8.3	6.8
Net cost of the intervention	-14.43	-12.3	-8.4

It is evident from the above analysis that the technology upgradation of brick kilns is a no regret option.

Interventions in other industries

Delhi NCR 2016-2019 has emerged as a centre for small scale industries which have registered growth rate of 16% from 2016 in number of industrial units. Operating units include sugar mills, rice mills, distilleries, textile dyeing units, paper, cement, ceramics, surface treatment, dairy, meat processing, etc. The source of energy in industries include coal, coke, biomass, firewood, diesel, LDO, HSD, electricity, and natural gas, based on the cheaper availability and heating requirements of the process involved. Boilers and furnaces of adequate capacity have been the preferred choice in the small scale industries for processing, besides other technologies. These industries however had not been rigorously monitored for air pollution control unlike thermal power plants and big industries. The air pollution issues arising from these industries are proposed to be addressed with a set of interventions. The cost associated with the introduction of the proposed measures for emission load reduction is worked out.

Industry-specific data on industries from State Pollution Control Boards (SPCBs)/Central Pollution Control Board (CPCB) has been collected. A bottom up approach has been undertaken to analyze industry data for each district within the Delhi-NCR region, in which the key industrial parameters including the process of application, technology usage for processing, and type of fuel usage have been assessed. The number of industries in NCR is presented below in Table 25, excluding brick kilns and thermal power plants.

Table 25: Total number of industries excluding brick kiln and power plants in Delhi NCR (2019)

	Total Industries	Industries using solid/liquid fuel
Number of Industries	4149	2972
Total Energy consumption (in PJ)	378.5	182.8

100% fuel switch from solid and liquid to gaseous fuels in 2022, 2025 and 2030

Consumption of solid fuels in industries has been long considered as a major contributor to pollution load in the region. In contrast, natural gas offers a potentially less polluting alternative fuel for the industrial sector in NCR region. The NCT of Delhi has already expanded the use of natural gas through channelizing the pipeline infrastructure to the industries. The upfront cost involved for purchasing new processing equipment and the higher cost of natural gas has been a restraining force for industry, as the existing configuration of boilers or furnaces using solid fuel cannot run on natural gas, and sometimes cannot be retrofitted but need to be replaced with new ones. However, the retrofitment is possible in the case of liquid fuel fired boiler.

[3] Levelised cost

The rationale behind using natural gas for industrial energy requirements has been explored by analyzing the expenditure on equipment, fuel cost, operational cost, and connection cost of PNG (including safety and automation requirements).

The total number of industries that rely on solid as well as liquid fuel as the energy source for heat requirements are 2972 out of a total 4149 industries in the NCR region. Out of these, boilers and furnaces are used in nearly 70% and 30% of industries respectively. Accordingly, the cost of boilers and furnaces have been considered in the analysis.

The cost to industry for switching to natural gas involves the cost of connection from the natural gas supplier agency, cost of new gas based thermal systems, Automation and Safety standards compliance cost, and change in operating cost, compared to conventional solid and liquid fuels. It is assumed that the cost of infrastructure will be reflected in the delivered cost of natural gas, creating the business case for the supplier, thus not considered separately.

5. **Cost of connection:** The upfront cost for a new connection includes:
    - Security deposit for meter
    - Payment security
    - Internal Piping + burner
6. **Safety and Automation cost:** The compliance of safety standards will include the installation of new burner temperature control device, pre mixture. The shift to gas as fuel can lead to higher NO_x emissions and thus the equipment needs to be operated at lower temperatures with the installed burner temperature control device.

Cost of Equipment: The solid fuel fired boilers and furnaces are replaced with the new gas fired ones demonstrating higher efficiency from natural gas usage. The efficiency for boilers increase from 60% to nearly 75-80% and for furnaces from 45-50% to 65-70%. The cost of a furnace is taken for the common configuration of 3000kg/hr capacity gas fired furnace while boiler capacity has been assumed at 5TPH, based on the interactions with industrial experts. Also, two boilers per industry have been considered. Whereas, the cost of retrofitment is taken for liquid fuel fired industries.

7. **Change in Fuel Cost:** The total energy consumption through solid and liquid fuels has been converted to peta joules of energy from the consumption data available using the calorific value of each type of fuel. The total energy requirement needed to be supplied by the new efficient boilers and furnaces is estimated, and then overall fuel cost to supply requisite energy is estimated.

The costs estimated for shifting of industries in NCR to gas are presented below in Table 26.

Table 26: Cost breakup of shifting of industries in NCR to gas (cumulative costs)

	Cost (in billion INR)
Cost of Natural Gas connection (including security deposits)	2.85
Safety and Automation cost	1.85
Cost of the new gas fired equipment	4.26
Annual Incremental change in Fuel cost (100% gas based industries v/s Current Mix)	80

The cost for industries to switch fuel to natural gas for their industrial application is estimated at net present value of INR 97 and 243 billion in years 2022 and 2025 respectively. There will be increase in fuel supply cost of 80 INR billion annually compared to fuel consumption mix in 2019.

Stricter enforcement of standards in industries through continuous monitoring equipment in 2022, 2025 and 2030

Continuous emission monitoring system (CEMS) are the equipment necessary to determine concentration or emission rate of a gas or particulate matter. The CEMS has an impact on industry's emissions, as change in behavior of industry is anticipated after installing the CEMS as the regulator may enforce penalties based on data. The effective penal mechanism and handholding is the key to success of the intervention, and needs to be seamlessly integrated into the industrial pollution reporting system. The system of CEMS must be introduced with a goal of more efficient pollution regulation and lower costs of compliance.

The financial burden of installation of these systems in industries in NCR has been examined. The first step for enforcing CEMS is to select a device (or combination of devices) suitable for the stack/ chimney characteristics of the industry. The two possible PM CEMS technologies are DC and AC Tribos, and almost all the firms in Surat have installed those (Greenstone et al., 2020).

The prices of CEMS Tribos ranges from Rs 200,000 to 300,000 and installation in the 4149 industries in the Delhi-NCR region would require by 2022. It is proposed that the CEMS system should be aggressively enforced in industries by 2022 with the integrated monitoring system, and emission reduction can be subsequently achieved.

Enforcement using wet scrubbers and low NO_x burners in industries

It is proposed to install wet scrubbers in industrial application like boilers, incinerators, foundries, lime kilns, chemicals, and pulp and paper industries to remove gaseous SO_2 pollutants and particulates from the exhaust streams.

- In gaseous pollutant control applications, wet scrubbers are used as absorbing units. Water is the most commonly used absorbent.
- Wet scrubbers use liquids to remove particulates from the exhaust stream, which collide with liquid droplets and are sometimes removed with scrubbing liquid.

In small scale industries, low NO_x burners are proposed to be installed to achieve emission standards, since SCRs are sometimes not feasible at small scale.

Enforcement of SO_2 and PM standards in industries in NCR can be better complied through installing wet scrubbers. Low temperature burners can be used for achieving NO_x standards. Cost parameters which are considered for enforcement includes the cost of equipment, cost of electricity for operations, and maintenance cost ,which includes replacement of bag filters. The cost of wet scrubbers having capacity 400m^3/ hr air volume has been considered. The estimated costs are presented in Table 27.

The cumulative cost of installing wet scrubbers in the projected number of industries in 2030 is estimated at net present value of Rs 1.51 billion , while the low NO_x burner installations in industries will cost Rs 0.84 billion.

Table 27: Cost breakup of installed wet scrubbers and low NOx burners in industries of NCR (cumulative costs)

	SO_2/ PM (Wet Scrubbers)	NO_x(low NO_x burner)
Cost of the equipment (billion Rs)	1.44	0.83
Operational(Power Consumption) & Maintenance Cost (billion Rs)	0.07	0.01
Total Cost of the intervention (billion Rs)	1.51	0.84

7.2.4 Road dust and construction

Re-suspended dust from roads is one of the significant contributors to air pollution in the NCR. Road dust in the city consists of loose soil on broken or unpaved roads, particles that settle on the road after emerging from the tailpipes of vehicles, and other dust related activities e.g. construction-demolition waste that settles on roads (TTO, 2019). Road dust is composed of a variety of materials including loose soil that has silica, aluminum and titanium. Dust particles that suspend on the road get re-suspended when vehicles move over them or when there is a strong wind. Besides, road dust also has fine particles emitted from tailpipes of vehicles and that produced by wear and tear of tyres.

The possible solutions to curb this source of pollution is to arrest the suspension of dust particles on the road by various ways. The most basic of them are ensuring better quality roads, paving of roads, covering the shoulders of the roads, and vacuum cleaning of roads. The targeted interventions in this study are listed below in Table 28.

Table 28: Road dust and construction sector interventions

100% Vacuum cleaning of arterial roads in 2022, 2025 and 2030
Wall to wall paving of arterial roads in 2022, 2025 and 2030
Control of dust from construction activities- barriers and fogging based controls 60% in 2022, 2025 and 2030

Vacuum cleaning of roads

Cleaning of roads is one of the important solutions to minimize road dust that generate re-suspended particles. This intervention focuses on the mechanical vacuum cleaning of roads. Vacuum-assisted and regenerative air sweepers are generally better than mechanical sweepers at removing finer sediments, while mechanical sweepers are better at removing larger debris (AIRUSE 2013). These vacuum sweepers are used in many countries since the past few decades; however their use in India is still at a nascent stage. These units usually have gutter brooms and strong vacuum head(s) for picking-up both large and small particles. These machines act like big vacuum cleaners, and have the capacity to intake large-size plastics and other waste, which gets collected in a bin mounted on top of a van (TERI 2018). While some models use water as a dust suppressor, others can operate in a dry mode (AIRUSE 2013).

According to the current guidelines set by the Ministry of Urban Development (MoUD, 2019) the vacuum cleaning of roads is done in two shifts per day, and of both the arterial and sub-arterial roads. The baseline cost estimates suggest that the vacuum cleaning should be done for around eight hours per day in two different shifts, and the frequency of cleaning of arterial roads once a week The total road length to be covered by the vacuum cleaning trucks in Delhi NCR is around 5,900 km out of which arterial roads are around 3,600 km. Therefore, according to the current working hours of the vacuum cleaning trucks, the number of cleaners required annually would be 60 for all the arterial roads. The baseline data and assumptions for the assessment of costs are given in Table 29.

Table 29: Baseline data and assumptions

Number of operating hours of one cleaning truck	8 (in two shifts per day)
Frequency of cleaning one stretch of road per week	Arterial – 1
Total Number of cleaning trucks required for Delhi NCR	Arterial – 60
Total Road length to be vacuum cleaned	Arterial – 3,600 km
Capital Cost (per Vacuum cleaning truck)	Rs. 40 lakh
Operations and Maintenance Cost (per km)	Rs. 41

The cost analysis of the intervention has been done according to the baseline data; however the working hours of machines has been increased in the analysis. The cost of intervention has thus been estimated for the arterial with a frequency of cleaning a stretch of road once a week. Assuming fewer working hours (8 hours) of the vacuum cleaning trucks according to the baseline data, the number of trucks estimated used is high. However if the working hours are assumed to be 16 hours per day, the number of cleaning trucks used would be proportionately fewer., i.e. 30 cleaning trucks. The speed of these trucks is assumed to be 5 km per hour and they have to make four rounds to cover a particular stretch of road.

Considering the total length of road to be vacuum cleaned, weekly frequency of cleaning and the total number of cleaners required, the total distance covered was estimated. Further the total cost of the intervention was estimated which includes both the capital cost and the O&M cost. The cost of the intervention according to the baseline data (8-hour running) is estimated to be higher than the cost in the higher efficiency 16-hour running. The reduced number of operating hours during the monsoon period has not been accounted in this analysis and it has been assumed that the vacuum cleaning trucks will be operating at their full capacity throughout the year. The following Table 30 summarizes the estimates of net present value of costs of intervention in different years:

Table 30: Cost estimates of vacuum cleaning of roads in Delhi-NCR (cumulative costs)

Cost Estimates (in million rupees)	2022- 100% coverage	2025- 100% coverage	2030- 100% coverage
Capital cost	0.51	1.27	2.53
O&M cost	11.15	27.9	55.76
Total cost	11.67	29.17	58.29

Therefore, the net cost of the intervention would be Rs. 11.67 million if 100% of the target is achieved in 2022, Rs. 29.17 million if achieved in 2025 and Rs. 28.29million in 2030.

Wall to wall paving of roads

The resuspended dust on roads increase with lack of proper paving on the sides of roads. Therefore, wall to wall paving of the roads, especially on the arterial and sub-arterial roads of the region (that have a higher footfall of vehicles) could reduce the road dust significantly (CRRI, 2018). In this intervention the cost of 100% wall to wall paving of arterial and sub-arterial roads in Delhi NCR has been estimated for 2022, 2025 and 2030.

The cost of wall to wall paving of all the roads in Delhi NCR has been estimated based on the total construction cost of the pavement and its annual repair cost. The width of the pavement has been considered differently for the arterial and sub-arterial roads, and it has been assumed that 80 per cent of the road length needs to be paved (adjusting for the intersections and the corners). Therefore, the total road length that needs to be paved is estimated to be 2,900 km of arterial roads and 1,800 km of sub-arterial roads. Baseline data is presented in Table 31.

Table 31: Baseline data and assumptions for wall to wall paving of roads

Proportion of total road length that needs to be paved	80%
Width of road	Arterial- 2.5m Sub-Arterial- 1.5m
Total cost of constructing concrete pavement (per sq m)	Rs. 650
Total Repair cost (per sq m)	Rs. 50

The cost of the intervention has been estimated considering the total road length that has to be paved, and the width of the pavement as per the type of the road. Table 32 summarizes the cost of the intervention in various target years.

Table 32: Cost Estimates of wall to wall paving of arterial and sub-arterial roads in Delhi-NCR (cumulative costs)

Cost Estimates (in billion rupees)	2022	2025	2030
Capital cost	9.70	7.29	4.52
O&M cost	0.74	0.56	0.34
Total cost	10.5	7.9	4.9

The net present value of the intervention targets is estimated to be Rs. 10.5 billion, Rs. 7.9 billion, and Rs. 4.9 in 2022, 2025, and 2030, respectively.

Control of dust from construction activities: use of water tankers/barriers/anti-smog machines (ASMs)

Construction is an integral part of infrastructure development. However, these activities lead to generation of dust particles that get air borne and may lead to health problems for nearby residents. The spread of dust can be controlled through several measures. Some of these are a) use of barriers to cover the construction site to avoid the spread of dust outside this area; b) use of water tankers to sprinkle water around the boundary of the construction site to minimize dust generation; and c) use of ASMs as a dust suppression machine to control dust pollution. This intervention aims at controlling dust from construction activities by using barriers, water tankers and Anti-Smog Machines (ASMs). The cost of the intervention is estimated for three different years, assuming 100% coverage of major construction sites in Delhi and surrounding areas in NCR in 2022, 2025 and 2030.

Cost of this intervention has been estimated by considering the cost of water tankers, constructing barriers, and the use of ASMs at the sites. Water tankers are usually rented and each water tanker on an average covers 3.5 km of stretch at full capacity. The requirement of each tanker is twice a day in summers and once a day during winters. For the physical barriers, the size has been assumed to be around 10 × 4 meters for which rent is around Rs. 200 per week. Lastly, the intervention also considers the use of Anti-Smog Machines (ASMs) at construction sites which on an average cover an area of 37,000 sq. meter at a time at full capacity. The baseline assumptions are listed in Table 33.

Table 33: Baseline data and assumptions for construction dust control interventions

Coverage of a water tanker	3.5 km
Requirement of a water tankers	Once a day during winters Twice a day in summers
Rent of a water tanker	Rs. 8000/day
Size of physical barrier	10 × 4 metres
Rent of a physical barrier	Rs. 200/week
Coverage of an ASM	37,000 sq. m
Capacity of an ASM	37 KWh
Capital cost of an ASM	Rs. 13 lakhs

Here the area under construction for the year 2020 is taken to be 54.04 sq. km. The costs of interventions have been estimated assuming that the area under construction is increasing at 4.9 % per year during the period of study . The following Table 34 summarizes the estimated cost of the intervention across the various target years.

Table 34: Cost estimates of controlling construction dust in Delhi NCR (Cumulative costs)

Intervention Specifics	Cost Estimates (billion rupees)		
	2022	2025	2030
Water Tankers	0.07	0.15	0.31
Barrier	0.12	0.23	0.36
Anti-Smog Machine	0.88	2.11	3.61

The results show that the net present value of using the water tankers would be Rs 0.07 billion; cost of using barriers would be Rs 0.12 billion; and Rs 0.88 billion for ASMs in 2022. The costs in 2025 will be Rs 0.15 billion, Rs 0.23 billion and Rs 2.11 billion, respectively. Finally in 2030, the cumulative costs of three measures will be Rs 0.31 billion; Rs 0.36 billion; and Rs 3.61 billion respectively.

7.2.5 Others

Full ban on refuse burning and combustion in Waste to energy plants

Waste is burned often to free up space at dump sites or to facilitate scavenging of non-combustible materials (such as metals), or for use as a heat source (CCAC, 2012). This burning of waste produces harmful pollutants like methane and black carbon that lead to an increase in the levels of air pollution and health related problems.

Waste burning in Delhi NCR is one of the contributors to air pollution and it alone contributes nearly to 3-4% of winter $PM_{2.5}$ concentrations. It has been estimated that around 2%-3% of the total municipal solid waste generated in Delhi is burned (TTI, 2020). In this direction, the National Green Tribunal (NGT) directed to impose a complete ban on the burning of waste in open places and announced a fine of Rs. 25,000 for each incident of bulk waste burning[4] and Rs. 5000 of environmental compensation in case of simple burning. The NGT also directed all civic bodies of the UT to implement the Solid Waste Management Rules 2016 to curb air pollution through burning of waste and prepare action plans to implement the rules (BS, 2016).

One of the solutions to this problem is the setting up and use of Waste-to-Energy (WTE) plants that help recover energy from the waste in the form of electricity and biogas/syngas (MNRE, 2020). The municipal solid waste is mostly incinerated and completely combusted by these WTE plants to produce steam, that in turn produces power through steam turbines. The resultant ash from incineration of solid waste can be used as construction material after necessary processing, while the residue can be safely disposed of in a landfill. This technology is well established and has been deployed in many projects successfully at commercial scale in India to treat Municipal Solid Waste and Industrial solid Waste, etc. and generate electricity. It has been estimated by MNRE that urban solid waste has a total energy generation potential of 1247 MW in India. Delhi alone has a capacity of 52 MW energy generation potential in 2019 (MNRE 201916). In the capital three operational WTE plants at Sukhdev Vihar, Ghazipur, and Narela-Bawana are collectively producing 52 MW of power. Four more WTE plants were proposed in 2019. Further, new technology WTE plants are also now being setup in Delhi with plasma gasification technology, with an energy generation capacity of 50 MW at Ghazipur dump site. This will generate energy from 200 MT of waste without generating any carbon emissions and residue[5].

The proposed intervention is a business model proposition of waste to energy plant in which all stakeholders will be benefitted considering the utilization of waste which is at no cost. However, proper framework for successful demonstration is needed to be established. Hence the cost for this intervention is not been estimated and proposed as a no-regret option.

7.2.6 Summary of cost estimates for different interventions in Delhi-NCR for control of air pollution

The summary of net economic costs for all proposed interventions across discussed sectors is presented in table 35. The net cumulative costs are presented up to year 2022, 2025, and 2030 for comparative evaluation. The costs for electrification of vehicle intervention however are not meant for the comparative evaluation as different targets are proposed for 2022, 2025, and 2030. Rest, in other interventions the similar targets are meant to be achieved in different time-frames of 2022,

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4 https://www.thehindu.com/news/national/NGT-bans-open-waste-burning/article16928115.ece

5 https://timesofindia.indiatimes.com/city/delhi/corpns-coming-up-with-four-more-say-city-of-2cr-people-has-no-option/articleshow/67763704.cms

Table 35: Summary of intervention wise net cumulative costs

Sector	Intervention	Costs (in Billion Rs)		
		2022	2025	2030
Biomass Burning	Increase in LPG penetration in residential sectors in families those still rely on biomass in NCR by 100% in 2022	-26.52	-	-
	Supply improved induction cook-stoves 100% in 2022 to households using biomass	-23.45	-	-
Transport	Electrification of vehicular fleet (Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%)			
	Public transportation -25% in 2022, 50% in 2025 and 100% in 2030	46	159	555
	Private electric vehicles- 20% in 2022 and 40% in 2025 and 100% in 2030 electric two-wheelers, and 100% three-wheelers in 2022	4	17	63
	Private electric vehicles- 10% in 2022, 20% in 2025 and 40% in 2030 electric cars	40	142	520
	Fleet modernization to BS-VI vehicles from 2022, 2025 and 2030			
	100% Fleet Modernization of trucks and buses to BS VI by 2022, 2025 and 2030	110	203	292
	100% Fleet Modernization of 2 & 4-wheelersto BS VI by 2022, 2025 and 2030	307	648	974
	25% Modal shifts of cars and 2-wheelers to CNG buses by 2022, 2025 and 2030	59	124	252
Industries	Power plant controls -implement stricter NO_x and SO_2 standards with continuous monitoring by 2022	54.3	-	-
	100% enforcement using wet scrubbers in industries in 2022, 2025 and 2030	0.46	0.84	1.51
	100% enforcement of zig-zag brick kiln technology in 2022, 2025 and 2030	-14.4	-	-
	100% fuel switch from solid and liquid to gaseous fuels in industries by 2022, 2025 and 2030	97	249	-
Road Dust and Construction	100% vacuum cleaning of arterial roads by 2022, 2025 and 2030	0.001	0.003	0.006
	100% Wall to wall paving of arterial roads by 2022, 2025 and 2030	10.5	7.9	4.9
	Control of dust from construction activities- barriers and fogging based controls 100% in 2022, 2025 and 2030	1.06	2.50	4.28

2025, and 2030.The fixed capital cost involved in the intervention is levelised for the duration of intervention, it is evident from the result that the costs are reasonably high for same intervention in 2025, and 2030 (e.g. fleet modernization)." It is to be noted that costs of some interventions are negative indicating that these interventions will show net economic benefits (due to efficiency gains) along with the air pollution benefits. These strategies include provision of LPG to replace biomass for cooking, electrification of 2 and 3 wheelers, zig-zag technologies for brick kilns, etc. The highest costs have been estimated for fleet modernization of private vehicles, followed by modernization of heavy duty vehicles, and electrification of cars.

7.3 Cost effectiveness of different interventions

After estimating the cost of different interventions, cost effectiveness in terms of cost in Billion Rupees per microgram per m^3 of $PM_{2.5}$ removed is estimated. The results for different interventions are presented in the Table 36. It is evident that both the interventions for residential sectors (i.e. increased in LPG penetration and supply of induction cook stoves) show negative costs per unit of $PM_{2.5}$ concentrations removed. In the transport sector, electrification of cars and fleet modernization of 2w and 3w to BSVI show the highest costs per unit of $PM_{2.5}$ removed. On the other hand, electrification of two and three wheelers and fleet modernization of trucks and buses show lower costs per unit change in $PM_{2.5}$ concentrations. Cost effectiveness of fleet modernization decreases with time as the potential to reduce pollution decreases with penetration of BS-VI vehicles. Industrial options of stricter enforcement of SO_2 and NO_x norms in power plants, conversion of brick kiln to Zig-Zag technology, installation of wet scrubbers in industries, and fuel switch from solid and liquid to gas in industries show low costs per unit of $PM_{2.5}$ removed. For dust generation from construction and demolition activities, strict enforcement of construction norms and vacuum cleaning of arterial roads is the most cost effective strategy. The use of agri. residue in power plants and biodiesel penetrations in transport sectors are no regret measures and should be implemented irrespective of considerations of their cost effectiveness.

Based on the cost effectiveness of various interventions, a set of interventions were selected to formulate an alternative scenario. The selected interventions and air quality concentration in alternative scenario is explained in the next section.

Economic benefits of some of the strategies like LPG penetration and induction based cooking are evident and hence show up as negative costs. However, in interventions like electric vehicle high costs can be seen due to high upfront capital costs involved. The absolute fixed costs of purchasing EV outweigh the benefit accrued by it at the time of operations. However, for the individual EV the benefits could've been more than the costs if we consider the incremental cost of purchasing EV over ICE vehicle. In fleet modernization scenarios, the costs per unit of $PM_{2.5}$ abated are found to increase with time. This is due to falling numbers of very old vehicles required to be modernized with time as in BAU, BS-VI penetration is already accounted. In case of cars, the costs of fleet modernization per unit of $PM_{2.5}$ abated are very high and become extremely high by 2030 as reductions achieved are expected to be very low considering very small reduction in $PM_{2.5}$ emissions in moving from BS-IV to BS-VI petrol cars. Diesel cars are already banned after 10-years and hence they will all be BS-VI in 2030 in BAU. Modal shift to public transport and electrification of public transport comes out to be quite cost effective in comparison to many other strategies. In addition, public transportation system provides additional social and economic benefits (that include reduced congestion, time and exposures, less expenditure on infrastructure creation and traffic management), there is a definite need for gradual transition towards multi-modal public transport system in the region The costs per unit of $PM_{2.5}$ removed by road dust control measures is relatively low and are expected to go down in future as the major costs are upfront with capital expenditure and benefits will continue in future.

Table 36. Cost effectiveness of different control options in terms of cost in Billion Rupees per microgram per m^3 of $PM_{2.5}$ removed from ambient air in Delhi (wrt BAU)

S.No.	Intervention	2022	2025	2030
1	LPG penetration	-5		
2	Induction cookstove	-4		
3	Public transport on EV	25	57	364
4	Electric 2W and 3W	1	4	10
5	Electric cars	359	319	1169
6	FM trucks & buses	11	30	1169
7	FM 2w & 4w	130	534	9740
8	Shift car & 2w to buses	63	130	529
9	SO_2 & NO_x norms in Power plants	19		
10	Wet scrubbers in industries	0.1	0.23	1.42
11	Zig-Zag brick kilns	-59		
12	Gas in industries	12	44	
13	Vaccum cleaning roads	0.002	0.005	0.009
14	Wall to wall paving	19	13	7
15	Construction controls	0.48	1.14	1.88

The cost effectiveness shown in the Table 36 can be compared across different interventions for same year. The costs here are the net present value of the intervention from year 2019 to 2022, 2025, and 2030. However, the reduction in ambient concentration is annual for particular year 2022, 2025, and 2030.

8. ALTERNATIVE SCENARIOS FOR AIR QUALITY IMPROVEMENT IN DELHI

Despite several interventions assumed to be in place, the BAU scenario shows only reduction of 28% in $PM_{2.5.}$ between the years 2019 and 2030. There is a need to enhance the stringency of interventions for effective control of pollution in Delhi and meet the NAAQS in the worst affected winter season. Based on analysis of interventions, it emerged that there are interventions which can provide significant air quality benefits. While these interventions can provide significant benefits when implemented at the NCR level, implementation of these interventions at the airshed level (areas beyond NCR contributing to air pollution in NCT Delhi) can provide even larger benefits, which can bring pollutant levels close to the prescribed limits of $PM_{2.5}$. Interventions have been tested for the worst case winter season $PM_{2.5}$concentrations and it is assumed that controlling emissions in winters can provide significant benefits in other seasons as well. The interventions which have been identified based on discussion with relevant stakeholders and selected for formulation of alternative air quality scenario for Delhi NCR are listed in Table 37.

Table 37: List of interventions selected for formulation of alternative scenario for Delhi NCR

Sector	Intervention
Domestic	100% LPG penetration by 2022
Agriculture residue and power plant	Use of 100% agriculture residue in power plants in the year 2022, 2025 and 2030
Transport	Private electric 2-wheelervehicles- 20% in 2022 and 40% in 2025 and 100% in 2030 electric two-wheelers
	Electric 3-wheeled vehicles- 100% three-wheelers sin 2022
	Electric cars- 10% in 2022, 20% in 2025 and 40% in 2030
	Fleet Modernization of trucks and buses to BS VI by 2022, 2025 and 2030
	Increase penetration of biodiesel to12% by 2025 and 20% by 2030
Power plant	Power plant controls -implement stricter NO_x and SO_2 standards with continuous monitoring by 2022
Industries	100% fuel switch from solid and liquid to gaseous fuels in 2022, 2025 and 2030
	Stricter dust control on stone crushers in with 80% and 40% removal efficiency for PM_{10} and $PM_{2.5}$, respectively.
Brick kiln	100% enforcement of Zig-Zag brick kiln technology in 2022, 2025 and 2030
Road dust	Vacuum cleaning of arterial roads - 100% in 2022, 2025 and 2030 in Delhi and NCR
Construction	100% control of dust from construction activities- barriers and fogging based controls with removal efficiency of 60% in 2022, 2025 and 2030

Figure 21 shows the reductions in winter season $PM_{2.5}$ concentration in NCT Delhi, which are possible with implementation of selected interventions at NCR and airshed levels.

It is observed that in alternative scenarios, $PM_{2.5}$ concentration falls during 2019-2025, and thereafter increases till the year 2030, as the growth in different sectors overwhelms the benefits of interventions. The winter season $PM_{2.5}$ concentrations are expected to fall by 19% in the ALT-NCR scenario, and by 35% in the ALT-Airshed scenario, with respect to the BAU scenario in 2030. In the ALT-NCR scenario, the $PM_{2.5}$ concentrations in Delhi are expected to be between 117-103 µg/m^3 in winters between 2022-2030. However, with enhanced reductions in ALT-Airshed scenario the winter $PM_{2.5}$ concentrations are fall to 86-82 µg/m^3 in the period 2022-2030.

In ALT-NCR scenario in the year 2030, dust blown across the international border is a major contributor (35%), followed by other sources (22%), transport (9%), industries (9%), brick kilns (8%), road dust (6%), power (5%), construction (3%), waste burning (2%) and domestic sources (1%). In ALT-air shed scenario, major contributor is dust from across the border (44%), followed by other sources (18%), transport (8%), brick kilns (11%), road dust (7%), power (5%), construction (4%), industries (2%), and domestic sources (1%).

It is evident that despite extending the implementation of interventions to the airshed region, the $PM_{2.5}$ concentration will still be above the prescribed standards during the winter season, while it is expected to meet the annual average standard. In order to achieve ambient air quality standards throughout the year, additional controls will be required. The $PM_{2.5}$ reduction benefits of these additional controls are shown as MFR (maximum feasible reduction) scenario in Figure 21. In addition to strategies taken for ALT-NCR and ALT-air shed scenario, MFR scenarios assumes control of ammonia release in farms, enforcement of full ban on refuse burning, converting all coal based power plants to cleaner energy based, most stringent dust suppression control, shift from Zig-Zag to gas based tunnel kiln technology for brick kilns, use of induction cook-stoves, full vacuum cleaning of arterial, sub-arterial and local roads, and stricter control of dust from construction activities. Figure 21 shows that in the MFR scenario, the $PM_{2.5}$ concentrations in Delhi can be brought under the limits even during winter season. MFR will result in 69% reduction in the year 2030 w.r.t 2019.

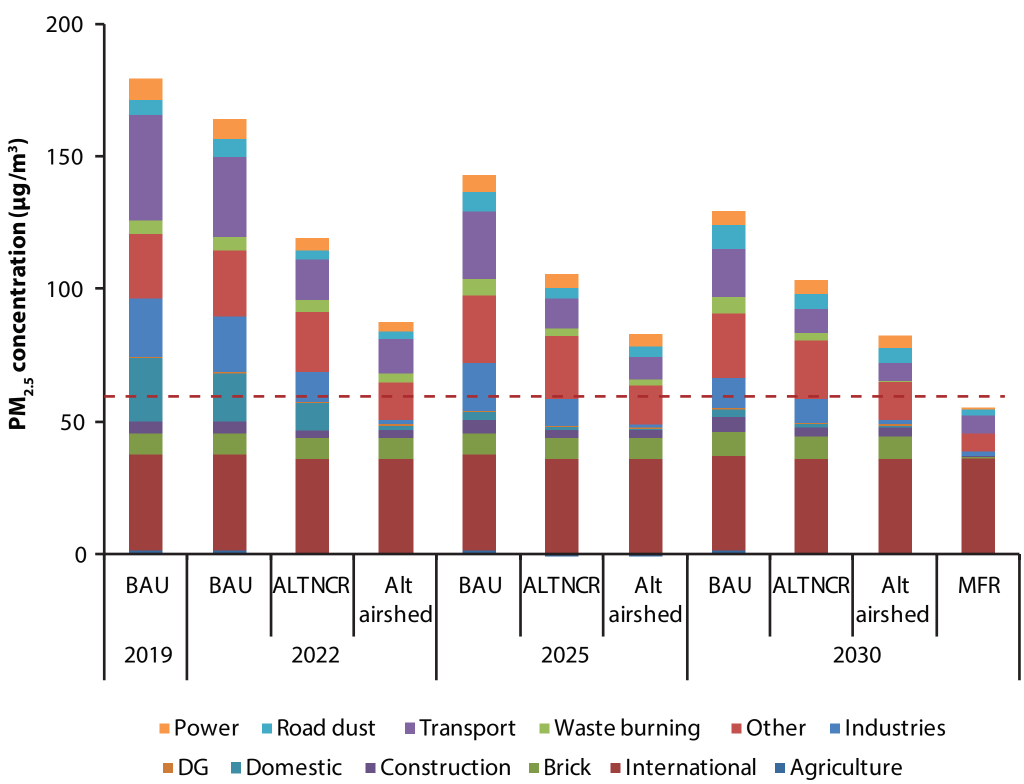

Figure 21: Estimated $PM_{2.5}$ concentration in winters in alternative scenarios for 2022, 2025 and 2030

Estimation of economic values of health impact in different scenarios

Human health and associated economic impact due to exposure to $PM_{2.5}$ in different scenarios have been quantified and are presented in the Annexure-I. Health impacts are quantified for Delhi and NCR in terms of disease-specific mortality attributable to exposure to ambient $PM_{2.5}$ concentrations. The study estimated the mortalities attributable to five diseases, cardiopulmonary diseases (COPD) (above 30), lung cancer (LC) (above 40), ischemic heart disease (IHD) (above 25), lower respiratory infections (LRI) (below 5) and stroke (all age groups) caused due to high ambient particulate matter concentrations. The health impact is indicatively captured through the integrated exposure risk function (IER) developed by Burnett et al. (2014). Results can be further refined as and when indigenous dose reponse relationships will be available. These mortalities estimated for different scenarios are then converted to the economic loss using the values of Disability Adjusted Life Years (DALY), value of DALY to GDP per capita and the GDP per capita of the region. We also recommend to develop indigenous dose response relationship for more robust assessments in future. It is estimated that despite reduction of 28% in $PM_{2.5}$ concentration in BAU scenario in the years 2022-2030, mortalities attributable to $PM_{2.5}$ pollution will increase from 14,400 in 2022 to 15,500 in 2030 in Delhi due to ageing population. The relative risk declines with increasing age, which relatively leads to lesser health benefits, even in a decreasing air pollution scenario. This is further affected by the non-linear nature of the relative risk function which does not decrease by the same rate as the concentrations decrease. In Delhi NCR, there are an estimated 7,300 avoided mortalities in 2022 and 6,200 in 2030 if ALT scenario is implemented instead of BAU, however if ALT Airshed is implemented, these avoided mortalities will double. In the whole Delhi NCR region, economic benefits arising from health impacts are estimated to be INR 480-430 billion between BAU and ALT Airshed in 2022-2030; however these benefits will decline by 48% if the ALT scenario is implemented instead of ALT Airshed. It has been concluded that moving from BAU to alternative scenario will have positive impacts as the benefit to cost ratios are more than one in all the years. Further details about the analysis can be found in the Annexure-I.

9. CONCLUSIONS

Air pollution is a serious concern in Delhi NCR. While there are source apportionment studies conducted in past to ascertain shares of different contributing sources, the interventions suggested for control have not been prioritized based on a full scale cost benefit analysis. This study provides estimates of possible costs and reductions in $PM_{2.5}$ concentrations attributable to various interventions for control. Along it the base year 2019, the study also provides a fair idea of plausible future scenarios and effect of different interventions on future air quality.

The broad conclusions of this study are:

- Air pollution levels are appreciably higher than the prescribed standards in Delhi and adjoining areas. $PM_{2.5}$ concentrations in Delhi during 2019 violate the annual average standards by about 3times.
- Transport (23%), industries including power plants (23%), and biomass burning (14%), are the major contributors to winter season $PM_{2.5}$ concentrations in NCT Delhi during 2019.
- In the BAU scenario, the winter season $PM_{2.5}$ concentrations are expected to fall by 9%, 21%, and 28% in 2022,2025, and 2030, w.r.t BAU 2019 respectively, despite which the levels will remain significantly above the standards.
- More stringent controls will be required to control emissions in the entire NCR and the rest of the airshed to bring winter season $PM_{2.5}$ levels down considerably.
- NCR and airshed level controls can reduce winter season $PM_{2.5}$ concentrations by 19-27%, and 35-47% by the year 2022-2030 w.r.t BAU.
- Effect of regional scale pollution is pronounced in Delhi's $PM_{2.5}$ concentrations and hence, regional level air quality planning and implementation is recommended for effective control of pollution in the entire region.
- Based on cost-effectiveness analysis, the following interventions are selected which shows negative costs or low cost to $PM_{2.5}$ reduction ratios:
    1. Full LPG/induction stoves penetration
    2. Use of agriculture residue in power plants
    3. 2-w and 3w vehicles on Electric modes
    4. Enforcement of Zig-Zag brick kiln technology
    5. Power plant controls -implement stricter NO_x and SO_2 standards with continuous monitoring
    6. Fuel switch from solid to gaseous fuels in industries
    7. Vacuum cleaning of all arterial roads
    8. Control of dust from construction activities- barriers and fogging based controls.
    9. Fleet modernization of Trucks and buses (in short term when the abundance of old vehicles is high)
- Some of the interventions are net negative cost options as they generate net economic benefits over a period of time. These include strategies like LPG penetration, induction cook-stoves, zig-zag brick kilns, use of agriculture residue in power plants, etc.

» High cost effectiveness has been observed for strategies for industrial and dust pollution with low costs per unit of $PM_{2.5}$ removal. These include electrification of 2w and 3w vehicles, gaseous pollutant controls in power plants, fuel switch from solid to gaseous fuels in industries, vacuum cleaning of roads, and control of dust from construction activities.

» Low cost effectiveness is found for fleet modernization of cars. However, it is high initially for heavy duty vehicles like trucks and buses. Modal shift to public transport and electrification of public transport comes out to be quite cost effective in comparison to many other strategies. In addition, public transportation system provides additional social and economic benefits that include reduced congestion, time and exposures, lesser expenditure on infrastructure creation and traffic management, there is a definite need for a gradual transition towards multi-modal public transport system in the region.

» Despite the reduction of 21% in $PM_{2.5}$ concentration in BAU scenario, mortalities attributable to air pollution will increase by 7.6% during 2022-2030 due to aging population.

» Implementation of alternative control strategies across the whole airshed (ALT airshed scenario) over BAU can avoid over 14000 mortalities in 2022 and 12,000 in the year 2030 in Delhi NCR. These avoided mortalities can result in economic benefits of around INR 480-430 billion in the year 2022-2030.

» Even in ALT scenario, benefits to cost ratio will remain greater than 2 in all the years, which clearly indicates that economic benefits of moving towards clean air will outweigh the costs.

This study provides useful insights for policy making for control of pollution in NCR in the short to long term. However, continued research is required to further refine the emissions inventories with additional surveys in different sectors. Improvement in resolution of inventories can further help in identification of hotspots which will need hotspot management along with city and regional level controls.

This study is limited to assessment of cost-effectiveness of strategies for control of $PM_{2.5}$ only. $PM_{2.5}$ is considered for the study as it is the pollutant of main concern in India, with major violations and health implications. Currently, NCAP's focus is also on reduction of ambient $PM_{2.5}$ concentrations. There is very limited monitoring of Ozone and other air toxics in the country, which if enhanced can help expanding the scope of this study which is limited to $PM_{2.5}$ related controls only. PM_{10} or Ultra-fine particles are other important pollutant to consider in future, when more detailed monitoring data, health studies, and standards are available in Indian context. In addition to $PM_{2.5}$ (air pollution) control, there are other benefits (e.g. decongestion, savings of fuels, time, GHGs etc) which are not assessed and monetized in this study, which can only make the case stronger for faster implementation of some of these strategies in Delhi-NCR We believe that the extent of trans-boundary governance and joint consideration of air quality control actions across different jurisdictions around Delhi is only going to get stronger. In this study, the cost-effectiveness of interventions is only tested at the NCR level, which needs to be expanded to the airshed level with availability of more detailed inventories and sectoral information . Finally, in order to understand the cost-effectiveness of emission control strategies only, the meteorological conditions have been assumed to be same across different years. In future studies, downscaled climate models for future years could be used to assess the impact of changing climatic conditions also.

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ANNEXURE

Health Impact of air pollution

Ambient air pollution is widely known to have severe negative impacts on human health. Many studies have established a strong correlation between air pollutants and human health impacts. The Indian Council of Medical Research (ICMR) considers air pollution as the second leading health risk factor in India after child and maternal malnutrition. In the past years, a number of additional studies (TERI 2018) estimated the health effects associated with ambient air pollution in India.

The study here has assessed the impacts of air pollution on human health in different scenarios envisaging implementation of air pollution control strategies in Delhi NCR. The health and the associated economic impact arising from exposure to atmospheric $PM_{2.5}$ have been quantified. The approach for estimating health and the associated economic costs is broadly divided in two components: the disease burden estimation (in terms of avoided mortality) and the economic quantification of the health impact or estimating the health benefit. The input to this health impact modelling exercise is the ambient annual average $PM_{2.5}$ concentrations that is derived from the Community Multi-Scale Air Quality model (CMAQ) for the Delhi-NCR region. The study then quantifies the positive health impact of alternative scenarios (consist of various interventions) in terms of decreased risk of mortalities. The associated avoided deaths and savings in the form of economic benefits due to improvements in air quality were analyzed based on the change in $PM_{2.5}$ concentrations in different scenarios and years (2019-2030). Based on the exposure of the population, health impacts are quantified in terms of disease-specific mortality attributable to by ambient $PM_{2.5}$ concentrations. The study estimates the mortalities attributable to five diseases, cardiopulmonary diseases (COPD) (above 30), lung cancer (LC) (above 40), ischemic heart disease (IHD) (above 25), lower respiratory infections (LRI) (below 5) and stroke (all age groups) caused due to high ambient particulate matter concentrations. The health impact is captured through the integrated exposure risk function (IER) developed by Burnett *et al.* (2014). These IERs are employed to estimate the relative risks attributable to $PM_{2.5}$ exposure for the five endpoints. The coefficients pertaining to each disease have been estimated using the data for $PM_{2.5}$ and the relative risks for 4042 data points provided by Apte *et al.* 2015. The coefficients estimated for LRI, COPD and LC are same through the age groups, however there exists age modified risk models for IHD and stroke. Epidemiological studies of risk factors for both IHD and stroke indicate that the RR declines with the logarithm of age, reaching 1 between 100 and 120 years of age. Thus, age modification to the RRs has been considered and the IER has been fitted for each age group separately.

This mortalities estimated for different scenarios are then converted to the economic loss using the values of Disability Adjusted Life Years (DALY), value of DALY to GDP per capita and the GDP per capita of the region. Both the human capital approach (HCA) and value of statistical life (VSL) approach is followed here to estimate the economic benefits in different alternative scenarios in comparison to the BAU scenario for reducing ambient air pollution. The HCA is a productivity-based approach, which presumes that the social worth of an individual is a function of his market productivity. The VSL on the one hand better aligned with economic theory, can be estimated using either a stated preference survey (e.g., contingent valuation or CV) or derived from labour market data (e.g., hedonic wage) (Gunatilake et al. 2014).

Any global assessment of the mortality risks associated with ambient $PM_{2.5}$ is contingent on assumptions about the shape of concentration-response (C-R) relationships for the full range of conditions experienced by the global population. There are evidences of a supra-linear C-R function where the marginal effects of exposure decline with increased exposure. Recent analyses that integrate information from studies of $PM_{2.5}$ ambient air pollution, second hand cigarette smoke exposure, and active cigarette smoking provide further evidence that the exposure response function is not linear throughout the range of potential exposures (Pope et al. 2015), but that it flattens out when exposure is extended to very high levels. The excess risk for the assumed supra-linear C-R function illustrated in Figure 1 is as shown in Equation 1.

Equation 1

RR = 1+α {1-exp [-β (C-C0) δ]} for C>C_0

RR = 1 for C<C_0

For each endpoint, C_0 represents a theoretical minimum-risk concentration above which there is evidence indicating health benefits of $PM_{2.5}$ exposure reductions, and parameters α, γ, and δ determine the overall shape of the concentration-response relationship as the result of a stochastic fitting process.

The mortality, M attributable to $PM_{2.5}$ for age stratum z and disease endpoint j for grid cell i located in region k using the attributable-fraction relationship is presented in Equation 2.

Equation 2

$M_{i,j} = P_i \times I_{j,k} \times (RR_j\ (C_i) - 1)$, where

where P_i is the population of grid cell i, $I_{j,k}$ is the reported regional average annual disease incidence (mortality) rate for endpoint j in region k, C_i represents the annual average $PM_{2.5}$ concentration in cell i, RR_j (*Ci*) is the relative risk for end point *j* at concentration *Ci* and represents the average population weighted relative risk for end point j within region k (Apte et al (2015).

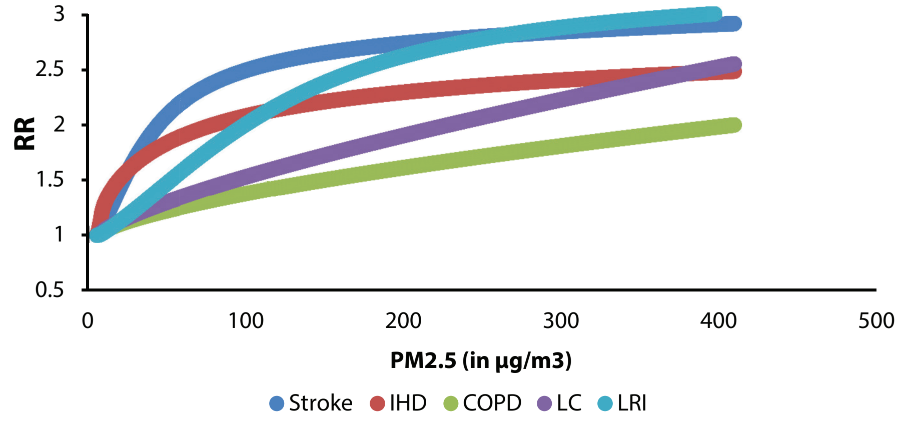

Figure 1A: Concentration-response function for $PM_{2.5}$ for five individual endpoints

In this estimation the avoided mortality has been calculated and the change in mortality is ΔM where $\Delta M_{i,j,}$ in grid cell i under a scenario where concentrations are changed from C_i to some arbitrary alternative concentration C_i* without altering the underlying incidence, the relationship is used is shown in Equation 3.

Equation 3

ΔMi,j = Pi × Ij,k × (RRj (Ci*) - RRj (Ci))

where P_i is the population of the grid cell *i*, $I_{j,k}$ is the reported regional average annual disease incidence (mortality) rate for an endpoint *j* in region *k*, C_i represents the annual average $PM_{2.5}$ concentration in cell *i*, $RR_j(C_i)$ is the relative risk for endpoint *j* at concentration $C_{i,}$ and $RR_j(C_i*)$ is the relative risk at the alternative concentration C_i* (Apte et al (2015)). The data of the population has been taken from the Census 2011 and then extrapolated for 2019, 2022, 2025 and 2030. The reported average annual disease incidence rate for the five endpoints has been derived from the Global Burden of Disease (GBD) database for the year 2020 and assumed to be constant for the future years.

Results of health impact assessment

Based on the methodology explained above, the total mortality as well as the avoided mortalities on different alternatives have been estimated under the different scenarios. The annual average $PM_{2.5}$ concentrations under the different scenarios in 2022, 2025 and 2030 are shown in the Figure 2 for both Delhi and NCR. The annual average $PM_{2.5}$ concentrations reduce by 27% in ALT scenario from BAU in 2022 and by 46% in ALT Airshed in the region.

Total Mortalities

Based on the above annual average $PM_{2.5}$ concentrations, the total mortalities in the Delhi NCR region have been estimated under the different scenarios. The estimated mortalities are shown in Figure 3. Despite a sharp reduction in the annual average $PM_{2.5}$ concentrations, the estimated mortalities increase slightly in the future years.

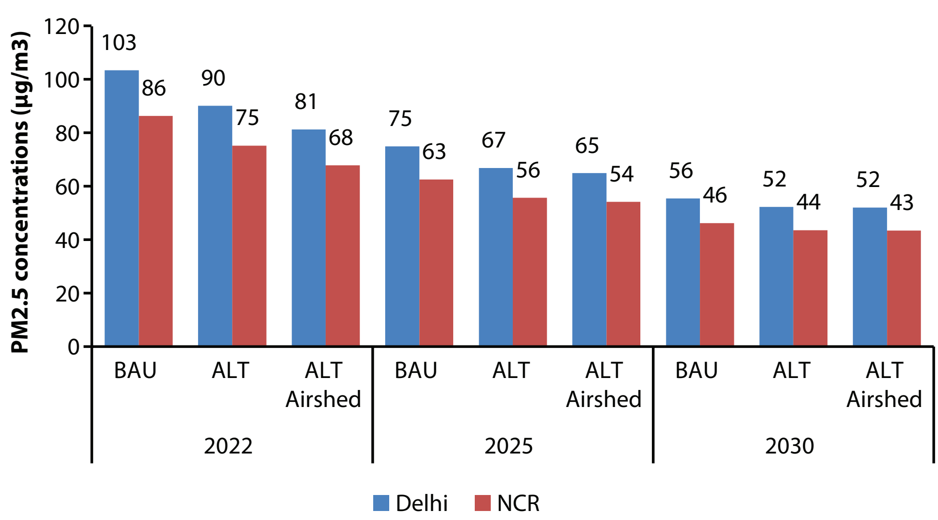

Figure 2A: Estimated a in Delhi and rest of NCR in different scenarios

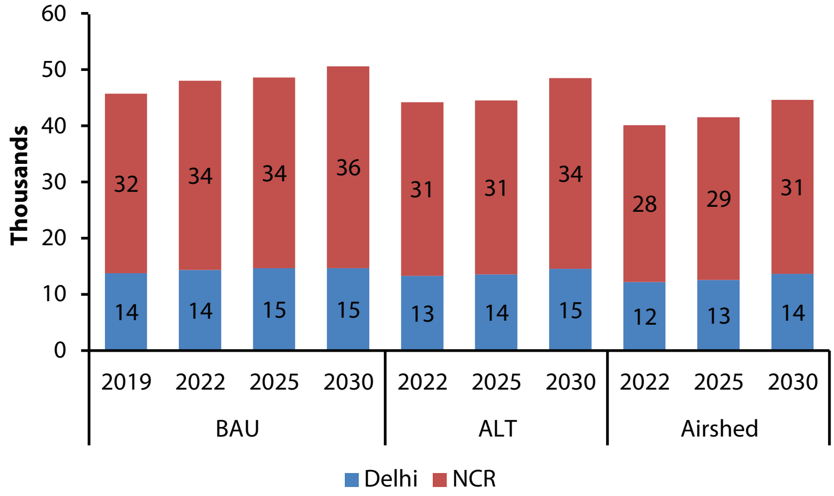

Figure 3A: Total estimated mortalities in Delhi and rest of NCR under different scenarios

The estimated mortalities in Delhi are the highest under the BAU scenario increasing from 14,400 in 2022 to 15,500 in 2030. These mortalities reduce by 8% in the ALT scenario and by 15% in ALT Airshed scenario in 2022 and by 6% and 12% respectively in 2030. It has to be noted here that despite a reduction of 27% in the concentrations in the ALT scenario from the BAU scenario in 2022, the mortalities reduce only by 8% due to the non-linear nature of the IER function. The rate of reduction of the relative risk from ambient air pollution is less than the rate of reduction of the concentrations, causing a less reduction in the overall mortalities. The reductions in mortalities are expected to steeper when reduced beyond 60 µg/m^3.

Also, despite a 21% reduction in the annual average concentrations in the BAU scenario from 2022 to 2030, the total mortalities increase by 7% in 2030 from 2022. Despite an overall reduction in the concentrations, the overall mortality marginally increases due to the rising population and the shift of people from the lower age group to the age zones where the relative risks is much higher.

Similar to Delhi, the estimated total mortalities in the NCR region increase by 8% in 2022 from BAU to ALT scenario and by 17% from BAU to ALT Airshed. Also despite a fall in the overall concentrations between 2022 and 2030, the total mortalities increase in the region due to the rising population of the whole area and the non-linear nature of the relative risk function. The total mortalities in the rest of NCR region are almost twice as in Delhi despite lower concentrations in the NCR region due to higher population in NCR compared to Delhi.

Table 1: Total estimated mortalities in Delhi NCR in different scenarios

Delhi NCR			
Total Mortalities	2022	2025	2030
BAU	48000	49000	50700
ALT	44200	45000	48200
ALT Airshed	40200	41500	44800

Table 1 shows the total mortalities in the Delhi NCR region attributable to $PM_{2.5}$ under the different scenarios in 2022, 2025 and 2030. There is an estimated 8% decrease between BAU and ALT and a 16% fall from BAU to ALT Airshed.

Avoided Mortalities

Other than the total mortalities estimated attributable to $PM_{2.5}$, the total avoided mortalities have also been estimated when switching from one scenario to another both for the Delhi and rest of NCR region. Figure 4 shows these estimated avoided mortalities.

The avoided mortalities are the highest when there would be a switch from the BAU to ALT Airshed scenario. If there is a switch from BAU to ALT Airshed, the total annual mortalities saved in Delhi region are estimated to be 4,000 in 2022 and 3,500 in 2030. Similarly the mortalities saved annually by moving from ALT to Airshed will be 2,150 in 2022 and 1,900 in 2030.

These avoided mortalities will be higher in NCR due to higher population of the region. From the BAU to ALT Airshed, the avoided mortalities will be 10,200 in 2022 and 8,800 in 2030. While switching from BAU to ALT, the avoided mortalities are estimated to be 5,400 in 2022 and 4,600 in 2030. Table 2 shows the total avoided mortalities in the Delhi NCR region due to the change in scenarios.

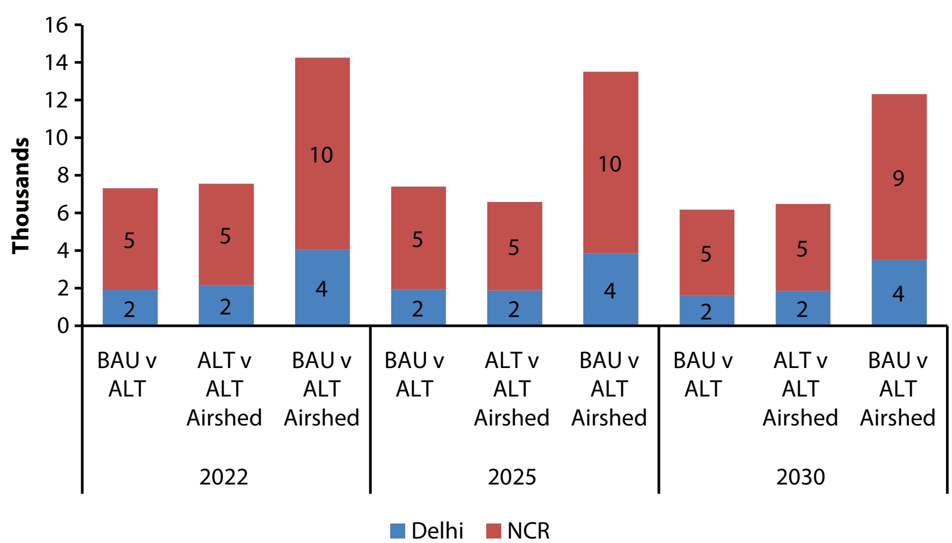

Figure 4A: Avoided mortalities between different scenarios in Delhi and rest of NCR

Table 2: Total avoided mortalities in Delhi NCR in different scenarios

Delhi NCR			
Total Mortalities	**2022**	**2025**	**2030**
BAU vs ALT	7300	7400	6200
ALT vs ALT Airshed	7500	6600	6500
BAU vs ALT Airshed	14200	13500	12300

There are an estimated 7,300 avoided mortalities in 2022 if ALT scenario is implemented instead of BAU, however if ALT Airshed is implemented, these avoided mortalities will double in Delhi NCR.

Economic Benefits

From the estimated avoided mortalities of Delhi NCR region, the economic benefits have been estimated. These economic benefits arise from the mortalities that can be avoided by adhering to better scenarios that have stricter interventions. Figure 5 shows the total economic benefits by switching between scenarios in 2022, 2025 and 2030 in both Delhi and NCR.

It can be observed from Figure 6 that the total economic benefits in Delhi are estimated to be highest when there is a switch from BAU to ALT Airshed, followed by the ALT vs ALT Airshed. The economic benefits are estimated to be INR 135 billion in BAU vs ALT Airshed and INR 72 billion in the ALT vs ALT Airshed in 2022.

Similarly, the total economic benefits are the highest in rest of NCR region when there is a change from the BAU to ALT Airshed. They are estimated to be INR 342 billion in BAU vs ALT Airshed and INR 181 billion in ALT vs ALT Airshed.

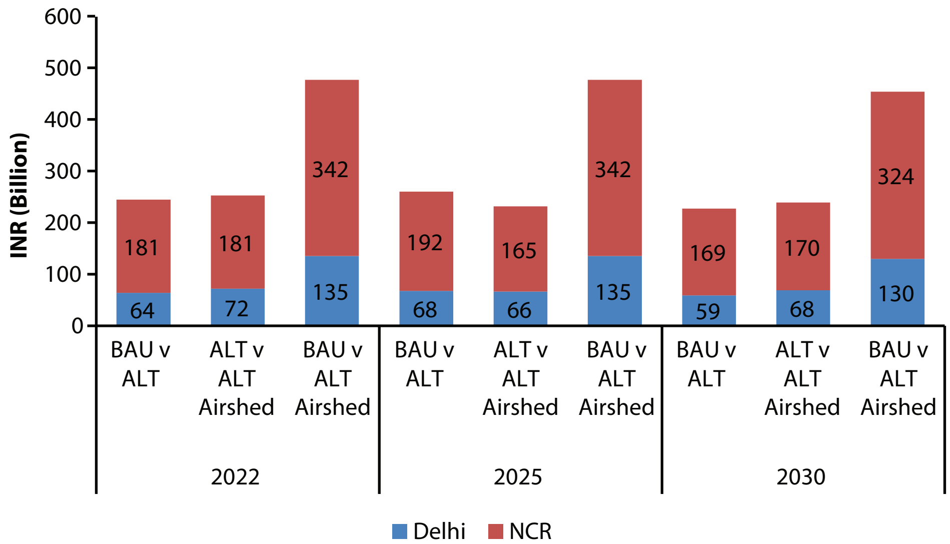

Figure 5A: Total economic benefits attributable to avoided mortalities in different scenarios (in INR bn)

Overall, in the whole Delhi NCR region these economic benefits arising from health impacts are estimated to be INR 480 billion between BAU and ALT Airshed in 2022, however these benefits will decline by 48% if the ALT scenario is implemented instead of ALT Airshed. Also, it has to be noted here that these benefits have been estimated both from the Human Capital Approach (HCA) and Value of Statistical Life (VSL) approach, hence results from both these approaches have been shown. These economic benefits of the Delhi NCR region from the HCA approach are shown in Table 3 and from the VSL approach are shown in Table 4. The VSL is estimated based on a number of past for India (Shanmugan, 1997; Madheswaran, 2007; Simon et al., 1999; Bussolo and O'Connor, 2001). Applying the growth factors an average VSL for the year 2022-2030 has been estimated to increase from INR 17.8 million to INR 46.8 million.

Table 3: Total economic benefits between different scenarios (in INR billion) (HCA approach)

Delhi NCR			
Total Economic Benefits (in INR bn)	**2022**	**2025**	**2030**
BAU vs ALT	245	260	230
ALT vs ALT Airshed	250	230	240
BAU vs ALT Airshed	480	470	450

Table 4: Total economic benefits between different scenarios (in INR billion) (VSL approach)

Delhi NCR			
Total Economic Benefits (in INR bn)	**2022**	**2025**	**2030**
BAU vs ALT	230	270	290
ALT vs ALT Airshed	240	240	300
BAU vs ALT Airshed	450	500	580

The estimated economic benefits are higher when estimated through the VSL approach compared to the HCA approach but still are in close range.

Per capita economic benefits

The total economic benefits estimated under the different scenarios are used to estimate the per capita benefit of all the interventions (Table 5).

Table 5: Per capita economic benefits through HCA approach (in INR)

	2022	**2025**	**2030**
Total Delhi NCR Population (in billion)	0.07	0.08	0.08
Total Benefit per capita (in INR)			
BAU v ALT	3500	3200	2800
ALT v ALT Airshed	3600	2900	2980
BAU v ALT Airshed	6800	5900	5700

Based on the analysis, the total per capita economic benefit is estimated to be the highest under the BAU vs ALT Airshed scenario that is INR 6,800 in 2022, followed by the ALT vs ALT Airshed scenario, INR 3,600 and then the BAU vs ALT scenario where the per capita benefit is estimated to be INR 3,500.

Table 6: Per capita economic benefits through VSL approach (in INR)

	2022	**2025**	**2030**
Total Delhi NCR Population (in billion)	0.07	0.08	0.08
Total Benefit per capita (in INR)			
BAU v ALT	3300	3400	3600
ALT v ALT Airshed	3400	3000	3800
BAU v ALT Airshed	6500	6200	7200

The total per capita economic benefit is higher when estimated through the VSL approach due to the higher total economic benefits. The per capita benefits are the largest when there is a switch from BAU to ALT Airshed followed by the ALT vs ALT Airshed and BAU vs ALT scenario.

Cost-Benefit Ratio

Based on the list of interventions selected for formulation of alternative scenario for Delhi NCR, their costs have been estimated for the years 2022, 2025 and 2030. For these costs, corresponding economic benefits from switching to BAU to ALT scenario have been estimated and thus they can be compared to arrive at the benefit to cost ratios. Table 7 shows these benefit cost ratios for the year 2022, 2025 and 2030 both from the HCA and VSL approach.

Table 7: Benefit to cost ratios

Year	2022	2025	2030
Total Cost of Interventions (in INR bn)	117	84	80
Total Benefits (in INR bn) (HCA)	245	260	230
Total Benefits (in INR bn) (VSL)	230	270	290
BCR(HCA)	**2.1**	**3.1**	**2.9**
BCR(VSL)	**2.0**	**3.2**	**3.6**

It has been estimated that moving from BAU to alternative scenario will have positive impacts as the benefit to cost ratios are more than one in all the years. These ratios are higher when estimated through the VSL approach compared to the human capital approach. This is conclusive that other than reduced suffering due to illness, there will be economic health benefits of moving towards clean air in Delhi NCR. The benefits estimated here are conservative as the economic impacts of morbidities, and impacts of air pollution on agriculture, buildings and climate has not been estimated and accounted in this assessment.

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