EXECUTIVE SUMMARY

Source Apportionment of $PM_{2.5}$ & PM_{10} Concentrations of Delhi NCR for Identification of Major Sources

Prepared by

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Disclaimer Notice

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The report has also been reviewed by the Technical Committee setup for the project.

Executive Summary

1.0. Introduction

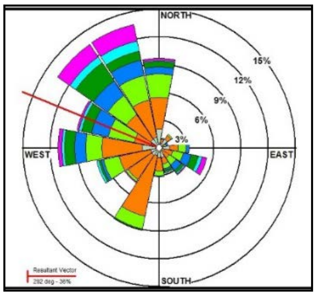
This study carried out source apportionment of $PM_{2.5}$ and PM_{10} concentrations in Delhi-National capital region (NCR) using two modelling-based approaches. The first approach relied upon monitoring and chemical characterization of $PM_{2.5}$ and PM_{10} samples. The chemically speciated samples along with source profiles were fed into the receptor model to derive source contributions. In the second approach, source-wise emission inventory, along with meteorological inputs and boundary conditions were fed into a dispersion model to simulate PM_{10} and $PM_{2.5}$ concentrations. The modelled concentrations were compared with actual observations for validation. The validated model has been used to carry out source sensitivity to derive source contributions and future projections of $PM_{2.5}$ and PM_{10} concentrations. Finally, various interventions have been tested which can reduce the pollutant concentrations in future years.

Independently derived source contributions from the two approaches (receptor and dispersion) for the year 2016 are compared to judge their mutual consistency. This will help the policy makers to take informed decisions and eventually the validated dispersion model can be used for future projection or intervention analysis. The results of the two approaches not only show consistency with each other but also with the previous study (IITK, 2015) in deriving source contributions. In comparison to the IITK (2015), this study has different monitoring locations and is based on different meteorological conditions prevailing in the year 2016. Moreover, this study has used newly developed emission factors, source profiles for some sources and also covered a wider study domain of NCR. Additionally, a chemical transport model has been used to account for chemical reactivity and long range transport of pollutants. This builds confidence in the estimates which may be used to formulate strategies for control of air pollution in Delhi-NCR.

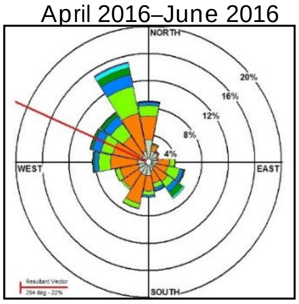
Some major findings of air quality monitoring, receptor modelling, emission inventory, dispersion modelling, and future projections are summarized in subsequent paragraphs

2.0. Air Quality Monitoring

- A comprehensive exercise of air quality monitoring was carried out for a period of two seasons in one year at 20 representative locations (9 in Delhi City, 4 in Uttar Pradesh, 7 in Haryana) in the NCR including kerbside, industrial, commercial, residential, and reference sites, which has different land use pattern and sources of activity (**Figure E.1**).
- Twenty monitoring sites as given below were distributed in Delhi-NCR based on land use type and prominent wind direction to capture air quality levels under different activity profiles.

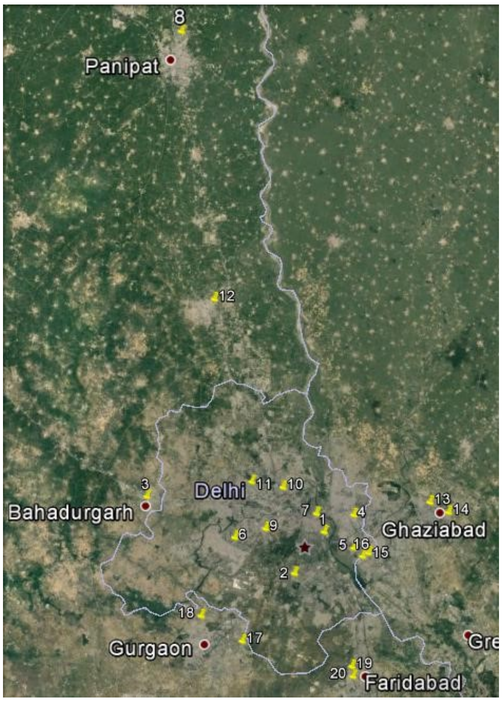


Windroses - Summer Season
April 2016–June 2016



Windroses - Winter Season
November 2016–Feb 2017

Site No.	Location	Site ID
1	ITO square	ITO
2	R. K .Puram, Sector 2	RKP
3	Bahadurgrah	BHG
4	Shahdara	SHD
5	Mayurvihar, Phase 1	MYR
6	Janakpuri	JNP
7	Chandani Chowk	CHN
8	Panipat	PNP
9	Naraiana Industrial Sector	NRN
10	Wazirpur Industrial Sector	WZP
11	Rohini, Sector 6	RHN
12	Sonipat	SNP
13	Ghaziabad 1	GHZ-1
14	Ghaziabad 2	GHZ-2
15	Noida- Sector 6	NOI-1
16	Noida- Sector 1	NOI-2
17	Huda sector, Gurgaon 1	GRG-1
18	Palam Vihar, Gurgaon 2	GRG-2
19	Faridabad 1	FBD-1
20	Faridabad 2	FBD-2



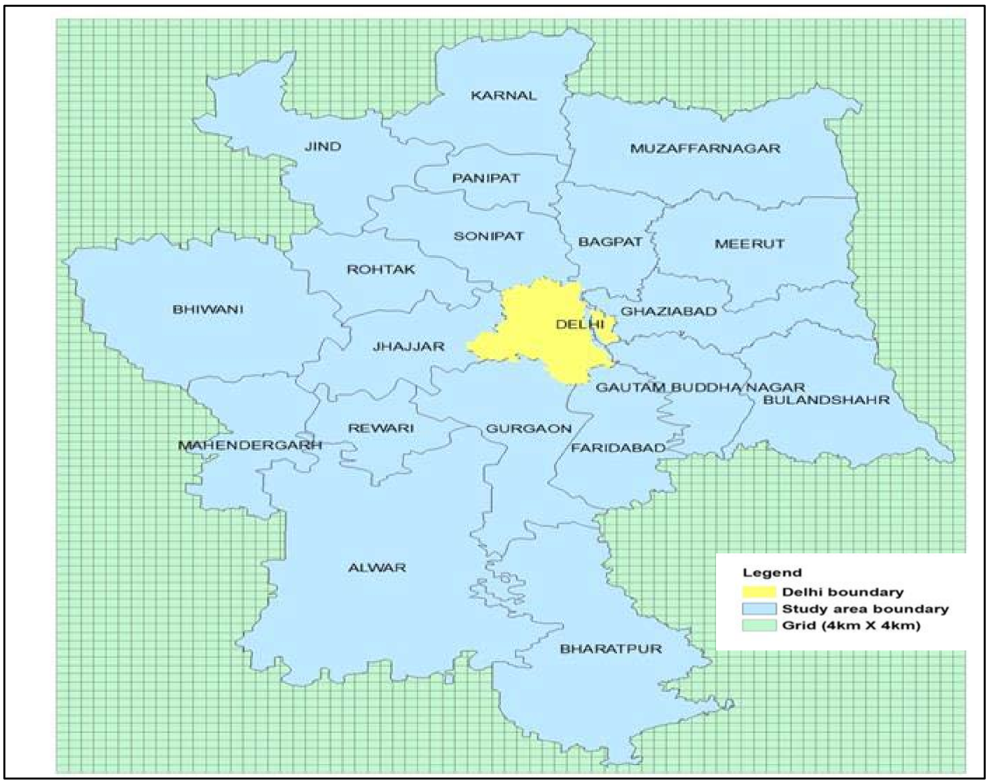


Figure E.1 : Details of locations of air quality monitoring sites and the study domain

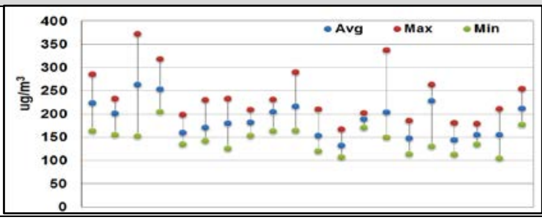
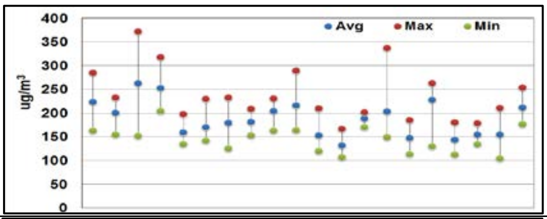
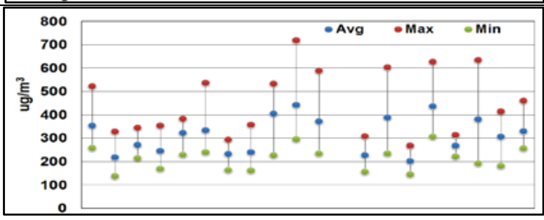
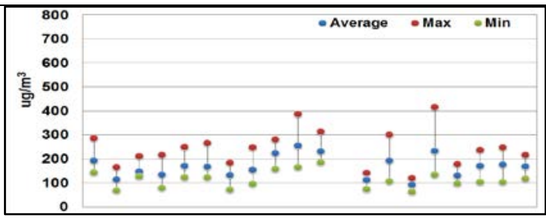
Parameter	All Site Average, µg/m³	Sitewise (Avg., Min., Max.) , µg/m³
Summer PM_{10} (µg/m³)	263 **188** 131	
Summer $PM_{2.5}$ (µg/m³)	130 **90** 65	
Winter PM_{10} (µg/m³)	441 **314** 201	
Winter $PM_{2.5}$ (µg/m³)	254 **168** 92	
	Max Mean Min	ITO RKP BHG SHD MYR JNP CHN PNP NYR WZP RHN SNP GHZ1 GHZ2 NOI1 NOI2 GRG1 GRG2 FBD1 FBD2

Figure E.2: Average PM_{10} and $PM_{2.5}$ mass concentration (µg/m³) at respective monitoring sites in summer and winter season

- Site-wise variation in concentrations of PM_{10} and $PM_{2.5}$ in summer and winter seasons is presented in **Figure E.2**. In summer season, average concentration of PM_{10} at all monitoring sites across Delhi-NCR was 188 ± 37 µg/m³. Concentration of PM_{10} varied from 131 to 263 µg/m³. Similarly, average concentration of $PM_{2.5}$ in summer season was 90±17 µg/m³ varying from 65 to 130 µg/m³.
- Both PM_{10} and $PM_{2.5}$ average concentrations were found to be more than the prescribed standard limit by the Central Pollution Control Board (CPCB).
- In winter season, average concentration of PM_{10} across all monitoring sites in Delhi-NCR was 314±77 µg/m³. Average maximum concentration was 441 µg/m³ while minimum average concentration was 201µg/m³. Similarly in $PM_{2.5}$, average concentration was 168±45 µg/m³ varying from 92 to 254 µg/m³.

3.0. Chemical analysis of samples

Chemical speciation of particulate matter samples collected on filter paper can be separated into the three most common categories: elements, ions (sulphates, nitrates, ammonium, etc.) and carbon fractions. **Figure E.3** depicts the overall scheme of chemical speciation of particulate samples.

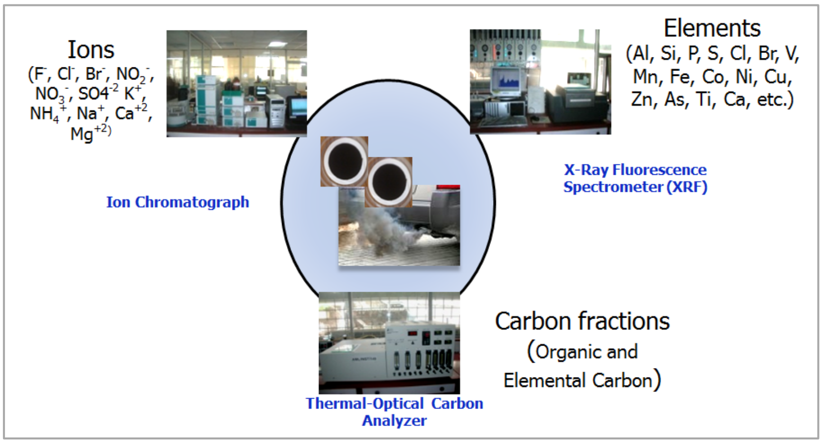


Figure E.3 : Chemical speciation of particulate matter samples

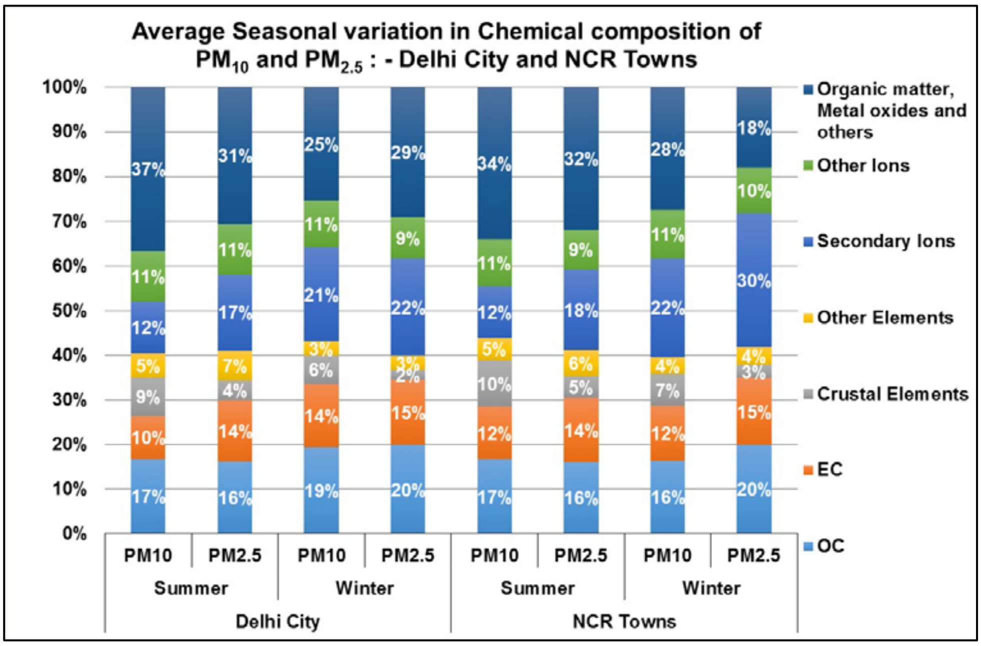


Figure E.4: Average chemical composition of PM_{10} and $PM_{2.5}$ in NCR Towns (excluding Delhi) and Delhi-city in summer and winter seasons

Seasonal variation in average chemical composition of PM_{10} and $PM_{2.5}$ for Delhi-city and NCR Towns is presented in **Figure E.4.**

Average chemical composition of PM_{10} and $PM_{2.5}$ at Delhi-city and NCR Towns in summer season:

- **PM_{10}:** OC (organic carbon) was similar (~17%) at Delhi-city and NCR Towns. EC (elemental carbon) was found to be slightly higher at NCR Towns (~12%) compared to Delhi-city (~10%). Contribution of crustal elements in Delhi City was 9% and in NCR Towns it was about 10%. Other elements contributed to about 5% in Delhi city as well as NCR Towns. Secondary ions (~12%) and other ions (~11%) were found to be similar in both Delhi city and NCR Towns. Remaining constituents of organic matter, metal oxides, and others were higher in Delhi-city (~37%) compared to NCR Towns (~34%).

- **$PM_{2.5}$:** Average chemical composition was found to be similar in both Delhi-city and NCR Towns. Both OC (~16%) and EC (~14%) were found to be similar. Both crustal elements (~4%–5%) and other elements (~6%–7%) were found to be similar. Secondary ions was found to be similar in NCR Towns (~17%–18%), whereas other ions were found to be higher in Delhi-city (~11%) compared to ~9% in NCR Towns. Remaining constituents of organic matter, metal oxides, and others were found to be similar (~31%–32%).

Average chemical composition of PM_{10} and $PM_{2.5}$ at Delhi-city and NCR Towns in winter season:

- **PM_{10}:** OC was found to be higher in Delhi-city, that is, ~19% compared to ~16% in NCR Towns. EC was found to be higher in Delhi-city (~14%) compared to ~12% in NCR Towns. Both crustal elements (~6%–7%) and other elements (~3%–4%) were found to be similar. Contribution of secondary ions was found to be significant with about 21% in Delhi city and about 22% in NCR Towns. Other ions contributed to about 11% in Delhi city and NCR Towns. Remaining constituents of organic matter, metal oxides, and others were higher in NCR Towns, that is, ~28% compared to ~25% in Delhi-city.
- **$PM_{2.5}$:** Contribution of OC was found to be about 20% in both Delhi city and NCR Towns. Similarly contribution of EC was about 15%. Contribution of crustal elements was found to be lower i.e. about 2% in Delhi city and about 3% in NCR Towns. Other elements (~3%–4%) were also found to be similar. Secondary ions were found to be higher (~30%) in NCR Towns compared to ~22% in Delhi-city whereas other ions were found to be similar i.e. about9% in Delhi city and about 10% in NCR Towns. Remaining constituents of organic matter, metal oxides, and others were found to be higher in Delhi-city (~29%) as compared to ~18% in NCR Towns.

4.0. Receptor modelling

The fundamental principle of receptor models is that mass conservation can be assumed and a mass balance analysis carried out to identify and apportion sources of airborne particulate matter in the atmosphere. The approach to obtain a data set for receptor modelling is to determine a large number of chemical constituents, such as elemental concentrations in a number of samples. Receptor models use monitored pollutant concentration and some information about the chemical composition of air pollution sources (profiles) to estimate the relative influence of these sources on pollutant concentrations at any single monitoring location.

The following approach was used for receptor modelling using USEPA's CMB model:

- Identification of probable contributing sources to the monitoring sites
- Selection of chemical species : Following species were analysed from the PM_{10} and $PM_{2.5}$ samples collected at respective sites in summer and winter seasons.
  - o Carbon fractions based on temperature (organic carbon and elemental carbon) using Thermal Optical Reflectance (TOR) Carbon Analyser,
  - o Ions (anions—fluoride, chloride, bromide, sulphate, nitrate; and cations—sodium, ammonium, potassium, magnesium, and calcium) using ion chromatography
  - o Elements (Al, Si, K, Ca, Ti, V, Fe, Co, Ni, Cu, Zn, As, Se, Zr, Mo, Pd, Cd, Ce and Pb) using Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF)
- Selection of representative source profiles, based on the source activities around the sites and considering sources that will impact the receptor locations based on wind direction, with the fraction of each of the chemical species and uncertainty.
- Site-specific wind trajectories during monitoring period were taken from website of Air Resource Laboratory, HYSPLIT, URL: *https://www.arl.noaa.gov/ready/hysplit4.html*
- Fire data was collected for the monitoring period from NASA, Earth data, Fire Information for Resource Management Systems (FIRMS), URL: *https://firms.modaps.eosdis.nasa.gov/firemap/.* This data was collected to assess magnitude and spread of fire activity in the upwind direction.

- A few study specific profiles were developed under this project and used. Details of source profiles selected are as follows:
  - o Vehicular sources:
    - a) New composite profiles of different fuel types developed for newer technology vehicles (post-2005) under this study and
    - b) Earlier profiles of pre-2005 vehicle technology. (CPCB, 2009, Vehicle Source Profiling report)
  - o Non-vehicular sources: Indigenous profiles developed by IIT-Bombay (CPCB, 2009, Stationary Source Profiling report)
  - o Site-specific profiles developed under this study are:
    - a) Refuse burning,
    - b) Agri-waste (sugarcane) combustion,
    - c) Agri-waste (rice) combustion,
    - d) Agri-waste (wheat) combustion,
    - e) Road and soil dust (composite of Delhi and NCR Towns).
- Estimation of both the ambient concentrations and uncertainty of selected chemical species from the particulate matter collected at respective sites; and
- Solution of the chemical mass balance equations was obtained through CMB-8.2 receptor model by using the chemical composition results of 24 hour daily samples collected in summers and winter season in 2016/17 at all sites and source profiles of applicable sources at respective sites as an input.
- Contributing sources were identified by averaging the contribution from sources observed based on daily samples across the monitoring period.

- Based on availability of source profiles and due to similar nature of source profiles leading to difficulty in resolving the CMB equation due to their collinearity, identified sources are categorized into dust and construction, biomass burning, vehicles, industry and others. Dust and construction source includes natural sources, such as soil dust and anthropogenic sources, such as paved and un-paved road dust and dust generated due to construction activity. Biomass burning includes agri-waste (sugarcane, wheat, and rice) burning and residential biomass burning. Vehicles include contribution from all categories of vehicles and all fuel-types. Distribution of contribution based on vehicle-type and fuel-type can be obtained from dispersion modelling results based on emission inventory presented in subsequent sections. Similarly detailed distribution of dust, biomass, and industrial sources is presented in dispersion modelling results.

Results of receptor modelling for summer and winter season:

- Average contribution of different sources towards PM_{10} and $PM_{2.5}$ in summer and winter seasons for sites in Delhi-city and NCR Towns is presented in **Figure E.5**.

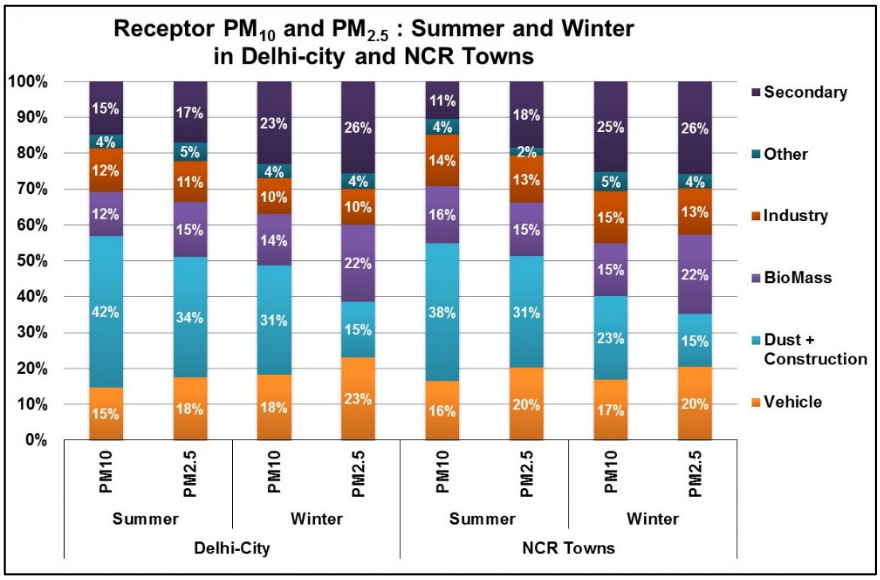


Figure E.5: Average source contribution to PM_{10} and $PM_{2.5}$ samples at representative sites in summer and winter season in Delhi-city and NCR Towns (excluding Delhi)

Seasonal variation of different sources of $PM_{2.5}$ and PM_{10}, obtained as an out of receptor modelling, in terms of percentage contribution is shown in **Figure E.5** for Delhi-city and NCR Towns.

4.1 PM_{10}

Seasonal variation of PM_{10} shows higher contribution of dusty sources in summer (38%–42%) as compared to winter in Delhi-city as well as NCR Towns. This can be attributed to dry conditions and higher wind velocities resulting in entrainment of dust. However, contribution of dusty sources (e.g. road, construction and soil dust) was also significant in winter season (23%–31%). Contribution of vehicles to PM_{10} was slightly higher in winter (17%–18%) in Delhi-city and NCR Towns than in summer (15%–16%). Biomass burning contribution was slightly higher in winter in Delhi-city (14%) than in summer (12%), whereas in NCR Towns the contribution was similar in both the seasons (15%–16%). Contribution from industrial sources was similar in both summer and winter seasons in Delhi-city (10%–12%) and NCR Towns (14%–15%). Contribution in NCR Towns was higher as compared to Delhi-city due to the presence of industries in the proximity. There are several types of industries operating in NCR Towns including bricks, sugar, paper, dyeing, rubber, chemical ceramics, iron & steel, textile, fertilizer, stone crushers, and casting & forging etc. Other sources, which include DG sets showed similar contribution of about 4%–5%. Contribution of secondary ions to PM_{10} is significantly higher in winter (23%–25%) than in summer (11%–15%) in both Delhi-city and NCR Towns.

4.2 $PM_{2.5}$

Seasonal variation of $PM_{2.5}$ shows significantly higher contribution of dusty sources in summer (31%–34%) as compared to winter (15%) in Delhi-city as well as NCR Towns. Higher contribution of dusty sources even in $PM_{2.5}$ can be attributed to dry conditions and higher wind velocities in summers resulting in contribution from far-off sources. Primary contribution of vehicles to $PM_{2.5}$ was higher in winter (20%–23%) in Delhi city and NCR Towns than in summer (18%–20%). Biomass burning contribution was significantly higher in winter in Delhi-city and NCR Towns (22%) than in summer (15%). Contribution from industrial sources was similar in both summer and winter seasons in Delhi city (10%–11%) and NCR Towns (13%). Contribution in NCR Towns was higher as compared to Delhi-city due to the presence of industries in the proximity. Other sources, which include DG sets showed contribution of less than 5%. Contribution of secondary ions to $PM_{2.5}$ was higher in winter (26%) than in summer (17%–18%) in both Delhi-city and NCR Towns.

- Significantly higher contribution of dust in PM_{10} and also in $PM_{2.5}$ particularly in summer season may be attributed to the transboundary contribution. Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at the sites particularly in summer shows wind flows from far-off regions.
- Variation in the contribution of sources, such as vehicles (15%–23%), biomass burning (12%–22%), and dust (15%–42%) may be attributed to the variation in activities at local level and meteorology.
- Secondary particulates were found to contribute significantly to both PM_{10} and $PM_{2.5}$ in winter season.
- Contribution from sources outside Delhi, such as residential cooking, agricultural waste burning, industries (tall stacks) and dust particles are likely due to winds carrying pollution with the incoming air to Delhi-city and NCR Towns.

5.0. Emissions inventory

Source-wise multi-pollutants inventories of air pollutants have been prepared for the year 2016, at a high resolution of 4x4 km^2. Along with PM, inventories of sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs) have also been prepared to account for secondary particulates formation. The major sectors which have been covered in the analysis are: 1)Residential, 2)Open agricultural residue burning, 3)Transport—tailpipe emissions , 4)Construction, 5)Industries (including bricks and stone crushers), 6)Power plants- stacks, coal handling units and fly-ash ponds, 7)Road dust, 8)Diesel generators, 9)Refuse burning, 10)Crematoria, 11)Restaurants, 12)Airports, 13)Landfills, 14)Waste incinerators, 15) Solvents, 16) Ammonia emission sources, etc.

Emissions estimates were based on activity type, emissions factors, pollution abatement technology used, and the efficiency of control. Activity data was collected from both primary and secondary sources. The newly developed database of vehicular emissions factors developed by the Automotive Research Association of India (ARAI) has been used for vehicular sources. Emissions estimated from various sectors have been allocated over the study domain as per area, line, and point source categories. ARCGIS software was used for estimation of gridded emissions (4x4 km^2) for different pollutants across the NCR.

The emissions inventory for Delhi and the NCR is shown in **Table E.1**. The estimates presented are the annual totals for different sectors, however, there are seasonal variations in emissions from different sectors, which have been accounted for during simulations. The total emissions of PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, and NMVOC are estimated for Delhi and NCR. The percentage share of sectors in overall inventory of PM_{10}, $PM_{2.5}$, NO_x, and SO_2 emissions are shown in **Figure E.6.** Amongst the sources within Delhi, the share of the transport sector is significant (39%) in $PM_{2.5}$ emissions. This reduces to 19% in PM_{10} emissions in Delhi, due to the presence of other major sources, such as road dust and construction, which emit more particles in the coarser range of PM. With the closure of some of the coal based power generating units, Transport now has a dominant share (81%) in the NO_x emissions amongst the sources within Delhi. SO_2 emissions within the city of Delhi are small and are mainly contributed by Badarpur coal-based power plant. Sectoral shares are significantly different, when the entire NCR is considered. Industries (28%), road dust (13%), residential (20%), and agricultural burning (17%) are the main contributors to PM_{10} emissions in NCR. For $PM_{2.5}$, industries (24%), residential (25%), agricultural burning (19%), and transport (13%) are the major contributors in NCR. Despite dominant use of LPG within Delhi city, the residential sector contributes significantly mainly due to biomass fuel used in about 3 million households in NCR. The share of transport in NCR reduces to 60% for NO_x emissions, considering other sources, such as power plants, DG sets, and industries in NCR. SO_2 emissions in NCR are about 27 times higher than Delhi, mainly due to the presence of industrial sources and power plants. Standards for control of NO_x and SO_2 in industrial setups have not yet been implemented, and hence these emissions have remained uncontrolled. Use of petcoke and FO (which are very high sulphur fuels) was a significant source of industrial SO_2 emissions in NCR during 2016, before they were banned. Emissions of ammonia were taken from IIASA's GAINS ASIA database for India.

It is evident that the emission share of different sectors is significantly different in Delhi and NCR. The air quality in Delhi is impacted by both local and outside sources, and hence, a simulations exercise is a pre-requisite to understand the contributions of different sectors lying within or outside the city of Delhi in the NCR. Other than emissions, meteorology also plays an important role in defining pollutant concentrations and source contributions.

TableE.1 : Annual emission inventory of pollutants (kt/yr) in Delhi city and NCR (including Delhi) for 2016

SECTOR	DELHI						NCR					
	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC
TRANSPORT*	12.8	12.4	126.9	1.1	501.1	342.1	68.6	66.5	528.9	4.4	1750.9	886.5
INDUSTRIES	1.3	1.1	1.6	4.6	0.2	0.0	288.3	127.4	85.2	556.2	620.0	27.0
POWER PLANTS	6.1	3.5	11.2	23.6	3.5	0.9	73.7	41.1	132.5	297.1	13.4	9.4
RESIDENTIAL	2.9	2.0	3.7	0.2	61.1	12.7	204.3	131.5	38.0	16.8	1700.3	374.1
AGRICULTURAL BURNING	0.5	0.4	0.1	0.0	2.7	0.3	174.1	102.2	30.6	9.0	781.1	209.2
ROAD DUST	24.0	5.8	0.0	0.0	0.0	0.0	137.2	30.6	0.0	0.0	0.0	0.0
CONSTRUCTION	14.2	2.7					43.7	7.8				
DG SETS	0.1	0.0	0.7	0.0	0.2	0.1	3.7	3.2	53.0	3.5	11.4	4.3
REFUSE BURNING	1.4	1.2	0.5	0.1	4.6	2.7	17.5	14.4	5.5	0.7	56.0	33.3
CREMATORIA	0.4	0.2	0.1	0.0	2.2	1.2	1.5	0.8	0.2	0.0	7.7	4.3
RESTAURANT	1.4	0.8	0.4	1.3	2.5	0.4	1.7	1.0	0.5	1.6	2.9	0.4
AIRPORT	0.1	0.1	6.6	0.5	13.6	7.0	0.1	0.1	6.6	0.5	13.6	7.0
WASTE INCINERATORS	0.5	0.3	4.1	1.6	0.9	0.0	0.5	0.3	4.1	1.6	0.9	0.0
LANDFILL FIRES	1.8	1.5	0.6	0.1	5.8	2.2	1.9	1.6	0.6	0.1	6.1	2.3
SOLVENTS						57.3						112.8
TOTAL	68	32	156	33	598	427	1017	528	886	892	4,964	1671

Note: These are annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations. Real world emissions have also been accounted for certain sectors. Power plants include stack, flyash ponds and coal handling emissions

*Including high emitters

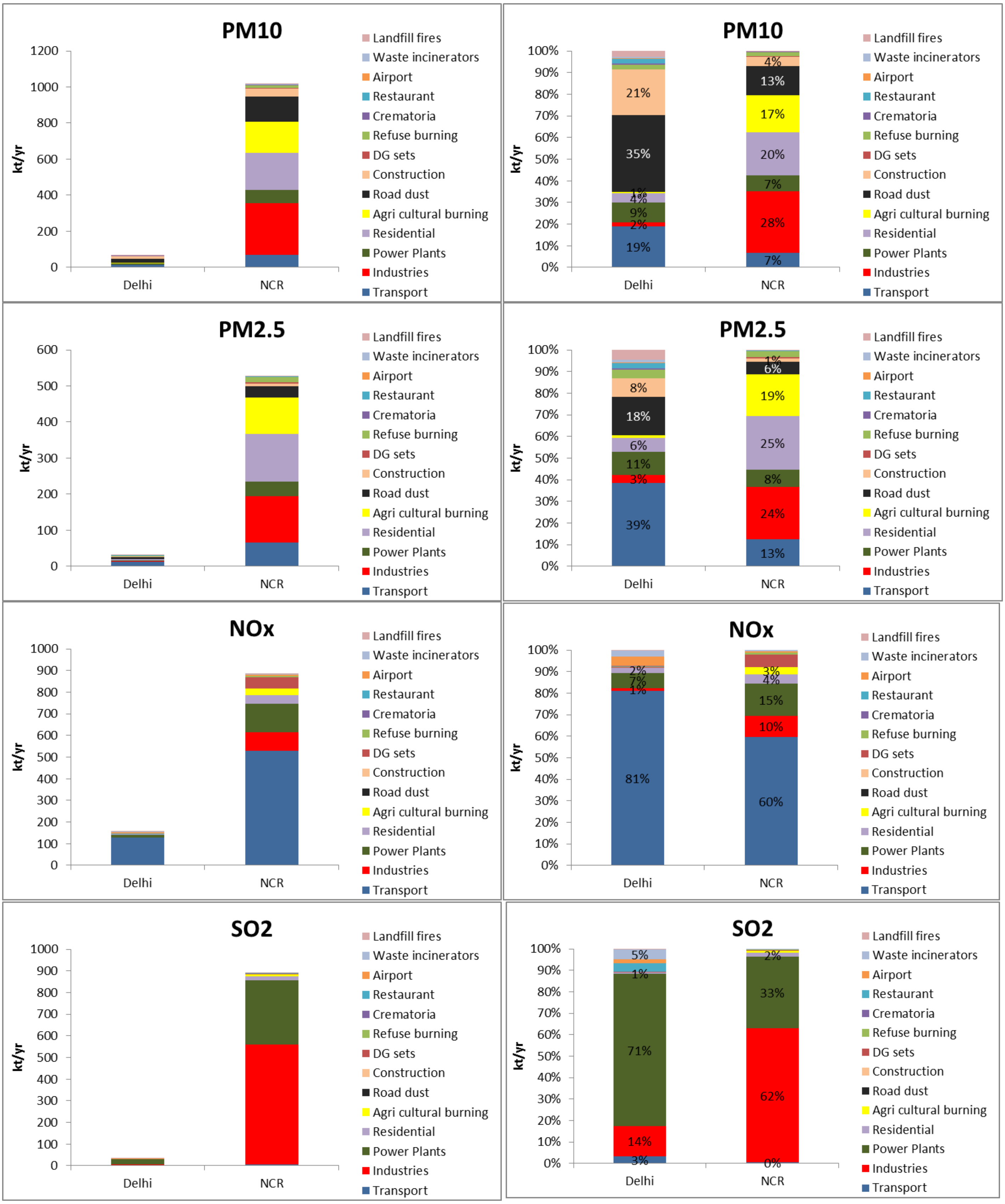


Figure E.6 : Absolute and percentage share of different sectors in overall inventory in NCR (including Delhi) and Delhi city

Note: These shares are based on annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations. The sources showing less than 1% of contributions are not labelled in the above Figure.

6.0. Simulation of air quality: dispersion modelling

Ambient PM_{10} and $PM_{2.5}$ concentrations were simulated in this study using the WRF-CMAQ model combination. WRF model runs have been carried out to generate 3-dimensional meteorological fields over the study domain which acts as input to the CMAQ model along with emission inventories. To account for contributions from outside NCR, India scale simulation runs have been carried out for the year 2016 using India-scale emissions inventory. In order to account for transport of pollutants from outside India, international boundary conditions have been adopted from global air quality products. Simulations have been performed for India and then for the NCR for the year 2016 to predict PM_{10} and $PM_{2.5}$ concentrations in NCR. The modelled concentrations were compared with the actual observations taken by ARAI for specific locations.

Evidently, the concentrations are significantly higher during winter than in summer, due to adverse meteorological conditions. Reduction in wind speed and boundary layer height during winter reduces the dispersive capacity of the atmosphere and leads to higher concentrations of pollutants near the ground.

Modelled $PM_{2.5}$ and PM_{10} concentrations were compared with the actual values for model validation. While the model captured seasonal variations quite well, the magnitude of PM concentrations was somewhat underestimated. The average ratio of modelled to observed $PM_{2.5}$ concentrations was 0.82–0.87. This performance of the model appears to be satisfactory, when compared with several previous studies (e.g. IITK (2015)). The small shortfall in the model estimates may be attributed to some unaccounted emissions from natural sources. Other than the overall, mass, the share of different constituent species of $PM_{2.5}$ is also satisfactorily reproduced by the CMAQ model. The validated model was used for estimating source contributions using source-sensitivity method.

6.1 Source apportionment in Delhi

Table E.2 shows the contributions of various sectors in $PM_{2.5}$ and PM_{10} concentrations, estimated using dispersion modelling for winter and summer seasons at 20 locations in Delhi-NCR. The results show source contributions in base case for the year 2016. It is to be noted that the contribution of agricultural burning is not fully accounted for in this study as the monitoring and modelling periods did not include the month of October, when the burning activities are generally at their maximum. Moreover, the sectoral contributions are averaged for the whole modelling/monitoring period, and hence, do not highlight the contribution of agricultural burning, which happens during a certain number of days and cause episodically high pollutant concentrations.

In $PM_{2.5}$ concentrations during winter, the average share of the transport sector varies from 28% in Delhi. Industries contribute to 30%, while biomass burning (in residences and agricultural fields) contributes 14%. Dust (soil, road, and construction) have a share of 17%. In $PM_{2.5}$ concentrations during summer, the share of the transport sector is about 17% in Delhi. Industries contribute 22%, while biomass burning in residences and agricultural fields contribute 15%. Dust (soil, road, and construction) have a share of 38% in summers. Significantly high contributions from outside of India have been observed during summer season. High contributions from international boundaries to India have also been reported by other studies (HEI, 2018; IITM 2017). Other sources contribute to 11% in winters and 8% in summer season.

In PM_{10} concentrations during winter, the average share of the transport sector is 24% in Delhi. Industries contribute to 27%, while biomass burning in residences and agricultural fields contributes 13%. Dust has a considerably higher share in PM_{10} concentrations (25%). During summer, the share of the transport sector is observed to be 15%. Industries contribute to 22%, while biomass burning (in residences and agricultural fields) contributes to 15%. Dust has a significantly higher share of 42% in PM_{10} fractions. Other sectors contribute to 10% PM10 concentrations in winters and 7% in summer season.

Table E.2 : Average sectoral contributions in $PM_{2.5}$ and PM_{10} concentrations in Delhi estimated using dispersion modelling during winters and summers

$PM_{2.5}$		
Sectors	**Winters**	**Summers**
Residential	10%	8%
Agri. Burning	4%	7%
Industry	30%	22%
Dust (soil, road, const.)	17%	38%
Transport	28%	17%
Others	11%	8%
PM_{10}		
Sectors	**Winters**	**Summers**
Residential	9%	8%
Agri. Burning	4%	7%
Industry	27%	22%
Dust (soil, road, const.)	25%	42%
Transport	24%	15%
Others	10%	7%

Note: Industries include power plants (stacks, flyash ponds and coal handling units) , brick manufacturing, stone crushers, and other industries. Others include DG sets, refuse burning, crematoria, airport, restaurants, incinerators, landfills, etc. Dust includes sources of natural and anthropogenic origin (soil, road dust re-suspension, and construction activities). Dust is also contributed through trans-boundary atmospheric transport from international boundaries.

7.0. Comparison of receptor and dispersion modelling results

A comparison of sectoral contributions obtained from receptor modelling using CMB8.2 and dispersion modelling is presented in subsequent sections. The results of both the approaches are compared at the locations of air quality monitoring.

7.1 $PM_{2.5}$

The results of receptor modelling are compared with the dispersion modelling outputs in **Figure E.7.** The receptor modelling results show primary sectoral contributions, and secondary particulates separately. It is to be noted that secondary particulates are also contributed by gaseous emissions from different sectors. The dispersion model was used to assess the contribution of different sectors to secondary particulates. The secondary particulates in the results of receptor modelling were accordingly allocated to different sectors to assess total sectoral contributions (primary and secondary).

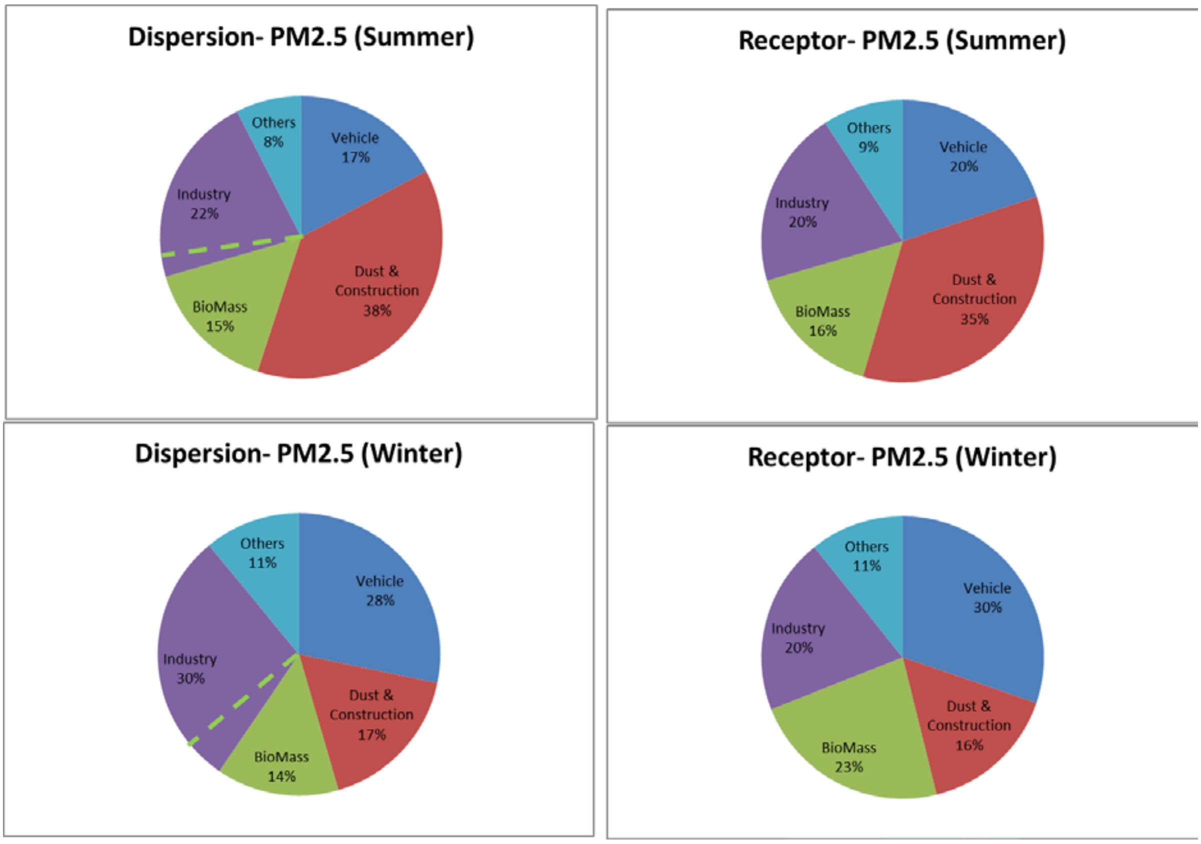


Figure E.7: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ in Delhi

* Green dotted line shows that some industries in NCR also use biomass

Figure E.7 shows that the results of the two approaches are close for most sectors. It is to be noted that in the dispersion modelling approach, the industrial sector (which seems to be overestimated) includes biomass as an industrial fuel. Dust includes contributions from road dust re-suspension, construction activities, and trans-boundary international contributions. Based on the assessment of species, it may be concluded that in summers, trans-boundary contributions are mainly composed of dust. However in winters, there are also some trans-boundary contributions from sectors, such as biomass burning and industries also.

Overall, the results of source apportionment seem to be consistent for most sectors in both the approaches. In the two seasons, the dispersion model shows contributions of transport sector as 17%–28%, in comparison to the receptor model estimations of 20%–30%. These findings are higher than the contributions of transport sector reported in IITK (2015) report, because in this study we included secondary particulates along with the primary contributions.

7.2 PM_{10}

Comparison of results of dispersion modelling with receptor modelling for PM_{10} is shown in **Figure E.8.** The results complement each other. Receptor modelling shows dust contributions of 31%–43%, which are shown to be in the range of 25%–41% by the dispersion modelling approach in the two seasons. The range of estimates for the transport sector is 15%–24% as per dispersion model runs in different seasons, while it is 17%–25% using the receptor model. Biomass burning consistently shows contributions in the range of 13%–15%. The two approaches show slight variation in industrial sector contributions, which ranges from 19%–27%.

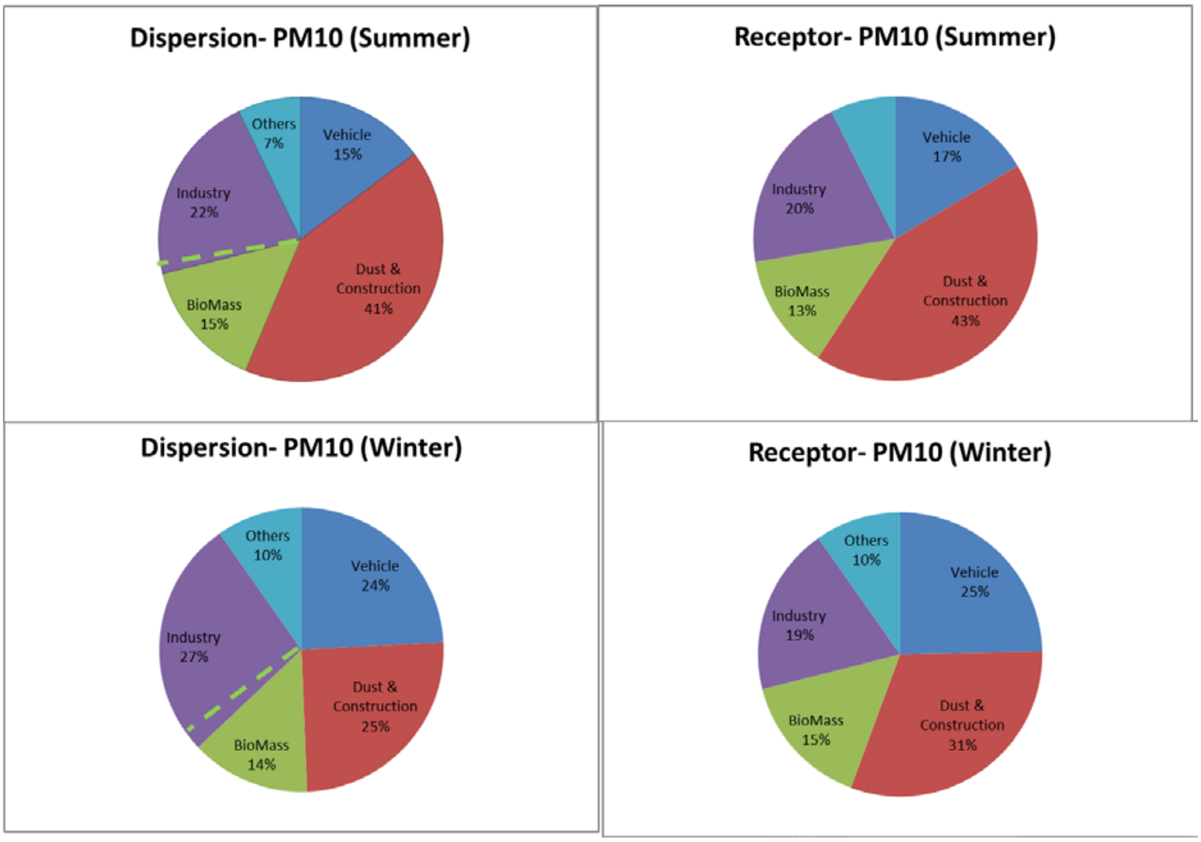


Figure E.8 : Comparison of results of dispersion and receptor modelling assessment for PM_{10} in Delhi for the two seasons

7.3 Sub-sectoral contributions to PM_{10} and $PM_{2.5}$ concentrations in Delhi and NCR

While, the broad sectoral shares have been shown in the previous section, this section shows the contribution of different sub-sectors towards $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR.

In the residential sector, biomass fuel is the dominant factor contributing to $PM_{2.5}$ and PM_{10} concentrations. It contributes to 8%–10% in $PM_{2.5}$ and 8%–9% in PM_{10} concentrations in the two seasons. Within the 30% contribution of the industrial sector in $PM_{2.5}$ concentrations (winter) in Delhi, 8% is contributed by bricks sector, 6% by power stations, 2% by stone crushers, while other industries (using coal, biomass, pet-coke, and furnace oil) contributed to about 14%. Later, in 2017, petcoke and furnace oil (FO) use were banned in the region. In the others category (within the overall contribution of 11% in winters $PM_{2.5}$ concentrations), DG sets (because of high PM and NOx emissions) contribute significantly (5%), followed by refuse burning (3%), and the rest other sources contributed to less than 1% each, towards winters $PM_{2.5}$ concentrations. In the dust category, road dust and construction sectors have 4% and 1% contributions in $PM_{2.5}$ concentrations, respectively. Within the transport sector in Delhi, trucks have the highest share of 8%, followed by two-wheelers (7%), and three-wheelers (5%). This is due to their higher shares in either or both $PM_{2.5}$ and NO_x emissions. The share of two-wheelers falls to 4% at NCR level, with increase in shares of buses (diesel buses) and tractors. The share of cars in winter and summer $PM_{2.5}$ concentrations is about 3.4% and 2%, respectively. Within this, the share of older cars on road is much higher than the newer ones. Older cars (BS-II and earlier) contribute to about 31%–50%, while BS-III cars have a contribution of 19%–22% in Delhi and NCR. BS-IV cars contributed to 50% and 28% in the overall car contributions to $PM_{2.5}$ in Delhi and NCR, respectively. The fuel-wise distribution shows that diesel has a major contribution of 67%–74% in the share of cars, followed by CNG (13%–20%), and petrol (13%–14%) cars. Although, CNG cars contribute minimally to primary PM emissions, they have some secondary nitrate contributions through NO_x to nitrate conversions. Considering 2.0%–3.4% overall share of cars in $PM_{2.5}$ concentrations in two seasons, and a 19%–27% contribution of BS-IV diesel cars within this, the overall share of all BS-IV diesel cars in $PM_{2.5}$ concentrations is estimated to be about 0.5%–0.9% in Delhi and 0.3%–0.5% in NCR. Within the heavy duty segment (buses and trucks), vehicles registered after 2010 have an emission share of 30%–60% in Delhi and 30%–42% in NCR, while the older vehicles with inferior emission norms have the remaining shares. Similarly, in case of two-wheelers, post 2010 vehicles have a share of 34%–35%, while the older vehicles with inferior emission norms have higher shares. It is to be noted that these are the shares of vehicles in 2016, and with fleet turn-over, the share of BS-IV vehicles will increase and the contribution of older vehicles will gradually decline, although, the absolute quantity emissions from BS-IV vehicles will be much lower than pre BS-IV vehicles due to improved technologies. In PM_{10}, the shares for different sub-sectors almost remain same as $PM_{2.5}$. However, the share of dust increases considerably, with road dust and construction contributing to 8% and 6% in Delhi's PM_{10} concentrations. Their share increases to 10% and 7%, respectively in NCR during winters.

8.0. Sectoral shares in other towns

The sectoral shares in PM_{10} and $PM_{2.5}$ concentrations have been shown in **Table E.3** based on both dispersion as well as receptor modelling techniques. There are stark variations across different towns due to different monitoring schedules (and corresponding modelling results) in the NCR Towns. There are also some variations in the estimates of sectoral shares between the two approaches, which could be attributed to limitations in monitoring (only 1 or 2 stations in each city) and spatial allocations of emissions. However, directionally the results are similar. In $PM_{2.5}$ the contribution of combustion based sources, such as vehicles, industries, biomass is higher, while dust (road, construction, and ex-NCR) contributes dominantly in PM_{10} concentrations. Summers show higher dust contributions from international boundaries (mainly of natural origin) due to higher wind speeds.

Table E.3: Sectoral shares estimated by dispersion and receptor modelling for various towns in NCR

NCR-City	Season	Parameter	Dispersion Modelling					Receptor Modelling				
			Vehicle	Dust	Biomass	Industries	Others	Vehicle	Dust	Biomass	Industries	Others
Bahadurgarh	Summer	PM_{10}	17%	49%	13%	16%	5%	13%	31%	24%	19%	12%
		$PM_{2.5}$	22%	39%	15%	19%	5%	20%	32%	22%	17%	10%
	Winter	PM_{10}	22%	40%	11%	22%	6%	20%	28%	13%	25%	14%
		$PM_{2.5}$	28%	26%	12%	27%	7%	23%	19%	23%	24%	10%
Panipat	Summer	PM_{10}	20%	31%	19%	25%	5%	10%	37%	21%	18%	14%
		$PM_{2.5}$	22%	33%	17%	23%	5%	20%	35%	18%	15%	13%
	Winter	PM_{10}	22%	25%	16%	31%	7%	19%	26%	16%	26%	14%
		$PM_{2.5}$	27%	12%	18%	35%	8%	29%	8%	16%	31%	15%
Ghaziabad	Summer	PM_{10}	8%	41%	12%	35%	4%	18%	42%	16%	17%	7%
		$PM_{2.5}$	10%	37%	14%	33%	5%	21%	36%	12%	23%	8%
	Winter	PM_{10}	13%	31%	16%	35%	5%	21%	27%	16%	24%	11%
		$PM_{2.5}$	18%	19%	18%	38%	6%	26%	16%	29%	18%	11%
Noida	Summer	PM_{10}	13%	47%	12%	22%	6%	15%	44%	10%	23%	8%
		$PM_{2.5}$	15%	46%	13%	20%	6%	20%	31%	12%	26%	11%
	Winter	PM_{10}	25%	29%	12%	25%	9%	21%	23%	12%	26%	18%
		$PM_{2.5}$	30%	20%	13%	28%	10%	23%	10%	22%	24%	21%
Gurgaon	Summer	PM_{10}	14%	52%	13%	13%	7%	19%	32%	19%	24%	6%
		$PM_{2.5}$	16%	49%	13%	13%	8%	26%	29%	16%	19%	10%
	Winter	PM_{10}	22%	30%	14%	26%	7%	16%	23%	20%	26%	15%
		$PM_{2.5}$	27%	21%	14%	30%	8%	26%	15%	27%	17%	15%
Faridabad	Summer	PM_{10}	9%	46%	18%	18%	9%	21%	42%	14%	16%	8%
		$PM_{2.5}$	10%	46%	18%	17%	9%	26%	29%	16%	19%	10%
	Winter	PM_{10}	21%	19%	18%	32%	10%	18%	23%	17%	24%	19%
		$PM_{2.5}$	24%	13%	18%	34%	11%	27%	23%	19%	18%	14%

Note: Share of sources vary across cities because of sources and also because of changing meteorology as the period monitoring varied across three months within a season.

9.0. Geographical contributions

This study also estimated the contribution of various regions towards $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR Towns. The average contribution of Delhi's own emissions in Delhi's $PM_{2.5}$ concentrations was found to be 36% in winters and 26% in summers with variations across different places in the city (**Figure E.9**). This finding is in-line with other recent studies for Delhi (Marrapu *et al.*, 2014; IITK, 2015; Kiesewetter *et al.*, 2017). In summers, the contribution of outside sources is higher on account of higher wind speeds and enhanced atmospheric transport of pollutants. In the NCR Towns, the contribution of emissions from Delhi city varies as per their location with respect to Delhi and prevailing wind directions. NOIDA city which is downwind of Delhi receives 28% and 40% of its $PM_{2.5}$ concentrations from Delhi-based sources, in summer and winter seasons, respectively. On the other hand, Panipat which is upwind of Delhi receives only 1% contribution from Delhi, and shows 56%–70% contribution from the remaining NCR regions. Ghaziabad also receives its major (61%–70%) contribution from NCR only.

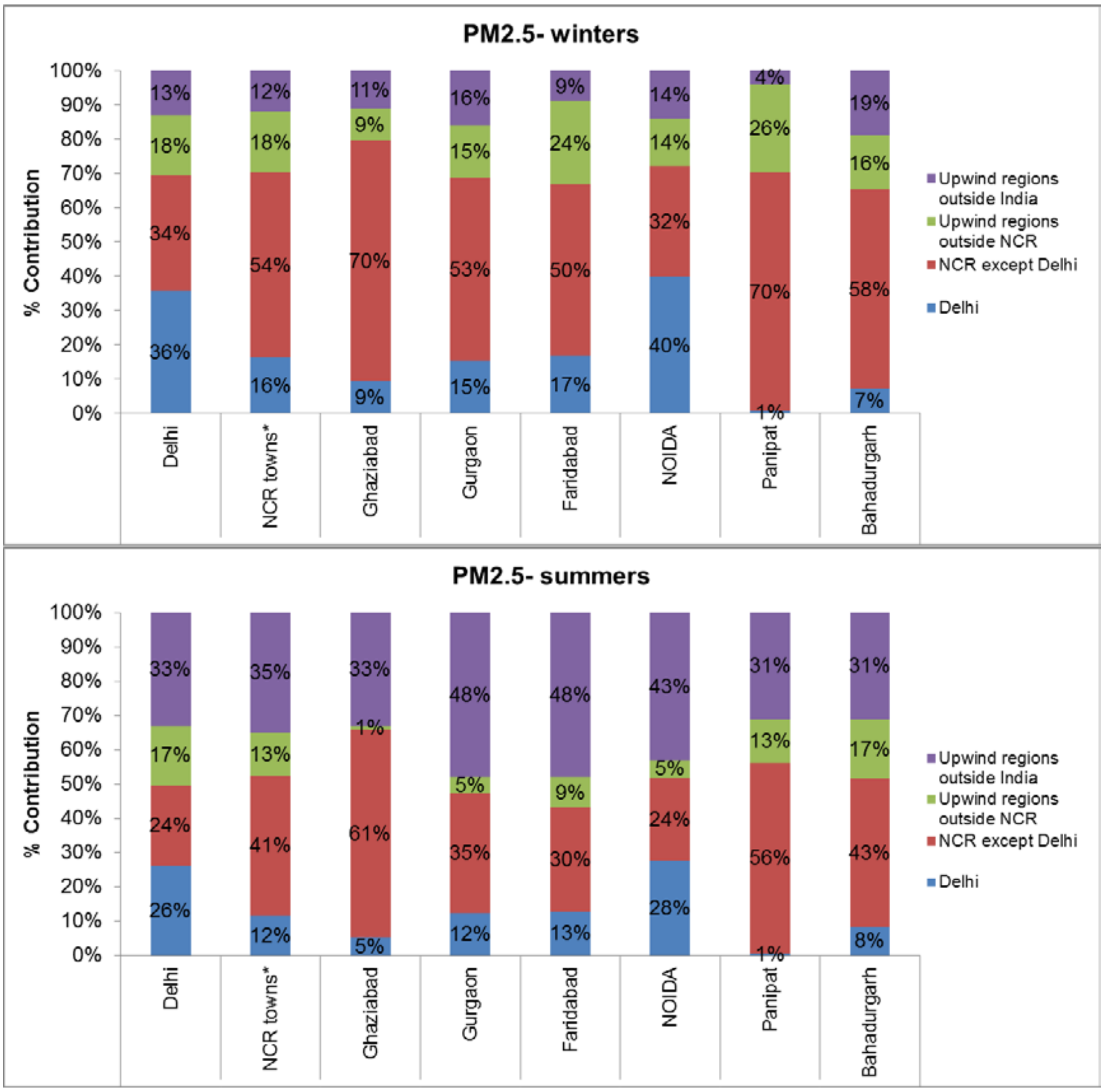


Figure E.9: Contribution of various geographical regions in $PM_{2.5}$ concentrations in different towns during winter and summer seasons

Note: Share of different regions vary across different cities because of sources and also because of changing meteorology as the period monitoring varied across three months within a season.

* Average of NCR towns excluding Delhi

10.0. Future projections

In order to understand the growth in different sectors contributing to air pollution in the region, future scenario analysis was also carried out. In this regard, possible future growth scenarios have been prepared for the year 2025 (medium term) and 2030 (long term). A Business as usual (BAU) scenario has been 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 pollution. A No-Further-Control (NFR) scenario has been analysed, in which impacts of these already planned interventions have been discounted. In order to assess the potential of various strategies for control of PM_{10} and $PM_{2.5}$ concentrations, about 27 interventions in different sectors have been tested on the model. Strategies which could provide significant air quality benefits have been identified and by combing them an alternative scenario (ALT) has been developed with the aim of meeting the prescribed air quality standards.

The BAU scenario shows that the total PM_{10} emissions will increase from 1,017 to 1,549 kt/yr during 2016–2030 (+54%), $PM_{2.5}$ emissions will grow from 528 to 791 kt/yr, by 50%. NO_x emissions will stabilize to about 913 kt/yr and SO_2 emissions will decrease from 892 kt/yr to 430 kt/yr. The increase in total PM emissions can be attributed to increase in industrial emissions which are projected to double and in the road dust and construction sector where the increase is 69%–82% by 2030. Emissions of NO_x are expected to stabilize during 2016 and 2030, mainly due to introduction of BS-VI emission norms in the vehicles sector, stringent NO_x and SO_2 standards in industries, and reduced usage of DG sets by 2030. The emissions of SO_2 are projected to decrease mainly due to banning of petcoke and FO (which are high sulphur fuels), and introduction of stringent standards for industries and power plants. With introduction of BS-VI norms, the PM emissions from the vehicle sector are expected to be 49% lower in 2030. Despite introduction of some controls, the industrial sector, due to its growth, will become the major sector contributing to $PM_{2.5}$ emissions in NCR. Contribution of residential sector reduces due to penetration of LPG and elimination of kerosene use for lighting. The share of agriculture residue burning is expected to reduce slightly considering the present focus on technologies and strategies for control. On the other hand, the contribution of road dust and construction activities is projected to increase in the BAU scenario.

Feeding the projected emissions for different sectors in the model, the BAU scenario still depicts an increase in PM_{10} concentrations (two season average) from 134 $\mu g/m^3$ in 2016 to 156 and 165 $\mu g/m^3$ in 2025 and 2030, respectively in NCR including Delhi. The $PM_{2.5}$ concentrations will increase from 109 $\mu g/m^3$ in 2016 to 114 and 118 $\mu g/m^3$ in 2025 and 2030, respectively. The increase could have been higher if the emissions control strategies (like BS-VI norms) envisaged in BAU are not implemented. These strategies are expected to contribute significantly towards reducing (30%) concentration of PM_{10} and $PM_{2.5}$ by the year 2030. Despite this, the BAU scenario shows slightly more pollutant concentrations in future than present, and hence, additional strategies will be required for control. In order to construct an alternative future scenario, intervention analysis is performed to estimate the emissions and concentrations reduction potential of different control strategies in transport, biomass, industries, road and construction dust and others sectors. The share of transport, industries, biomass , dust and others in $PM_{2.5}$ concentrations (winters) in 2030 is found to be 16%, 44%, 13%, 19%, and 8%, respectively.

The reductions have been estimated for various strategies across different sectors for the winter season (**Table E.4**). In the biomass burning sector, it was found that a 6%–7% reduction in ambient concentration of $PM_{2.5}$ and PM_{10}, respectively in 2030 may be achieved by using agricultural residues as pellets in households. However, when agricultural residues are burnt in power plants by replacing coal, it leads to a reduction of 7%–8% in PM_{10} and $PM_{2.5}$

concentrations. The main reduction is by eliminating the agricultural burning activity. Additional benefits of pelleting in households (improved cooking efficiency) and reduced use of sulphur-based coal in power plants have also been accounted for. LPG penetration leads to a reduction of 6% in $PM_{2.5}$ and PM_{10} concentrations in 2030.

As the projected share of transport in 2030 is low (16% in winter season), the impact of strategies in this sector is found to be somewhat lower than other sectors. Higher penetration of electric vehicles in transport such as 2-wheelers, buses and cars shows the reduction of 5%–6% in $PM_{2.5}$ and PM10 concentrations in 2025-2030. Reducing real world emissions by congestion management can lead to 4%–3% reduction in $PM_{2.5}$ and PM_{10} concentrations in 2030. Fleet modernization leads to 8%–6% reduction in 2025 and 3%–2% reduction in $PM_{2.5}$ and PM_{10} concentrations in 2030.

On the other hand, the projected share of industries is high (44% in winters) in 2030, and hence the impact of strategies on PM concentrations is found to be higher than other sectors. Fuel switch to gaseous fuels can lead to a massive reduction of 12% in PM_{10} and $PM_{2.5}$ concentrations in 2025. The reduction grows to 23% in 2030. Alternatively, the implementation of a stringent standard for $PM_{2.5}$/PM_{10} in industries can lead to 8%–10% reductions in PM concentrations in 2025, and 11%–12% in 2030. Better enforcement with continuous monitoring of industrial emissions will result in lower industrial emissions and a reduction of 9%–10% may be achieved in PM concentrations in 2025 and 2030. The impact of other strategies, such as zig-zag technology in brick kilns, and introduction of standards for gaseous pollutants is found to be less than 4%.

The share of dust in PM_{10} concentrations in 2030 is high, that is, 20% from road and construction activities. The strategy of enhanced vacuum cleaning of roads results in 6% and 2% reduction in PM_{10} and $PM_{2.5}$ concentrations, respectively in winters. Control of dust from C& D activities can reduce 2% and 1% of PM_{10} and $PM_{2.5}$ concentrations, respectively in NCR in 2030. Banning of open refuse burning and using it in waste to energy (WTE) plants reduces PM_{10} and $PM_{2.5}$ concentrations by 3% and 4%, respectively, in 2030. Supply of 24x7 electricity may reduce $PM_{2.5}$ concentrations by 2% in 2030 by reducing DG set usage. The rest of the strategies in others category having different reduction potentials are shown in **Table E.4**.

Table E.4 : Concentration reduction potential of various strategies (winter seasons) in 2025 and 2030.

S.N0	Strategies	2025		2030	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Biomass				
1	Increase in LPG penetration in NCR by 75% in 2025- 100% in 2030	-6%	-6%	-6%	-6%
2	Supply improved biomass cook-stoves 75% in 2025 and 100% in 2030 to households using biomass in 2025	-6%	-6%	-4%	-4%
3	Supply improved induction cook-stoves 75% in 2025 and 100% in 2030 to households using biomass in 2025	-6%	-6%	-6%	-6%
4	Use of agricultural residues in WTE (With adequate tail-pipe controls) *	-4%	-5%	-4%	-4%
5	Use of agricultural residues in power plants *	-8%	-8%	-8%	-7%
6	Use of agricultural residues pellets in local households *	-7%	-7%	-6%	-6%
	Transport				
7	Electrification of vehicular fleet (Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%)	-6%	-5%	-6%	-5%
7a	*Public transportation -25% and 50% electric buses in 2025 and 2030*	*-1%*	*-1%*	*-1%*	*-1%*
7b	*Private electric vehicles- 20% in 2025 and 40% in 2030 electric two-wheelers, and 100% three-wheelers*	*-4.7%*	*-3.5%*	*-3.9%*	*-2.8%*
7c	*Private electric vehicles- 20% in 2025 and 40% in 2030 electric cars*	*-0.24%*	*-0.17%*	*-1.4%*	*-1%*
8	Fleet modernization - Restricted entry/movement of pre-BS-VI	-8%	-6%	-3%	-2%
9	Banning entry of pre BS-IV trucks and buses - to be modernized/retrofitted	-3%	-2%	-1%	-1%
10	Improved inspection and maintenance system- High emitters	-2%	-1%	-1%	-1%
11	Reducing real world emissions from vehicles by 50% through congestion management	-5%	-4%	-4%	-3%

S.N0	Strategies	2025		2030	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
12	Shift of 50% cars and 2-w users to shared commuter transport (public/private) (based on EVs)	-2%	-1%	-1%	-1%
13	Increase penetration of biodiesel to12% by 2025 and 20% by 2030	0%	0%	-0.4%	-0.3%
	Industries				
14	Power plant controls -implement stricter NO_x and SO_2 standards with continuous monitoring	-2%	-2%	-5%	-4%
15	Stricter enforcement of standards in industries through continuous monitoring and other mechanisms	-9%	-10%	-9%	-10%
16	Enforcement of SO_2/NO_x standards in industries 50% and 100% in 2025 and 2030	-1%	-1%	-2%	-2%
17	Enforcement (75-100%) of zig-zag brick technology in 2025 and 2030	-4%	-4%	-4%	-3%
18	Fuel switch from solid to gaseous fuels	-12%	-12%	-23%	-23%
19	Stricter dust control on stone crushers	-0.1%	-1%	-0.1%	-2%
20	Introduce and implement stringent PM_{10} and $PM_{2.5}$ norms in industries	-8%	-10%	-11%	-12%
	Road dust				
21	Vacuum cleaning of roads - silt load reduction of 25% and 50% in 2025	-0.3%	-2%	-2%	-6%
22	Wall to wall paving- silt load reduction of 25% and 50% in 2025	-0.3%	-2%	-2%	-6%
23	Control of dust from construction activities- barriers and fogging based	-0.3%	-1%	-1%	-2%
	Others				
24	Full ban on refuse burning activities and combustion in WTE	-4%	-3%	-4%	-3%
25	Landfill fire control	-0.1%	-0.2%	-0.5%	-0.4%
26	Stricter standards for DG sets using innovative PM and NO_x emissions control technologies	-2%	-2%	-1%	-1%
27	Supply 24x7 electricity leading to 90–95% reduction in DG set usage by 2025 and 2030,	-2%	-2%	-2%	-1%

The table shows the reduction potential of different strategies and detailed techno-economic feasibility studies will be required for some of the strategies before actual implementation.

* This only shows the average effect over the whole season but in addition it will also help in reducing the peak of pollution during post-harvesting season.

After conducting the intervention analysis, a set of interventions, which are most feasible to implement and also have substantial impact on PM concentrations are selected for constructing the alternative scenario. **Figure E.10** shows the change in concentrations of $PM_{2.5}$ and PM_{10} in BAU and alternative scenario. In alternative scenario, in 2030, $PM_{2.5}$ emissions have reduced by 55% and PM_{10} emissions have reduced by 67% and the corresponding reduction in average concentration (of both seasons) was 58% in $PM_{2.5}$ and 61% in PM_{10}. The alternative scenario envisages meeting the prescribed daily standards in the winter season and hence, it may be safely assumed that annual average standards may be met considering lower concentrations during other seasons.

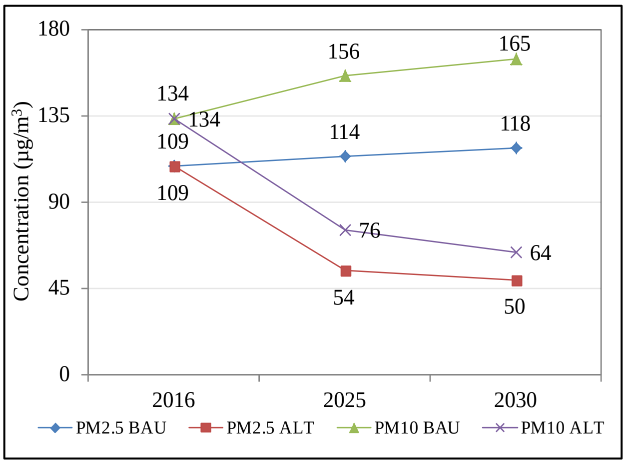


Figure E.10: Average of two seasons (winter and summer) PM_{10} and $PM_{2.5}$ concentrations in Delhi-NCR in seasons in BAU and ALT scenarios

11.0. Proposed Action Plan

An action plan including all the selected strategies in the alternative scenario has been presented in **Table E.5**. The time frames and possible implementing agencies of these strategies are also suggested.

Table E.5.: Action plans with the list of interventions selected for reduction of pollutant concentrations in Delhi-NCR

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
	Biomass Burning			
1	Increase in LPG penetration in NCR by 75% in 2025- 100% in 2030	Convert 75% and 100% biomass to LPG in 2025 and 2030, respectively	100% LPG penetration by 2026	MoPNG

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
2	Use of agricultural residues as briquettes in power plants	Zero-open burning and use of residue briquettes in power plants	Agricultural residue usage in power plants by 2020	MoP, MoA
	Transport			
3	Public transportation system on electric vehicles; followed by private vehicles	25% and 50% electric buses in 2025 and 2030, respectively	25% and 50% electric buses in 2025 and 2030, respectively	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
4	Improved inspection and maintenance system	Setting up OBD/remote sensing based and advanced I&M centres. High emitter emissions go down from 25% to 10% (in 2025) and 25% to 5% in 2030	15 advanced I&M centres in NCR by 2021 and 30 by 2025. To support, existing PUCs to be upgraded for OBD-based testing.	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
5	Fleet modernization	All vehicles to be BS-VI	Fleet modernisation mechanisms along with scrappage centres by 2025	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
6	Reducing real world emissions from vehicles by congestion management	Reduce real world emissions by 50% by congestions management strategies	Introduce congestion pricing schemes in Delhi by 2019 and expand to NCR by 2021to shift from private to public modes of transportation*	MoUD and states urban development and transport departments
7	Shift of 50% cars and 2-w to shared commuter transport	Shift 50% of personal transport on shared taxis in 2025 and 2030	Promote private players to enhance shared transport modes by 2019	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
	Industries			
8	Power plant controls with continuous monitoring	Implement stricter NO_x and SO_2 standards	Install tailpipe control devices	Power plant companies, MoP,

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
			by 2020.	SPCBs, and CPCB
9	Stricter enforcement of standards in industries through continuous monitoring	In industries, reduce real world emissions by 50%	Install continuous stack emission monitors in 25% industries by 2020 and 50% by 2025	Industries, SPCBs, and CPCB
10	Introduction and enforcement of new SO_2 and NO_x standards	75% and 100% enforcement of SO_2/NO_x standards in industries in 2025 and 2030, respectively	Install tailpipe control devices in 75% of industries by 2021 and 100% by 2026	Industries, SPCBs, and CPCB
11	Enforcement of zig-zag brick technology	75% and 100% enforcement of zig-zag brick technology in 2025 and 2030, respectively	75% and 100% enforcement of zig-zag brick technology in 2021 and 2026, respectively	SPCBs and CPCB
12	Strict PM control on stone crushers	Increase PM_{10} control efficiency from 40% to 80% and $PM_{2.5}$ from 20% to 40% in 2025 and 2030	Install wet dust suppression system and dry collection techniques in all stone crushers by 2021	SPCBs and CPCB
13	Fuel switch to gas from solid fuels	25% and 50% fuel switch to gas from solid fuels in 2025 and 2030, respectively	Fuel switch to gas from solid fuels in 25% and 50% industries in 2025 and 2030, respectively	MoPNG, State Industrial departments
	Road dust			
14	Vacuum cleaning of roads	Silt load reduction 25% and 50% in 2025 and 2030, respectively	Mechanized road cleaning at 25% and 50% roads in 2025 and 2030, respectively	Municipal corporations
15	Wall to wall paving of roads	Silt load reduction 25% and 50% in 2025 and 2030, respectively	Wall to wall paving of 25% and 50% roads in 2025 and 2030, respectively	PWD

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
16	Control of dust from construction activities	Barriers and water controls (30% and 60% control on PM emissions in 2025 and 2030, respectively)	Mandatory implementation of barriers and water controls in major construction sites by 2021 and all by 2026.	PWD, NHAI, Municipal bodies, PCBs
	Others			
17	Use of refuse in WTE	Reduced emissions from refuse burning in WTE plants fitted with controls	Immediate market mechanism for collection and transportation of refuse to WTE	Municipal corporations and panchayats
18	Supply 24x7 electricity	Supply 24x7 electricity , DG set emissions to reduce to 10% and 5% in 2025 and 2030, respectively	Immediate arrangements for regulatory and tariff structure to make use of the power surplus situation and thereby ensuring 24x7 power supply	State electricity departments

The table shows the reduction potential of different strategies and detailed techno-economic feasibility studies will be required for some of the strategies before actual implementation.

*the revenues collected from congestion pricing scheme should mandatorily be used for enhancement of public transport.

12.0. Conclusions

- Air pollution levels are extremely high in Delhi and NCR, especially in winters.
- The assessment of both the scientific approaches reveals that transport, biomass burning, and industries are the three major contributors to $PM_{2.5}$ concentration in Delhi NCR during winter. In summer, the contributions of dust from inside and outside of India eclipses the shares of these three major sectors in the $PM_{2.5}$ concentrations, however, the contributions still remain significant.
- The assessment for PM_{10} shows that other than transport, biomass burning, and industries, road dust and construction dust also contribute significantly to concentrations. Like $PM_{2.5}$, during summers, the contributions of dust from outside of India reduce the shares of these local sectors in the PM_{10} concentrations.

- The study has quantified the contributions of different sources at present and in future time-frames (2025–2030). The $PM_{2.5}$ concentrations are expected to increase by 5% in 2025 and by 8% in 2030 with respect to 2016, in a BAU scenario. The PM_{10} concentrations are expected to increase by 16 and 23% in 2025 and 2030, respectively, in a BAU scenario. This is after accounting for growth in different sectors and also taking into account the possible enforcement of the interventions which have already been notified for control of air pollution. Discounting these planned interventions, the growth in $PM_{2.5}$ concentrations could be 30% higher in 2030.
- The study analysed various interventions and estimated their possible impacts over $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR. An alternative scenario has been developed considering the interventions which can provide maximum air quality benefits. The alternative scenario results in a reduction of 58% and 61% in $PM_{2.5}$ and PM_{10} concentrations in 2030, with respect to the BAU scenario, and achieves the daily ambient air quality standards for PM_{10} and $PM_{2.5}$.
- The interventions which have identified as the ones with highest impact on PM concentrations in 2030 are:
  - Eradication of biomass use in NCR by enhanced LPG penetration in rural households
  - Use of agricultural residues in power plants and other industries to replace high ash coal
  - Introduction of gaseous fuels and enforcement of new and stringent SO_2/NO_x/$PM_{2.5}$ standards for industries using solid fuels
  - Strict implementation of BS-VI norms
  - Improvement and strengthening of inspection and maintenance system
  - Fleet modernization and retro-fitment programmes with control devices
  - Penetration of electric and hybrid vehicles
  - Reducing real world emissions by congestion management
  - Stricter enforcement of standards in large industries through continuous monitoring
  - Full enforcement of zig-zag brick technology in brick kilns
  - Vacuum cleaning of roads, wall to wall paving of roads
  - Control of dust from construction activities using enclosures, fogging machines, and barriers
  - Elimination of DG set usage by provision of 24x7 electricity and control by innovative tail-pipe control technologies