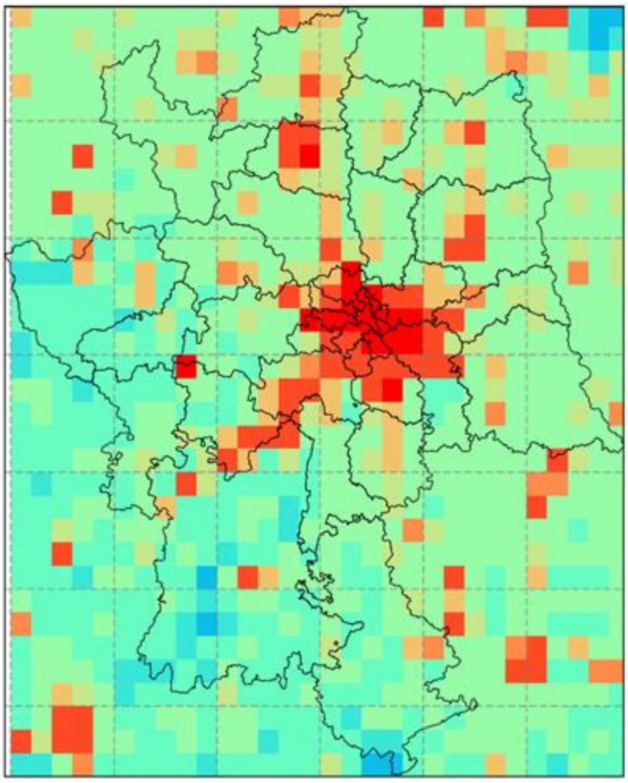
Framework for Development of Emission Inventory and Emission Based Source Apportionment in Delhi NCR

Commission for Air Quality Management in NCR and Adjoining Areas



April 2025

Table of Contents

F No B-110021/18/Sc-01/2020/CAQM/1175 DT

राष्ट्रीय राजधानी क्षेत्र और निकटवर्ती क्षेत्रों में वायु गुणवत्ता प्रबंधन आयोग

Commission for Air Quality Management in NCR & Adjoining Areas

17वीं मंज़िल, जवाहर व्यापार भवन (एस.टी.सी. बिल्डिंग) टॉलस्टॉय मार्ग, नई दिल्ली – 110001

17th Floor, Jawahar Vyapar Bhawan, (STC Building), Tolstoy Marg, New Delhi – 110001

Date:20/12/2024

ORDER / आदेश

Sub.: Constitution of Steering Committee for development of Framework for new emission inventory and source apportionment in Delhi NCR.

The Commission, in exercise of the powers conferred upon it under Section 12 of the Commission for Air Quality Management in National Capital Region and Adjoining Areas Act, 2021, has constituted following Steering Committee for development of Framework for new emission inventory and source apportionment in Delhi NCR.:

1.	Dr. S. D. Attri, Member Technical, CAQM	-	Chairman
2.	Member Secretary, CAQM	-	Member
3.	Director, NEERI	-	Member
4.	Member Secretary, CPCB	-	Member
5.	MS, HSPCB	-	Member
6.	MS, RSPCB	-	Member
7.	MS, UPSPCB	-	Member
8.	MS, DPCC	-	Member
9.	Prof. Mukesh Sharma, IIT, Kanpur	-	Member
10.	Dr. Sachin Ghude, IITM, Pune	-	Member
11.	Dr. Sumit Sharma, UNEP, Delhi	-	Member
12.	Sh. Moqtik Bawase, ARAI Pune	-	Member
13.	Dr. Sri Harsha Kota, IIT Delhi	-	Member
14.	Sh. R Suresh, TERI	-	Member
15.	Dr. Vikas Singh, Scientist E, CAQM	-	Member-Convener

Terms of Reference of the Steering Committee are as follow:

1. Identification of Polluting Sectors and activities in NCR.
2. Standardization of Methodology for developing inventories/carrying out Source Apportionment Studies.
3. Development of updated Emission Factors and Source Apportionment Strategies including real-time models.

Steering Committee will submit the recommendations regarding the framework by 31.01.2025. It may co-opt any member if required.

This is issued with the approval of the competent authority.

Yours faithfully,

(R. K. Agrawal)
Director-Technical
Tel.: 011-23446806

To,

All member of the Committee

Executive Summary

Delhi-NCR (National Capital Region) faces severe air pollution challenges throughout the years, especially during winter months when the entire region experiences poor air quality. The level of air pollution in the region is governed by several factors viz. emission, meteorology, chemical reactions responsible for production, losses and deposition processes etc. The pollution in Delhi-NCR can be due to both primary and secondary pollutants. The primary pollutants are emitted from both natural and anthropogenic sources such as vehicular emissions, industrial activities, stubble burning, road dust, residential practices etc. Addressing the issue of air pollution requires robust Emission Inventory (EI) and Source Apportionment (SA) studies for evidence-based strategies development for effective air quality management.

This document highlights the gaps in the existing approaches and aims to provide comprehensive framework for the development of emission inventory and emission-based source apportionment in Delhi NCR. The Framework provides guidance on the pollutants, polluting sectors, geographical extent, time period and spatial resolution for the EI development for Delhi NCR. It also incorporates in detail data driven methodologies, sector-specific data collection, emission factors and source categorization to provide high-resolution geo-spatial data and source contribution of pollutant across Delhi-NCR and adjoining regions. The Framework suggests integrating primary surveys, secondary data, and advanced Geographic Information Systems (GIS) to spatially map emissions, enabling targeted interventions and evidence-based policymaking. The Framework provides a general guidance for developing a high-resolution emission inventory to identify and quantify pollution sources across sectors such as transport, industry, household activities, crop residue burning, road dust, and waste burning etc.

The Framework emphasizes the need for a gridded emission dataset with resolutions as fine as 500m x 500m for Delhi and adjoining areas, enhancing the ability to identify polluting sources and hotspots at finer resolution. Moreover, it proposes pollutants like PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, Non-methane Volatile Organic Compounds (NMVOCs), NH_3 and pollutants such as BC, OC, HCL and other pollutants based on the availability of the emission factors. To ensure reliability, the Framework introduces a robust QA/QC mechanism for data validation, emphasizing transparency in reporting and systematic documentation. This includes comparing estimates across multiple datasets, cross-checking transcription errors, and peer reviews. Importantly, uncertainty quantification is suggested using established methodologies, such as Monte Carlo simulations, to account for data variability. For dissemination, the Framework suggests making gridded emissions and activity data available online in GIS formats, enhancing accessibility for researchers and decision-makers.

The Framework also acknowledges significant challenges in activity data availability, accuracy and stakeholder coordination. Addressing these challenges is critical to refining emission estimates, reducing uncertainties, and developing effective air quality management strategies. The Framework proposes enhanced data collection, adoption of standard methodologies, and utilizing advanced modeling approaches to develop an emission inventory and emission-based source appointment.

The Framework also highlights both measurement-based and emission inventory-based approaches for source apportionment. While receptor models like Positive Matrix Factorization (PMF) and Chemical Mass Balance (CMB) analyze ambient air samples to identify pollution sources, emission inventory-based methods, coupled with chemical transport models like Community Multiscale Air Quality (CMAQ) and WRF-Chem, offer predictive capabilities and detailed spatial assessment of pollution dynamics, including secondary pollutant formation and regional transport. The emission inventory based source apportionment offers overall advantages, especially in the context of air quality management because of its predictive capability in terms of spatial and temporal resolution enabling targeted actions at specific locations and times. However, the accuracy of the SA results highly depends on the goodness of the emission inventory and the Chemical Transport Model (CTM) being used. It is suggested to use the up-to-date EI for Delhi NCR along with a validated CTM to conduct an EI based SA on a regular basis in addition to the measurement-based SA.

In conclusion, the Framework would facilitate the development of an accurate and up-to-date emission inventory and emission-based source apportionment to identify the polluting sources in Delhi-NCR. While this Framework acts as a guidance, the researchers/scientists/academicians are encouraged to use the most recent and innovative methods to improve the accuracy of the emission inventory and source apportionment. The Framework shall act as a live document and could be updated based on emerging emission sources and scientific methodologies.

CHAPTER 1

Introduction

Air pollution in Delhi-NCR is a major environmental concern throughout the year and especially during the winter months when the entire region experiences high levels of particulate matter ($PM_{2.5}$ and PM_{10}) exceeding the Indian National Ambient Air Quality Standards (NAAQS) leading to poor air quality which can have adverse effects on health.

The pollution in Delhi-NCR can be due to both primary and secondary pollutants contributing to the poor air quality issues in Delhi. The level of air pollution in the atmosphere is governed by several factors viz., emission, meteorology, chemical reactions responsible for production, losses and deposition processes etc.

The emission of air pollutants involves the release of air pollutants into the atmosphere from different sources and processes. These emission sources can be local, i.e. originating in the vicinity or can be transported from different areas/regions including transboundary referred to as non-local/regional.

Pollutants can be released into the atmosphere from both natural and anthropogenic sources. Natural sources include dust storms, biogenic emission, sea-salt spray, forest fires and volcanoes etc. While the anthropogenic sources of pollution include vehicular emissions, road dust, industries, construction dust, open burning, residential emissions, stubble burning etc.

1.1 Emission Inventory

An emission inventory is a comprehensive geo-spatial dataset having information of the sources and amount of emission discharge within an area over a certain period. Inventorization of pollutant sources in terms of their location and time is required to track and analyze the sources and amounts of pollutants released into the atmosphere. Therefore, emission inventory is crucial for effective air quality management that enables researchers and policymakers to identify major pollution sources, assess trends, and develop suitable mitigation strategies.

The development of emission inventory involves estimation of emissions from various activities such as vehicular, industrial, residential, commercial, etc. to be made using primary as well as secondary data collection from various sources including conducting surveys, wherever necessary. Impact of pollution from these sources depends on many factors, viz., vicinity of emission sources, the concentration of pollutants, temporal and spatial variations in emission pattern and receptor types, etc. The emission inventories provide the essential geo-spatial data needed to understand and identify the sources of pollution and quantitative expression of pollution load within a defined area.

A calculation of emission from a source relies on two key components, namely activity data and emission factors and can be represented by the following equation:

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right) \quad (1.1)$$

Where,

E is the amount of pollutant emission,

A is the activity of the source that generates emissions,

EF is the emission factor that is a coefficient that quantifies the amount of pollutant emitted per unit of activity,

ER is overall emission reduction efficiency due to control devices.

1.1.1 Activity Data

Getting accurate activity data (A) and deriving precise Emission Factors (EF) is crucial in emission inventory development. The activity includes fuel consumption, Vehicle Kilometer Travelled (VKT), and production quantities, operation hours etc. These data can be detailed or can be averaged for a polluting sector or an area. The accurate activity data when combined with accurate emission factors allows for the accurate calculation of pollutant emissions.

1.1.2 Emission Factors

Emission Factors (EFs) are coefficients that quantify the amount of pollutant emitted per unit of activity. EFs are expressed as the weight of a certain pollutant divided by a unit weight, volume, distance, or duration of the polluting activity. These EFs are derived from scientific studies and measurements and can vary depending on the technology, process, or region.

Although the method of emission inventorization looks simple, it is a complex process due to the consideration of a number of factors for the emission inventory development. Some of the factors include:

- Method to be adopted such as top-down or bottom-up.
- Number of pollutants to be included.
- Sources: Sectors and Sub-sectors (point, area, line, stationary/mobile) to be included in the study.
- Geographical area to be studies such as administrative area or airshed or rectangular domain.
- Time period of the study such as past year, current year, future projection for 2030, 2050 etc.
- Spatial Resolution of the emission inventory.
- Temporal resolution for the EI development (annual, monthly, daily or hourly).
- Emissions quantities to be estimated (e.g. total emission, tons, Gg or kg or emission rate kg/day etc.).

1.2 Source Categorization

Emissions can originate from various types of sources and can be categorised according to origin such as anthropogenic and natural. Emission sources can also be classified by movement of the sources as stationary and mobile sources. Industries are a good example of stationary source whereas on road vehicles are an example of mobile source. However, for the sake of development of emission inventory, the sources are classified into point, line, and area sources based on their characteristics.

1.2.1 Point Sources

Point sources of emission are mostly identifiable stationary locations where pollutants are emitted. These sources are typically stationary such as stacks in factories, power plants, refineries, industries, waste incineration, brick kilns etc. Being stationary in nature, these sources are relatively easy to monitor and estimate the emission based on activity data.

1.2.2 Line Sources

Line sources of emissions are mobile sources in which emissions occur along a linear path or line segment, such as road, rail or aviation. These sources are typically associated with transportation activities, where pollutants are emitted continuously while traveling along the routes. These emissions are complex and dynamic in nature therefore difficult to monitor and estimate the location and time of the emission.

1.2.3 Area Sources

Area Sources of emissions include smaller dispersed sources spread over an area. These sources include human activities such as residential cooking and heating, activities in commercial facilities and industries, agricultural activities, and the use of paints and solvents. While the individual emissions from these sources are smaller and scattered, their cumulative impact over the geographical area can be significant. These emissions are also complex in nature as they are scattered over an area.

1.3 Emission Inventory Studies for Delhi/NCR

The “Catalogue of Indian Emission Inventory Report” (TERI, 2022) contains publicly available existing emission inventory reports/studies in India. About 200 EI studies/reports have been tabulated as per the source contribution (total emissions, transport, residential, industrial, power plants, agriculture, waste and others) along with details such as geography, grid size, emission factors used, and type of data collected (primary surveys or secondary literature). Each sector list also consists of the pollutants studied and highlights those reports that have adhered closely to the existing CPCB guidelines (CPCB, 2010). This report highlights the urgent need to bolster the availability of robust data, quantify the uncertainties, adopt standard methodologies and create fine spatial resolution inventory.

As far as Delhi or Delhi-NCR regions is concerned, a number of studies have been conducted in the past (e.g. NEERI, 2010; Sahu et al, 2011; Guttikunda and Calori, 2013; Sindhwani et al., 2015; Mishra and Goyal, 2015; IITK, 2016; SAFAR, 2018; TERI & ARAI, 2018; Sahu et al., 2023; TERI/IITK, 2023). While there are many studies for Delhi, detailed EI studies have been conducted by the Indian Institute of Technology-Kanpur (IITK) for Delhi for base year 2014; by The Energy and Resources Institute (TERI) and the Automotive Research Association of India (ARAI) for base year 2016 for Delhi-NCR, by Indian Institute of Tropical Meteorology (IITM) for base year 2018 also known as SAFAR emission inventory, and most recent by IITK/TERI in 2023 for base year 2021. The emission estimates from the major EI studies are compared and shown in Table 1.1. IITK (2016) conducted a comprehensive study of PM_{10}, $PM_{2.5}$, NO_x, SO_2, and CO in Delhi, focusing on ~14 sources for the base year 2014 (November 2013–June 2014) at a 2 km resolution. The results showed that road dust (56 %), concrete batching (10 %), industrial sources (10 %), and vehicles (9 %) are the major contributors to PM_{10} emissions. Though the study involved site sampling for a few of the sectors, it also lacked an absolute sampling number (limitation), and most of the activity data were collected from secondary sources. Thereafter, TERI and ARAI (2018) initiated a source apportionment study for identifying sources responsible for $PM_{2.5}$ and PM_{10} in the Delhi NCR and developed a coarse-resolution (4 km×4 km) emission inventory of a few pollutants (PM, NO_x, SO_2, CO, and non-methane volatile organic compounds – NMVOCs) for 2016. The results stated that, in the case of PM_{10}, road dust and construction dust contributed significantly, where the contribution of dust from surrounding regions was comparatively higher in summers, which reduced the proportion of major sectors in the PM_{10} emission load. SAFAR (2018) estimated emission of eight air pollutants ($PM_{2.5}$, PM_{10}, CO, NO_x, VOC, SO_2, BC, and OC) at a resolution of 400m x 400m for 2018 for a broader region of Delhi and surrounding areas (70x65 km^2). The annual emissions for $PM_{2.5}$, PM_{10}, CO, NO_x, SO_2, VOC, BC, and OC were estimated to be 107.8, 268.4, 575.8, 412.6, 619.8, 679.4, 24.2 and 41.3 Gg yr^{-1}. Further, Sahu et al. (2023) extended the SAFAR emission over the same domain for 2020 and estimated annual emissions for $PM_{2.5}$, PM_{10}, CO, NO_x, SO_2, VOC, BC, and OC to be 123.8, 243.6, 799.0, 488.9, 425.8, 730.0, 33.6, and 20.3 Gg yr^{-1} respectively. While their study provides very high-resolution emission, their geographical extend does not include entire NCR. The most recent study by TERI/IITK (2023) estimated emission at 500m x 500m resolution for the year 2021-22 for major pollutants other than OC and BC. In this study, the total particulate matter emissions i.e. PM_{10} and $PM_{2.5}$ from different polluting sectors in Delhi were estimated as 40.21 Kt and 20.32 Kt respectively during 2021-22. Total PM_{10} load from different polluting sectors in Delhi revealed that road dust (42%) was identified as a major contributor of PM_{10}, followed by transport sector (25%). Similarly, the highest share of $PM_{2.5}$ emissions were observed from the transport sector 47%) followed by road dust (20%) and gas based power plants (8%). In general, presence of $PM_{2.5}$ in the ambient atmosphere is mainly generated from combustion sources. This study shows slight decline in PM and NO_x emission w.r.t. earlier study in 2018. However, it shows a large increase in CO emissions and a sharp decline in SO_2 emissions.

The emission inventory studies conducted for Delhi-NCR do not follow a consistent approach and therefore show large variations. Emission variations across studies can be due to the different methodology, assumptions, geographical differences, source sectors and activities, data collection methods, temporal variations, and emission factors. In addition to the precise emission factors, the accuracy and frequency of data collection methods play a critical role in emission estimation. A unified data driven approach is essential to reduce emission uncertainty and for developing effective air quality management in Delhi NCR.

Table 1.1. Inter-comparison of major EI studies over Delhi-NCR (units are in Gg/yr)

Related Studies	**NEERI, 2010**	**IITK, 2016**	**SAFAR, 2018**	**TERI & ARAI, 2018**	**TERI/IITK, 2023**	**TERI/IITK, 2023**
Base Year	*2007*	*2014*	*2018*	*2016*	*2021*	*2021*
Study Area	Delhi	Delhi	Delhi and Surrounding area	Delhi-NCR	Delhi-NCR	Delhi
$PM_{2.5}$	-	21.43	107.8	528.5	518.8	20.32
PM_{10}	53.74	52.33	268.4	1016.8	869.5	40.21
CO	136.55	141.13	575.8	4964.3	80777.3	19434.3
NO_x	167.92	113.85	412.6	885.7	867.6	153.5
SO_2	97.72	51.69	619.8	891.5	246.4	4.43
VOC	-	-	679.4	1670.6	1187.2	180.52
BC	-	-	24.2	-	-	-
OC	-	-	41.3	-	-	-

1.4 Major Issues and Challenges in the Development of the Emission Inventory of Delhi NCR

A significant challenge lies in the availability of accurate emissions factors and detailed activity data that limits the accurate estimation of emission. A major challenge is in the data limitations, with incomplete, outdated, and missing datasets, compounded by delays in acquiring the necessary information. Coordination among multiple stakeholders and agencies further complicates efforts, while the exclusion of emissions from unorganized sectors often leads to underestimations. Seasonal variations in air pollution levels are frequently overlooked, and achieving high-resolution data has proven challenging due to financial constraints.

In the transport sector, the collection of primary data has been disproportionately focused on Delhi, leaving other NCR districts underrepresented due to limited financial resources. The lack of reliable secondary datasets, such as toll plaza records and camera-based traffic data, hampers efforts to bridge data gaps. Fuel consumption data, essential for validating emissions estimates, is unavailable at the district level, creating further uncertainties. Additionally, while emission reductions for BS-VI vehicles have been estimated, the absence of Indian-specific BS-VI emission factors and real-world data undermines the accuracy of these estimates. Further, getting road dust (silt load) for all types of the roads is still a major challenge.

Industrial sector data used in analyses is often outdated, with 2020 being the reference year, and the information provided is generally categorized by type rather than industry. This complicates the distribution of emissions across sectors. In the case of brick kilns, only district-level counts are available, forcing uniform assumptions about production across all kilns.

The residential, refuse, and landfill sectors face similar issues. Household fuel consumption data is collected only once every decade, and annual LPG consumption data for NCR districts is unavailable. Changes in fuel consumption patterns have been estimated using outdated surveys, limiting their relevance. Municipal solid waste (MSW) data is also sparse, with no comprehensive records of waste generation, collection, or disposal across NCR towns or rural areas. For landfills, uniform assumptions about untreated waste are made in the absence of concrete data.

Other challenges include the lack of detailed information on diesel generator (DG) sets, such as their number, capacity, and fuel consumption, which makes surveys infeasible. Similarly, there is no official record of fuel usage in hotels and restaurants, and data on construction activities is limited to large-scale projects, leaving smaller initiatives untracked.

There is a need for improved data collection, enhanced coordination among various stakeholders and data owning agencies to address these challenges effectively. Addressing these gaps is crucial to developing a comprehensive air quality emission inventory for the NCR.

CHAPTER 2

Study Area and Sources

2.1 Geographical Area for Emission Inventory

The sources of air pollution in Delhi are not limited to emission from sources in Delhi but also from the emission sources located in the NCR and adjoining areas. The emissions, such as stubble burning, dust etc. originating outside the NCR may contribute to the pollution levels in Delhi though long-range transport processes. The pollution problem in Delhi may be viewed as a regional issue rather than a problem confined within Delhi. Therefore, an airshed approach is needed for tackling air pollution in Delhi-NCR and emission inventory for the entire airshed is needs for the effective air quality management and provide inputs to the air quality models.

The geographical area for the development of EI may be divided into three regions of rectangular shape:

1) NCT Delhi and Adjoining Cities of Gurugram, Faridabad, Noida and Ghaziabad (NCT-AC)
2) National Capital Region (NCR)
3) Adjoining areas beyond NCR. (NCR-AA)

The map of the spatial extent of the proposed region is shown in Figure 2.1 and tabulated in Table 2.1.

Table 2.1

Spatial extent and resolution of the proposed region

S.No.	Region	Spatial Extent (min Lon, max Lon, min Lat, Max Lat)	Resolution
1.	NCR-AC	(76.65, 77.80, 28.05, 29.10)	500 m x 500 m ~(0.005° x 0.005°)
2.	NCR	(75.4, 78.5, 26.7, 30.0)	2 km x 2 km ~(0.02° x 0.02°)
3.	NCR-AA*	(72.1, 82.1, 23.7, 33.7)	5 km x 5 km ~(0.05° x 0.05°)

*This may be extended to North India including IGP or entire India if enough resources are available.

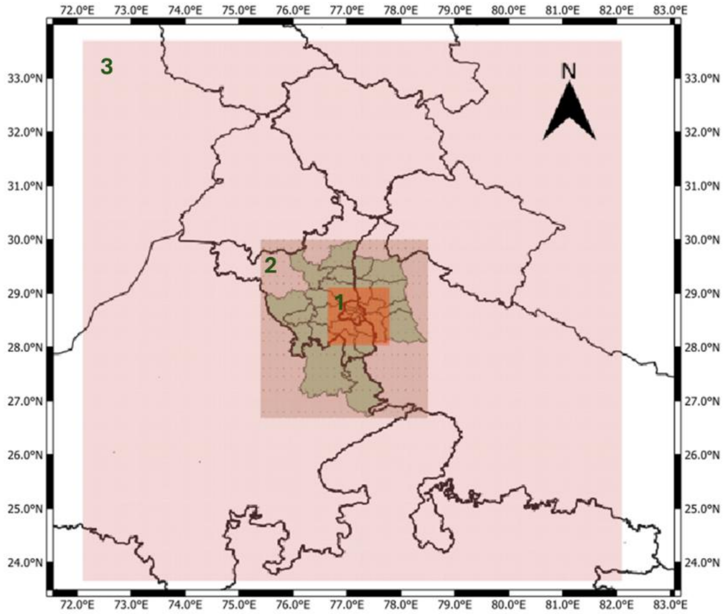


Figure 2.1. Map showing the spatial extent of the proposed regions (1) NCT-AC, (2) NCR and (3) NCR-AA

2.2 Spatial Resolution

High spatial resolution of an emission inventory is very important to accurately identify pollution sources and pin-point its location. This is particularly important in populous areas like Delhi, where pollution sources can be highly heterogenous. The high resolution emission inventory provides a detailed map of the emissions that can be helpful in effective air quality management. However, high resolution maps can introduce uncertainties associated with the quality of input data and method used for spatial disaggregation. With growing data collection from various sources, it is important to consider the optimal resolution of the emission inventory by improving the data quality input to the emission inventory. The earlier guidance from CPCB recommends EI to be developed at 2 km x 2 km spatial resolution. However, keeping in view of developing high resolution emission inventory, it is proposed the EI may be developed over a rectangular domain at a spatial resolution of 500m x 500m for Delhi and adjoining cities (Gurugram, Faridabad, Ghaziabad and Gautam Buddha Nagar), 2 km x 2 km NCR and 5 km x 5 km beyond NCR. The target should be to develop highest resolution (i.e. 500m x 500m) for the entire domain.

2.3 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) is a tool that is actively used in the development of emissions inventories. GIS can integrate and analyze spatial activity data from various pollution sources such as traffic, residential, industries etc. to create detailed map and visualization of the emission sources. It is proposed that all the activity data collected as a part of EI development must be geotagged and processed through GIS. The emission may be gridded at a desired resolution and emission data/map for different pollutants and sectors be made available for the dissemination for further use.

2.4 Pollutants

The EI for Delhi NCR should include PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, NMVOCs, NH_3 and may include pollutants such as BC, OC, HCL and other pollutants based on the availability of the emission factors.

2.5 Emission Sectors

The EI for Delhi NCR may include the following anthropogenic emission sectors:

1. Transport
2. Industries
3. Open burning of MSW/Biomass/Misc Waste
4. Household emission
5. Non-exhaust and dust emissions
6. C&D activities
7. DG sets
8. Agricultural emissions including crop residue burning

While this list is indicative and covers the major sectors, the emissions from other minor sectors and natural sources such as dust storms, biogenic emission, forest fires etc. within the specified region (Figure 2.1) may also be reported.

2.6 Emission Factors

The proposed Emission Factors for various sectors has been compiled and is included in the annexure. Please note that this annexure is for reference only. It is suggested to review the literature and use the most up-to-date emission factors.

CHAPTER 3

Emission from Industries

3.1 Introduction

Industrial emissions resulting from various activities across different categories of industries within the study area are released through chimneys/stacks to the surrounding area. The emissions primarily result from the burning of various fossil fuels in boilers, furnaces, as well as from manufacturing operation. The Central Pollution Control Board (CPCB) has revised classification of industries. The methodology classified the industries into red (highly polluting), orange (moderately polluting), green (non-polluting), white (practically non-pollutant), and blue (Essential Environmental Service Sectors for Domestic/Household Waste) categories based on the pollution potential of a sector on the environment.

3.2 Methodology for Industrial Sector

3.2.1 Survey and data collection methods

Activity data is the measure of activities generating emissions of different types of pollutants. However, emission factors are the average emission rate of a given pollutant from a given source per unit source activity. Information pertaining to different source activities is mainly collected through primary survey.

For industrial sector, the activity data are maintained and provided by the respective State Pollution Control Boards (SPCBs). Data such as site information, including the location (latitude and longitude of the unit), information on the product being manufactured, its quantum, type and quantity of fuel used, air pollution control system (APCD) adopted by the industries etc. are to be collected from them. SPCB may also provide stack monitoring data, if necessary, to assess emissions from sectors lacking fuel consumption and production data. The type of data and responsible agency to provide the data is shown in the Table 3.1.

Table 3.1

Sector specific data required from relevant agency

Sector	Data type – Secondary data collection	Relevant departments
Industry	• Latitude and longitude of the unit, product being manufactured and its quantum, type and quantity of fuel used, Status of the industries, Air Pollution Control Devices (APCD) • Stack monitoring - required to assess emissions from sectors for which fuel consumption and production data is not available	Respective State Pollution Control Boards/Pollution Control Committees

3.2.2 Emission Factors

Approach adopted in compiling emission factors:

Emission factors based on the type of industry, fuel used for its operations, APCD device installed, product manufactured, process/technology used to be referred. An attempt has been made to include available emission factors for all the major category of industries.

Type of fuel used and APCD installed are the important aspects for calculation of EFs. Similarly, the product type and process/technology being adopted are also to be considered, as emission factors may change depending on these specifications. Therefore, wherever available, a range of EFs is provided, along with the relevant reference, so that the user of the factors can apply the appropriate EFs.

BC/OC emission factors have been added, wherever available, in the database. In case EFs for BC/OC are required for emission inventory by a user, the user may utilise the results of filter based chemical speciation carried out or other such published peer-reviewed studies conducted in the study area/sector, for use in estimating the emissions.

Where possible, emission factors for fugitive emissions should be included to ensure a comprehensive emission assessment. The emission factors for Industrial sector are annexed.

3.3 Emission Estimation Method

3.3.1 Emission from industries

A bottom-up approach to be used to calculate the emissions from industrial sectors. The emissions from industries depend on the quantity of fuel consumed and the effectiveness of emission controls. Following equation may be used to estimate emissions from industries:

$$E_p = \sum_{(a=1)}^{n} [C_f]_a \times EF_{(f,p)} \times (1 - RE_a) \quad (3.1)$$

Where, E_p is the emission of a particular pollutant (p), C_f is annual consumption of a particular fuel in industry type a, $EF_{(f,p)}$ is emission factor of pollutant (p) of the fuel type (f), RE_a is the removal efficiency (in fraction) of installed pollution control device in industry type (a). $EF_{(f,p)}$ is emission factor of a particular pollutant (p) from a particular fuel type (f).

Fugitive emissions (fE_p) from industrial arc furnace and induction furnaces can be estimated using the following equation:

$$fE_p = \sum_{(u=1)}^{2} [M]_u \times EF_{(p,u)} \times (1 - RE_u) \quad (3.2)$$

where, E_p is the emissions of a particular pollutant (p) from particular furnace (u), M is the amount of materials processed in a particular type of furnace (u), RE is the removal efficiency (in fraction) of the control device used. u=1 is arc furnace while u=2 is induction furnace in the above equation, EF is emission factor for a particular pollutant (p).

In stone crusher industry similar formula may be used as mentioned in equation 3.1. Here, instead of using fuel consumption in industry, quantity of stone crushed is used. In case of non-availability of fuel usage in industries, the emissions for large-scale industries will be estimate based on production data, which may be collected from respective pollution control boards.

Emission from DG sets installed in industrial units should be included in the industrial sector emission inventory. The details of sector specific data required and EFs to be used for estimating industrial DG sets emission load are provided in chapter 09, on the DG sets (other than industries).

In the case of MSMEs, where process/technology being adopted or stack monitoring data is not available, fuel base EFs may be used for estimating emission from respective MSME unit.

In the absence of fuel consumption and production data, emissions from industrial sector are estimated based on stack monitoring data or data collected (such as concentration of pollutant, flow rate of gas, operational hours etc.) from respective pollution control boards and are estimated using the following equation:

$$E_i = C_i \times FR \times T \quad (3.3)$$

Where,

E_i= Emission of pollutant of type i

C_i = Concentration of pollutant of type i

FR= Flow rate of gas

T= Operational hours

$$FR\left(\frac{m^3}{s}\right) = Area\ of\ Stack \times V_s \quad (3.4)$$

$$Area\ of\ Stack\ (m^2) = \left(\frac{\pi}{4}\right) \times D_s^2 \quad (3.5)$$

Where,

Ds = Diameter of the stack

Vs = velocity of the flue gas

3.3.2 Emission of Brick kilns

Brick kilns are among the largest consumers of coal in India. The primary brick firing technologies in the country include Bull's Trench Kilns (BTK) and clamp kilns. Other technologies used are Vertical Shaft Brick Kiln (VSBK), Hoffman, Zig-zag, Down Draught Kiln (DDK), and tunnel kilns. The brick manufacturing sector operates largely in an unorganized manner, relying on outdated technologies with low combustion efficiency and minimal control over air pollutant emissions. The growing demand for bricks has led to increased fuel consumption. The emissions from the brick kilns can be calculated using the following equation:

$$[E_p]_{bt} = \sum_{(t=1)}^{n} [W_b]_t \times EF_{p,t} \quad (3.6)$$

where, $[E_p]_{bt}$ is the emissions of a particular pollutant p for fire technology t, $[W_b]_t$ is the total weight of the bricks produced by a particular technology t, $EF_{p,t}$ is the pollutant and technology specific emission factor. Total weight of the bricks produced by a particular firing technology is estimated from the total number of bricks produced annually and weight of each fired brick.

3.3.3 Emission from Power Sector

Coal-Based Thermal Power Plants

Coal-based thermal power plants account for major part of India's electricity generation, with natural gas also contributing to power production. The combustion of coal in TPPs results in the release of fly ash, bottom ash, and emissions of air pollutants such as PM, SO_2, and NO_x. Emission levels depend on factors such as fuel quality (ash and sulfur content), boiler type, and the efficiency of APCD. To estimate emissions, data from CPCB's continuous monitoring system should be used whenever available. However, if the data is inaccessible or unreliable, emissions should be calculated using equations 3.7 and 3.8:

$$[E_{PM}]_c = \sum_{(a=1)}^{n} [P_c]_{aj} \times A_c \times (1 - fb_r) \times \mathrm{M} \times (1 - RE_a) \quad (3.7)$$

$$[E_{Pg}]_c = \sum_{(a=1)}^{n} [Pg]_{aj} \times EF_{pg} \times (1 - RE_a) \quad (3.8)$$

Where, E_{PM} is the emission of particulates, E_{pg} is the emission of gaseous pollutants, $[P_c]_{aj}$ is annual coal consumption in plant a and coal type j, A_c is ash content of coal type, fb_r is the ratio of bottom ash to total ash from AP-42 (typically 0.2, unless specified for a specific TPP), M is particulate mass fraction (0.4 for $PM_{2.5}$ to PM_{10} and 0.75 for PM_{10} to total particulates following USEPA, 2015), RE is the removal efficiency (%) of installed emission control equipment and EF_{pg} is the emission factor of the particular gaseous pollutant (p).

Gas Based Thermal Power plants:

For the estimation of emissions from gas-based power plant, the following equation can be used (TERI, 2021):

$$[E_{Pg}]_c = \sum_{(a=1)}^{n} [Pg]_a \times EF_p \times (1 - RE_a) \quad (3.9)$$

Where, E_p is the emission of particular pollutant (p), $[P_g]_a$ is the annual gas consumption in power plant a, EF_p = Emission factor of the particular pollutant (p). Gas consumption (P_g) in each power plant for the base year.

3.3.4 Emission from oil/gas refineries

Oil and gas refineries generate emissions from flaring during various stages of processing and maintenance. Flaring occurs when excess or waste gases are burned in flare stacks to prevent their uncontrolled release. Pollutants emitted include NO_x, non-methane volatile organic compounds (NMVOCs), SO_x, CO, heavy metals, particulate matter (PM), including black carbon. The emissions from refinery flaring can be estimated using the following equation:

$$E_p = V_{NG} \times S_D \times EF_{pollutant} \quad (3.10)$$

Where E_p is the emission of pollutant, V_{NG} is the volume of natural gas i.e., quantity of gas flared and net production of refined gas as the annual throughput, S_D is the specific density of natural gas, $EF_{pollutant}$ is the associated emission factors.

3.4 Emission estimation approach and temporal reporting

A bottom-up approach is recommended for industrial emissions. A few industrial sectors may not operate continuously throughout the year, therefore the Industrial emissions may be reported on annual and monthly basis.

CHAPTER 4

Emission from Transport

4.1 Introduction

The transport sector is one of the major sources of emissions particularly in urban set-up. The emissions from transport sector are calculated using data generated from primary surveys for on-road vehicle counts, parking lot surveys, data available in from different Government Departments etc.

4.2 Data and Method

4.2.1 Sector specific data source

Secondary data for transport sector emissions can be obtained or generated from various sources as given below-

- Road Network: Open Street Map Database, Google Earth imagery
- Vehicle Registration Data: VAHAN Portal/Transport Department
- Future Demand: Comprehensive mobility plans for area/ region
- Fuel Sales Data: Oil manufacturing companies

4.2.2 Survey and data collection method

Data collection for the transport sector emissions involves various elements including road network and its digitization, parking-lot surveys, traffic counts at various representative locations, etc.

4.2.3 Road Network Digitization

Road network in the study area is digitized using GIS software. Roads are generally classified into five categories viz.

i) Highways,
ii) Major roads,
iii) Intermediate roads- roads connecting to major roads,
iv) Minor roads- roads connecting to intermediate roads,
v) Residential roads- roads in the residential areas leading to the minor roads.

After complete digitization, road lengths are required to be calculated for each link in the network using GIS software. Category-wise gridded road lengths should also be computed using GIS software.

4.2.4 Reconnaissance survey

Reconnaissance surveys are conducted in the study area to select the locations for traffic count and parking lot surveys to understand the traffic movement in the city, major traffic locations, type of vehicles, etc. The survey locations are identified to perform the classified vehicle count surveys while areas/localities in selected grids are selected for parking lot surveys.

4.2.5 Vehicle fleet characteristics

Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data VAHAN Portal (Parivahan Analytics) provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in the study area shall be categorised into six categories: 2-wheelers (motorcycles, scooters and mopeds), 3-wheelers/autos, passenger cars both private and commercial, light commercial vehicles (LCV) such as delivery vans, heavy duty vehicles (HDV) such as trucks and lorries and buses and coaches.

Each vehicle category is further differentiated in up to four fuel or engine types, viz., Gasoline/E20, Diesel, Natural Gas, and Electric vehicles. In addition, vehicular emission calculations require the vehicle fleet by technology (BS emission levels/Technology/Age), as mass emission factors are significantly different for each vehicle type and control technology. The survival rate, which is a fraction of vehicles survived in the fleet after a certain age, is to be calculated for each vehicle category. Based on approach adopted by Baidya and Borken-Kleefeld (2009), the in-service vehicles are calculated using Survival Function which models the vehicle's finite service life.

4.2.6 Traffic flow/ Vehicle counts

Since the traffic flow or pattern varies with type of road and the land-use type, counting of vehicles for assessment of traffic flow is to be done on four different types of roads (highways, major roads, intermediate roads, minor roads) representing each land-use type (Industrial, Residential, Commercial, Fringe, Rural) in each district. Counting shall be done preferably using 24-hour video recording for continuously 7 days including weekdays and weekend. Video recordings may be utilised for counting of different types of vehicles with hourly resolution. To strengthen the vehicle-count data, CCTV recordings/ Automatic Number Plate Recognition (ANPR) data available with transport department shall be used. The data thus generated gives information on the different categories of vehicles. This data is further differentiated into fuel-type and technology based on the parking lot surveys, reconnaissance survey, registration data on VAHAN portal.

4.2.7 Surveys/ Questionnaires

For identification of fleet characteristics and vehicle driving pattern, questionnaire-based surveys are conducted at parking-lots. Information such as Vehicle registration number, Vehicle Type, Make, Model, Engine/Fuel Type, Vehicle Registration Year, Mileage in km per litre or km per kg, Fuel used per month in litre or kg, Travelling Per Day, Capacity, Servicing period in months, etc. is collected through such surveys. This information is utilised for differentiating the vehicle categories by technology and fuel-types.

4.2.8 Vehicle Kilometers Travelled (VKT)

An approach to compute the Vehicle Kilometres Travelled (VKT), based on classified vehicle count surveys and parking lot surveys in the study area for bottom-up emission inventorization, is as follows-

- The classified vehicle count surveys are to be performed on different types of roads such as Highways, Major, Intermediate, Minor, etc.
- Allocation of vehicle numbers on each type of road based on land-use, population, activities, and potential for growth in future.
- The number vehicles on each type of road are then multiplied by road length to get the total daily VKT.
- The total daily VKT is then further disaggregated by using data on fleet composition such as vehicle type, sub-type, emission standard, fuel type, etc. These data are generally collected during from parking lot surveys.

4.2.9 Consideration of Super-emitters

A small fraction of vehicles with poor maintenance or with outdated technology contributes a significant portion of total emission and is termed as "super-emitters." Bond et al., (2004) assumed mean, lower and upper bound values of super emitter fraction as 20% (5–60%) for the Asian countries. The actual data on vehicle category-wise super-emitters can be obtained by using latest technologies such as Remote Sensing Devices (RSD). In absence of such information, a conservative mean value of 20% can be used to estimate the on-road population of super-emitter in each category regardless of their age.

4.3 Emission estimation method

The vehicular exhaust tailpipe emissions are calculated using equation below:

$$E_p = \left(\sum_{i=1}^{z} \sum_{j=1}^{y} \sum_{k=}^{z} VKT_{i,j,k} \times EF_{p,i,j,k} \right) \times RWCF \times 10^{-6} \quad (4.1)$$

Where, E_p is the total emissions of pollutant p in tonnes per day, $VKT_{i,j,k}$ is the Vehicle Kilometres Travelled per day by vehicle type i, having fuel type j and the Bharat standard / age of vehicles k; $EF_{p,i,j,k}$ is emission factor in g/km for pollutant p for vehicle type i, having fuel type j and the Bharat standard / age of vehicles k; RWCF is the real-world correction factor.

4.3 Emission Factors

4.4.1 Emission Factors

Vehicular emissions are dependent on the large range of variables such as vehicle technology, age, condition, road profiles, driving habits, emission control regulatory levels, fuel and payload (Bawase et al., 2021). EFs developed by ARAI during 2010 and 2018 through laboratory-test are used to calculate the vehicular exhaust emissions. The emission factors are developed under laboratory conditions, whereas the field conditions using on chassis dynamometer may differ in real drive conditions. Hence, the total emissions quantified by above approach are to be corrected using a real-world correction factor. Pollutant-wise and vehicle category-wise correction factors for real-world emissions are applied to the laboratory-test based emission factors and the corrected emission factors are listed in Annexure Table 4.1. It is important to note that, the mass emission factors for in-service BS-VI vehicles in India are not available. Hence, the emission factors for such vehicles were derived using BS-VI emission limits introduced in the year 2020.

4.4.2 Considerations for super-emitters

Emission factors for super-emitters can be considered as 2.5 times the respective emission factors and can be applied to 20% of vehicle fleet.

4.4.3 Temporal resolution

Vehicle count data is to be measured on hourly basis, which will result in VKT data generated on hourly basis and subsequent emission inventory on hourly basis.

4.5 QA/QC Method

4.5.1 Validation of VKT

For validation of VKT data generated using bottom-up approach, an approach based on vehicle registration data can be used as follows:

- Collecting information on total number of different types of vehicles from vehicle registration data available on VAHAN Portal (Parivahan Analytics).
- Total in-use vehicles to be calculated using the survival function.
- The historic registration data of the region is used to calculate the in-use vehicles in the study area.
- The average daily kilometer travelled for different vehicles is estimated from parking lot surveys.
- The number of in-use vehicles are then multiplied by daily kilometer travelled to get total VKT of the study area.

4.5.2 Fuel consumption data

Total fuel consumption (lit/day) by different categories of thevehicles shall be calculated based on the fuel efficiency (km/lit) of that respective category and total VKT (km/day). Total fuel consumption thus calculated shall be compared with the fuel sale data obtained from oil manufacturing companies (lit/day) for the study area/region.

4.6 Emission Estimation Approach and Temporal Reporting

A bottom-up approach may be used. The emissions may be reported in annual and monthly basis along with diurnal profile to capture the diurnal variability in the traffic emissions. The emission uncertainty may be calculated using the method described in the Chapter 11.

4.7 Emissions from Aviation Sector

Emissions from aircrafts are estimated for the domestic and international flight movement at the respective airports. Emissions from aircrafts are calculated from the aircraft movements in a Landing and Take-off (LTO) cycle. Two aircraft movements constitute one LTO cycle and emissions are calculated using equation below:

$$E_p = N_{LTO} \text{ X } EF_p \quad (4.2)$$

Where, E_p is the emission of a particular pollutant p, N_{LTO} is the average number of landing and take-off (LTO) cycles per day, and EF_p is Emission factor for pollutant p.

The data on monthly flight movements at respective airport obtained from Airport Authority of India (AAI, Business Traffic News). This data is converted to number of LTO cycle per day and emission factors (Eastern Research Group, 2024; Kristin Rypdal, 2001) listed at Annexure Table 4.2, are used to calculate the aircraft emissions. The emissions from aircraft are allocated only to grids covering the airport area.

CHAPTER 5

Non-Exhaust and Dust Emissions from Roads and Open Areas

5.1 Introduction

On-road PM emissions can be characterized into the exhaust and non-exhaust components. The exhaust PM is emitted from the tailpipe as a result of incomplete combustion of fuel inside the engine chamber. Non-exhaust PM is generated from the abrasion of tyres, road, and brake wear as well as from resuspension of the dust from the road surface due to vehicle-induced turbulence (Amato, 2018).

5.2 Data and Method

5.2.1 Vehicular Data

The average daily traffic (ADT) is one of the main parameters to calculate the on-road exhaust and non-exhaust emissions. The vehicular classification and activity data discussed in Chapter 4 needs to be used also for estimation of non-exhaust emissions.

5.2.2 Vehicle Weight

The weight of a vehicle is an important parameter, which affects the non-exhaust emissions. The weight of the vehicles can vary depending upon the model, make, engine, and load. However, an average vehicle weight of 0.175, 0.45, 1.425, 15, 20, and 7.5 tons, for 2W, 3W, Cars, Buses, HCV, and LCV respectively can be used in the EI development (NEERI, 2010).

5.2.3 Silt Load

The amount of dust present per unit area of a road is called silt load (sL) and expressed as g/m^2. Silt (particles less than 75 µm) present on the road is an important factor for resuspension, and depends upon several factors including source, season, and geographical region. The silt load can be determined by collecting dust sample from a dry road surface over an area of one square meter and the passing the dry dust through a 200-mesh screen/ sieve. The procedure for sampling surface/bulk dust loading on paved and unpaved surfaces recommended by US-EPA may be followed

(USEPA, https://www3.epa.gov/ttn/chief/ap42/appendix/app-c1.pdf). Regular silt load mapping is required for all types of roads.

5.3 Non-Exhaust Emission Factors

5.3.1 Road wear, tyre and brake wear emission factor

The wear emission factors are not available for Indian conditions. Therefore, it is proposed to use the wear emission factors based on the EMEP/EEA air pollutant emission inventory guidebook 2023 – Update 2024 (EEA, 2023). The emission factors for 3W may be taken as the average of the emission factors for the 2W and cars. The road wear, tyre and brake wear emission factors proposed to be used in the emission calculations are shown in Annexure Table 5.1.

5.3.2 Emission Factors for Paved Roads

The particulate matter resuspension emission factors on paved roads can be calculated using the USEPA AP-42 formula (USEPA, 2011, AP-42) as given below:

$$Ef = K \times (sL)^{0.91} \times (W)^{1.02} \times \left(1 - \frac{P}{4 * N}\right) \qquad (5.1)$$

Where

Ef = particulate emission factor (g/VKT)

K = particle size multiplier for particle size range(g/VKT)

sL = road surface silt loading (grams per square meter) (g/m^2), and

W = average weight (tons) of the vehicles traveling the road.

P = Number of wet days

N = Number of days in the average period (365 for annual)

The emission factors depend on the vehicular weight (W), silt load (sL), and a number of rainy days (P) in a year.

The particle size multiplier (K) is 0.62 g/VKT for PM_{10} and 0.15 g/VKT for $PM_{2.5}$ (USEPA, 2011). The average number of wet days (P) may be taken from Indian Meteorological Department, Delhi.

5.3.3 Emission Factors for Unpaved Roads

The particulate matter resuspension emission factors for vehicles traveling on unpaved surfaces at industrial sites can be calculated using the following formula:

$$E = k\left(\frac{s}{12}\right)^a \left(\frac{W}{3}\right)^b \tag{5.2}$$

For vehicles traveling on publicly accessible roads dominated by light duty vehicles can be calculated using:

$$E = \frac{k\left(\frac{s}{12}\right)^a \left(\frac{S}{30}\right)^d}{\left(\frac{M}{0.5}\right)^c} - C \tag{5.3}$$

Where:

- k, a, b, c and d are empirical constants
- E = size-specific emission factor (g/km)
- s = surface material silt content (%)
- W = mean vehicle weight (tons)
- M = surface material moisture content (%)
- S = mean vehicle speed (mph)
- C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

5.4 Emission Calculation

A bottom-up approach be used to estimate both exhaust and non-exhaust emissions and the emission may be estimated for a grid using the following formula:

$$E_i = \sum_{j=1}^{6} V_{i,j} \times EF_{j,k} \times L_i \qquad (5.4)$$

Where,

- $V_{i,j}$ is the number of vehicles on the road *i* of category *j,*
- $EF_{j,k}$ is the emission factor for vehicle category *j*, non-exhaust emission type *k,* The non-exhaust type (*k*) includes road wear, brake wear, tyre wear, and resuspension,
- L_i is the length of the road link *i.*

5.5 Emission Estimation Approach and Temporal Reporting

A bottom-up approach, similar to the traffic emission, may be used. The emissions may be reported in annual and monthly basis along with diurnal profile to capture the diurnal variability in the traffic emissions. The emission uncertainty may be calculated using the method described in the Chapter 11.

5.6 Emission from Open Areas

The PM emissions from open areas depend on the extent of disturbed and undisturbed vacant land area, emission factors by soil group and wind speeds. A detailed mapping of the erodible open area needs to be done by identifying the location coordinates of open area, soil type based on soil properties and composition etc. It is recommended that online models such as dust schemes of WRF-Chem may be used for estimation wind-blown dust emission. As these emissions are not continuous, these should be reported separately.

CHAPTER 6

Emissions from Households

6.1 Introduction

Household air pollution is considered one of the world's major environmental risk factors. It is mainly caused by the use of unprocessed solid fuels for cooking activity which includes biomass (e.g., wood, crop residues, dung cake), coal and kerosene. People from low socio-economic backgrounds in rural India and urban slums rely on solid biomass fuels due to ease of availability and as a cheaper alternative.

6.2 Data and Method

6.2.1 Data collection

A primary survey should be undertaken to gather the required information for preparing the emission inventory of the residential sector. Representative households covering the rural and urban areas of each NCR district including the NCT of Delhi be interviewed to gather required information related to cooking, lighting and heating activity. The survey should be conducted based on the socio-economic profile and land use pattern of the respective NCR districts. Primary survey should also be done in slums falling under the urban area of NCR district to gather the required information.

During the survey, pre-designed questionnaire (Annexure Questionnaire 1) may be used to gather cooking, lighting, and heating activity-related information from interviewed households. Information about household size, type of fuel used for cooking, and daily consumption of cooking fuel should be collected from the interviewed households. Daily household level consumption of cooking fuel and family size of household may be used to derive daily per capita consumption of cooking fuel. Also, information related to household electrification, duration of power cut on a daily/monthly basis, an alternative source of lighting during a power cut, the quantity of kerosene used for lighting, etc. should be collected during the primary survey. In addition, apart from cooking, fuelwood is also used in residential households for space heating during the winter season in several parts of NCR. Therefore, fuelwood used for the residential space heating activity should be separately accounted for in this study, and consumption patterns of fuelwood for space heating should be collected through interviewed households during the primary survey.

Apart from the primary survey, secondary information related to the residential sector available with various Central/State Government should be collected for developing the emission inventory. Different Central/State Government Departments will be approached to gather the required information. LPG usage/consumption information gathered from oil companies, Food, civil suppliers, and consumer affairs departments will be useful in understanding the LPG penetration rate in NCR districts, particularly in the rural areas. The type of data and responsible agency to provide the data are illustrated in the Table 6.1 as under:

Table 6.1

Type of residential sector information and responsible department/agency

Type of information	**Latest data availability**	**Required Data**	**Responsible agency**
Total population and number of households in rural and urban areas of NCR districts/wards	India Census (2011) or most recent survey	Population and number of households of rural and urban areas of NCR districts. If population is not available then registered birth and death numbers of respective districts	Municipal corporation/municipalities, Block development office
Households using different types of fuel for cooking activity	India Census (2011), State level percentage of households using a particular type of fuel for cooking (NSS 76th Round Report 2018)	Percentage of households (rural and urban areas) using different fuels for cooking activity in NCR districts	Census of India
Per capita consumption of different fuels at rural/urban areas of NCR districts	State-specific per capita consumption of different fuels (NSSO 2011-12)	Per capita consumption of different fuels for cooking purposes in respective rural/urban areas of NCR districts	NSSO If data is unavailable need to carry out the primary survey in respective NCR districts to gather the required information
Domestic LPG consumption in Rural and Urban non-PMUY and PMUY LPG connection and refill data in NCR districts from 2019 to the current year		Domestic LPG consumption in respective rural and urban areas of NCR districts during the last 5 years. Rural and Urban non-PMUY and PMUY LPG connection and refill data in NCR districts from 2019 to the current year	Oil Companies (IOCL, BPCL, HPCL), Food, civil suppliers and consumer affairs department

The district/ward-specific emissions of different pollutants will be distributed spatially over a (0.5 ×0.5 km^2) grid using the ratio of the area of each polygon and the area of the respective NCR district. The distributed emissions will be useful for understanding the spatial variations of emissions of different pollutants from the residential sector.

6.2.2 Emission calculation

The basic equation employed for emission estimation from residential sector is:

$$E_p = \sum_{a=1}^{n}\sum_{f=1}^{6} Pop_{(a,f)} \times C_{(a,f)} \times EF_{(f,p)} \tag{6.1}$$

where, Ep is the emission of a particular pollutant (p) from the residential sector, $Pop_{(a,f)}$ is the population of rural/urban area of NCR district using a particular type of fuel (f) for cooking, lighting and heating, $C_{(a,f)}$ per capita consumption of particular fuel in rural/urban area of NCR district, $EF_{(f,p)}$ = Emission factor of particular pollutant (p) for particular fuel type (f). Six major fuels namely fuel wood, dung cake, crop residue, coal, kerosene, and LPG are used in residential households for cooking, heating, and lighting purposes will be included in this emission inventory development. Kerosene is used for both cooking and lighting purposes, Different $EF_{(f,p)}$ will be used for kerosene lighting and cooking activity. Fuel-specific emission factors of different pollutants ($EF_{(f,p)}$) are taken from Datta and Sharma (2014), Pandey et al. (2014), Saud et al., (2012); Huy et al., (2021); Lu et al., (2011). List of EFs is provided in the EF annexure Table 6.1.

6.3 Emission estimation approach and temporal reporting

A bottom-up approach based on the grid/ward level population may be used. The emissions may be reported in annual and monthly basis. The uncertainty in the emission estimates must be reported.

CHAPTER 7

Emission from Open burning other than CRB

7.1 Introduction

Refuse material burning refers to the open combustion of waste materials, including household garbage, residues, industrial waste, and other discarded materials. This practice is common in many regions, particularly in areas lacking adequate waste management infrastructure.

7.2 Data and Method

7.2.1 Data collection

A primary survey should be undertaken to gather the required information for preparing the emission inventory of waste burning sector. Representative households covering the rural and urban areas of each NCR district including the NCT of Delhi should be interviewed to gather required information related to waste burning. The survey should be conducted based on the socio-economic profile and land use pattern of the respective NCR districts. Also, primary survey may be done in slums falling under the urban area of NCR district to gather the required information.

During the survey, pre-designed questionnaire (Annexure Questionnaire 2) will be used to gather waste generated and burned related information from interviewed households. Information about the quantity of waste generated from households per day, household size, type of waste disposal mechanism: door-to-door collection, community bins, on the roadside, frequency of waste collected, waste burning incident, and frequency of burning incident taking place in a nearby area (once a week, twice a week, etc.) of interviewed households should be asked during the primary survey. Apart from the primary survey, secondary information related to the waste sector available with various Central/State governments should be collected for developing the emission inventory. Information such as the quantity of solid waste generated, collected, processed, and going to landfill in respective NCR districts, composition of waste materials, number of landfill sites, and amount of waste getting treated at landfill sites in NCR districts, etc. should be collected. The type of data and responsible agency to provide the data is illustrated in the Table 7.1 below:

Table 7.1

Type of waste sector information and responsible department/agency

Type of Data	**Latest data availability**	**Required Data**	**Responsible agency**
Total population of rural and urban areas of NCR districts/wards	India Census (2011) or most recent	Population of rural and urban areas of NCR districts for the base year. If population is not available then registered birth and death numbers of respective districts Number of slums or percentage of slums residing at each city/town of NCR districts	Municipal Corporation/Municipalities, Block Development Office Municipal Corporation/Municipalities
		Quantity of solid waste generated, collected, processed, and going to landfills in NCR districts Composition of waste materials	Solid waste management department of Municipalities/MC, Block Development Office (for village level data)

The district-specific emissions of different pollutants should be distributed spatially over a (0.5 ×0.5 km^2) grid using the ratio of the area of each polygon and the area of the respective NCR district. The distributed emissions will be useful for understanding the spatial variations of emissions of different pollutants from the waste-burning sector.

7.2.2 Emission calculation for waste burning

Generally, the uncollected fraction of waste becomes subject to burning. The amount of refuse materials burned (Wba) in a particular area is calculated using the following equation:

$$E_p = Pop_{(a)} \times C_{w(a)} \times (1 - \emptyset) \times W_f \times B_f \times EF_p \quad (7.1)$$

Ep is the emission of pollutants, Pop(a) is the population of rural/ urban area of NCR district, Cw(a) is per capita solid waste generated from rural/urban area of NCR district, ϕ is the collection efficiency of solid waste, B_f is the fraction of waste material burned, W_f is the composition of waste material (biomass, paper, plastic, rubber etc), EF_p is pollutant specific emission factor from burning of waste materials. The EF of different pollutants from burning of refuse materials is taken from Cheng et. al (2020); Akagi et al. (2011). The suggested emission factor is shown in Annexure Table 7.1.

7.2.3 Emission calculation from landfill fire

A landfill fire is a challenging and serious environmental issue that occurs when waste materials in a landfill get ignited and burned. The pathway of waste going to a landfill site often involves the process of collection, transportation, sorting/treatment, and disposal. The occurrence of landfill fires depends on the volume of waste remaining at a disposal site. Municipal solid waste reaching a landfill site mostly comprises organic materials (kitchen waste, food waste), combustible substances (paper, plastic, rubber, textile, etc.), and inter-materials. Fires at landfill sites are caused due to the self-combustion of waste materials under conditions facilitating increased aerobic decomposition activities, which causes a notable rise in landfill temperature. Also, methane produced in the landfill often sets fire to the landfill area when it encounters atmospheric oxygen. Moreover, a large variety of air pollutants and toxic gases are released into the atmosphere when waste gets burned at a landfill site.

The basic equation employed for emission estimation from landfill fire sector is:

$$A_{AF} = Nf_e \times A_f \times D_f \times \delta_w \times \left(1 - \frac{D_p}{4 \times 365}\right) \quad (7.2)$$

Where, A_{LF} is the amount (kg) of waste materials subject to burn at a landfill site, N*fe* is the number of fire events at the landfill site, A*f* is the area (m^2) affected by the fire event, D*f* is the depth (m) of fire, δw is the density of waste (kg/m^2), and Dp is the number of wet days (rainfall >2 mm).

The volume impacted by fire events was estimated based on the affected area and its depth at the landfill sites. The emission factor (EF) of different pollutants is in annexure Table 7.2.

7.3 Emission estimation approach and temporal reporting

A bottom-up approach may be used for the large burning activities where the exact location is known. For smaller and dispersed open burning activities, a top-down approach may be considered. The emissions may be reported in annual and monthly basis. The uncertainty in the emission estimates must be reported.

CHAPTER 8

Emission from C&D

8.1 Introduction

Emissions during construction activities arise from various processes such as land clearing, drilling, excavation, cut-and-fill operations, and equipment usage. These emissions are primarily composed of fugitive particulate matter (PM), which varies significantly depending on activity levels, site conditions, and meteorological factors. Unlike other fugitive dust sources with relatively stable emissions, construction emissions are highly variable and site-specific.

8.2 Data and Method

Emission estimation in the construction sector relies on multiple methodologies, each catering to different levels of detail and spatial scales. The primary methods include:

i. Tier-1 methods based on generalized emission factors (USEPA and EEA Tier-1 approaches).
ii. Tier-2 methods incorporating moderate spatial resolution data and refined activity parameters.

8.2.1 Survey and Data Collection Method

Survey methodologies include identifying active construction locations/zones based on the data available with the ULB in combination with remote sensing techniques. Sampling of soil silt and moisture content at construction sites may be done for accurate emission factor adjustments. The meteorological parameters may either be monitored at the site or can be taken from the IMD.

8.2.2 Emission Estimation Method

1.1.1.1 Tier-1 Estimation (USEPA and EEA)

The USEPA and EEA Tier-1 methods apply general emission factors to estimate total PM emissions:

$$EPM = A_{C,S} EF_{PM} (12 - R_S) \qquad (8.1)$$

Where:

- EPM: Emission of PM (Mg/acre)

- $A_{C,S}$: Area of construction (Acre)
- EF_{PM}: Emission factor
- R_S: Fraction of months receiving rainfall > 100 mm

The EEA method distinguishes construction into residential, non-residential, and road construction and applies specific emission factors for each.

1.1.1.2 Tier-2 Estimation (Method 2 - EEA 2.A.5.b, 2019)

The method involves multiplying a specific emission factor for each type of construction with the total area affected and the average duration of the construction. The equation used is:

$$EM_{PM} = EF_{PM} A_{C,s} d(1 - CE) \frac{24}{PE} \frac{s}{9\%} \tag{8.2}$$

Where:

- d: Average duration of construction (months)
- CE: Emission control efficiency
- PE: Thornthwaite precipitation evaporation index
- s: soil silt content (%)

8.3 Emission Factors (EFs)

$EF_{PM(TSP)}$: 1.2 Mg/acre/month (Muleski et al, 2005)

EF_{PM10}: 0.42 Mg/acre/month (35% of EFPM)

$EF_{PM2.5}$: 0.072 Mg/acre/month (6% of EFPM)

8.4 Emission Estimation Approach and Temporal Reporting

A bottom-up approach may be used for the large construction sites where the exact location on the construction site is available. For smaller construction sites, a top-down approach may be considered. The emissions may be reported on Annual basis with bifurcation in on Monthly basis.

CHAPTER 9

Emission from DG sets (other than industries)

9.1 Introduction:

High demand of electricity leads to power cuts. For uninterrupted work operations in sectors like residential buildings, shopping complexes, industries and commercial buildings, IT centers, malls, DG sets are used as source of backup power.

1.2 Methodology for DG sets

9.2.1 Survey and data collection method

Emissions from this sector primarily depend on DG set capacity, fuel consumption, and operational hours. To estimate these emissions, collect information on the number of DG sets, their capacity, operational hours, fuel consumption, and whether a RECD/dual fuel kit has been installed through a primary survey in selected grids in different regions. For industries and large commercial establishments, DG set information needs to be provided by the respective pollution control boards. For residential and smaller commercial establishments, it is recommended to contact the respective Municipal Corporations (MCs) or Urban Local Bodies (ULBs) or Chief Electrical Inspectorate to obtain the necessary information regarding Diesel Generator (DG) sets. If required, a field survey as per pre-designed questionnaire (Annexure Questionnaire 3) may be conducted. Based on the information received, emissions estimation may be carried out for each surveyed grid. Per capita emissions based on population density in each grid and emissions data may be calculated to extrapolate emissions to all grids. The survey locations should cover residential areas, industrial locations, commercial hubs, transport congested areas in the study area to capture the actual scenario of DG sets usage and emissions. Ideally, information should be available in a season-wise manner, as power outages are more common in summer, leading to higher DG set usage compared to winter.

9.2.2 Spatial distribution of DG sets:

The DG set of industrial and commercial locations can be spatially distributed based on the actual location of industries and commercial establishments. However, for other

DG set users, the emissions from the surveyed grids are estimated, and per capita emissions should be calculated for different land-use categories using grid-level population derived using the GIS tool. These per capita emission values will then be extrapolated using population data to distribute total emissions for NCR districts, including the NCT of Delhi. The type of data and responsible agency to provide the data is shown in the Table 9.1.

Table 9.1

Details of sector specific data required from relevant agency

Sector	Data type - primary data collection	Sample size (numbers)	Data type- Secondary data collection	Primary survey/Relevant departments
DG sets	Survey shall be carried out to obtain information on fuel consumption in DG sets, running time and capacity of DG sets, RECD/dual fuel kit	The survey shall carried out in minimum 7 grids inside the city and 7 grids outside the city in different land use categories in the district.	Data on DG sets installed >19kw, if available.	Primary survey to be carried out in their respective regions
	DG sets in commercial establishments			Respective pollution control boards
	DG sets of residential and other institutions/ establishments			Respective pollution control boards /Municipal Cooperation/Urban local body

9.2.3 Emission factors:

The proposed EFs (uncontrolled) to be used in the emission calculations are shown in Annexure Table 9.1.

9.2.4 Emissions estimation method:

A bottom-up approach is used for accurately estimating emissions from DG sets. The emissions from DG sets can be estimated based on the DG set capacity, power factor, operational hours, amount of fuel consumed, calorific value of fuel and the emission factor by using the following equations:

$$E_c = C \times F_{sc} \times P \times t \times cal_d \qquad (9.1)$$

$$E = E_c \times EF \qquad (9.2)$$

Where, E_c is the energy consumption of the DG sets, C is the capacity of the DG sets (kVA) , P is the Power factor, t is generators running time (hours), cal_d is the calorific value of diesel which is 45.5 MJ/Kg and Fsc is the fuel specific consumption. For simplicity, cal_d x F_{SC}, i.e. the conversion factor from KW-hr to Joules can be considered as 3600000, EF is the Emission Factor, E is the emissions.

9.3 Emission Estimation Approach and Temporal Reporting:

A bottom-up approach may be used. The information should be compiled either on monthly or seasonal intervals, considering that power outages are more frequent during summer, which may result in higher DG set usage compared to winter.

CHAPTER 10

Emission from Agriculture Sector including Crop Residue Burning

10.1 Introduction

Agricultural food production is indispensable to public health. However, it significantly contributes to environmental degradation through the emission of air pollutants primarily arising from crop residue burning (CRB), livestock management, tillage activities (TA), and fertilizer application (FA). The primary aim of this section is to outline a detailed methodology for EI for multiple activities of the Indian agricultural sector.

1.2 Data and Method

10.2.1 Data sources

Agriculture related data such as crop area, tillage area, fertilizer application and type, crop production and type, crop harvesting, crop residue etc. may be obtained from the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare.

For crop residue burning incidences and burnt area estimation, high-resolution multispectral satellite images (e.g., Sentinel-2) in combination with active fire location and fire radiative power data as per protocol developed by ISRO based on VIIRS, MODIS fire incidences may be used.

Additional data such as tillage frequency, type of crops at required spatial resolution may be determined through a combination of Government data, satellite products and field surveys at various administrative levels. The meteorological or soil data such as temperature, soil moisture, wind speed etc. may be obtained from soil grids 250, IMD or validated reanalysis products.

The population data of various livestock categories and products across NCR districts, can be obtained from the Indian Livestock Census conducted by the Department of Animal Husbandry, Dairying, and Fisheries

10.2.2 Surveys and data collection method

To ensure comprehensive coverage, a minimum of three villages are to be surveyed and for each crop in a village, at least three surveys (from farmers) are to be conducted to capture diverse perspectives and practices. For districts where field surveys are not feasible, data are to be collected from agronomists/soil scientists affiliated with respective states' Krishi Vigyan Kendras (KVKs), State Agriculture Universities (SAU), and ICAR institutes. This secondary source information provides insights into agricultural practices in areas not covered by field surveys.

10.2.3 Emission from Crop Residue Burning

Emission of various pollutants from crop residue burning for each pollutant can be estimated using the following or any similar equation:

$$E_{CRB} = \sum (CP_j \times RC \times f_{DM} \times f_{burnt} \times f_{BE} \times EF_k) \quad (10.10)$$

Where:

- CP_j: Represents the Crop Production i.e. total quantity of crop (kg) harvested in a given district or region.
- RC: The ratio of crop residue produced per unit of harvested crop
- f_{DM}: Represents the fraction of the residue that remains after moisture removal.
- f_{burnt}: Proportion of the total crop residue subjected to burning.
- f_{BE}: Represents the fraction of residue fully oxidized during the burning process.
- EF_k: Specifies the quantity of each pollutant emitted per unit mass of residue burned.

Table 10.5 of Annexure_EF_Table provides the EFs adopted for various crop types and pollutants for CRB emission estimation

10.2.4 Emission from Fertilizer Application (FA)

The total emission of NH_3 (E_{total}, units: kg) from FA using the amount of fertilizer N-applied (A, Units: kg) and fertilizer type-specific EF (Units: % NH_3 of N) can be estimated using the following equation

$$E_{total} = A \times EF \quad (10.1)$$

Because direct measurements of NH_3 emissions from synthetic fertilizers in NCR are scarce, EFs (derived from literature) must be modified to local conditions of NCR using equation below.

$$\mathrm{EF} = \mathrm{EF}_{pH} \times MF_M \times MF_R \times MF_T \qquad (10.2)$$

where EF_{pH} is the soil pH-specific EF; and, MF_M, MF_R, and MF_T represent the modification factor for the dressing type (M, i.e. basal and top dressing), application rate (R, Units: kg N applied per hectare cropland), and ambient temperature, respectively. The EFs adopted from literature along with the modification factors adopted are provided in Table 10.1 of Annexure_EF_Table.

The MF_T can be estimated using equation:

$$MF_T = \frac{e^{0.0223T}}{\frac{1}{12}\sum_{k=1}^{12} e^{0.0223T}} \qquad (10.3)$$

where k and T represent the month and monthly air temperature (˚C) at 2 m elevation, respectively.

10.2.5 Emission from Tillage Activity (TA)

PM emissions from TA can be estimated using the following equation

$$E_{TA} = \sum_{c,d} A_{c,d} \times F_{c,d} \times EF \qquad (10.4)$$

Where E_{TA} is emissions from TA in kg/hectare, $A_{c,d}$ is the area under tillage of crop type c in a district d, $F_{c,d}$ is the frequency of TA for crop type c in a district d, and EF is the emission factor. Direct measurements of PM emissions from TA are limited, and those that exist show significant variability across different fields. Therefore, EFs for TA were calculated using the AP-42 method (1), as outlined in equation below may be used. The estimated EFs for TA in NCR region are provided in Table 10.2 of Annexure_EF_Table.

$$EF_i = k \text{ x } 5.38 \; (S_i)^{0.6} \text{ x } MF_{iWS} \text{ x } MF_{iSM} \quad (10.5)$$

Where EF_i is the emission factor for a grid i (kg/hectare), S_i is the silt content of surface soil (%) at grid level i, k is the particle size multiplier (k = 0.21 for PM_{10} and 0.10 for $PM_{2.5}$), and

MF_{iWS} and MF_{iSM} is the modification factor for wind speed and soil moisture at grid level i, respectively. MFs for SM and WS can be adopted from (10.2).

10.2.6 Emission from Livestock

NH_3 emissions from Manure Management (MM) can be estimated using the following equation

$$E_{NH3,MM} = \sum_{z=1}^{12} \sum_i P_{(i,y,Z)} \text{ x } EF_{NH3\,(y)} \text{ x } MF_{(T,i,Z)} \quad (10.6)$$

Where $E_{NH3,\,MM}$ represents the total annual NH_3 emissions from MM (kg/month), P denotes the population of various livestock categories y at grid level i, $EF_{NH3,\,y}$ represents the NH_3 emission factor from MM for various y livestock categories, $MF_{T,i,z}$ accounts for the temperature modification factor at grid level i at monthly temporal resolution z. NH_3 EFs adopted for estimating emissions from MM are provided in table 10.3 of Annexure_EF_table.

NH_3 emissions from Manure Application (MA) can be assessed by calculating the annual nitrogen (N) contribution from animal manure applied to agricultural soils. The following equation can be used to estimate the amount of N in animal manure applied to the soil

$$F_{AM,T} = P_y \text{ x } N_{ex,y} \text{ x } N_y \text{ x } (1 - Frac_{Fuel} - Frac_{Graz} - Frac_{Feed} - Frac_{Const}) \quad (10.7)$$

Where F_{AM} denotes the annual amount of animal manure N applied to soil, P_y indicates the population of the y livestock category, $N_{ex,\,y}$ defines the annual average excretion rate per head for each livestock category in kg per animal, N_y represents the nitrogen content of y livestock category manure. The fractions of manure burned for fuel (FracFuel), deposited on the soil during grazing (FracGraz), used as feed (FracFeed), and for construction (FracConst) can be taken as 51%, 20%, 0%, and 2%, respectively, based on IPCC (2006). The $N_{ex,y,}$ and N_y values can be adopted in between 3 to 5.

The following equation can be used to estimate NH_3 emissions from MA

$$E_{NH3,\,MA} = \sum_{y,i} F_{AM,y,i} \; x \; EF_{NH3,y} \; x \; MF_{TW,i} \tag{10.8}$$

Where $E_{NH3,\,MA}$ represents annual NH_3 emissions in kg from MA, EF represents the emission factor for NH_3 for each livestock category y (% N volatilized as NH_3), $MF_{TW,i}$ represents the modification factor considering temperature and WS at grid level i. Table 10.4 of Annexure_EF_Table provides the NH_3 EFs adopted for MA. $MF_{TW,i}$ can be calculated at grid level using following equation:

$$MF_{TW} = \frac{e^{(0.0223T_Z + 0.0419W_Z)}}{\frac{1}{12}\sum_{Z=1}^{12} e^{(0.0223T_Z + 0.0419W_Z)}} \tag{10.9}$$

Where MF_{TW} denotes the modification factor for temperature, and WS, Tz, and Wz represent the monthly temperature and WS, respectively

10.3 Emission Factors

Emission factors for various pollutants ($PM_{2.5}$, CH_4, CO_2, NH_3, SO_2, CO, NO_x, OC, BC) can be selected from relevant literature (e.g. Kumar et al., 2021), similar to the approach followed by Thirunagari et al., (2025) and Ambulkar et al., (2025), or other related studies. The suggested EFs for TA (Table 10.2), FA (Table 10.1), LS (Table 10.3 for MM and Table 10.4 for MA) and CRB (Table 10.5 and Table 10.6) are in annexure of Emission Factors.

10.4 Emission Estimation Approach and Temporal Reporting

For all operations (tillage, livestock, crop residue burning and fertilizer application), it is recommended to use Bottom-up approach for gridded emission development and top-down approach for the validation of the estimated emissions. The desired temporal resolution of the dataset is daily or hourly. To prepare emissions for incorporation into day-to-day air quality forecasting, some measure of day-to-day real-time fire activity needs to go into the procedure. The procedure should be able to generate daily gridded emissions from farm fires. However, for Annual emission inventory, the data should be estimated for both the CRB seasons (Paddy and Wheat Stubble Burning season) but should be reported in monthly time scale.

CHAPTER 11

QA/QC and Data reporting

11.1 QA/QC Planning for Emission Inventory

The QA/QC plan for the emission inventory should address all procedural and technical issues to produce an inventory. QA/QC procedures require resources, expertise and time. However, the quality control requirements, improved accuracy and reduced uncertainty need to be balanced against requirements for time and cost effectiveness. So, focusing detailed QA/QC activities on key source categories will lead to the most significant improvements in the overall inventory estimates, However, it is essential to conduct at least the general QA/QC procedures outlined subsequently for the development of the new Emission Inventory.

General Inventory Level QC procedures, and a peer review of the inventory estimates are minimal QA/QC activities necessary for all inventory compilations. A review of the final inventory report by experts not involved in the compilation must be done to ensure the transparency and quality.

The focus of general QC techniques is on the processing, handling, documenting, archiving and reporting procedures that are common to all the inventory source categories. General QC procedures list the general QC checks that the inventory agency should use routinely throughout the conduction of the inventory. Most of the general QC checks shown in Table 11.1 (adapted from CPCB guidelines, 2010) could be performed by cross-checks, recalculation, or through visual inspections.

Table 11.1

General EI QC Checks

QC Activity	**Procedures**
Check that assumptions and criteria for the selection of activity data and emission factors (used if any) are documented.	• Cross-check descriptions of activity data and emission factors with information on source categories and ensure that these are properly recorded and archived.

Check for transcription errors in data input and reference.	• Confirm that bibliographical data references are properly recorded. • Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.
Check that emissions are calculated correctly.	• Reproduce a representative sample of emissions calculations.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used.	• Check that units are properly labeled in calculation sheets. • Check that units are correctly carried though from beginning to end of calculations. • Check that conversion factors are correct. • Check that temporal and spatial adjustment factors are used correctly.
Check the integrity of database files.	• Confirm that the appropriate data processing steps are correctly represented in the database. • Confirm that data relationships are correctly represented in the database. • Ensure that data fields are properly labeled and have the correct design specifications. • Ensure that adequate documentation of database and model structure and operation are archived.
Check for consistency in data between source categories.	• Identify parameters (e.g. activity data, constants) that are common to the multiple-source categories and confirm that there is consistency in the values used for these parameters in the emissions calculations.
Check that the movement of inventory data among processing steps is correct.	• Check that emissions data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries. • Check that emissions data are correctly transcribed between different intermediate products.

QC Activity	Procedures
Check that uncertainties in emissions and removals are estimated or calculated correctly.	• Check that qualifications of individuals providing expert judgments for uncertainty estimates are appropriate. • Check that qualifications, assumptions and expert judgments are recorded. • Check that calculated uncertainties are complete as far as possible. • If necessary, duplicate error calculation.
Undertake review of internal documentation.	• Check that there is detailed internal documentation to support the estimates and enable checks of the emission and uncertainty estimates. • Check that the inventory data, supporting data, and inventory records are archived and stored. • Check integrity of any data archiving arrangements.
Check methodological and diurnal changes	• Change the temporal consistency in time series input data for each source category. • Check for consistency in the algorithm/method used for calculations throughout the time series.
Undertake completeness checks.	• Confirm that estimates are reported for all source categories. • Check that known data gaps that result in incomplete source category emissions estimates are documented.
Compare estimates to earlier estimates if any	• For each source category, current inventory estimates should be compared with earlier estimates. If there are significant changes or departures from expected trends, re-record and explain any difference.

These necessarily minimum requirements should be applied irrespective of the type of data used to develop the inventory estimates and are equally applicable to source categories where default values or secondary data are used as the basis for the estimates.

Due to the large quantity of data that needs to be checked for many air pollution source categories, automated checks are recommended wherever possible. QA/QC procedure could be set up to use an automated range check (based on the range of expected values of the input data from the original reference) for the input values as recorded in the database. A combination of manual and automated checks may constitute the most effective procedures in checking large quantities of input data. However, the procedures for such checks are required to be documented. Further, the QA/QC Guidelines mentioned in Chapter VI of "Conceptual Guidelines and Common Methodology for Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Indian Cities" (CPCB, 2010) may be followed.

11.2 Uncertainty Calculation

Primarily, the uncertainty in emission estimates is a function of the uncertainty of input data i.e. activity and emission factors used to compile the inventory. The uncertainty in the activity data (u_{AD}) collected from authorities, local administration and primary surveys is mainly of a statistical nature, stemming from incompleteness, representativeness of sampling, the imputation of missing data, and extrapolation (Rypdal and Winiwarter, 2001; Olivier, 2002; IPCC, 2006; Solazzo et al., 2021). The urban level statistics and data are believed to be comparatively more reliable and robust than the rural and other areas. Hence, the sector-wise activity data uncertainties for urban or city areas and other areas should be calculated, separately.

The uncertainty in the EF (u_{EF}) has many sources – for example, the degree of representativeness of the limited number of observations underlying the EF, including the under-representativity of operating conditions, the inaccuracy of assumptions and/or of source aggregation, bias, variability, and/or random errors (IPCC, 2006; Solazzo et al., 2021).

As per method prescribed by IPCC (IPCC, 2006), the emission uncertainty (u_E) is the sum of the squares of the uncertainty of activity data (u_{AD}) and the uncertainty of emission factors (u_{EF}) as shown in equation below. It is assumed that uncertainties of different source categories are uncorrelated (e.g. Industries and Waste Burning).

$$u_E = \sqrt{u_{AD}^2 + u_{EF}^2} \tag{11.1}$$

Depending on the uncertainties in individual data sources, an overall uncertainty needs to be quantified and reported. An appropriate scientific method may be used to estimate the uncertainty for each emission sector. For example, the coefficient of variations (CVs) and data distribution of various input parameters associated with emission formula across different sectors may be estimated or adopted from existing literature. To quantify uncertainty, Monte Carlo simulations may be performed, employing a 95 % confidence interval to evaluate the associated uncertainties.

11.3 Data Dissemination

Data dissemination is a meaningful way plays a crucial role in making information accessible and useful for decision-making, research and public awareness. The emission inventory data should be disseminated through a website in a format required by the decision-makers and researchers with all the relevant information. All the data should be in consistent units and in formats. A suitable map of the emission inventory along with data tables in consistent units and formats should be made available.

The activity data and sector wise gridded emission should be made available in GIS formats preferably in shape file along with the attribute table. In addition, the data may also be made available in the excel/csv file in the format provided in the Table 11.2 to 11.4 as below. A pi-chart indicating the percentage sectoral contribution must be provided. The end user should be able to select the pollutants, area, time period etc. to download/visualize the emission maps or data.

Table 11.2

Format for reporting Annual/Monthly Sector wise gridded emissions in Tonne/Year

S.No.	**Grid ID**	**Lat**	**Long**	**Sector**	**PM10 (Tonne/Year)**	**PM2.5 (Tonne/Year)**	**NO2 (Tonne/Year)**	**…**	…
1.	G0000001	28.705	77.105	Transport					
2.	G0000002	28.705	77.110	Transport					
3.	….								

Table 11.3

Format for reporting Annual/Monthly Total gridded emissions in Tonne/Year

S.No.	**Grid ID**	**Lat**	**Long**	**Sector**	**PM10 (Tonne/Year)**	**PM2.5 (Tonne/Year)**	**NO2 (Tonne/Year)**	**…**	**…**
1.	G0000001	28.705	77.105	Total					
2.	G0000002	28.705	77.110	Total					
3.	….								
…	…				…	..	…	…	…
…	…				…	..	…	…	…

Table 11.4

Format for reporting Annual/Monthly Total Sectoral/Sub-Sectoral emissions in Tonne/Year

S.No.	**Sector**	**Sub-Sector**	**PM10 (Tonne/Year)**	**PM2.5 (Tonne/Year)**	**NO2 (Tonne/Year)**	**…**	**…**
1.	Traffic	Car					
2.	Traffic	Bus					
3.	Traffic	HDV					
…	…	..	…	..	…	…	…
…	…	..	…	..	…	…	…
--	Industries	Boilers					
…	Industries	TPP	…	..	…	…	…
…	Industries	Brick-Kiln	…	..	…	…	…

CHAPTER 12

Emission Inventory Based Source Apportionment

12.1 Methods of SA

Source Apportionment (SA) refers to determining the share of air pollution sources that contribute to the ambient air pollution. This can be accomplished by using emission inventories, source-oriented models (dispersion models) and receptor-models (receptor models). The source apportionment methods can be either measurement or model-based or both.

12.2 Measurement based SA

In measurement based approach, the pollution sources are determined using a Receptor Model based on measurement of ambient air quality samples at single locations or multiple locations in a city/area. The commonly used receptor models include Positive Matrix Factorization (PMF) and Chemical Mass Balance (CMB). PFM is a statistical method used to analyse air quality measurement data to identify and quantify different sources of pollution. It analyses chemical composition of air samples and decomposes a matrix of pollutant concentrations into smaller matrices representing the contribution of each source to the ambient air pollution. The CMB method matches the chemical profiles of sources with ambient samples and uses mass balance equations to determine the contributions of different sources to the chemical composition of air samples. Other methods also include Principal Component Analysis (PCA) to infer the sources by conducting multivariate analysis.

The measurement based SA has been used for a long time. However, these methods have inherent limitations. They require high-quality, time-resolved data, which can be expensive and resource-intensive to collect continuously. These methods need accurate and comprehensive source profiles, which may be either outdated or unavailable. These methods provide limited information on the spatial distribution of the sources as the SA results are for specific monitoring sites without capturing broader geographical variations. Additionally, distinguishing between mixed or overlapping sources becomes challenging due to similarities in chemical signatures. Receptor models can only analyze past measurements and are unable to predict future pollution scenarios or the impact of mitigation measures. Moreover, despite these limitations, receptor models remain valuable when complemented by emissions-based approaches for a more holistic understanding of pollution sources.

The Conceptual Guidelines and Common Methodology for Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Indian Cities outlines in detail the Guidelines for Ambient Air Monitoring for conducting measurement based source apportionment. The document clearly specifies the ambient air sampling criteria, analytical methods for PM speciation to determine chemical composition such as elements, ions, EC/OC etc. The document also suggests QA/QC procedure applicable for Analytical procedure to measurement based Source Apportionment. Further, the most up-to-date source chemical profiles of PM_{10} and $PM_{2.5}$ available through CPCB, SPECIATE (US-EPA) and SPECIEUROPE repositories may be used.

12.3 Emission Inventory & Source Apportionment

Emission inventories are a critical component of model based source apportionment studies. It provides a detailed data on the types, amounts, and locations of pollutants emitted into the atmosphere from various sources that is essential to model air quality and assess the contribution of different sources to pollution levels over a location or a region. While Emission Inventories itself can provide the first assessment of the sources, they do not consider the dispersion and chemical transportation of the pollutants. With the recent advancement in data collections and improved air quality models, emission inventory in combination with air quality dispersion models are becoming increasingly effective in identifying sources of air pollution and air quality management. For example, the Integrated Source Apportionment Method (ISAM) within the Community Multiscale Air Quality Modeling System (CMAQ) identifies and quantifies the pollutant sources and their contributions. The CMAQ model or a suitable Chemical Transport Model (CTM) such as the Weather Research and Forecasting with Chemistry (WRF-Chem) can provide users the concentration and deposition fields of multi-pollutant species. These species are usually combinations of different types of primary emissions and secondary formation that have been physically and chemically transformed in the model. However, sometimes it's desirable to know specific source attribution information for the model outputs. A similar approach has been employed in the Decision Support System (DSS) of Indian Institute of Tropical Meteorology (IITM), MoES. The DSS integrates a Chemical Transport Model (WRF-Chem), Emission Inventory and Data Assimilation system, to provide the forecast of source contribution by quantifying the emissions from various sources within Delhi and surrounding districts, as well as from crop residue burning. Such integrated systems also have scenario analysis capabilities.

The US-EPA suggests both, air quality monitoring with receptor model and emission inventory with dispersion model based approaches to perform Source Apportionment. Table 12.1 highlights the pros and cons of both the methods.

Table 12.1

Comparison of emission inventory based SA and air quality monitoring based SA method.

Assessment Parameters	**Emission Inventory with Dispersion Model**	**Air quality monitoring with Receptor model**
Spatial	Entire airshed (local/non-local including transboundary)	Area near the sampling location, may need multiple studies for a city
Temporal	hour/day/year	Temporal (day and time of the sample collected).
Sectoral	Multi-sectoral	Sectors based on profiles
Laboratory needs	Variable – Mainly EF development	HIGH - sampling, storage, chemical analysis, source profiling,
Computational needs	High to Very High	Minimum
Scientific needs	HIGH – Air quality data, modelling and HPC	HIGH – Observation, Air quality lab
Study time scales	VARIABLE (More in the beginning, less later)	Typically, 1-2 years for each study
Major limitations	Goodness of the Emission Inventory and model	Data collection and spatial/temporal and sectoral representativeness
Financial burden	Variable	High

The Emission Inventory based Source Apportionment offers overall advantages, especially in the context of air quality management because of its predictive capability in terms of spatial and temporal resolution enabling targeted actions at specific locations and times. However, the accuracy of the SA results highly depends on the goodness of the Emission Inventory and CTM being used. It is suggested to use the up-to-date EI for Delhi NCR along with a validated CTM to conduct an EI based SA for Delhi NCR on a regular basis in addition to the measurement based SA.

References

Airport Authority of India. Airport Authority of India: AAI Traffic News. https://www.aai.aero/en/business-opportunities/aai-traffic-news

Amato, F. (Ed.). (2018). Non-exhaust emissions: An urban air quality problem for public health; impact and mitigation measures. Academic Press.

Ambulkar, R., Govardhan, G., Gavhale, S., Kalita, G., Pande, C., Jat, R., Kulkarni, S., Khare, M., Attri, S. D., & Ghude, S. D. (2025). Crop residue burning in north-western India: Emission estimation and uncertainty quantification. Journal of Geophysical Research: Atmospheres, 130(4), e2024JD042198.

Automotive Research Association of India (ARAI). (2008). Emission Factor development for Indian Vehicles as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies. The Automotive Research Association of India.

Automotive Research Association of India (ARAI). (2018). Emission factors for Indian in-use post-2005 vehicles. The Automotive Research Association of India.

Baidya, S., & Borken-Kleefeld, J. (2009). Atmospheric emissions from road transportation in India. Energy Policy, 37(10), 3812–3822. https://doi.org/10.1016/j.enpol.2009.07.010

Bawase, M., Sathe, Y., Mulla, S., & Thipse, S. (2021). Chemical Profiling of Exhaust Particulate Matter from Indian In-Service Vehicles. Symposium on International Automotive Technology. https://doi.org/10.4271/2021-26-0192

Bond, T. C., Streets, D. G., Yarber, K. F., Nelson, S. M., Woo, J.-H., & Klimont, Z. (2004). A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Research, 109, D14203. https://doi.org/10.1029/2003JD003697

Central Pollution Control Board. (2010). Conceptual Guidelines and Common Methodology for Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Indian Cities. Central Pollution Control Board. https://cpcb.nic.in/displaypdf.php?id=c291cmNlYXBwb3J0aW9ubWVudHN0dWRpZXMucGRm ER

Cheng, K., Hao, W., Wang, Y., Yi, P., Zhang, J., & Ji, W. (2020). Understanding the emission pattern and source contribution of hazardous air pollutants from open burning of municipal solid waste in China. Environmental Pollution, 263, 114417.

Datta, A., Mohan, I., & Sharma, S. (2016). Emission inventory of residential sector during. In S. Sharma & A. Kumar (Eds.), Air pollution emissions scenario for India. Ver.1. TERI-Press, The Energy and Resources Institute, New Delhi.

Eastern Research Group, Inc. (2024). 2022 National Emissions Inventory: Aviation Component. https://gaftp.epa.gov/air/emismod/2022/v1/reports/mobile/airports/Aviation2022%20Documentation%20v4.pdf

European Environment Agency (EEA). (2019). EMEP/EEA Air Pollutant Emission Inventory Guidebook. https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2019

European Environment Agency (EEA). (2023). EMEP/EEA air pollutant emission inventory guidebook 2023. https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023

Fu, J., Li, R., Wu, X., Zhang, M., Chen, W., & Tong, D. (2022). High-resolution inventory of emissions of atmospheric PM10 from agricultural tillage and harvesting operations in China: Historical trend, spatio-temporality, and optimization methodology. Air Quality, Atmosphere & Health, 1–13.

Guttikunda, S., & Calori, G. (2013). A GIS based emissions inventory at 1 km×1 km spatial resolution for air pollution analysis in Delhi, India. Atmospheric Environment, 67, 101–111. https://doi.org/10.1016/j.atmosenv.2012.10.040

Huy, L. N., Kim Oanh, N. T., Phuc, N. H., & et al. (2021). Survey based inventory for atmospheric emissions from residential combustion in Vietnam. Environmental Science and Pollution Research, 28, 10678–10695.

Intergovernmental Panel on Climate Change (IPCC). (2006). IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme Japan; IPCC: Geneva, Switzerland.

Kumar, A., Hakkim, H., Sinha, B., & Sinha, V. (2021). Gridded 1 km × 1 km emission inventory for paddy stubble burning emissions over north-west India constrained by measured emission factors of 77 VOCs and district-wise crop yield data. Science of The Total Environment, 789, 148064. https://doi.org/10.1016/j.scitotenv.2021.148064

Lam, N. L., Chen, Y., Weyant, C., & et al. (2012). Household light makes global heat: High black carbon emissions from kerosene wick lamps. Environmental Science & Technology, 46(24), 13531–13538.

Lu, Z., Zhang, Q., & Streets, D. J. (2011). Sulfur dioxide and primary carbonaceous aerosol emissions in China and India, 1996–2010. Atmospheric Chemistry and Physics, 11, 9839–9864.

Ministry of Earth Sciences, G. of I. (2010a). Development of High Resolution Emission Inventory for National Capital Region Delhi (Special Scientific Report, SAFAR-2010A). http://safar.tropmet.res.in/source.pdf

Ministry of Earth Sciences, G. of I. (2010b). Development of High Resolution Emission Inventory for National Capital Region Delhi (Special Scientific Report, SAFAR-2010A). http://safar.tropmet.res.in/source.pdf

Ministry of Road Transport and Highways, Govt. of I . Parivahan Analytics and Reporting Portal. https://analytics.parivahan.gov.in/analytics/publicdashboard/vahan?lang=en

Mishra, D., & Goyal, P. (2015). Quantitative Assessment of the Emitted Criteria Pollutant in Delhi Urban Area. Aerosol and Air Quality Research, 15, 1601–1612. https://doi.org/10.4209/aaqr.2014.05.0104

Mishra, S. N., Mitra, S., Rangan, L., Dutta, S., & Singh, P. (2012). Exploration of 'hot-spots' of methane and nitrous oxide emission from the agriculture fields of Assam, India. Agriculture & Food Security, 1, 1–13.

Muleski, G.E., Cowherd Jr, C. and Kinsey, J.S., (2005). Particulate emissions from construction activities. Journal of the Air & Waste management association, 55(6), pp.772-783.

National Environmental Engineering Research Institute (NEERI). (2010). Air Quality Assessment, Emissions Inventory and Source Apportionment Studies: Mumbai. Final report. Central Pollution Control Board, New Delhi. http://mpcb.gov.in/ereports/pdf/Mumbai_report_cpcb.pdf

NEERI. (2010). Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Delhi. https://cpcb.nic.in/displaypdf.php?id=RGVsaGkucGRm

Olivier, J. G. J. (2002). On the quality of global emission inventories. Approached, methodologies and uncertainty (pp. 58–88). Wilco BV Amersfoort, the Netherlands.

Pandey, A., Sadavarte, P., Rao, A. B., & Venkataraman, C. (2014). Trends in multi-pollutant emissions from a technology-linked inventory for India: II. Residential, agricultural and informal industry sectors. Atmospheric Environment, 99, 341–352.

Pappu, A., Saxena, M., & Asokar, S. R. (2007). Solid Waste Generation in India and Their Recycling Potential in Building Materials. Journal of Building and Environment, 42(6), 2311–2324.

Parihar, S., Saini, K., Lakhani, G., Jain, A., Roy, B., Ghosh, S., & Aharwal, B. (2019). Livestock waste management: A review. Journal of Entomology and Zoology Studies, 7(3), 384–393.

Rypdal, K. Background Paper: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Statistics Norway. https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf

Rypdal, K., & Winiwarter, W. (2001). Uncertainties in greenhouse gas emission inventories – evaluation, comparability and implications. Environmental Science & Policy, 4, 107–116.

SAFAR (2018). Safar-High Resolution Emission Inventory of Mega City Delhi – 2018, System of Air Quality and Weather Forecasting And Research (SAFAR) – Delhi, Special Scientific Report, ISSN 0252-1075.

Sahil, F. M., Narayanan, M., & Ilampooranan, I. (2023). Nitrous oxide emissions dynamics in Indian agricultural landscapes: Revised emission rates and new insights. Agriculture, Ecosystems & Environment, 356, 108639.

Sahu, S. K., Beig, G., & Parkhi, N. S. (2011). Emissions inventory of anthropogenic PM2.5 and PM10 in Delhi during Commonwealth Games 2010. Atmospheric Environment, 45, 6180–6190. https://doi.org/10.1016/j.atmosenv.2011.08.014

Sahu, S. K., Mangaraj, P., & Beig, G. (2023). Decadal growth in emission load of major air pollutants in Delhi. Earth System Science Data, 15, 3183–3202. https://doi.org/10.5194/essd-15-3183-2023

Saud, T., Gautam, R., Mandal, T. K., & et al. (2012). Emission estimates of organic and elemental carbon from household biomass fuel used over the Indo-Gangetic Plain (IGP), India. Atmospheric Environment, 61, 212–220.

IITK (2016). Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi. https://cerca.iitd.ac.in/uploads/Reports/1576211826iitk.pdf

Sindhwani, R., Goyal, P., Kumar, S., & Kumar, A. (2015). Anthropogenic Emission Inventory of Criteria Air Pollutants of an Urban Agglomeration – National Capital Region (NCR). Aerosol and Air Quality Research, 15, 1681–1697. https://doi.org/10.4209/aaqr.2014.11.0271

Solazzo, E. & et al. (2021). Uncertainties in the Emissions Database for Global Atmospheric Research (EDGAR) emission inventory of greenhouse gases. Atmospheric Chemistry and Physics, 21, 5655–5683. https://doi.org/10.5194/acp-21-5655-2021

TERI & IITK. (2023). High Resolution Multi Pollutants Emissions Inventory of National Capital Region (NCR).

TERI (The Energy and Resources Institute) & ARAI (The Automotive Research Association of India). (2018). Source Apportionment of PM2.5 & PM10 of Delhi NCR for Identification of Major Sources.

https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf

TERI. (2022). Catalogue of Indian Emission Inventory Report. TERI. https://www.teriin.org/sites/default/files/files/Indian-Emission-Inventory-Report.pdf ER

The Energy and Resources Institute (TERI). (2018). Development of Spatially Resolved Air Pollution Emission Inventory of India: Chapter 10 – Construction Sector. TERI. https://www.teriin.org/sites/default/files/files/ap-Chapter10.pdf

Thirunagari, B. K., Kumar, R., & Kota, S. H. (2025). Assessing and mitigating India's agricultural emissions: A regional and temporal perspective on crop residue, tillage, and livestock contributions. Journal of Hazardous Materials, 137407.

U.S. Environmental Protection Agency. (1995). Emission factor documentation for AP-42 Section 9.1, Tilling Operations.

United States Environmental Protection Agency (USEPA). (2011a). AP 42. In Chapter 13: Miscellaneous sources (5th ed., Vol. I). https://www3.epa.gov/ttn/chief/ap42/ch13/index.html

United States Environmental Protection Agency (USEPA). (2011b). AP-42, Compilation of Air Pollutant Emission Factors. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors-stationary-sources

Woodall, B. D., Yamamoto, D. P., Gullett, B. K., & Touati, A. (2012). Emissions from small-scale burns of simulated deployed US military waste. Environmental Science & Technology, 46(20), 10997–11003.

Annexure

Compilation of Emission Factors

Note:

This compilation of Emission Factors has been done for reference only. It is suggested to review the literature and use the most up-to-date emission factors.

Table 3.1

Emission Factors for Large-scale industries

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
1	Aluminium production	2	1	1	6	120				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)	
		0.7	0.6	1	4.5	120		2.3 % of (PM2.5)		• EEA Guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-3-aluminium-production-2023/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes in the aluminium primary or secondary production. However, EFs based on the process and control measures are given in the link.
		*100-0.03								• USEPA AP -42 Ch-12.1 • (https://www.epa.gov/sites/default/files/2020-11/documents/c12s01.pdf)	• EF range's are due to the variation in processes, and control measures.
2	Glass manufacturing industry	0.27	0.24	8.12	1.74	0.1		0.062 % of (PM2.5)		• EEA Guidebook 2023, • Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021),	
		*<0.1-8.4		3.1-4.3	0.1-2.8	0.1				• USEPA AP -42 Ch-11.15 • (https://www.epa.gov/sites/default/files/2020-10/documents/c11s15.pdf)	• EF range's are due to the variation in processes, and control measures.
3	Paper and Pulp industry	0.8	0.6	1	2	5.5	2	2.6 % of (PM2.5)		• EEA Guidebook 2023, • Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)	
		*0.25-90			0.1-3.5	0.05-5.5				• USEPA AP -42 Ch-10.2 • (https://www.epa.gov/sites/default/files/2020-10/documents/c10s02.pdf)	• EF range's are due to the variation in processes, and control measures.
4	Fertilizer indust Fertilizer	0.33	0.22	2	0.04	62.25				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)	

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries										References	Remarks
	Industry		PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
		Phosphate fertilizer	*0.013-1.39			0.034-0.05					• USEPA AP -42 Ch-8.5 • (https://www.epa.gov/sites/default/files/2020-09/documents/final_background_document_for_phosphate_fertilizers_section_8.5.pdf)	• EF range's are due to the variation in processes, and control measures.
		Urea	*0.01-120								• USEPA AP -42 Ch-8.2 (Urea) • (https://www.epa.gov/sites/default/files/2020-09/documents/8.2_urea.pdf)	• EF range's are due to the variation in processes, and control measures.
		Fertilizer		0.3	1.1	2.7		3.7-3.8	0.1	0	• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)	
		Fertilizer		10.4					1		• Atmospheric optical and radiative effects of anthropogenic aerosol constituents from India," M. S. Reddy,Atm. Env. (2000)	
		Ammonium nitrate	*0.01-146								• USEPA AP -42 Ch-8 • (https://www.epa.gov/sites/default/files/2020-09/documents/8.3_ammonium_nitrate.pdf)	• EF range's are due to the variation in processes, and control measures.
		Synthetic ammonia				0.0288	1.0-6.9				• USEAP AP-42 Ch-8 • (https://www.epa.gov/sites/default/files/2020-09/documents/8.1_synthetic_ammonia.pdf)	• EF range's are due to the variation in processes, and control measures.
5	Iron and Steel		0.14	0.18			1.7	0.046			• EEA Guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-1-iron-and/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
			*0.0003-39.5				9-69				• USEPA AP-42 Ch-12.5 • (https://www.epa.gov/sites/default/files/2020-11/documents/c12s05.pdf)	• EF range's are due to the variation in processes, and control measures.

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
			1.2-1.9	1.9- 3	5.2-8.6		0.4-0.7	0.3-0.4	0.2-0.3	• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)	• Based on PAT & Non-PAT EF's
		0.1-0.024	0.08-0.021	0.5-0.01	1-0.06	12-1.7	0.138- 0			• The Energy and Resources Institute, Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)	• EF range's are due to the variation in processes used. (https://www.teriin.org/sites/default/files/2021-05/Exxon-Report.pdf)
			8.84					1		• Atmospheric optical and radiative effects of anthropogenic aerosol constituents from India," M. S. Reddy, Atm. Env. (2000)	
6	Cement	0.234	0.130					3% of PM2.5		• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-a-mineral-products/2-a-1-cement-production-2023/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
		*0.024-130, 0.084-16		1.9-3.7	0.27-4.9	0.06-1.8				• USEPA AP-42 Ch-11.6 (https://www.epa.gov/system/files/documents/2025-02/c11s06_final_2-2025_0.pdf)	• EF range's are due to the variation in processes, and control measures.
			2.3- 2.4	2.1	1.2		0.1	0	0.1	• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)	• Based on PAT & Non-PAT EF's
			13					1		• Atmospheric optical and radiative effects of anthropogenic aerosol constituents from India," M. S. Reddy,Atm. Env. (2000)	
		*0.01-257		2.2	4.9	0.27				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)	• EF range's are due to the variation in processes used. (https://www.teriin.org/sites/default/files/2021-05/Exxon-Report.pdf)

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
7	Lead production	0.005	0.0025		2.05					• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-5-lead-production-2023/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
		*0.004-0.21 0.005-0.43								• USEPA AP -42 Ch-12.6 (https://www.epa.gov/sites/default/files/2020-11/documents/c12s06.pdf)	• EF range's are due to the variation in processes, and control measures.
8	Zinc production	0.013	0.012		1.35					• EEA-Guidebook-2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-6-zinc-production-2023/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
		*3.3-1083								• USEPA AP -42 Ch-12.7 (https://www.epa.gov/sites/default/files/2020-11/documents/c12s07.pdf)	• EF range's are due to the variation in processes, and control measures.
9	Copper production	0.25	0.19		3			0.1 % of (PM2.5)		• EEA guidebook 202 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-7-a-copper/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
		*70-5								• USEPA AP -42 Ch-12.3 (https://www.epa.gov/sites/default/files/2020-11/documents/c12s03.pdf)	• EF range's are due to the variation in processes, and control measures.
10	Nickel production				18					• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-	

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
										product-use/2-c-metal-production/2-c-7-b-nickel/@@download/file)	
11	Other Metal production				26					• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-c-metal-production/2-c-7-c-other/@@download/file)	
12	Mining activities (Coal)	*0.048-0.047								• Ghose M.K. (2004) Emission factors for the quantification of dust in Indian coal mines. Journal of Scientific & Industrial Research, 63, 763–768.	
		0.042	0.005				0.8			• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-b-fugitive-emissions-from-fuels/1-b-1-a-fugitive/@@download/file)	• This is Tier 1 EFs assume an ‘averaged’ or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
		*#0.0125-13	1.9	0.08	0.036-0.7					• USEPA AP -42 Ch-11.10 (https://www.epa.gov/sites/default/files/2020-10/documents/c11s10.pdf)	EF range’s are due to the variation in processes, and control measures.
13	Solvent						500-1000			• EEA guidebook 2023 (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-d-2-l-other/2-d-3-a-domestic/@@download/file)	• This is Tier 1 EFs assume an ‘averaged’ or typical technology and abatement, and integrate all different sub-processes. However, EFs based on the process and control measures are given in the link.
							1000			• USEPA AP -42 Ch-4.6 (https://www.epa.gov/sites/default/files/2020-10/documents/c4s06.pdf)	• EFs based on the process are given in the link.

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
14	Metallic mineral process (crushing)	*0.005-14.4, 0.002-13								• USEPA AP -42 Ch-11.24 • (https://www.epa.gov/sites/default/files/2020-10/documents/c11s24.pdf)	• EF range's are due to the variation in processes, and control measures.
15	Crushed Stone Processing	*0.00007-0.15, 0.036-$8x10^{-6}$	0.00005-$6.5x10^{-6}$							• USEPA AP -42 Ch-11.19.2 • (https://www.epa.gov/sites/default/files/2020-10/documents/c11s1902.pdf)	• EF range's are due to the variation in processes, and control measures.
16	Plastic manufacturing Polyvinyl Chloride (PVC)	*17.5								• USEPA AP -42, Ch-6 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s06-1.pdf)	
	Poly-styrene						0.001 – 2.96			• USEPA AP -42, Ch-6.6 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s06-1.pdf)	• EF ranges are due to the variation in processes, and control measures.
	Poly-propylene	*1.5								• USEPA AP -42, Ch-6.6 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s06-3.pdf)	
	Poly (ethylene Terephthalate)	*0.0003–0.165					0.0005-3.4			• USEPA AP -42, Ch-6.6 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s06-2.pdf)	• EF range's are due to the variation in processes, and control measures • Refer the link for more information.
17	Soaps and Detergents	*0.023-45								• USEPA AP-42, Ch-6.8 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s08.pdf)	• EF range's are due to the variation in processes, and control measures. • Refer link for more information.
18	Synthetic rubber						0.1 - 8.45			• USEPA AP -42, Ch-6.10 (Organic chemical Process Industry)	• EF range's are due to the variation in processes, and control measures • Refer link for more information.

S N	Industry		PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC	References	Remarks
											• (https://www.epa.gov/sites/default/files/2020-10/documents/c06s10.pdf)	
19	Paint and Varnish		10					10-80			• USEPA AP -42, Ch-6.4 (Organic chemical Process Industry) • (https://www.epa.gov/sites/default/files/2020-10/documents/c06s04.pdf)	• EFs range is due to the type of the product manufactured. • Refer the link for more information
20.	Wood industry		*0.09-0.215		0.235 -1.15		0.35-0.65				• USEPA AP-42, Ch-10 • (https://www.epa.gov/sites/default/files/2020-10/documents/c10s09.pdf)	• EFs range due to variation of emissions at different stages of wood processing.
	Wood industry	Plywood Manufacturing	0025-0.175 Kg/m^3		0.06 Kg/m^3		0.0038-1.6 kg/m^3				• USEPA, AP-42, Ch-10 • (https://www.epa.gov/sites/default/files/2020-10/documents/c10s05.pdf)	• EFs range due to variation of emissions at different stages of wood processing.
21	Waste incineration industry	Industrial waste/hazardous waste/Sewage sludge Incineration	0.007	0.004	0.87	0.047	0.07	7.4	3.5		• EEA guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/5-waste/5-c-1-b-industrial/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes in the aluminium primary or secondary production. However, EFs based on the process and control measures are given in the link.
	Waste incineration industry	Sewage sludge incineration	4.1	1.1	2.5	14	15.5	0.84	3.5		• EEA guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/5-waste/5-c-1-b-industrial/@@download/file)	• Given EFs are technology specific. Refer the link for more details.
	Waste incineration industry	Municipal waste incineration	0.003	0.003	1.071	0.087	0.041	0.0059	0.0035		• EEA guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/5-waste/5-c-1-a-municipal/@@download/file)	• This is Tier 1 EFs assume an 'averaged' or typical technology and abatement, and integrate all different sub-processes in the aluminium primary or secondary production. However, EFs based on the process and control measures are given in the link.

Emission factors (Kg/Mg) of different pollutants from various large-scale industries

S N	Emission factors (Kg/Mg) of different pollutants from various large-scale industries									References	Remarks
	Industry	PM10	PM2.5	NOx	SO_x	CO	NMVOC	BC	OC		
22	Food and beverages industry						2			• EEA guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-h-other-industry-production/2-h-2-food-and/@@download/file)	
23	Road paving with asphalt	3	0.4				0.016			• EEA guidebook 2023 • (https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/2-industrial-processes-and-product-use/2-d-2-l-other/2-d-3-b-road/@@download/file)	

***Total PM; # Coal cleaning; 'EFs Range' is due to variation in processes, and control measures**

Table 3.2

Emission Factors for Small and Medium Scale Industries

Emission factors kilotons/petajoule (Kt/PJ), for small and medium industry										References
Fuel	**PM10**	**PM2.5**	**NOx**	**SO2**	**CO**	**HC**	**BC**	**OC**	**VOC**	
Coal	3.75	2.03	0.13	0.57	0.01	0.02				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
		1.36 g/Kg	7.5 kg/MT	9.5 kg/MT	1 kg/MT		1 g/kg	0.9 g/Kg	0.001 Kg/GJ	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
Natural gas		0.002	0.002	0.07	0.02	0.04				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
		0.34 g/Kg	0.0028 kg/ m3	0.0000096 kg/m3	0.000272 kg/ m3		0.216 g/Kg	0.001 g/Kg	0.005 Kg/GJ	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
Biomass	0.12	0.11	0.03	0.3	0.8					• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
Furnace oil	0.11	0.07	0.15	1.73	0.01	0.09				• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
		0.65 g/Kg	7.5 kg/KL	77 kg/KL	0.63 kg/KL					• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
Diesel	0.77	0.26	0.08	0.94	0.04					• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)

Emission factors kilotons/petajoule (Kt/PJ), for small and medium industry										References
Fuel	PM10	PM2.5	NOx	SO2	CO	HC	BC	OC	VOC	
	0.0009 kg/unit	0.97 g/Kg	2.75 kg/KL	31.05 kg/KL	0.63 kg/KL		0.35 g/Kg	1.4 g/Kg	0.15 Kg/GJ	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
Light Diesel	0.77	0.26	0.08	0.94	0.04					• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
Naptha	0.1	0.1	0.07	0.02	0.04					• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
Kerosene		0.34 g/Kg					0.03 g/Kg	0.04 g/Kg	0.9 Kg/GJ	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
Wood								3.2 g/Kg	0.6 Kg/GJ	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
LPG	0	0.31 g/Kg	1.45 kg/KL	0	0.19 kg/KL		0.0002 g/Kg	0.04 g/Kg	0	• Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)

Emission factors are in kiloton/petajoule (Kt/PJ), unless specified

Table 3.3
Emission Factors for Brick-Kiln

Technology-wise emission factors for brick kiln (g/Kg of fired bricks)								**References**
Technology	**PM10**	**PM2.5**	**SO2**	**NOx**	**CO**	**VOC**	**EC**	
Bull's trench kiln (BTK)	0.875	0.18	0.59	0.00005	2.94	0.1		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021), • Rajarathnam et al., 2014, Chowdhury et al.,2022
		0.33			2.7		0.72	• Emissions from South Asian Brick Production,
		3.6	9.8	3.8				• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)
Vertical Shaft Brick Kiln (VSBK)	0.1	0.09	0.32	0.01275	2.99	0.08		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021), • Chowdhury et al.,2022
		0.05			2.8		0.002	• Emissions from South Asian Brick Production
		2.3	9.8	3.8				• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)
Tunnel kiln (TK)	0.31	0.18	0.72	0.018	2.45	0.016		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021), • Rajarathnam et al., 2014, Chowdhury et al.,2022
		0.24				4.5	0.001	• Emissions from South Asian Brick Production,
Down drought zig-zag (DDK)	1.56	0.97	0.00002	0.0001	5.395	0.15		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021), • Rajarathnam et al., 2014
		13.2			0.5		0.19	• Emissions from South Asian Brick Production,
Natural draft zig-zag (NDZ)		0.16			0.9		0.03	• Emissions from South Asian Brick Production,

Forced draft zig-zag		0.05			0.8		0.02	• Emissions from South Asian Brick Production,
Hoffman (HD)	0.12	0.08	0.72	0.067	2.5	0.013		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021)
Clamp	1.3	1	0.3	0.00015	10	0.15		• Development of Spatially Resolved Air Pollution Emission Inventory of India (TERI 2021), Rajarathnam et al., 2014
		4.2	9.8	3.8				• Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)," C. Venkataraman M. Brauer (2018)

Table 3.4

Emission Factors for Energy Industry

Emission factors (g/kg of fuel used) for thermal power plants- coal and gas based										**References**
Source categories	Tech Mix	SO2	NOx	NMVOC	PM2.5	BC	OC	PM10	CO	
Thermal Power plant- coal	Sub-critical	7.3	4.5	0	1.8	0	0			Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)-Venkataraman et al. (2018)
	Super-critical	6.5	4	0	1.6	0	0			
	Ultra super critical	5.7	3.5	0	1.4	0	0			
	IGCC	4.9	3	0	1.2	0	0			
	Not Defined				0.6			2.3		Emissions inventory of anthropogenic PM2.5 and PM10 in Delhi during Commonwealth Games 2010," S. K. Sahu, G. Beig, N.Parkhi, Atmospheric Environment 45, 34, 6180-6190 (2011)
									0.06	Development of High Resolution Emission Inventory for Ahmedabad Metropolitan Region (AMR) (SAFAR)
			1.44							Emerging pattern of anthropogenic NOx emission over Indian subcontinent during 1990s and 2000s," S. K. Sahu, G. Beig, N. S. Parkhi, Atmospheric Pollution Research 3, 3, 262-269 (2012)
Thermal power plant - oil & gas	Sub-critical	0	3.8	0	0	0	0			Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050)-Venkataraman et al. (2018)
	Super-critical	0	3.4	0	0	0	0			
	Ultra super critical	0	2.9	0	0	0	0			
	IGCC	0	2.3	0	0	0	0			

Table 4.1

Emission factors for On-road transport

Vehicle Type	Technology	Fuel	Vehicle-Exhaust Emission Factors (g/km)								
			PM10[a]	PM2.5[b]	CO[a]	HC[a]	NOx[a]	OC[c]	BC[c]	NMVOC[d]	SO_2[e]
2W- Motorcycle	**BS-II**	Petrol	0.00750	0.00675	2.85000	1.27500	0.65825	0.00398	0.00045	0.70000	0.000412
2W- Motorcycle	**BS-III**	Petrol	0.00585	0.00527	1.28123	0.63015	0.63288	0.00230	0.00045	0.70000	0.000412
2W- Motorcycle	**BS-IV**	Petrol	0.00497	0.00448	1.08904	0.53563	0.53794	0.00196	0.00039	0.70000	0.000412
2W- Motorcycle	**BS-VI**	Petrol	0.00367	0.00330	0.31875	0.10200	0.12033	0.00145	0.00028	0.70000	0.00033
2W-Scooter	**BS-II**	Petrol	0.01050	0.00945	2.72250	1.01250	0.53750	0.00558	0.00063	0.70000	0.000412
2W-Scooter	**BS-III**	Petrol	0.00975	0.00878	2.71200	0.64725	0.58000	0.00384	0.00076	0.70000	0.000412
2W-Scooter	**BS-IV**	Petrol	0.00829	0.00746	2.30520	0.55016	0.49300	0.00326	0.00064	0.70000	0.000412
2W-Scooter	**BS-VI**	Petrol	0.00367	0.00330	0.31875	0.10200	0.12033	0.00145	0.00028	0.70000	0.00033
Three-Wheeler	**BS-II**	Diesel	0.65145	0.58631	4.90005	0.49995	2.19175	0.13839	0.33583	0.13000	0.000737
Three-Wheeler	**BS-III**	Diesel	0.21045	0.18941	0.59445	0.20700	1.79250	0.05065	0.08548	0.13000	0.000737
Three-Wheeler	**BS-IV**	Diesel	0.05419	0.04877	0.48450	0.12750	0.59500	0.01304	0.02201	0.13000	0.000737
Three-Wheeler	**BS-VI**	Diesel	0.02125	0.01913	0.18700	0.03400	0.19448	0.00511	0.00863	0.13000	0.000737
Three-Wheeler	**BS-II**	CNG	0.17700	0.15930	1.35000	3.09000	0.47500	0.11479	0.00390	0.05000	0
Three-Wheeler	**BS-III**	CNG	0.11820	0.10638	1.30275	1.28370	2.44825	0.05908	0.01162	0.05000	0
Three-Wheeler	**BS-IV**	CNG	0.03188	0.02869	1.19850	0.51000	1.14750	0.01593	0.00313	0.05000	0
Three-Wheeler	**BS-VI**	CNG	0.01250	0.01125	0.37400	0.25500	0.15802	0.00625	0.00123	0.05000	0
Three-Wheeler	**BS-II**	LPG	0.17700	0.15930	1.35000	3.09000	5.15000	0.07321	0.01207	0.05000	0
Three-Wheeler	**BS-III**	LPG	0.11820	0.10638	1.30275	1.28370	2.44825	0.04889	0.00806	0.05000	0
Three-Wheeler	**BS-IV**	LPG	0.03188	0.02869	1.19850	0.51000	1.14750	0.01318	0.00217	0.05000	0

Vehicle Type	Technology	Fuel	Vehicle-Exhaust Emission Factors (g/km)								
			PM10[a]	PM2.5[b]	CO[a]	HC[a]	NOx[a]	OC[c]	BC[c]	NMVOC[d]	SO_2[e]
Three-Wheeler	**BS-VI**	LPG	0.01250	0.01125	0.37400	0.25500	0.15802	0.00517	0.00085	0.05000	0
Car	**BS-II**	Diesel	0.09000	0.08100	0.45000	0.39000	1.22500	0.01658	0.05373	0.13000	0.00129
Car	**BS-III**	Diesel	0.04035	0.03632	0.54953	0.10373	1.05038	0.00743	0.02409	0.13000	0.00129
Car	**BS-IV**	Diesel	0.02310	0.02079	0.33735	0.06938	0.54612	0.00335	0.01402	0.13000	0.00129
Car	**BS-VI**	Diesel	0.00383	0.00344	0.16500	0.14450	0.09724	0.00055	0.00232	0.13000	0.00129
Car	**BS-II**	Petrol	0.00300	0.00270	1.26000	0.18000	0.22500	0.00087	0.00051	0.25000	0.00129
Car	**BS-III**	Petrol	0.00146	0.00132	1.47563	0.14213	0.15000	0.00043	0.00020	0.25000	0.00129
Car	**BS-IV**	Petrol	0.00098	0.00088	1.42650	0.12675	0.13375	0.00029	0.00013	0.25000	0.00129
Car	**BS-VI**	Petrol	0.00038	0.00034	1.86615	0.23858	0.14315	0.00011	0.00005	0.25000	0.001032
Car	**BS-II**	CNG	0.00300	0.00270	8.25000	1.65000	2.32500	0.00095	0.00053	0.05000	0
Car	**BS-III**	CNG	0.00105	0.00095	5.14500	1.01850	1.96575	0.00025	0.00043	0.05000	0
Car	**BS-IV**	CNG	0.00098	0.00088	1.53075	0.28200	0.08500	0.00027	0.00014	0.05000	0
Car	**BS-VI**	CNG	0.00065	0.00059	0.85000	0.08500	0.08500	0.00018	0.00010	0.05000	0
Car	**BS-II**	LPG	0.00300	0.00270	4.08000	0.34500	0.50000	0.00101	0.00037	0.25000	0
MUV	**BS-III**	Diesel	0.08655	0.07790	0.88905	0.15045	1.60000	0.01528	0.05228	0.13000	0.001606
MUV	**BS-IV**	Diesel	0.07395	0.06656	0.71100	0.07395	1.19675	0.01305	0.04467	0.13000	0.001606
MUV	**BS-VI**	Diesel	0.00383	0.00344	0.42500	0.08500	0.17000	0.00068	0.00231	0.13000	0.001606
MUV	**BS-IV**	CNG	0.00225	0.00203	2.01705	0.42730	0.40700	0.00066	0.00043	0.05000	0
MUV	**BS-VI**	CNG	0.00383	0.00344	0.85000	0.08500	0.12750	0.00112	0.00072	0.05000	0
LCV	**BS-II**	Diesel	0.44675	0.40208	2.89125	1.23850	4.76542	0.17646	0.24594	0.14000	0.002
LCV	**BS-III**	Diesel	0.18100	0.16290	2.15250	0.45200	4.23083	0.07149	0.09964	0.14000	0.002
LCV	**BS-IV**	Diesel	0.08580	0.07722	0.59460	0.06870	2.40250	0.03206	0.02770	0.14000	0.002
LCV	**BS-VI**	Diesel	0.00383	0.00344	0.33694	0.03893	0.22313	0.00143	0.00123	0.14000	0.002
LCV	**BS-IV**	CNG	0.00450	0.00405	1.53850	0.11050	0.21250	0.00253	0.00044	1.40000	0

Vehicle Type	Technology	Fuel	Vehicle-Exhaust Emission Factors (g/km)								
			PM10[a]	**PM2.5[b]**	**CO[a]**	**HC[a]**	**NOx[a]**	**OC[c]**	**BC[c]**	**NMVOC[d]**	**SO_2[e]**
LCV	**BS-VI**	CNG	0.00383	0.00344	1.30773	0.09393	0.15938	0.00215	0.00038	1.40000	0
HCV-Truck	**BS-II**	Diesel	0.22950	0.20655	6.12000	1.68300	26.77500	0.02685	0.15025	0.87000	0.003333
HCV-Truck	**BS-III**	Diesel	0.24480	0.22032	8.33850	1.19340	19.12500	0.02864	0.16026	0.87000	0.003333
HCV-Truck	**BS-IV**	Diesel	0.04590	0.04131	6.12000	0.84150	13.38750	0.00635	0.02553	0.87000	0.003333
HCV-Truck	**BS-VI**	Diesel	0.01530	0.01377	6.12000	0.24480	1.75950	0.00212	0.00851	0.87000	0.003333
HCV-Truck	**BS-IV**	CNG	0.04590	0.04131	6.12000	0.84150	13.38750	0.02584	0.00453	1.40000	0
HCV-Truck	**BS-VI**	CNG	0.01530	0.01377	6.12000	0.24480	1.75950	0.00861	0.00151	1.40000	0
HCV-Bus	**BS-III**	Diesel	0.72300	0.65070	7.10175	1.81770	12.92875	0.08459	0.47333	0.87000	0.003175
HCV-Bus	**BS-IV**	Diesel	0.04590	0.04131	3.44250	1.05570	7.65765	0.00635	0.02553	0.87000	0.003175
HCV-Bus	**BS-VI**	Diesel	0.02295	0.02066	9.18000	0.36720	1.00643	0.00318	0.01276	0.87000	0.003175
HCV-Bus	**BS-III**	CNG	0.36720	0.33048	12.50775	1.79010	10.93950	0.16886	0.02273	1.40000	0
HCV-Bus	**BS-IV**	CNG	0.06885	0.06197	9.18000	1.26225	7.65765	0.03876	0.00680	1.40000	0
HCV-Bus	**BS-VI**	CNG	0.02295	0.02066	9.18000	0.36720	1.00643	0.01292	0.00227	1.40000	0

Notes:

(a) Emission factors are generated using laboratory testing. In absence of emission factors, 85% of emission limit values for the category and fuel-type are considered.

(b) Most of the particles from vehicle exhaust fall under fine fractions. 90% of particles of total particles are considered as PM2.5.

(c) Derived using the fraction of OC and BC in the source profiles. In case of BS-VI, fraction of BS-IV is applied.

(d) NMVOC Emission factors are taken from Atmospheric Brown Cloud Emission Inventory Manual, Shreshta et al., 2013

(e) SO2 emission factors are estimated using average fuel efficiency for each vehicle category and sulfur content of liquid fuels (10 ppm for diesel and 8 ppm for Gasoline)

Table 4.2

Emission Factors for aviation sector

Pollutants	PM10[8]	PM2.5[8]	CO[9]	NO_X[9]	NMVOC[9]	SO_2[9]
Emission Factor (kg/LTO)	0.49	0.48	3.67	4.63	1.18	0.36

8: Source-USEPA

9: Source-IPCC

Table 5.1

Emission factors (g/km/vehicle) for non-exhaust emissions

Vehicle Type	Tyre and Brake Wear combined		Road surface Wear	
	PM10	**PM2.5**	**PM10**	**PM2.5**
2W	0.0064	0.0034	0.003	0.0016
3W*	0.0124	0.0064	0.0053	0.0029
Cars	0.0184	0.0093	0.0075	0.0041
LCV	0.0271	0.0139	0.0105	0.0057
Bus	0.059	0.0316	0.038	0.0205
HCV	0.059	0.0316	0.038	0.0205

*Average of 2W and Cars

Source (EMEP/EEA air pollutant emission inventory guidebook 2023 – Update 2024, 1.A.3.b.vi-vii Road tyre and brake wear 2024).

European Environment Agency. (2024). *EMEP/EEA air pollutant emission inventory guidebook 2023 – Update 2024, 1.A.3.b.vi-vii Road tyre and brake wear*. European Environment Agency. https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-vi

Table 6.1

Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector

Fuel type	$PM_{2.5}$	PM_{10}	SOx	NOx	CO	NMVOC	NH3	BC	OC
Fuel wood	4.6	6.8	0.8	1.7	66.5	15.9		0.4**	
Crop residue	5.7	8.6	0.7	1.8	64.0	8.5		0.3**	
Dung cake	4.4	10.5	0.6	1.0	78.6	24.1		0.4**	
Coal	4.0	8.3	15.3	2.2	59.5	10.5		0.08***	
Kerosene (for cooking)	3.0	3.6	0.4	1.3	43.0	13.3		0.6****	
Kerosene (for lighting)	91.3*	91.3*	NA	NA	29.3*	NA		76*****	
LPG	0.4*	0.4*	0.4*	2.9*	2.0*	19*			

* Pandey et al. (2014); others were adopted from Datta and Sharma (2016)
NA: Not available; ** Saud et al., (2012); *** Huy et al., (2021); **** Lu et al., (2011);***** Lam et al., (2012)

Datta, A., & Sharma, C. (2016). *Development of Spatially Resolved Air Pollution Emission Inventory for India*. The Energy and Resources Institute (TERI). https://www.teriin.org/sites/default/files/2021-05/Exxon-Report.pdf

Pandey, A., Sadavarte, P., Rao, A. B., & Venkataraman, C. (2014). Trends in multi-pollutant emissions from a technology-linked inventory for India: II. Residential, agricultural and informal industry sectors. *Atmospheric Environment*, *99*, 341–352. https://doi.org/10.1016/j.atmosenv.2014.09.080

Saud, T., Gautam, R., Mandal, T. K., & et al. (2012). Emission estimates of organic and elemental carbon from household biomass fuel used over the Indo-Gangetic Plain (IGP), India. *Atmospheric Environment*, *61*, 212–220.

Lu, Z., Zhang, Q., & Streets, D. J. (2011). Sulfur dioxide and primary carbonaceous aerosol emissions in China and India, 1996–2010. *Atmospheric Chemistry and Physics*, *11*, 9839–9864.

Huy, L. N., Kim Oanh, N. T., Phuc, N. H., & et al. (2021). Survey based inventory for atmospheric emissions from residential combustion in Vietnam. *Environmental Science and Pollution Research*, *28*, 10678–10695.

Lam, N. L., Chen, Y., Weyant, C., & et al. (2012). Household light makes global heat: High black carbon emissions from kerosene wick lamps. *Environmental Science & Technology*, *46*(24), 13531–13538.

Table 7.1

Emission factor (g/kg) of different pollutants from burning of waste materials.

$PM_{2.5}$	PM_{10}	NOx	SO_2	CO	NMVOC	NH3	BC	OC
9.8	11.9	3.74	0.5	38	15.5	0.94	0.65	5.27

Source: Cheng et. al (2020); Akagi et al. (2011)

Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., Crounse, J. D., & Wennberg, P. O. (2011). Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics*, *11*(9), 4039–4072.

Cheng, K., Hao, W., Wang, Y., Yi, P., Zhang, J., & Ji, W. (2020). Understanding the emission pattern and source contribution of hazardous air pollutants from open burning of municipal solid waste in China. *Environmental Pollution*, *263*, 114417.

Table 7.2

Emission factor (g/kg) of different pollutants from landfill burning.

$PM_{2.5}$	PM_{10}	NOx	SO_2	CO	NMVOC	NH3	BC	OC
5.4	8.0	3.0	0.5	42.0	21.5		0.65	

Source: Akagi et al. (2011); USEPA, AP42 EF database

Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., Crounse, J. D., & Wennberg, P. O. (2011). Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics*, *11*(9), 4039–4072.

United States Environmental Protection Agency (USEPA). (2011). *AP-42, Compilation of Air Pollutant Emission Factors*. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors-stationary-sources

Table 8.1

Emission factors for C&D

$EF_{PM(TSP)}$: 1.2 Mg/acre/month (Muleski et al, 2005)

EF_{PM10}: 0.42 Mg/acre/month (35% of EFPM)

$EF_{PM2.5}$: 0.072 Mg/acre/month (6% of EFPM)

Muleski, G.E., Cowherd Jr, C. and Kinsey, J.S., (2005). Particulate emissions from construction activities. Journal of the Air & Waste management association, 55(6), pp.772-783.

Table 9.1

Emission factors for DG sets

Emission factors (uncontrolled) for DG set:

Pollutant	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC	BC	NH_3
ng/J	133.3	*85% of PM_{10}	124.7	1896.3	408.5	154.8	*60% of PM_{10}	3.06**

Source: https://www3.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf

* Sharma et.al 2016 (Sharma S, Kumar A, 2016, Air Pollutant Emissions Scenario for India, The Energy and Resources Institute, New Delhi)

** https://www3.epa.gov/ttn/chief/old/efdocs/ammonia.pdf

It is to mention that in Delhi-NCR, Retrofitted Emission Control Devices (RECDs) and dual fuel kits (70% gas and 30% diesel) are being installed as per directions of CAQM. With these RECDs and dual fuel kits, PM emissions are expected to be reduced by ~70%.

Table 10.1

EFs adopted for NH_3 from FA

Modification Factor	Value (% NH_3-N)	Reference
Emission factor from literature (EF)	8.8 % NH_3-N in Acidic soil for Urea	(Huang et al., 2012; Zhu et al., 1988)
	30.1 % NH_3-N in Alkaline soil for Urea	
	7.3 % NH_3-N in acidic soil for DAP	(Li et al., 2021)
	7.3 % NH_3-N in Alkaline soils for DAP	
Modification factor for dressing type (MF_M)	0.32 for basal dressing	(Li et al., 2002; Fan et al., 2006)
	1 for top dressing	
Modification factor for application rate (MF_R)	1.18 for ≥ 200 kg N/ha	(Huang et al., 2012; Cai et al., 2002; Fillery et al., 1986)
	1 for < 200 kg N/ha	

Table 10.2

PM_{10} EFs for tillage activity in NCR states

State	PM_{10} EF (kg/ha)	$PM_{2.5}$ EF (kg/ha)
Rajasthan	1.35053844	0.643113543
Uttar Pradesh	0.898038882	0.427637563
Haryana	0.735847753	0.350403692
Delhi	0.518045692	0.246688425

Table 10.3

NH_3 emission factors adopted for estimating emissions from MM

Livestock category	EF (kg NH_3-N/head/year)	Source
Cattle	4.5	(Yamaji et al., 2004; Aneja et al., 2012)
Buffalo	3.4	
Sheep	1.4	
Goat	1.1	
Horses and Ponies	7	
Donkeys and Mules	7	
Camel	7	
Pig	1.5	
Poultry	0.12	

Table 10.4

NH_3 EFs for manure application

Livestock Category	NH_3 EF (% NH_3-N)	Source
Cattle, Buffalo, Pigs and Poultry	20	(Yan et al., 2003)
Other categories	10	

Table 10.5

Crop-wise emission factors (g/kg) for CRB emission estimation

Crop	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOC	CO	BC	OC	NH_3
Rice	8.3[a,b]	9.1[a]	2[c]	3.1[c]	7[a]	93[a]	0.58[d]	3.5[d]	4.1[a]
Wheat	7.6[a]	8.3[c]	0.4[f]	1.7[e]	7[b]	60[c]	0.68[d]	3.15[d]	1.3[f]
Sugarcane	3.8[a]	4[a]	0.21[a]	2.6[a]	2.2[a]	34.7[a]	0.73[d]	3.3[a]	1[a]
Mustard	7.8[e]	8.58[e]	1.2[h]	3.11[i]	7[b]	102[i]	0.7[j]	1.7[j]	1.3[a]
Groundnut	7.9[c]	8.69[c]	0.24[h]	3.11[i]	7[b]	92[k]	0.7[j]	1.7[j]	1.3[a]
Other oilseeds	3.9[a]	8.05[a]	0.216[a]	3.11[i]	7[a]	86.3[a]	0.7[j]	1.7[j]	1.3[a]
Fiber crops	5.9[d]	10.85[d]	0.28[d]	3.03[d]	7[b]	105.82[a]	0.82[d]	3.17[d]	1.3[a]
Maize	7.9[c]	8.69[c]	0.4[c]	3.38[k]	10[a]	92[k]	0.75[d]	3.71[d]	0.68[a]
Coarse Cereals	4.1[a]	4.3[a]	0.44[a]	4.3[a]	10[a]	114.7[a]	2[j]	2.25[a]	0.68[a]
Pulses	3.9[b]	8.05[b]	0.216[b]	0.7[b]	7[b]	86.3[b]	0.7[j]	0.7[b]	1.3[b]

a: Kanabkaew et al., 2011
b: Ravindra et al., 2019
c: Sahu et al., 2021
d: Zhang et al., 2019
e: Sahai et al., 2007
f: Yang et al., 2008
g: Yokelson et al., 2009
h: Levine et al., 2000
i: Akagi et al., 2011
j: Venkataraman et al. 2006
k: Gadde et al., 2009

Huang X, Song Y, Li M, Li J, Huo Q, Cai X, et al. A high-resolution ammonia emission inventory in China. Global Biogeochemical Cycles. 2012;26(1).

Zhu Z, Cai G, Simpson J, Zhang S, Chen D, Jackson A, et al. Processes of nitrogen loss from fertilizers applied to flooded rice fields on a calcareous soil in north-central China. Fertilizer Research. 1988;18:101-15.

Li B, Chen L, Shen W, Jin J, Wang T, Wang P, et al. Improved gridded ammonia emission inventory in China. Atmospheric Chemistry and Physics. 2021;21(20):15883-900.

Li G, Li B, Chen D. Ammonia volatilization from large field planted with winter wheat and summer maize. Acta Agriculture Boreall-sinica. 2002;17:76-81.

Fan X-h, Song Y-s, Lin D-x, Yang L-z, Luo J-f. Ammonia volatilization losses and^{15} N balance from urea applied to rice on a paddy soil. Journal of Environmental Sciences. 2006;18(2):299-303.

Cai G, Chen D, Ding H, Pacholski A, Fan X, Zhu Z. Nitrogen losses from fertilizers applied to maize, wheat and rice in the North China Plain. Nutrient cycling in Agroecosystems. 2002;63:187-95.

Fillery I, Simpson J, De Datta S. Contribution of ammonia volatilization to total nitrogen loss after applications of urea to wetland rice fields. Fertilizer research. 1986;8:193-202.

Yamaji K, Ohara T, Akimoto H. Regional-specific emission inventory for NH_3, N_2O, and CH_4 via animal farming in South, Southeast, and East Asia. Atmospheric Environment. 2004;38(40):7111-21.

Aneja VP, Schlesinger WH, Erisman JW, Behera SN, Sharma M, Battye W. Reactive nitrogen emissions from crop and livestock farming in India. Atmospheric environment. 2012;47:92-103.

Yan X, Akimoto H, Ohara T. Estimation of nitrous oxide, nitric oxide and ammonia emissions from croplands in East, Southeast and South Asia. Global Change Biology. 2003;9(7):1080-96.

Kanabkaew T, Kim Oanh NT. Development of spatial and temporal emission inventory for crop residue field burning. Environmental Modeling & Assessment. 2011;16:453-64.

Ravindra K, Singh T, Mor S. Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. Journal of cleaner production. 2019;208:261-73.

Sahu SK, Mangaraj P, Beig G, Samal A, Pradhan C, Dash S, et al. Quantifying the high resolution seasonal emission of air pollutants from crop residue burning in India. Environmental Pollution. 2021;286:117165.

Zhang X, Lu Y, Wang Qg, Qian X. A high-resolution inventory of air pollutant emissions from crop residue burning in China. Atmospheric environment. 2019;213:207-14.

Sahai S, Sharma C, Singh D, Dixit C, Singh N, Sharma P, et al. A study for development of emission factors for trace gases and carbonaceous particulate species from in situ burning of wheat straw in agricultural fields in India. Atmospheric Environment. 2007;41(39):9173-86.

Yang S, He H, Lu S, Chen D, Zhu J. Quantification of crop residue burning in the field and its influence on ambient air quality in Suqian, China. Atmospheric Environment. 2008;42(9):1961-9.

Yokelson RJ, Crounse J, DeCarlo P, Karl T, Urbanski S, Atlas E, et al. Emissions from biomass burning in the Yucatan. Atmospheric Chemistry and Physics. 2009;9(15):5785-812.

Levine JS. Global biomass burning: a case study of the gaseous and particulate emissions released to the atmosphere during the 1997 fires in Kalimantan and Sumatra, Indonesia. Biomass burning and its inter-relationships with the climate system: Springer; 2000. p. 15-31.

Akagi S, Yokelson RJ, Wiedinmyer C, Alvarado MJ, Reid JS, Karl T, et al. Emission factors for open and domestic biomass burning for use in atmospheric models. Atmospheric Chemistry and Physics. 2011;11(9):4039-72.

Venkataraman C, Habib G, Kadamba D, Shrivastava M, Leon JF, Crouzille B, et al. Emissions from open biomass burning in India: Integrating the inventory approach with high-resolution Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data. Global biogeochemical cycles. 2006;20(2).

Gadde B, Menke C, Wassmann R. Rice straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation. Biomass and bioenergy. 2009;33(11):1532-46.

Table 10.6

EFs for Paddy Crop Residue Burning in (g kg^{-1}) (Kumar et al, 2021)

Pollutant	Recommended Emission Factor
CH_4	3.849
CO_2	1292.93
NH_3	0.986
SO_2	0.8
CO	72.943
NO_x	2.398
$PM_{2.5}$	8.153
BC	0.424
OC	4.864

Kumar, A., Hakkim, H., Sinha, B., & Sinha, V. (2021). Gridded 1 km × 1 km emission inventory for paddy stubble burning emissions over north-west India constrained by measured emission factors of 77 VOCs and district-wise crop yield data. Science of The Total Environment, 789, 148064. https://doi.org/10.1016/j.scitotenv.2021.148064

Questionnaire 1: Residential sector survey (template)

a) Location
b) Lat, Long
c) Number of members in your family
d) What type of fuel do you use for cooking
   (1) Fuelwood (2) Dung cake (3) Crop Residue (4) Coal (5) Kerosene (6) LPG

e) How much Fuelwood do you use daily/ Monthly? Kg
f) How much Dung cake do you use daily/ Monthly? Kg
g) How much crop residue do you use daily/ Monthly? Kg
h) How much coal do you use daily/ Monthly? Kg or INR
i) How much Kerosene do you use daily/ Monthly? Litre
j) How many days does one LPG cylinder last in your kitchen?
k) Which size/capacity of LPG cylinder do you use in your kitchen (14.2 Kg or 5.5 Kg)
l) Do you have an electricity connection at your home?
m) If No, what is the source of lighting at your home
   (1) Kerosene lamp (2) Solar (3) Inverter

n) What quantity of Kerosene is consumed for lighting? Litre

Questionnaire 2: Waste sector survey (template)

a) Location
b) Lat, Long
c) Number of members in your family
d) Do you separate dry waste and wet waste
e) (Yes:1 No:2)
f) How much quantity of waste is generated from your household per day (kg)
g) Do you burn waste outside your premises? (Yes:1 No:2)
h) If yes, how often? Once a week:1, Twice a week:2,
i) Thrice a week: 3, Everyday:4
j) What is the approximate quantity of waste you burn? (kg)
k) Whether door to door collection facility is available in your area (Yes:1 No:2)
l) If Yes, what is the frequency of waste collected? Once a week:1, Twice a week:2,
m) Thrice a week: 3, Everyday:4
n) How do you dispose of your household waste?
o) Community Bin:1, Door to Door Collection:2
p) On the road side:3
q) Have you noticed a waste-burning incident in your colony?
r) (Yes:1 No:2)
s) If Yes, what is the frequency of waste burning? Once a week:1, Twice a week:2,
t) Thrice a week: 3, Everyday:4

Questionnaire 3: Generator Set Survey Form

Location:
Lat, Long
Ward Number:
Name and contact details of the respondent:

Commercial/house/hotel/restaurant/Hospital/Mall/Construction site/any other (please specify)? ……………………………………………

1. Do you use any power back-up at your home/shops/hotel/restaurant/Hospital/Mall/Construction site, etc.?

   Yes ☐ No ☐

2. If yes to Q1, what are you using? Along with number

   A. Generator B. Inverter C. Common generator D. Any other (please specify)

3. How many hours per day do you generally require power back-up?

   Summer Hours ☐

   Winter hours ☐

   Monsoon hours ☐

4. If the answer to Q2 is 'Generator', Name, make and manufacturing year of the generator : …………………………………………..
5. What is the capacity of the generator that you are using? Pl specify the unit also

   …………………….. kVA or kW

6. What type of fuel is used for your generator?

   A. Diesel B. Kerosene C. Any other ___________________________

7. What is the average monthly consumption of fuel (litres)for your generator?

   Summers ☐

   Winter ☐

   Monsoon ☐

8. Emission standards applicable to Generator Set:
9. Emission Control Devices installed, if any: (RECD/DFK/any other):
10. Emission test report (in case of Diesel Genset having capacity more than 800 kW):
11. Any other relevant information: