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How are the Two Most Polluted Metro-cities of India Combating Air Pollution? Way Forward after Lifting of COVID-19 Lockdown

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ABSTRACT

The national capital region of Delhi and Kolkata are the two metro cities in India worst affected by poor air quality. Multiple policies have been declared and implemented by the city authority in the recent past with the hope of improving the air quality of the cities and to attain the national ambient air quality standard. This study assesses that these present policies can help to reduce air pollution in these cities as much as 20% in the optimistic assessment, which may not be sufficient to attain the clean-air goal soon. During April and May 2020, the nationwide lockdown to control the pandemic of COVID-19 has unintentionally resulted in improved air quality due to force reduction at pollution emission sources. Significant pollution emitting sectors in NCR-Delhi are still not covered in current policy measures adequately. The substantial contribution of secondary aerosol formation from its precursor gases is still not addressed in any city-specific policies. The present study attempts to assess these gaps in current air pollution control policies. A way forward is indicated to empower these two polluted metro cities to attain clean air after lifting of the lockdown for the safety of the city inhabitants.

Keywords: Air pollution control policy, COVID-19, Lockdown, $PM_{2.5}$, Emission inventory, Kolkata, NCR-Delhi

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1 INTRODUCTION

Poor air quality in the urban area is a global concern, especially in developing countries like India. Studies show that heavily polluted cities may achieve the benefit of long term national and local air pollution control measures, and such local policies are also crucial for mitigating and adapting to global climate change (Slovic *et al.*, 2016, Cui *et al.*, 2020). Successful long-term implementation of such policies in Jinan city of China leads to significant benefits in air quality and co-benefits in terms of improved public health and reduced economic burden. (Cui *et al.*, 2020). The similar post-policy accomplishment of reduced air pollution and GHG as co-benefit was reported for Greater London, UK (Chong *et al.*, 2014), Yogyakarta, Indonesia (Dirgahayani, 2013); Bangkok Metropolitan Area, Thailand (Li and Crawford-Brown, 2011); Mexico City, Mexico; Khon Khaen, Thailand; Beijing, China; Bogota, Colombia (Labriet *et al.*, 2009).

The national capital region (NCR) of Delhi, one of the most polluted cities globally, struggles with its air quality for the past decade. Kolkata metropolitan city, although not as polluted as Delhi but is still emerging as the second most polluted Indian metro (WHO, 2018). With millions of inhabitants facing severe health risks (Pervez *et al.*, 2020), authorities in both cities are attempting to reduce the pollutant emission at source by implementing various policies for different sectors (Aman *et al.*, 2017; Bhennerkar *et al.*, 2019; Majumdar *et al.*, 2020).

The pandemic outbreak of COVID-19 was initiated from Wuhan city of China in December 2019 (Zhou *et al.*, 2020). Govt. of China imposed a countrywide lockdown to contain the pandemic, and soon many countries followed suit. Since March 2020, more than half of the world population and major cities worldwide are under some form of lockdown (Tosepu *et al.*, 2020; Wilder-Smith and Freedman, 2020). Such a lockdown resulted in restricted transportation and economic activities, which are related to significant air pollution emitting sources. Considerable short term improvement of air quality have been observed in cities across the globe. Cities in China having a formal lockdown have witnessed a 17% decline in ambient $PM_{2.5}$ level. Chinese cities not having official lockdown but having other disease control measures like social distancing or stay at the home practice also experienced a decline (7%) in $PM_{2.5}$ level (He *et al.*, 2020). Menut *et al.* (2020) reported a 5% to 15% reduction of ambient $PM_{2.5}$ in Western European countries as a result of lockdown measures. Almaty, Kazakhstan also witnessed significant decline (21%) in ambient $PM_{2.5}$ as compared to the previous year for the quarantine session (Kerimray *et al.*, 2020). Both NCR-Delhi and Kolkata went to complete lockdown with the whole nation from 24th March 2020, which lasted three weeks till 14th April. A partial lockdown followed from 15th April to 31st May. Sharma *et al.* (2020) reported a 43% overall reduction of ambient $PM_{2.5}$ in 22 cities of India compared to 2017 for the period of complete lockdown. Delhi witnessed as high as a 50% reduction in ambient $PM_{2.5}$ compared to the pre-lockdown level (Mahato *et al.*, 2020) similar trend also observed for Mumbai, Hyderabad, Kolkata, and Chennai (Kumari *et al.*, 2020; Singh and Chauhan, 2020). During the lockdown period amidst the pandemic situation, both cities witnessed significant air quality improvement due to reduced or no activity in specific sectors, resulting in the lowering of pollutant's emission from sources. However, this lockdown is a temporary measure to control the pandemic and is feared to have profound nationwide economic losses. Eventually, the lockdown will be withdrawn, and both the cities, along with the rest of the nation, will require to resume regular economic activities. Reduced air pollution during the lockdown period emphasizes the requirement of comprehensive policies to control pollutant emission at source and strict implementation thereof to attain the national air quality goal after lifting of lockdown. Here, I have tried to assess the possible reduction effect of policies undertaken or implemented in NCR-Delhi and Kolkata city in the past couple of years, considering $PM_{2.5}$ as the indicator.

2 METHODS

- Published latest emission inventory for NCR-Delhi (Bhannerkar *et al.*, 2019) and Kolkata (Majumdar *et al.*, 2020) is adopted for contributions towards the emission of $PM_{2.5}$ in the ambient air of the cities.
- The city-specific policies implemented and declared after 2018 are taken into consideration. Based on possible implementation intensity, the reduction potential of the specific policy on the total $PM_{2.5}$ load is assessed. The overall emission reduction potential from policies covering the different sectors for both the cities is also evaluated.
- The observed level of $PM_{2.5}$ during the past three years as well as during COVID-19 lockdown has been taken into consideration
- An attempt has been made to co-relate the impact of various city-specific policies for emission reduction as well as forced and unintentional emission reduction during the COVID-19 lockdown with the observed level of $PM_{2.5}$
- Finally, an attempt has been made to assess the gap in present policies to identify the way forward toward clean air goals.

Fig. 1 presents the schematics of the study design adopted for the present work.

3 RESULTS AND DISCUSSION

Table 1 lists all the city-specific policies implemented in the past few years in both NCR-Delhi and Kolkata, and there estimated pollution reduction potential considering $PM_{2.5}$ as an indicator.

There are five major almost equal contributors to $PM_{2.5}$ in Delhi air (Bhannerkar *et al.*, 2018). In NCR-Delhi, the highest $PM_{2.5}$ emitting source is the exhaust emission from the active vehicular fleet, contributing about 22% of total $PM_{2.5}$. There are multiple policies targeted for controlling emission from this sector; one such significant measure taken by the city authority during November 2019 is the four-wheelers' odd-even scheme. This system allowed the four-wheeler vehicles with registration number ending with an odd digit to ply on the odd days, whereas

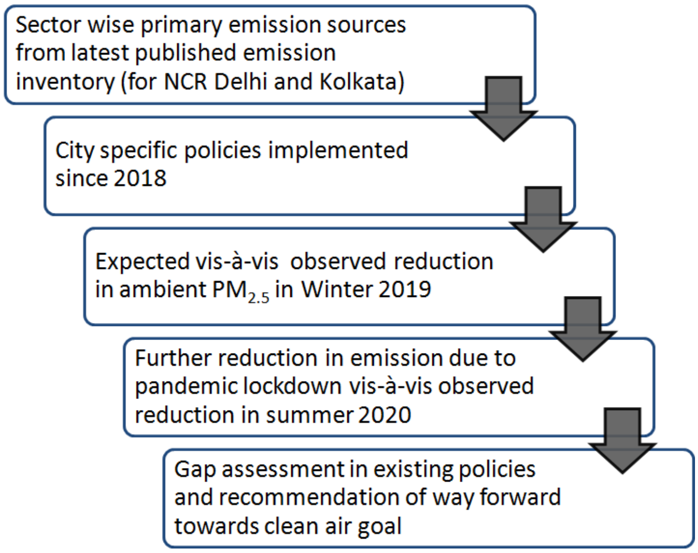

Fig. 1. Schematic of the study Design.

Table 1. City-specific policy and their impact potential implemented after 2016–17.

	City-specific policies	% Reduction potential
NCR-Delhi		
1.	Odd-even scheme' on the 4-wheelers plying on the roads	2
2.	Enhanced Parking Fees by Four Times	1
3.	Prohibition on the entry of overloaded and non-destined trucks in Delhi and imposition of 'Green tax Ban' on Entry of Trucks	7.2
4.	More trips by metro, increased numbers of public transport buses	na*
5.	Sweeping of road	1.7
6.	Ban on burning of leaves/ biomass in Delhi	5.4
7.	Stringent provision for ash content in coal for thermal power plants	2
8.	Stringent industrial emission standards	<1
9.	Revision of rules pertaining to construction and demolition waste. Ban on Civil Construction and Strict compliance of Graded Response Action Plan	<1
	Cumulative reduction potential for NCR Delhi	**~20**
Kolkata		
1.	Fuel switch from kerosene and solid fuel to LPG in the residential-commercial sector	10
2.	Road sweeping and water sprinkling	2.3
3.	Decreased consumption in the power sector	3.2
4.	Initiation of the electric bus – no net reduction	-
5.	Strict ban on open burning of waste.	2.9
6.	Strict implementation of existing norms in the construction sector	1
7.	Strick compliance to industrial emission norms	< 1
	Cumulative reduction potential for Kolkata	**~20**

*na-not assessed.

allowed vehicles with registration number ended with an even integer to ply on the even days. The scheme aimed to reduce the active vehicular (four-wheelers) fleet volume of the city. Four-wheelers are responsible for about 20% of the emission from the vehicular fleet, i.e., about 4% of the total atmospheric load. If a complete implementation of this policy is assumed, then a maximum 50% reduction in 4-wheeler fleet would result. Such a reduction in the active fleet may reduce only up to 2% of the total $PM_{2.5}$ emission load. Enhanced parking fees are again to minimize four-wheelers from plying, which may reduce another 50% from the active-fleet of four-wheelers after reducing the active fleet due to odd-even rule. A further 1% reduction in total $PM_{2.5}$ emission load may be possible due to this policy implementation. 25% reduction in the heavy-vehicle fleet due to the ban on entry of non-destined truck may result in a maximum of 3.7% $PM_{2.5}$ emission due to reduced exhaust emission.

Another primary sector, contributing 20%, is residential and commercial combustion. These are from the burning of kerosene and solid fuel like coal, biomass used for cooking, lighting households, and commercial eateries. Except for the national drive of Pradhan Mantri Ujjwala Yojana (PMUY for providing subsidized LPG to the economically weaker section for cooking), there is no specific policy in place towards cleaner fuel in Delhi for tackling this second primary $PM_{2.5}$ source.

The third major contributor in NCR-Delhi (19%) is the power sector with three gas-based and two coal-fired thermal power plants with ESP-II already installed. The only city-specific policy that has been considered after 2010 to reduce the $PM_{2.5}$ emission from this sector is to reduce ash content in coal. An optimistic 2% reduction from existing ash content (estimated 35%) may result in a 10% reduction from the power plant, a ~2% reduction in total $PM_{2.5}$ load.

The fourth major contributor (18%) is waste and open burning. The policy of ban on burning on leaves and biomasses, if implemented effectively (~30%), this policy has the potential to reduce as much as 5.4% of the total $PM_{2.5}$ emission load.

The fifth prominent source is resuspended road dust from vehicles' movement, among which heavy-vehicle movement causes more than 80%. Hence odd-even rule for 4-wheeler is of little impact in reducing $PM_{2.5}$ from road dust. A combination of control measures, i.e., sweeping of road and water sprinkling measures may reduce up to 25–30% of $PM_{2.5}$ load from road dust re-suspension. TERI, 2019, indicates inefficient output from the mechanical sweeping machine in exchange for combustion emission from ~100 lit of diesel per device per day. So considering an overall 10% reduction from road-dust re-suspension, a decrease of 1.7% on total $PM_{2.5}$ load may be expected from this measure. The present government policy of increased public transportation in the form of the enhanced number of trips of the metro will be contributing to emission reduction. However, the impact of increased public buses is not that straight forward. The emission factor for road dust re-suspension is heavily dependent on the weight of the vehicle. A 40 seater bus (~10 ton) contribute about 40 times more than a four-wheeler (~1 ton) towards $PM_{2.5}$ emission in Indian road (5–10 gm m^{-2} silt content), whereas only ten times more efficient in carrying a passenger (sitting). Even after considering minimal combustion emission from CNG busses against diesel/petrol-driven cars, the trade-off between four-wheeler and buses requires caution. Ban on entry of outside trucks may be useful to reduce $PM_{2.5}$ emission; if the active heavy-vehicle fleet is reduced by 25%, then 3.4% $PM_{2.5}$ emission reduction may be expected from the decrease in road dust re-suspension. The rest of the two policies on the industrial and construction sectors have minimal impact ($<$ 1%) as these two sectors are responsible for only about 4% of total $PM_{2.5}$ load.

In Kolkata city, the $PM_{2.5}$ contribution is somewhat different from the country capital, with 50.4% coming from domestic combustion that includes residential and commercial cooking and lighting using kerosene and solid fuels, including coal biomass. The city-specific initiative of shifting towards cleaner energy, especially in the domestic-commercial sector, is expected to reduce 10% of the total $PM_{2.5}$ load if 20% implementation is assumed. The second major contributor (16.3%), the power sector, has seen some reduction in activity since 2010 as two out of five coal-fired thermal power plants were closed due to various issues. Considering a 20% decrease in coal consumption, about 3.2% reduction is expected from this sector. The ban in the open burning of waste was already in place for Kolkata city. Still, if assumed to be imposed more stringently in the past couple of years, then the emission from this sector (9.8%), which is third-highest among all sources, may be expected to reduce up to 30% resulting in a total emission reduction of 2.9%.

Vehicle exhaust (7.8%) and road dust re-suspension (7.7%) are already contributing less in atmospheric $PM_{2.5}$ of Kolkata than Delhi, mostly due to policy since 2009 to ban old commercial vehicles and having an efficient network of underground metro-railway. The recent initiative for the electric driven bus will have only a minor impact on exhaust emission. In contrast, emission due to road dust will increase anyway with increased fleet volume thus may not have any resultant reducing impact. The effective road cleaning and water sprinkling with surfactant in the winter of 2019 may have reduced $PM_{2.5}$ from road dust re-suspension by 30%, giving an overall reduction of 2.3%. The proposed strict implementation of existing norms in the construction sector may reduce a 40% reduction in contribution from this sector (2.2%), then an overall 1% reduction in $PM_{2.5}$ emission may be expected.

50% of present city-specific policy for Delhi deals with the transport sector and may reduce 11.9% of the current $PM_{2.5}$ load in a very optimistic assessment. Comprehensive implementation of the rest of the policies together may cut another ~8% with a total expected reduction of about 20%. One vital sector, domestic combustion, is yet to be covered by any city-specific policy. City authority needs to impose more strategies in critical areas other than the transport sector. In Kolkata, city-specific pollution policies are spread across sectors to deal with primary polluting sources, and all these policies, if appropriately implemented, may reduce about 20% of total $PM_{2.5}$ emission. Still, more number of strategies are required to address all the significant sources. The key is to impose a policy where it will impact more in terms of pollution control.

It is essential to recognize that apart from the primary emission within the city boundary, the observed level of $PM_{2.5}$ will also correspond to i) secondary pollutant formed in-situ, ii) pollutant received from an immediate neighboring region, iii) pollutant in the aged air mass transported from long distance. The annual average $PM_{2.5}$ in 2018 (143 µg m^{-3}; WHO, 2018) was 257% higher than the national ambient air quality standard (NAAQS) of 40 µg m^{-3}. In 2019 Delhi observed a substantial 31% reduction from the 2018 $PM_{2.5}$ level (annual average: 98.6 µg m^{-3}, IQAir, 2019). Annual average $PM_{2.5}$ level in Kolkata (74 µg m^{-3}; WHO, 2018) was 85% higher than the NAAQS in 2018 and has witnessed a 19% reduction in $PM_{2.5}$ level from 2018 to 2019 (59.8 µg m^{-3}; IQAir, 2019).

Fig. 2(a) depicts ambient $PM_{2.5}$ in both the cities for the past three years during the winter months of December and January when air quality is at its worst. Several city-level policies, as mentioned in Table 1, have been implemented in the last few years, which have been particularly stringent since 2019 after the declaration of India's Nation Clean Air Program (NCAP). The NCAP includes a list of altogether 122 non-attainment cities of India. These cities will require to reduce their air pollution level at least 20% compared to 2017 air quality. Under this program each non-attainment city will have to follow a pre-defined city-specific action plan to attain the clean air goal.

The decreased ambient $PM_{2.5}$ level in 2019 demonstrate that the pollution control policies implemented at the city level have started to show the reduction effect in ambient $PM_{2.5}$ level in both the cities. The policies targeting the particulate emission reduction from combustion sources such as vehicular exhaust, power plant, residential combustion, and open burning are also contributing as co-benefit towards the reduction of oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Photochemical reactions of VOCs in the presence oxide of nitrogen (NO_x) and ozone give rise to secondary organic aerosol (SOA). As much as 33% and 40% of ambient $PM_{2.5}$ in Delhi and Kolkata are of secondary origin (Chatterjee *et al.*, 2012; Tiwari *et al.*, 2015; Sahu *et al.*, 2018; Priyadharshini *et al.*, 2019; Purohit *et al.*, 2019). Reduction in secondary aerosol precursor gases, thus resulted in the reduced in-situ formation of $PM_{2.5}$, facilitated the

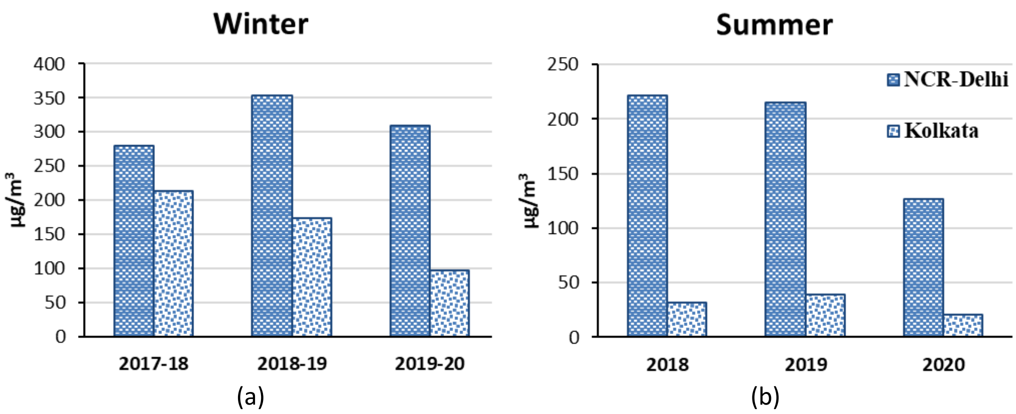

Fig. 2. Ambient $PM_{2.5}$ in Delhi and Kolkata (2017–2020) during Winter (December and January) and Summer (April and May) (a) In winter, the reduction in ambient $PM_{2.5}$ from 2018–19 to 2019–20 reflects the effect of policy intervention. (b) In Summer, decrease in ambient $PM_{2.5}$ from 2019 to 2020 demonstrates the impact of lockdown to control COVID-19 pandemic (source: CPCB, 2020).

overall decrease in ambient $PM_{2.5}$ level. However, there is a lack of specific policies to control these secondary aerosol precursor gases, especially VOCs. The most prominent VOCs source in the air is the vehicular exhaust emission contributing about half and third of total emission for Delhi and Kolkata, respectively. other VOC sources for Delhi and Kolkata respectively include solvent use (19% and 25%), fuel distribution (18% and 18%) and domestic sector contributing 4% and 14%) (Bhannarker *et al.*, 2019; Majumdar *et al.*, 2020). VOCs' sources from the domestic sector include household products like paints, paint strippers, and other solvents; wood preservatives; cleansers and disinfectants; moth repellents and air fresheners; stored fuels and automotive products, dry-cleaned clothing, cosmetics etc. Installation of a vapor recovery system is mandatory for petrol pumps in Delhi only. No other national or city-specific policy is in place for emission control of VOCs from emission sources in both the cities.

Both NCR-Delhi and Kolkata went to complete lockdown with the whole nation from 24th March 2020, which lasted three weeks till 14th April. The partial lockdown continued from 15th April to 31st May. Activities such as industrial production, transportation, waste burning, construction were reduced substantially during this lockdown period resulting in reduced or no contribution from these sectors towards ambient $PM_{2.5}$. Fig. 2(b) depicts the reduction in ambient $PM_{2.5}$ in both the metro cities during April and May of 2018 to 2020. NCR Delhi witnessed about 40% reduction in $PM_{2.5}$ during the lockdown period of April & May 2020 as compared to the same period of 2019. Even after lockdown ambient $PM_{2.5}$ level in Delhi, the air is far higher than the NAAQS. Kolkata, on the other hand, observed even higher (48%) reduction in $PM_{2.5}$ level compared to the same period last year. Both in 2019 and 2020, during April and May, Kolkata attained the NAAQS.

The significant emission reduction was from the transport sector due to restricted mobility. Limited activity in the industries and construction sector also reduced emissions from these sources. Emission from residential combustion possibly has decreased due to reduced activity in commercial kitchens as hotels and restaurants were under the purview of lockdown; however, residential emission is likely to be unaffected. Sources like open burning have been reduced to some extent but may not entirely. Emissions from the power sector were minimally affected. The emissions from the cities' immediate neighbouring areas have also been reduced as the lockdown impacted the whole nation. Apart from the primary emission from $PM_{2.5}$ sources, a reduction is also likely from the secondary in-situ formation of $PM_{2.5}$ due to a decrease in emission of precursor gases (NO_x and VOCs) from the sources affected by the lockdown, such as the transport sector, residential combustion, open burning, etc. The unintentional improvement in air quality during the lockdown period in the two megacities indicates the possibility of achieving better air quality through restrictions at emission sources of both particulate and precursor gases. However, such improvement in air quality comes with a hefty price of significant economic losses and contradicts the concept of sustainable development. It is thus necessary to implement comprehensive and strict city-specific policies to reduce both primary emission and secondary formation of $PM_{2.5}$ without hindering the socio-economic aspects after lifting of the pandemic related lockdown.

4 CONCLUSIONS

Substantial implementation of present policies has already taken place for both NCR-Delhi and Kolkata city. Even after extensive application, those policies may result in at most 20% of the primary emission for both NCR-Delhi and Kolkata. Both the cities have already started to witness the reducing effect of the present policies since winter 2019–20. However, NCR-Delhi is far from attaining the NAAQS, while Kolkata also has to reduce the ambient $PM_{2.5}$ substantially during winter shortly. The forced reduction of primary emission due to reduced activity from some sources during the COVID-19 lockdown in summer, April, and May 2020 resulted in a substantial decrease in ambient $PM_{2.5}$ level in both cities. The unintentional reduction in air pollution during the lockdown emphasizes the requirement of widespread control policies at emission sources of particulate and secondary aerosol precursor gases to achieve better air quality. Even after such a considerable reduction in primary emission, ambient $PM_{2.5}$ in NCR-Delhi is far from attaining the NAAQS goal. We expect that both the cities will resume the regular activity soon enough after lifting the lockdown. The effect of the already implemented policy will have only a limited impact on the reduction of ambient $PM_{2.5}$, whereas increased population and growth will result in even more emissions. More strategies and control policies must cover all significant sources and to be urgently implemented.

It is essential to recognize that the emission contribution in total pollutant load in the atmosphere may differ from the source contribution obtained in specific observational sites through receptor modeling. The total emission of a city and the source contribution experienced at receptor points can be linked through dispersion modeling, acknowledging the impact of meteorology. However, the policies can only impose control or restrictions at source and not on the final source contribution experienced at receptor points. So, while implementing strategies for the reduction of air pollution, it is only prudent to consider the significant pollution sectors, their respective contribution, along with the possibility of implementation and the extent of so. The understanding of the possible impact of such policies at the receptor end is also needed. Unless there are more city-specific policies over and above the present policies covering all prominent sources, clean city air is a far sight.

In addition to the city's primary emission load emission from a neighbouring area, especially from stubble burning, pollution from a long-range is also contributing. More substantial co-operation between states is essential to deal with such contributions. The considerable contribution of secondary aerosol formation from its precursor gases is still not addressed in present city-specific policies. Some of the strategies targeted towards sources such as the transport sector, domestic combustion, or waste burning may result in the reduction of those gases as co-benefit. More policies should focus on the emission of secondary aerosol precursor gases, especially VOCs. Emission of VOCs from combustion and non-combustion sources needs to be controlled with new city-specific policies for NCR-Delhi and Kolkata to reduce ambient $PM_{2.5}$ level and to achieve clean air goal shortly.

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