What is Polluting Delhi's Air?

Understanding Uncertainties in Emissions Inventories

Issue Brief I March 2019

Ishita Jalan and Hem H. Dholakia

According to the SAFAR (2018) study, the average speed of vehicles on major Delhi roads is 20-30 km/hr. This leads to poor vehicle mileage and more emissions.

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ABOUT CEEW

The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain - and change - the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

In 2019, CEEW once again featured extensively across nine categories in the '2018 Global Go To Think Tank Index Report', including being ranked as South Asia's top think tank (15th globally) with an annual operating budget of less than USD 5 million for the sixth year in a row. CEEW has also been ranked as South Asia's top energy and resource policy think tank in these rankings. In 2016, CEEW was ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings.

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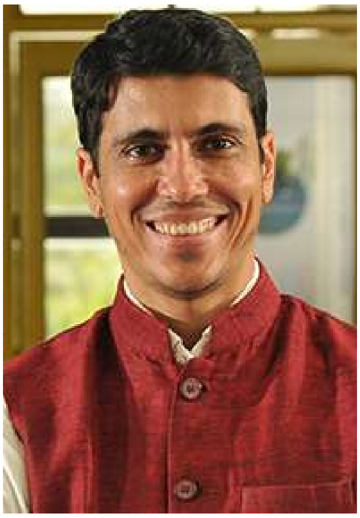
Ishita is a Research Analyst at CEEW. As a part of her work in the Risks and Adaptation team, Ishita has worked on issues related to climate risks, air pollution, and water. Ishita is currently working on understanding water-use efficiency in agriculture and estimating the potential of water saving. She is interested in exploring emerging technical tools that enhance data information and support policy analysis. She has a BTech in Environmental Engineering from Delhi Technological University.

"Through this study, we hope to bring clarity on the existent discrepancies in the system of building source apportionment. This is an essential step before we scale our efforts to 104 cities as a part of the National Clean Air Programme (NCAP)."



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"This synthesis provides a lens to understand the gaps and opportunities in source apportionment studies. We believe it will help inform the larger dialogue between experts, government and, civil society on developing inventories and prioritising action around air pollution mitigation in India."

Image: iStock

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ABBREVIATIONS

ARAI	Automotive Research Association of India
CEA	Central Electricity Authority
CEMS	Continuous Emissions Monitoring System
CMAQ	Community Multiscale Air Quality monitoring system
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
DDA	Delhi Development Authority
DG	diesel generator
DIC	District Industrial Centre
DMRC	Delhi Metro Rail Corporation
DPCC	Delhi Pollution Control Committee
EF	emissions factor
EPCA	Environmental Pollution Control Authority
GAINS	Greenhouse gas-Air pollution INteractions and Synergies model
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
LPG	liquefied petroleum gas
MODIS	Moderate Resolution Imaging Spectroradiometer
MoRTH	Ministry of Road Transport and Highways
MoUD	Ministry of Urban Development
MSW	municipal solid waste
NCR	National Capital Region
NSSO	National Sample Survey Organisation
PM	particulate matter
PUC	pollution under control
PWD	Public Works Department
SAFAR	System of Air Quality and Weather Forecasting And Research
USEPA	United States Environmental Protection Agency
VKT	vehicle kilometres travelled
WRF	Weather Research and Forecasting model
WRF-CMAQ	Two-way coupled meteorology and air quality model composed of the Weather Research and Forecasting (WRF) model and the Community Multiscale Air Quality (CMAQ) modelling system

The transport sector is the largest emitter of $PM_{2.5}$ particles (17.9 per cent to 39.2 per cent) and road dust is the largest countributor of PM_{10} particles (35.6 per cent to 65.9 per cent).

Image: iStock

Executive Summary

In India, every year, air pollution causes 1.24 million deaths. In Indian cities, most of the year, the average concentration of particulate matter (PM) exceeds Central Pollution Control Board (CPCB) standards. Making decisions on mitigation and control requires an understanding of air pollution sources. Source apportionment estimates the contribution of each source.

The process uses two methodologies - top-down and bottom-up. The two methodologies complement each other in cross-checking and validating the source apportionment analysis; therefore, it is advised to use both for a region. Delhi is popular in the narrative of air pollution, and it has been covered extensively by source apportionment studies (CPCB 2010; IIT Kanpur 2016; TERI 2018; SAFAR 2018; Guttikunda 2018).

These studies have played an instrumental role in describing the variety of sources that contribute to air pollution in Delhi and the National Capital Region (NCR), but their estimates differ significantly. Given that source apportionment information guides pollution mitigation policy and actions, differences can make the determination of exact sources uncertain and air quality improvement measures ineffective.

By comparing the existing emissions inventories for Delhi or NCR, this study aims to explain the differences in these estimates. To detail these differences, we focus on PM_{10} and $PM_{2.5}$ in transport, industries, power plants, road dust, and construction - the five major contributing sectors. An emissions inventory uses the bottom-up method and forms the basis for a source apportionment study. A dispersion model is used to calculate the distribution of pollution using the emissions inventory and meteorological data as input parameters.

The biggest contributor of $PM_{2.5}$ is the transport sector; its contribution ranges from 17.9 per cent to 39.2 per cent. Road dust is the second largest source of $PM_{2.5}$; it contributes between 18.1 per cent and 37.8 per cent. It also contributes 35.6 per cent to 65.9 per cent of PM_{10} as the largest source. Similar trends exist for other sectors. The differences are due to each study's domain area; year; sampling season chosen; and methodologies of sampling, estimation, and emissions factors. These factors explain the discrepancies only partially, however; emissions inventories are different for other, unexplained reasons.

To improve the understanding of air pollution and formulation of policy, several changes are necessary. Information on sampling frame and sample details needs to be transparent. Uncertainty should be quantified to explain the spread of observations for a sector. Multiple-year inventories would capture the dynamic nature of air pollution and enable accurate, real-time information. Common regulatory guidelines would help in building robust inventories. Source apportionment based on emissions inventories and dispersion modelling should be reconciled with receptor modelling to enable convergence between the modelling and measurement approaches.

Delhi, as a major urban agglomeration, experiences frequent construction activities. In 2018, construction activity along with industrial activities were banned twice in the month of November and December as directed by the Environment Pollution (Prevention & Control) Authority (EPCA).

Image: iStock

1. Introduction and Methods

Worldwide, 9 out of 10 people breathe polluted air[1]. Air pollution poses one of the biggest risks to human health. About 29 per cent of deaths and disease due to lung cancer; 43 per cent from chronic obstructive pulmonary disease; and 25 per cent of deaths due to heart disease and stroke[2] are attributable to ambient air pollution. The Global Burden of Disease 2017 reported 1.24 million deaths can be linked to air pollution (Madhipatla et al., 2018).

Pollution is one of the largest causes of morbidity and mortality; it also puts a great burden on the Indian economy, causing losses of approximately $56 billion in 2013 alone (World Bank, 2016). Air quality management measures, short- and long-term, require an understanding of pollution sources and of the temporal and spatial distribution of pollutants. Several studies have compiled emissions inventories for India and other Asian countries. Delhi, among the most polluted cities worldwide, and often discussed in the popular narrative, is one of the most studied regions in India in the context of air pollution. This study compares inventories developed for Delhi and its surrounding regions.

1.1 What is an emissions inventory?

An emissions inventory of a given study region is a stock of all its pollution-emitting sources, such as vehicles, industries, power plants, road dust, construction dust, residential, diesel generator (DG) sets, biomass/waste burning, crematoria, and hotels. Developing an emissions inventory is a step in the bottom-up approach of apportioning sources. Apart from direct emissions estimates, emissions in these sectors are calculated by multiplying energy consumption with the emissions factor to derive the pollution per unit energy consumed. This information is an input to the dispersion model, which converts pollution estimates (mass/year) to ambient concentration (mass/volume). Ambient concentration is directly comparable to source apportionment estimated using receptor modelling.[3]

1 https://www.who.int/news-room/detail/02-05-2018-9-out-of-10-people-worldwide-breathe-polluted-air-but-more-countries-are-taking-action
2 https://www.who.int/airpollution/ambient/health-impacts/en/
3 Information used from: http://www.urbanemissions.info/publications/primer-on-pollution-source apportionment

Several emissions inventories have been developed for Delhi or larger areas that include the NCR.[4] These inventories contribute to source apportionment studies. Often, this drive pollution control decision making in the region by statutory agencies such as the Environment Pollution Prevention and Control Authority (EPCA), Central Pollution Control Board (CPCB), and other State Pollution Control Boards (SPCB).

Few studies compare emissions inventories across anthropogenic and combustion-related emissions of air pollutants or analyse uncertainties in inventory measurement (input parameters). Therefore, the extent of uncertainty in source apportionment (output parameter) is unclear. In this note, we compare the emissions inventories for Delhi and the NCR.

Emissions inventory contribute to source apportionment studies. These studies often drive the pollution control decision making by statutory agencies

Image: Jaun Rizvi

4 NCR has been defined in the given link: http://ncrpb.nic.in/ncrconstituent.html

1.2 Methods

This work relies on existing emissions inventories that provide estimates for Delhi or the NCR. The NCR encompasses the entire national Capital Territory (NCT) of Delhi (1,483 square kilometres (sq km) and a few districts of Haryana (thirteen), Uttar Pradesh (eight), and Rajasthan (two) (totalling 53,600 sq km).

The 13 districts of Haryana are Faridabad, Gurugram, Mewat, Rohtak, Sonepat, Rewari, Jhajjhar, Panipat, Palwal, Bhiwani (including Charkhi Dadri), Mahendragarh, Jind, and Karnal. The eight districts of Uttar Pradesh are Meerut, Ghaziabad, Gautam Budh Nagar, Bulandshahar, Baghpat, Hapur, Shamli, and Muzaffarnagar. The two districts of Rajasthan are Alwar and Bharatpur.

We studied five inventories developed over the past decade for Delhi or the NCR (CPCB 2010; IIT Kanpur 2016; TERI 2018; SAFAR 2018; Guttikunda 2018). All the studies used the bottom-up approach to develop their emissions inventory.

We compared emissions of $PM_{2.5}$ and PM_{10} from source sectors including transport, industries, power plants, residential, road dust, construction, DG sets, biomass/waste burning, crematoria, hotels, and others. These 10 categories were common to all the studies, and were therefore suitable for comparison.

The ‘others’ classification was used to aggregate the rest of the emissions category; it is different for each study. Their constituents have been specified in Figures 1 and 3. Previous studies (Saikawa et al. 2017) have run simulations for India using different inventories to assess differences in emissions inputs. However, unlike Saikawa et al (2017), we did not run any air quality simulations. Instead, we compile the results (ranges) across different studies to show the absolute and percentage variation in input parameters.

According to SAFAR (2018), the Central, Eastern and South-Eastern zone of Delhi host large number of industries contributing to $PM_{2.5}$ emissons in the range of 25-250 tons/yr.

Image: Pixabay

2. Results

This section discusses and analyses the studies and presents the magnitude of variations in their emission inventories.

2.1 Description of the studies

We present a description of the emissions inventories in Table 1. The inventories were developed for different years ranging from 2007 to 2018. Each study developed the inventory for a particular year i.e. no multi-year inventories were available.

	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Year	2018	2018	2016	2013-14	2007
Season	Continually updated	Summer	Winter and Summer	Winter and Summer	NA
Area	NCT Delhi, Gurgaon, Faridabad, Ghaziabad cities	NCR	Delhi*	Delhi	Delhi
Horizontal resolution	1 x 1 km^2 resolution for an area of 80 km x 80 km^2	400 x 400 m^2 for an area of 70 km x 65 km^2	4 x 4 km^2 grid for entire study area of 292 km x 364 km^2	2 x 2 km^2 grid for the entire city	2 x 2 km^2 grid for 10 zones near monitors extrapolated to city
Total PM_{10} Emissions load (kt/year)	238.68	268.40	67.49	52.34	64.73
Total $PM_{2.5}$ Emissions load (kt/year)	99.15	107.70	31.99	21.39	NA
Total PM_{10} Emissions load (ton/day)	654	735	185	143	177

TABLE 1: Description of emissions inventories used in this study

Source: CEEW analysis, 2019

Two studies (CPCB and IIT Kanpur) were limited to Delhi and three (Guttikunda, SAFAR, and TERI) to the NCR. Among the studies of the NCR, Guttikunda (2018) covered only urban areas of Delhi - Gurugram, Faridabad, and Ghaziabad - and excluded rural areas. The SAFAR study considered Gurugram, Faridabad, Sonepat, and Jhajjhar (Haryana) and Ghaziabad, Baghpat, and Gautam Buddha Nagar (Uttar Pradesh).

The horizontal resolution varied from 400 m by 400 m (SAFAR), 1 km by 1 km (Guttikunda), and 4 km by 4 km grid (TERI). To draw a comparison using TERI's findings, we have considered only the emissions inventory for Delhi region, reported separately.

In the SAFAR study, a primary survey was carried out with the help of 150 students guided by scientists to generate missing primary data, validate secondary data, and collect available secondary data. Information was found for 26 sources of air pollution, but the final estimate has been presented for six categories - transport, industries, power plants, residential, wind blown dust, and others. The 'others' category contains the rest of the 20 sources of air pollution, such as slums, brick kilns, street vendors, hotels, dhabas, construction sites, hospitals, tourist places, shopping malls, traffic junctions, railways, airports, waste burning, burning of biomedical waste, crematoria, schools and colleges, diesel generator sets, mobile towers, and milk and vegetable vans.

The TERI study considered particulate formation through secondary pollutants. Secondary pollutants are formed by the chemical reaction when primary pollutants interact with the atmosphere. Photochemical smog, for example, is a secondary pollutant formed when the sun's ultraviolet rays react with nitrogen oxides in the atmosphere. Secondary particulate concentration is estimated through a model output. TERI used, in addition to the dispersion model, the Community Multiscale Air Quality Modelling System (CMAQ) as it can accept multiple pollutants simultaneously and also include photochemistry. Therefore, at the emissions inventory level, the numbers only represent the primary pollutants, which have been considered for comparison.

The CPCB study did not develop an inventory for $PM_{2.5}$. All other studies included inventories for particulate matter (PM_{10}), sulphur dioxide (SO_2), nitrogen oxides (NOx), hydrocarbons, and black carbon.

2.2 Variations in emissions inventories

Figures 1 and 3 display the variations in emissions inventory for PM_{10} and $PM_{2.5}$ across the five studies, and Table 2 details the maximum and minimum percentage values associated with each sector. For the analysis, the main sectors we consider are transport, industries, power plants, residential, road dust, construction, DG sets, biomass/waste burning, crematoria, and hotels and restaurants. The 'other' category includes emissions from landfills, airports, waste/hospital incinerators, concrete batching, and agriculture. Details on the particulate matter load for both PM_{10} and $PM_{2.5}$, along with the percentage contribution for each sector, are shared in Tables A1 and A2 in the Annexure.

Road dust contributes the maximum to the PM_{10} pollutant load, varying from 35 per cent to about 66 per cent across studies, and differing by a factor of two. The next biggest contributors include power plants and transportation. For $PM_{2.5}$, transport and road dust are the largest contributors to pollutant loads. Together, these two categories account for over 40 per cent of the total $PM_{2.5}$ load across all studies.

Figure 2 shows the variation by sector for PM_{10} and Figure 4 for $PM_{2.5}$. The 'others' category has been dropped, as they are not comparable. We observe high variation across the major pollutant categories of transport, industries, power plants, road dust, and construction. These variations in sectoral emissions can lead to a large variance in the concentration of pollutants and to uncertainty around the actual contribution of each source to pollution. This can also lead to ineffective policy measures as the primary sources of pollution remain contested.

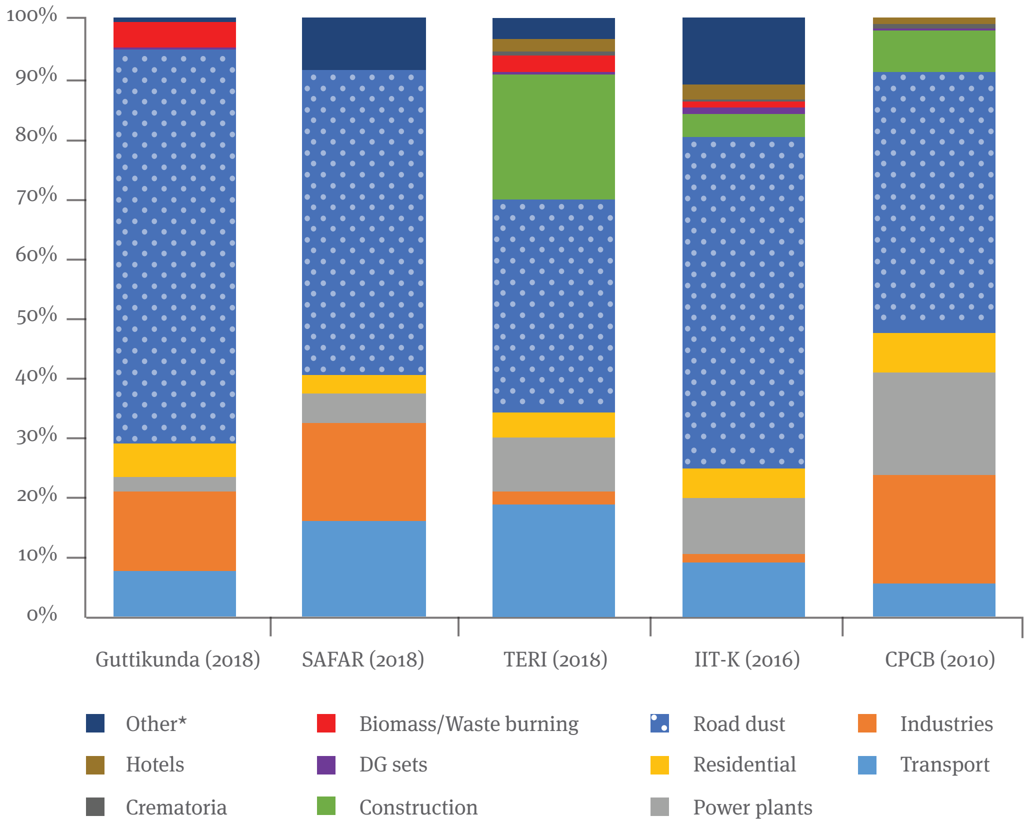


FIGURE 1:
Sector-wise contribution to PM_{10} (%)

Source: CEEW analysis, 2019

*Other
Guttikunda: funeral homes, fireworks, and earthen material baking

SAFAR: MSW treatment plants, MSW disposal sites, brick kilns, crematory, aviation, incense sticks, etc.

TERI: Landfill fires, waste incinerators/hospital incinerators, and airports

IIT-K: Waste incinerators, airport, concrete batching, and agriculture soil dust

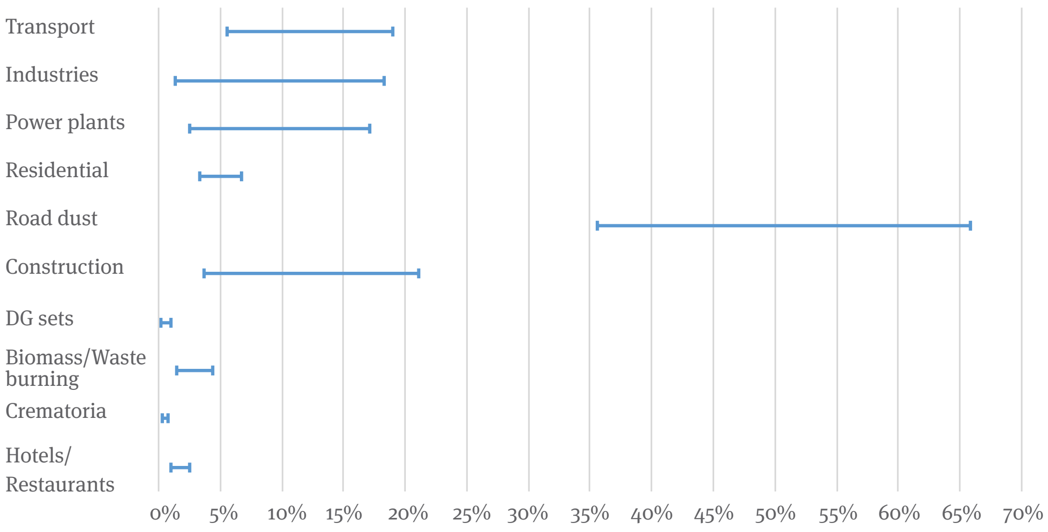


FIGURE 2:
Sector-wise variation in the emission inventory for PM_{10} (%)

Source: CEEW analysis, 2019

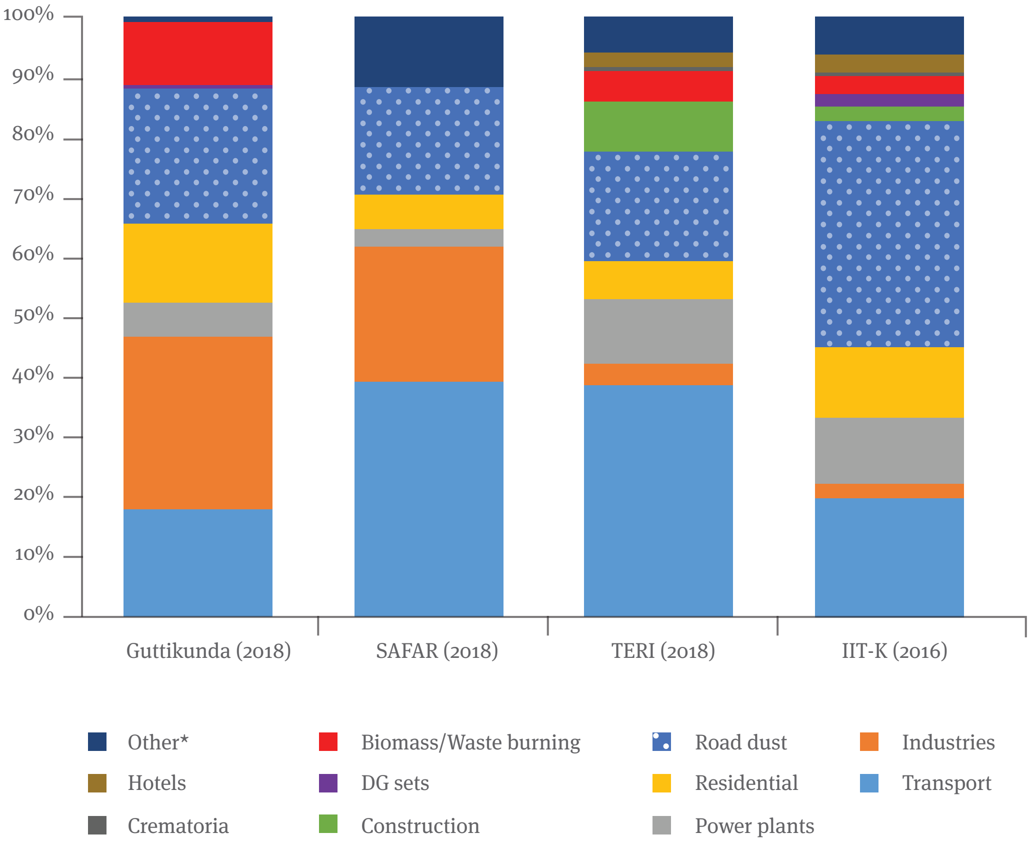


FIGURE 3:
Sector-wise contribution to $PM_{2.5}$ (%)

Source: CEEW analysis, 2019

**Other*
Guttikunda: funeral homes, fireworks, and earthen material baking

SAFAR: MSW treatment plants, MSW disposal sites, brick kilns, crematory, aviation, incense sticks, etc.

TERI: Landfill fires, waste incinerators/hospital incinerators, and airports

IIT-K: Waste incinerators, airport, and concrete batching

CPCB did not develop an inventory for $PM_{2.5}$

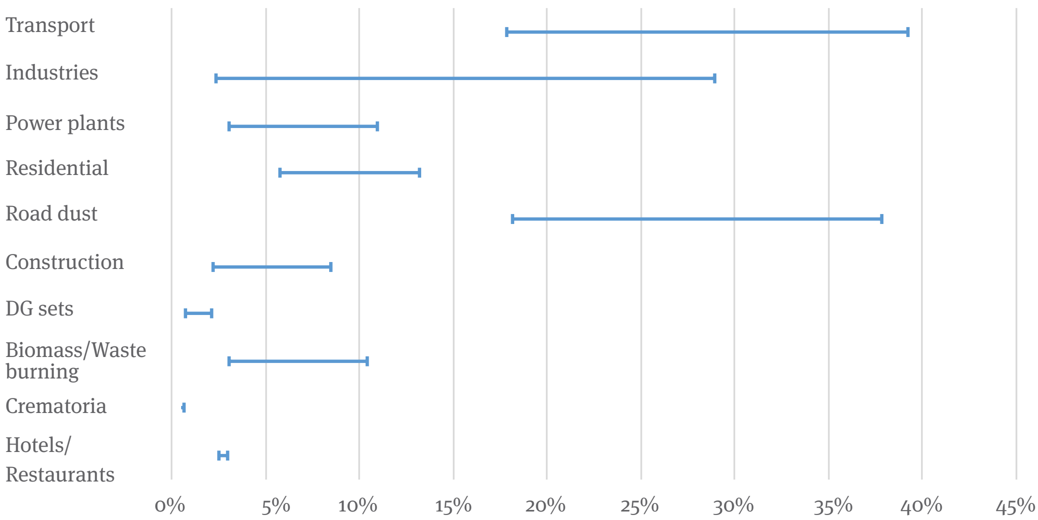


FIGURE 4:
Sector-wise variation in emissions inventory for $PM_{2.5}$ (%)

Source: CEEW analysis, 2019

The variation in emissions inventories are due to several factors, which include domain area of the study, number of sampling stations, time period of sampling, season of sampling, quality of surveys, emission factors, assumptions, and data on emission abatement technologies and efficiency of control. Therefore, we compared the methodological approaches used across studies. Whereas the key differences are presented for the five sectors with the largest variations (Sections 2.2.1 to 2.2.5), a more detailed picture is provided in Tables A3 and A4 in the Annexure. Table 2 summarises the variation in the inventory for the five key sectors.

TABLE 2: Summary of variation in the emissions inventory for PM_{10} and $PM_{2.5}$ in five key sectors

Source: CEEW analysis, 2019

Sector	Variation	
	PM_{10} (%)	$PM_{2.5}$ (%)
Transport	5.5-19.0	17.9-39.2
Industries	1.3-18.3	2.3-28.9
Power plants	2.5-17.0	3.1-11.0
Road dust	35.6-65.9	18.1-37.8
Construction	3.6-21.0	2.2-8.4

2.2.1 Transport

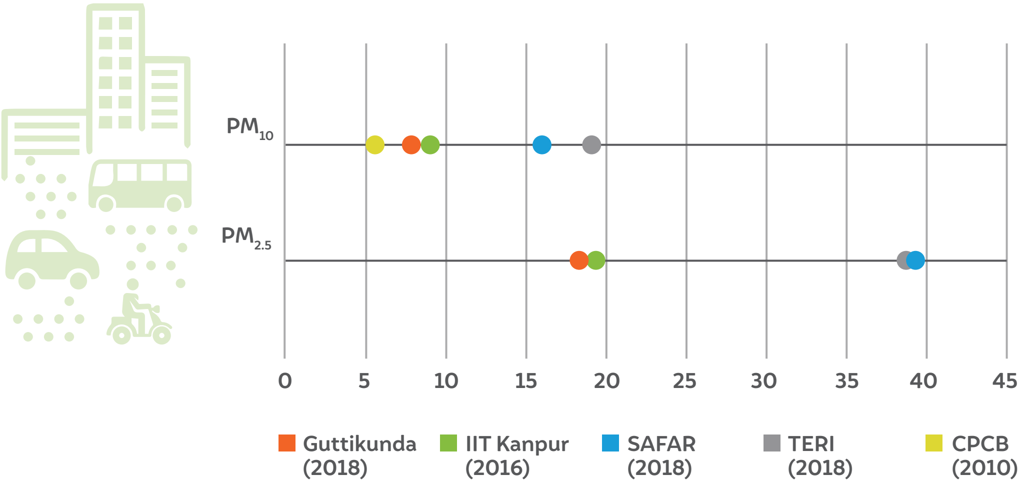


FIGURE 5: Variation in transport emissions inventory (%)

Source: CEEW compilation, 2019

The major source of $PM_{2.5}$ is the transport sector; the variation in inventory, from 17.9 per cent to 39.2 per cent, is due to the differing methodologies used - the number of survey points, in estimating traffic, and on vehicle fleet composition, fuel consumption, and emission factor. Also, as data is updated, there are differences in the final numbers.

What is included as transport? The SAFAR (2018) study included data for tourist vehicles in tourist places, vehicles in shopping malls, and data for commercial taxis. TERI (2018) and IIT Kanpur (2016) surveyed parking lots, while CPCB (2010) surveyed petrol pumps, bus terminals, taxi stands, and parking lots.

Sampling: For their primary survey on traffic, SAFAR (2018) used 87 locations and TERI (2018) used 72 locations; IIT Kanpur (2016) used secondary data by CRRI. The CPCB (2010) surveyed 10 locations. Guttikunda (2018) used government data for vehicle fleet composition given by the Ministry of Road Transport and Highways (MoRTH), vehicle kilometres travelled (VKT) and trip length by the Ministry of Urban Development (MoUD), and age mix of vehicles given by Pollution Under Control programme.

Emissions factor: The source information for emission factors is different such as from the latest ARAI report to the ARAI (2011), to the older versions such as ARAI (2008) and ARAI (2007). Few studies have referred to other sources of information on emissions factor - CPCB (2010 and 2011), Sahu et al. (2011), Developing Integrated Emissions Strategies for Existing Land -(DIESEL) (2008), and GAINS (2010). Emissions factors vary by vehicle category, within which there is further categorisation by fuel type (petrol, diesel, CNG, etc.); emission norms (e.g., BS VI); engine category; reference mass; and deterioration factor.[5]

Transport is a major contributor to $PM_{2.5}$. A common database might help in reducing the uncertainties in transport inventories

5 The information has been taken from: https://www.araiindia.com/pdf/Indian_Emission_Regulation_Booklet.pdf

2.2.2 Industries

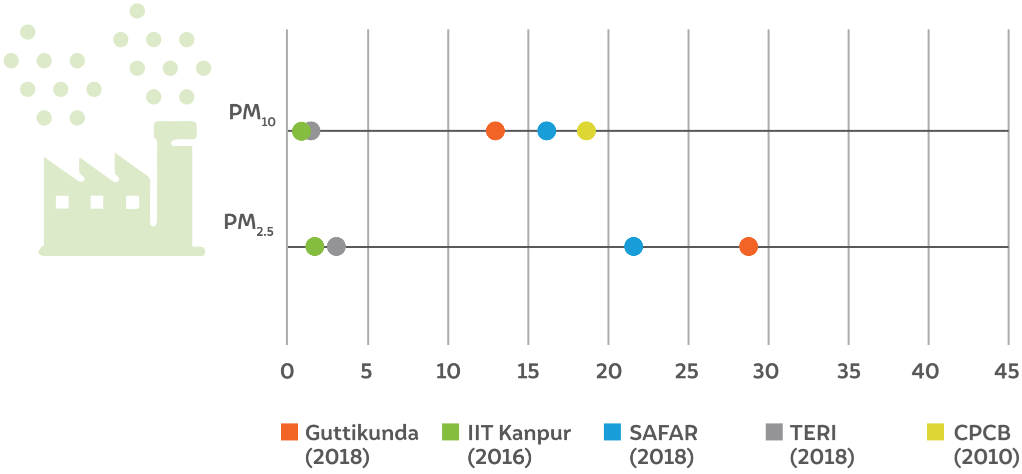


FIGURE 6: Variation in industries emissions inventory (%)

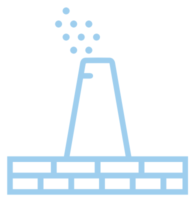
Source: CEEW compilation, 2019

Estimates of industry's contribution of PM_{10} and $PM_{2.5}$ vary widely across the studies. For PM_{10}, similar figures were estimated by CPCB (2011), SAFAR (2018),and Guttikunda (2018), but their methodologies are very different, and Guttikunda (2018) included the NCR. The estimates by TERI (2018) and IIT Kanpur (2016) are similar. Industrial contribution to $PM_{2.5}$ had similar numbers by Guttikunda (2018) at 28.9 per cent and SAFAR (2018) at 22.4 per cent, while TERI (2018) estimated it at 3.4 per cent and IIT Kanpur (2016) at 2.3 per cent.

What is included as industry? One of the reasons for variations in the inventory is the difference in what constitutes industrial activity and the method used to calculate emissions. For example, CPCB (2010) did not include brick kilns for their estimate. Guttikunda (2018) included construction as an industrial activity, including brick and cement industries and resuspension of dust.

TERI (2018) used red and orange category industries where it included fuel consumption as well as stack emissions data for the final estimate. The study included brick kilns and stone crushers. IIT Kanpur approached the calculation by dividing the sources into two categories - line sources (stack height < 20 m) and point sources (stack height > 20 m) and included information on fuel consumption. They have not specified if brick kilns formed a part of their sampling. In SAFAR (2018), brick kilns formed a separate category and, therefore, was combined in 'other' category in the final estimation.

Sampling: To calculate emissions, CPCB used primary data of 36 industrial estates, along with data from the Delhi Pollution Control Committee (DPCC); concerned government institutions; Office of Commissioner of Industries; Government of NCT, Delhi; the District



What is captured as industrial activity has significantly varied across studies. For instance, few studies do not include brick kilns in their estimation

Industrial Centre; and others. SAFAR (2018) used primary survey data for small industries and secondary data by DPCC for fuel consumption and production capacity of industries. They identified 40 types of industries in the survey. TERI (2018) used information on stack emissions and fuel consumption sourced by DPCC. Similarly, IIT Kanpur (2016) used fuel consumption data for industries given by DPCC. The study by Guttikunda (2018) used total energy consumption by the industries in Delhi NCR given by GAINS (2010) and CPCB (2010).

Emissions factor: Emissions factors differed by study. The CPCB study used AP-42 while SAFAR used AP-42 and Reddy and Venkataraman (2002). Emission factors for the TERI study included four literature studies (Irfan et al. 2014; CPCB 2011; Jaygopal et al. 2017; Mantananont et al. 2011). The IIT Kanpur study took emissions factors from CPCB (2011) and a compilation of emissions factors by the US Environment Protection Agency (USEPA) (AP-42).

2.2.3 Power plants

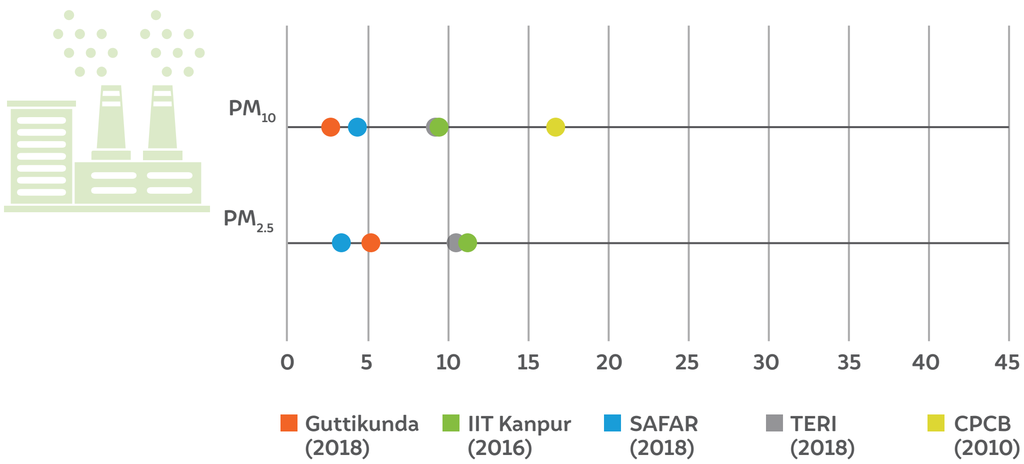


FIGURE 7: Variation in power plants emissions inventory (%)

Source: CEEW compilation, 2019

The difference in the numbers is a result of varying sources of information on power plants and the method used to calculate the emissions. The method includes emission sources such as fuel, stacks, ash content, information pollution control devices, and emissions factors.

Data and method: CPCB (2010) included five major power plants, but did not state other information on stack emissions or fuel consumption of power plants. IIT Kanpur (2016) used data from CEA (2012) on power plants. TERI (2018) referred to CEA (2017) data to develop emission inventory. Guttikunda (2018) referred to the State of the Environment Report for Delhi for data on six major power plants of Delhi. SAFAR (2018) used secondary data on location, capacity, coal usage, and pollution control device from DPCC and the official website of Northern Coalfields Limited.

Emissions factor: IIT Kanpur (2016) and SAFAR (2018) used AP-42 for emissions factor. In TERI (2018), PM emission factors were estimated for coal-based power plants through ash content, bottom ash ratios, and tail pipe controls. Guttikunda (2018) used GAINS (2010) for emissions factor.

2.2.4 Road dust

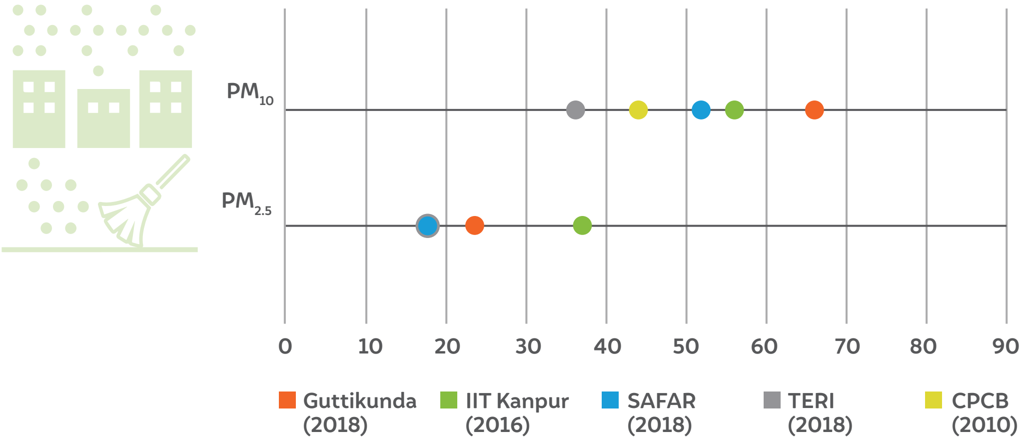


FIGURE 8:
Variation in road dust emissions inventory (%)

Source: CEEW compilation, 2019

Road dust was the highest contributor to the PM_{10} pollutant load. Across the five studies, road dust emission calculations are based on AP-42 method. The number of sampling sites, road types, and road categories varies by study and affects the representative sampling of the phenomenon.

Method: Guttikunda (2018) adopted the methodology given by USEPA (AP-42), which is applicable for roads with average road speed 88.5 km/h. The study estimated dust load for feeder roads, arterial roads, ring roads, and main roads based on vehicle density, mix of vehicles, silt loading, and vehicle speed. Data on density of vehicles was taken from CRRI. TERI (2018) used the AP-42 methodology of collecting silt samples for calculating silt loading at various road types. Estimated VKT was multiplied with the road-wise emissions factor estimated using silt loading data for dust suspension. CPCB (2010) used a very similar methodology, and took samples from 10 study zones incorporating arterial, main, and feeder roads.

IIT Kanpur (2016) used an empirical equation that estimated dust from paved and unpaved road based on silt loading data and average weight of vehicles travelling on the road. Silt load samples were taken from 16 locations. The study by SAFAR (2018) categorised PM_{10} and $PM_{2.5}$ as windblown dust, which included road dust, fly ash, and soot. Two formulae have been applied for estimating dust contribution from paved and unpaved road sources. Secondary information to calculate the estimate was derived from AP-42 and other studies done previously. There is lack of clarity on how data for flyash and soot have been included in the estimate for dust contribution.

2.2.5 Construction

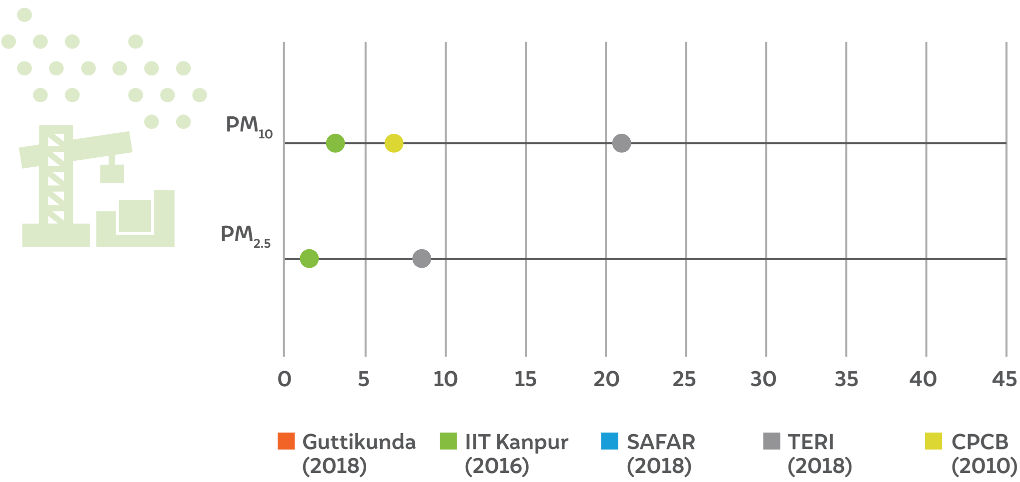


FIGURE 9: Variation in construction emissions inventory (%)

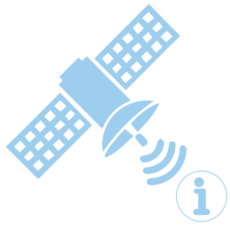
Source: CEEW compilation, 2019

In the calculation of construction emissions, TERI (2018) and IIT Kanpur (2016) had similar approaches, while the studies by CPCB (2010) and SAFAR (2018) were different. Each of the four studies included different activities in the construction sector, which explains the significant difference in the final inventory.

Method: TERI (2018) and IIT Kanpur (2016) estimated construction dust similarly, by using secondary data from satellite images and government data sources such as DMRC, PWD, and DDA. The constituents of construction activity were different, however. TERI (2018) used four main construction types: big housing complexes, flyovers, roads, and Delhi Metro construction in Phase 3. IIT Kanpur (2016) did primary survey of construction and demolition activities and used satellite data for verifying observations.

The studies by CPCB (2010) and SAFAR (2018) approached the estimation differently. The CPCB (2010) study estimated construction dust by obtaining secondary data from the Municipal Corporation of Delhi (MCD) and PWD. Building construction data was classified into new construction and renovation. Further, road construction data was considered. SAFAR (2018) lists construction as a source of air pollution, but considers cooking emissions based on fuel and its quantity used in that category. The final figure against that category is missing in the table in the study. Guttikunda (2018) has included the construction sector as a part of the industry emissions inventory.

Emissions factor: TERI (2018), IIT Kanpur (2016), and CPCB (2010) use AP-42 for calculating emissions factor. TERI (2018) used the conversion from PM to PM_{10} and $PM_{2.5}$ based on the methods of Chow and Watson (1998).



Information from satellite data has played an important role in locating construction activities for emissions inventory studies

Rickshaw pullers and auto drivers are among the most vulnerable populations on the road as they are constantly exposed to polluted air while operating in open vehicles.

Image: iStock

3. Discussion and Recommendations

In comparing various emissions inventories of air pollutants for Delhi and the NCR, this study finds significant differences in their estimates of total pollutant load and, especially, sectoral emissions.

To improve air quality, we need to design effective emissions inventories and, in turn, harmonise the inventories. To create better emissions inventories, we need to improve data transparency, quantify uncertainties, develop multiple-year inventories, common guidelines, and reconcile the top-down and bottom-up methods.

3.1 Improve data transparency

We can infer that differences in studies result from activity data or emissions factors, but we need transparent data to understand the reasons for discrepancies. In the transport sector, inventory depends on the number of on-road vehicles, their age distribution, fuel type, and VKT. Because there is no common database, studies rely on primary data collection efforts.

The study surveys were carried out across several locations - 72 locations for the TERI (2018) study and 87 locations for the SAFAR (2018) study - but it is unclear whether these constitute a representative sample. If the studies used a purposive sampling approach, it may introduce a bias; and it may not be appropriate to generalise their findings to the NCR. This lack of transparency and information in sampling frame and sample details is common to all sectors and studies.

3.2 Quantify uncertainties

There are two sets of uncertainties. The first arises from activity data such as fuel consumption and efficiency of pollution control equipment. The second set of uncertainties can be attributed to emissions factors, even though most of these are determined based on controlled experiments. When considered together, the uncertainties can compound.

Uncertainties for $PM_{2.5}$ may be as high as 86 per cent for the power sector, 201 per cent for industry, 94 per cent for road transport, and 259 per cent for the domestic sector; for the entire inventory, overall uncertainty may be as high as 145 per cent (Kurokawa et al. 2013).

With no clear understanding on uncertainties, it is difficult to gauge the spread and confidence levels for each emissions inventory estimate

However, no study except Guttikunda (2018) provides standard deviations for inventory estimates. This makes it difficult to gauge the spread and confidence levels for each parameter. Therefore, authors need to quantify the uncertainty in their studies.

3.3 Develop multiple-year inventories

Air pollution is dynamic in nature. As policies to control different sources are put in place, the total pollution level changes, as does the relative contribution of different sources. Developing multi-year inventories helps pollution control agencies identify pollution sources and design control responses accurately and on time. Further, continual emissions monitoring systems that measure pollutant loads in the industrial and power sectors are more accurate than a bottom-up calculation based on fuel use.

This comparison posits, and we argue here, that an emissions inventory needs to be continually updated. However, each of the studies considered here developed an emissions inventory for a single year. Therefore, we recommend that ministries and academic/research groups collaborate to build an ongoing, long-term emissions inventory that is updated every 1-3 years.

Developing multi-year inventories helps pollution control agencies identify pollution sources and design control responses accurately and on time

3.4 Evolve common guidelines

The USEPA lays down guidelines for state and local agencies to collect comprehensive and detailed estimates of pollutants and develop a single, common National Emissions Inventory. In India, however, the CPCB does not offer similar guidelines or directives. Therefore, several uncertainties arise in inventory development, and studies become difficult to compare. There is a need to develop inventories and carry out source apportionment studies across India.

3.5 Reconcile top-down and bottom-up methods

There is a need to better reconcile source apportionment based on emissions inventories and dispersion modelling with receptor modelling (Pant et al., 2012) and, thereby, bring about convergence between the modelling and measurement approaches.

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Annexures

Category	Guttikunda (2018)^	%	SAFAR (2018)	%	TERI (2018)#	%	IIT Kanpur (2016)	%	CPCB (2010)	%
Transport	49,123.3	7.5	118,356.2	16.1	35,068.5	19.0	12,914	9.0	9,750	5.5
Industries	86,701.4	13.3	120,274.0	16.4	3,561.6	1.9	1,810	1.3	32,478.6	18.3
Power plants	16,068.5	2.5	35,068.5	4.8	16,712.3	9.0	13,485	9.4	30,245.4	17.1
Residential	36,969.9	5.7	24,383.6	3.3	7,945.2	4.3	7,381	5.1	11,860	6.7
Agricultural burning	0.0	0.0	0.0	0.0	1,369.9	0.7	NA	0.0	NA	0.0
Road dust	430,824.7	65.9	372,602.7	50.7	65,753.4	35.6	79,626	55.5	77,275	43.6
Construction	0.0	0.0	0.0	0.0	38,904.1	21.0	5,166.83	3.6	12,290	6.9
DG sets	1967.1	0.3	NA	0.0	274.0	0.1	1,387	1.0	534	0.3
Refuse burning/open burning	28,764.4	4.4	NA	0.0	3,835.6	2.1	1968	1.4	1.4	0.0
Crematoria	NA	0.0	NA	0.0	1,095.9	0.6	346	0.2	1,300	0.7
Hotels/ restaurants/ bakeries	NA	0.0	NA	0.0	3,835.6	2.1	3,493	2.4	1,731	0.9
Airport	NA	0.0	NA	0.0	274.0	0.1	54	0.0		0.0
Waste incinerators/ hospital incinerators	NA	0.0	NA	0.0	1,369.9	0.7	44.9	0.0	18	0.0
Landfill fires	NA	0.0	NA	0.0	4,931.5	2.7	NA	0.0	NA	0.0
Solvents	NA	0.0	NA	0.0	NA	0.0	NA	0.0	NA	0.0
Concrete batching	NA	0.0	NA	0.0	NA	0.0	14,370	10.0	NA	0.0
Agricultural soil dust	NA	0.0	NA	0.0	NA	0.0	1,353	0.9	NA	0.0
Others*	3,520.5	0.5	64,657.5	8.8	NA	0.0	NA	0.0	NA	0.0
Total	**653,939.7**	**100**	**735,342.5**	**100**	**184,931.5**	**100**	**143,398.7**	**100**	**177,363.4**	**100**

TABLE A1:
Total emissions load (in kg/day) for Delhi by category for PM_{10}

 # The figures are included for Delhi region only.

^The region of study includes New Delhi, Faridabad, Ghaziabad, Noida, Greater Noida, and Gurugram.

** Others category by Guttikunda contains intermittent sources of pollution: funeral homes, fireworks, and earthen material baking. In the SAFAR study, constituents of this category are the relatively new emerging contributors: MSW treatment plants, MSW disposal sites, brick kilns, crematory, aviation, incense sticks, etc.*

Source: CEEW compilation, 2019

Category	Guttikunda (2018)^	%	SAFAR (2018)	%	TERI (2018)#	%	IIT Kanpur (2016)	%
Transport	48,528.8	17.9	115,616.4	39.2	33,972.6	38.8	11,623	19.8
Industries	78,465.8	28.9	66,027.4	22.4	3,013.7	3.4	1,367	2.3
Power plants	15,482.2	5.7	9,041.1	3.1	9,589.0	10.9	6,431	11.0
Residential	35,789.0	13.2	16,986.3	5.8	5,479.5	6.3	6,940	11.8
Agricultural burning	0.0	0.0	0.0	0.0	1,095.9	1.3	NA	0.0
Road dust	60,832.9	22.4	53,424.7	18.1	15,890.4	18.1	22,165	37.8
Construction	0.0	0.0	0.0	0.0	7,397.3	8.4	1291.71	2.2
DG sets	1926.0	0.7	0.0	0.0	0.0	0.0	1,248	2.1
Refuse burning/open burning	28,189.0	10.4	0.0	0.0	3,287.7	3.8	1,771	3.0
Crematoria	0.0	0.0	0.0	0.0	547.9	0.6	312	0.5
Hotels/ restaurants/ bakeries	0.0	0.0	0.0	0.0	2,191.8	2.5	1,758	3.0
Airport	0.0	0.0	0.0	0.0	274.0	0.3	54	0.1
Waste incinerators/ hospital incinerators	0.0	0.0	0.0	0.0	821.9	0.9	40.9	0.1
Landfill fires	0.0	0.0	0.0	0.0	4,109.6	4.7	NA	0.0
Solvents	0.0	0.0	0.0	0.0	NA	0.0	NA	0.0
Concrete batching	0.0	0.0	0.0	0.0	NA	0.0	3,594	6.1
Agricultural soil dust	0.0	0.0	0.0	0.0	NA	0.0	0	0.0
Others*	2,424.7	0.9	33,972.6	11.5	NA	0.0	NA	0.0
Total	**271,638.4**	**100**	**295,068.5**	**100**	**87,671.2**	**100**	**58,595.6**	**100**

TABLE A2:

Total emissions load (in kg/day) for Delhi by category for $PM_{2.5}$

 # The figures are included for Delhi region only.

^The region of study includes New Delhi, Faridabad, Ghaziabad, Noida, Greater Noida, and Gurugram.

**Others category by urban emissions contains intermittent sources of pollution: funeral homes, fireworks, and earthen material baking. In the SAFAR study, constituents of this category are the relatively new emerging contributors: MSW treatment plants, MSW disposal sites, brick kilns, crematory, aviation, incense sticks, etc.*

$PM_{2.5}$ has not been covered by CPCB 2008 study

Source: CEEW compilation, 2019.

TABLE A3: Methodological approach for estimating pollutant loads

Source: CEEW compilation, 2019

NA: not available

Category	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Transport	ASIF methodology by Schipper et al. (2000) to calculate vehicle exhaust emissions. The variables are total travel activity, vehicle-km travelled per day (MoUD), energy use per km, and emissions factor. Number of vehicles in each category taken from MoRTH (2011). Data on age mix of vehicle fleet taken from PUC programme.	Primary survey of traffic done at 87 major/ minor roads. Secondary data from Delhi Municipal Corporation (transport and traffic departments).	Primary traffic count at 72 locations for arterial, sub-arterial, and minor roads. Fuel consumption data from oil companies. VKT estimated. Adjustment for high-emitting vehicles.	Primary parking lane survey at 20 locations for vehicle count. Data on vehicle counts at 64 locations by CRRI.	Primary data on vehicle counts at 10 locations. Supplemented by CRRI survey (2002). Diesel locomotive emissions estimated based on train numbers and USEPA emission factors.
Industries	Total energy consumption was taken for industries in NCR, classified on the basis of fuel. Data taken from GAINS (2010) and CPCB (2010). Brick production rate was taken for calculating emissions from the sector. Construction activities included for resuspension of dust.	Secondary data from DPCC on fuel consumption, production capacity, etc.	Industries included bricks, sugar, paper, dyeing, rubber, chemical ceramics, iron and steel, textile, fertilisers, stone crushers, and casting and forging. Secondary data on production and fuel consumption and stack monitoring data from SPCBs. 5,000 brick kilns using Google Earth.	Inclusion of industries with stack height <20 m as line source. Area source of industries was taken for major industrial areas. Secondary data on fuel consumption from DPCC.	Industries covered are metallurgical, engineering, food, textiles, plastic, rubber, chemicals, and others. Secondary data on fuel consumption, industry type and capacity from DPCC and CPCB. Primary survey of industry representatives and industrial units.
Power plants	Six major plants included in the study. Data by SoEDelhi (2010).	Secondary data on location, capacity, coal usage, pollution control device attached, etc. obtained from DPCC, official website of Northern Coalfields Limited.	Secondary data from CEA (2017) and stack emissions from CPCB. Estimate of coal handling unit emissions.	Secondary data from CEA (2012) and stack emissions from CPCB.	NA

Category	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Residential	Census (2001) data. High population density in a grid signified LPG, low density signified use of coal, biomass, cow dung, wood, kerosene, and LPG.	For biomass burning in households, 87 slums in Delhi were visited.	Population from Census 2011 projected upto 2016. Per capita fuel consumption NSSO (2012). Pradhan Mantri UjjwalaYojna taken.	Population and fuel use from Census 2011.	Population and fuel use from Census (2001) data. Primary data on household fuel consumption near 10 monitoring sites.
Agricultural burning	*Category not considered*	NA	Secondary data on district-wise crop production, crop-to-waste ratios,and primary surveys.	*Not explicitly considered – study domain was only Delhi*	*Not explicitly considered – study domain was only Delhi*
Road dust	UESPA AP-42 method for road dust resuspension Vehicle density figures taken from CRRI.	AP-42	Primary data of road dust from arterial, sub-arterial, and minor roads; and chemical analysis.	Primary data of road dust from 20 locations.	Estimated based on USEPA methods by road type.
Construction	*This category has been included in the industries*	NA	Active construction sites data was collected through DMRC, PWD, and DDA. High-res images from Google Earth were used for calculating the area under construction of big housing complexes, flyovers, roads, and Delhi Metro Phase III.	Primary data using field survey + satellite validation. Concrete batching emissions estimate of 40 plants of 120 m3/hr running for 16 hours.	Secondary data on construction from Public Works Department and DDA.
DG Sets	Site survey for fuel consumption.	NA	Secondary data from Chief Electrical Inspectorates in various districts + primary data survey on DG set usage.	Secondary data from DPCC on DG set usage.	Secondary data on DG set usage from generator suppliers.
Refuse burning/ open burning	SoEDelhi (2010)	NA	Estimate based on secondary literature Assumption that ~3% waste is burnt in Delhi.	Estimate based on secondary literature. Assumption that ~3% waste is burnt in Delhi.	Estimate based on secondary literature. Assumption that ~1% waste is burnt in Delhi.

Category	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Crematoria	*Category not considered*	Out of 62 cremation sites, 56 are traditional and 6 are electric. Total number of deaths in Delhi was taken from Ministry of Home Affairs, GoI website.	Secondary data on death counts in different districts Estimate of wood use per cremation through surveys.	Secondary data on death counts in different districts. Assumption of ~216 kg wood/ cremation.	Secondary data on death counts in different districts. Assumption of ~350 kg wood/ cremation.
Restaurants/ Hotels	*Emissions from this sector were divided between Residential sector and DG sets sector.*	Street vendor data was obtained from 1,653 samples from 27 locations. Secondary data from Delhi Municipal Corporation.	Secondary data on number of hotels from Delhi Statistical Handbook and primary survey on fuel use.	Secondary data on number of hotels from Delhi Statistical handbook. Assumption on fuel use (25% use tandoor).	Secondary data on number of hotels from Delhi Statistical handbook Primary data on restaurant fuel consumption near 10 monitoring sites.
Airports	Public domain data on flight information. Emissions from this sector were included in the transport sector.	NA	Secondary data on total aircraft movements at Delhi airport.	Assumption on aircraft movements at Delhi airport ~800 flights per day.	*Not explicitly considered*
Waste incinerators	*Category not considered*	Data was collected for three waste-energy plants in Delhi. The source of data has not been mentioned.	Secondary data from European Environment Agency.	Secondary data on activity & capacity from DPCC.	Secondary data on activity and capacity from DPCC.
Landfill fires	*Emissions from landfills have been included in the refuse burning category.*	NA	Landfills identified using Google Earth + fire incidences using MODIS satellite data.	*Not considered*	*Not considered*

TABLE A4: Emission factors used for estimating pollutant loads

Category	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Transport	CPCB (2010) DIESEL (2008) GAINS(2010)	ARAI, Air Quality Monitoring Project-Indian Clean Air Programme, 2007 report CPCB (2010) Sahu et al. (2011)	ARAI	ARAI (2011) CPCB (2011)	ARAI 2008
Industries	Reddy and Venkataraman (2002) Gurjar et al. (2004) GAINS (2010) CPCB(2010) For EF for brick kilns – Maithel et al.	Reddy & Venkataraman (2002) AP-42	Irfan et. al (2014) CPCB (2011) CPCB (2009) Jaygopal et al. (2017) Mantananont et al. (2011) GAINS India Database	CPCB (2011) AP-42 (USEPA, 2000)	CPCB AP-42 (USEPA, 2000)
Power plants	GAINS (2010)	AP-42	The PM emission factors for coal-based power stations was customised using the ash content, bottom ash ratios, and efficiency of tailpipe controls	AP-42 (USEPA, 2000)	CPCB AP-42 (USEPA, 2000)
Residential	Zhang et al. (1999) Bhattacharya et al. (2000) Zhang et al. (2000) GAINS (2010)	Reddy & Venkataraman (2002) Source Apportionment Report, ARAI	Datta and Sharma (2016)	CPCB (2011) AP-42 (USEPA, 2000)	CPCB AP-42 (USEPA, 2000)
Agricultural burning	NA	NA	Datta and Sharma (2016)	NA	NA
Road dust	USEPA AP-42	NA	AP-42	Empirical equation to calculate road dust using variables - silt loading (particles less than size 75 µm) and average weight of vehicles travelling on the road	USEPA methodology based on silt loading, weight of vehicles, road length, etc.

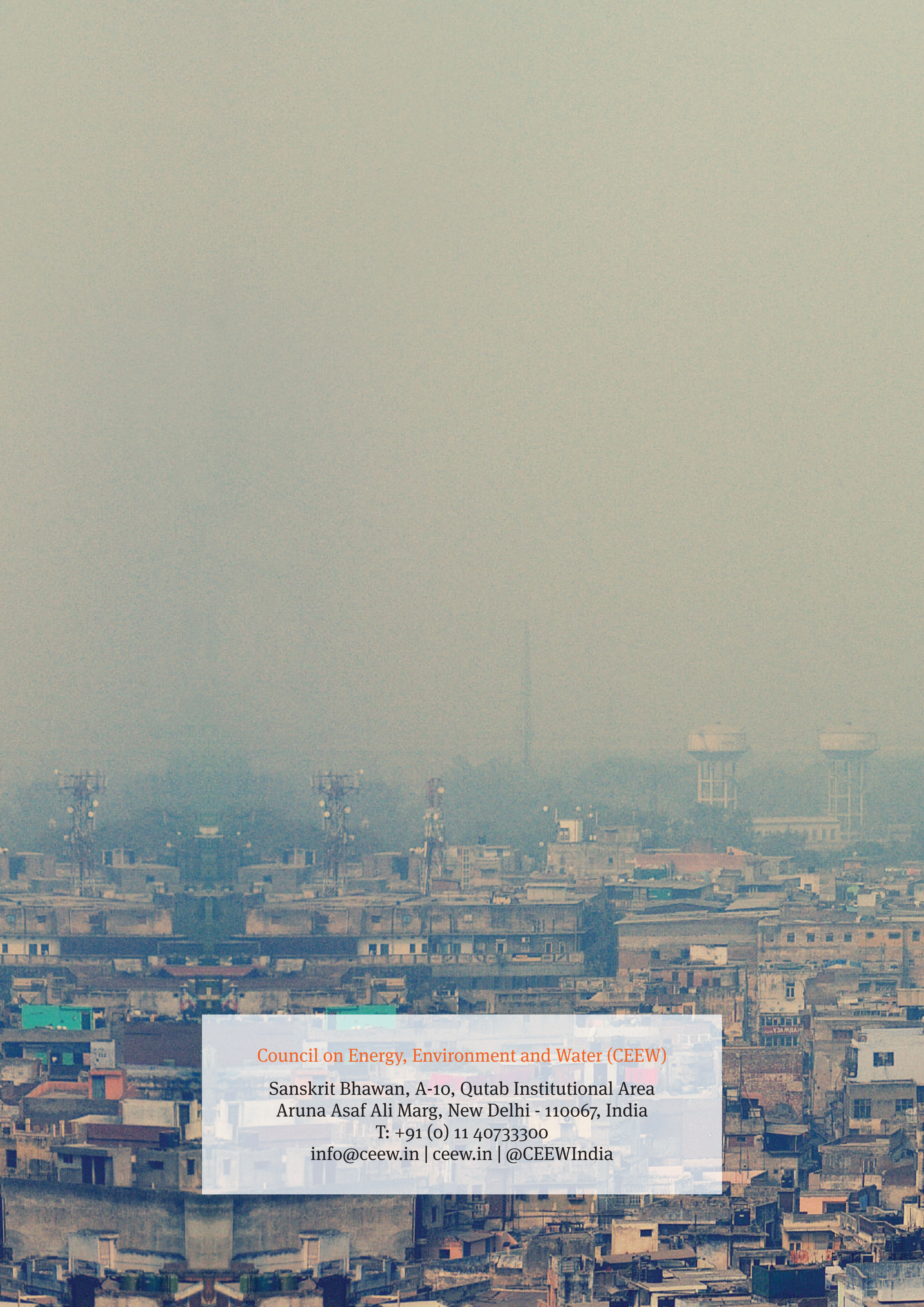
Source: CEEW compilation, 2019
NA: not available

Category	Guttikunda (2018)	SAFAR (2018)	TERI (2018)	IIT Kanpur (2016)	CPCB (2010)
Construction	NA	NA	AP-42	AP-42 (USEPA, 2000)	CPCB AP-42 (USEPA, 2000)
DG sets	GAINS (2010)	NA	*Not mentioned explicitly*	CPCB (2011)	CPCB AP-42 (USEPA, 2000)
Refuse burning/open burning	*Not mentioned explicitly*	NA	Woodall et.al (2012) Pappu et al. (2007)	CPCB (2011) AP-42 (USEPA, 2000)	CPCB AP-42 (USEPA, 2000)
Crematoria	NA	NA	Akagi et al. (2008)	CPCB (2011)	CPCB AP-42 (USEPA, 2000)
Restaurant	NA	NA	CPCB (2011)	CPCB (2011)	CPCB AP-42 (USEPA, 2000)
Airport	*Not mentioned explicitly*	NA	EEA (2013) IPCC (2000)	International Civil Aviation Organization (ICAO)	NA
Waste incinerators/ Medical waste incinerators	NA	NA	EEA (2016)	AP-42 (USEPA, 2000) CPCB (2011)	AP-42 (USEPA, 2000)
Landfill fires	NA	NA	Woodall et.al (2012) Pappu et al. (2007)	NA	NA
Solvents	NA	NA	NA	NA	NA

TERI (2018) estimated that if vacuum-assisted sweeping is done twice a month, road dust would decrease by 42%.

Image: iStock


Air
PERSONAL
TRAINER



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