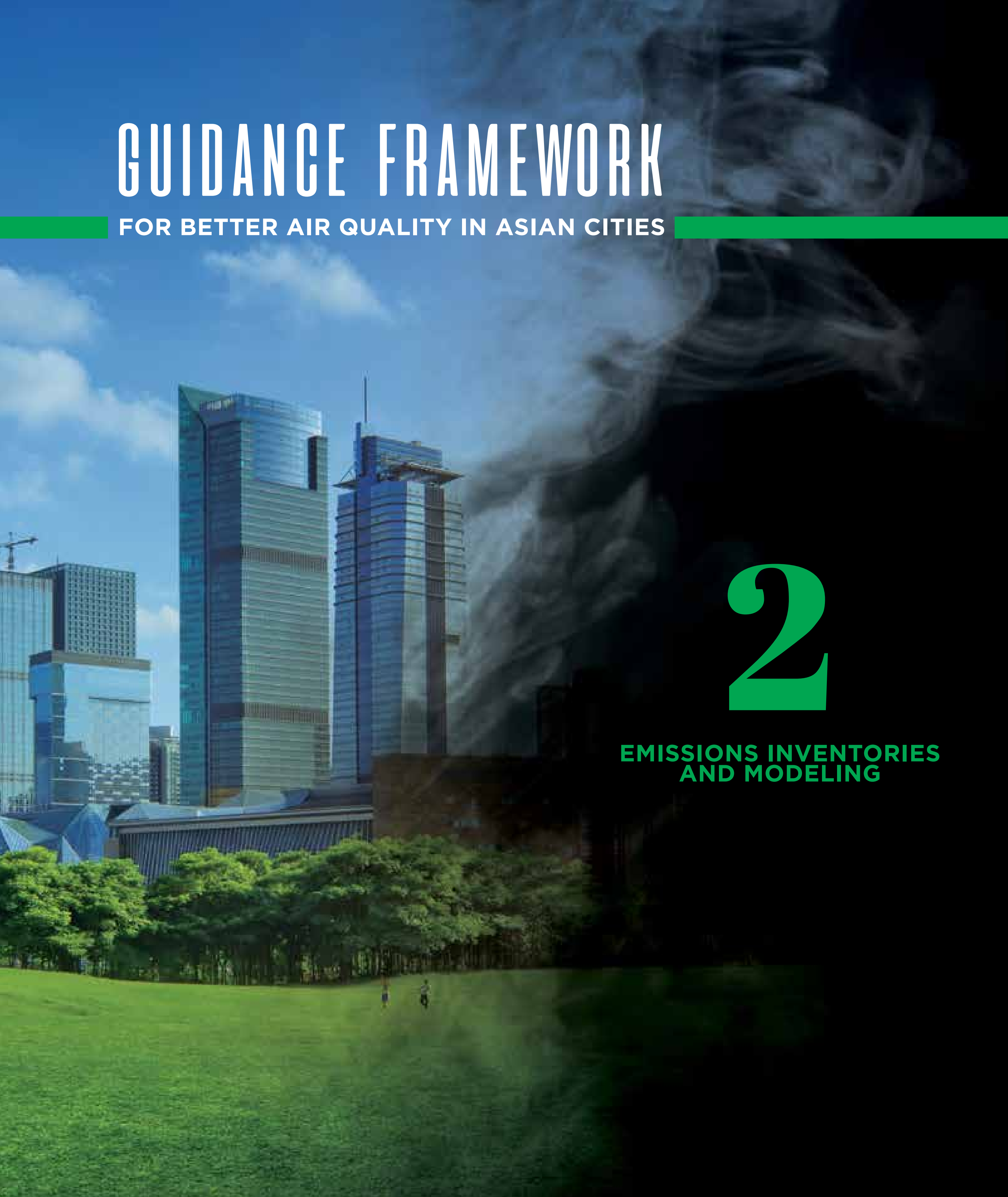
GUIDANCE FRAMEWORK

FOR BETTER AIR QUALITY IN ASIAN CITIES



2

EMISSIONS INVENTORIES AND MODELING

Integrated Programme for Better Air Quality in Asia

UNEP

CLEAN AIR ASIA

GUIDANCE FRAMEWORK

FOR BETTER AIR QUALITY IN ASIAN CITIES

Guidance Area 2: Emissions Inventories and Modeling

Published by Clean Air Asia, 2016. "Guidance Framework for Better Air Quality in Asian Cities". Pasig City, Philippines.
ISBN: 978-621-95434-0-8

Photo credits: iStock, Shutterstock, Design Muscle Inc., Clean Air Asia, and Maria Katherina Patdu. Cover design by Meriam Otarra.

Disclaimer

The views expressed in this publication are those of the authors, Clean Air Asia staff, and management, and do not necessarily reflect the views of the Board of Trustees of the Clean Air Asia Center. The Clean Air Asia Center does not guarantee the accuracy of the data included in this publication and does not accept responsibility for consequence of their use.

The full contents of this publication do not necessarily reflect the views of the United Nations Environment Programme.

Citation

This publication may be cited as:

Clean Air Asia. (2016). Guidance Framework for Better Air Quality in Asian Cities. Pasig City, Philippines: Author.

Contact

Clean Air Asia Center
Unit 3505 Robinsons Equitable Tower
ADB Avenue, Pasig City, 1605 Philippines
Tel +632 6311042
Fax +63 2 6311390
center@cleanairasia.org

Clean Air Asia India Office
1st Floor, Building No.4
Thyagraj Nagar Market Lodhi Colony
110003, India
Tel +91 11 60120260
Fax +91 11 43850032
india@cleanairasia.org

Clean Air Asia China Office
11152, JianGuoMenWai
Diplomatic Residence
Compound, No.1 XiuShui Street,
ChaoYang District, Beijing, China,
100600
Tel/Fax:+86 10 8532 6972
china@cleanairasia.org

Country Networks in China, India, Indonesia, Nepal, Pakistan, Philippines, Sri Lanka, Malaysia, Vietnam

ABOUT THE GUIDANCE FRAMEWORK FOR BETTER AIR QUALITY IN ASIAN CITIES

The Guidance Framework is a voluntary and non-binding guidance document developed as an outcome of the biennial Governmental Meetings on Urban Air Quality in Asia, co-organized by Clean Air Asia and United Nations Environment Programme Regional Office for Asia Pacific (UNEP ROAP). It is an outcome of an extensive development process, which began in 2006 when the Long Term Vision for Urban Air Quality in Asia (LTV) was envisioned by representatives of environment ministries in the region. The LTV describes the desired state of urban air quality in Asian cities by 2030; the Guidance Framework serves as a guide for cities and countries to achieve this vision.
In 2016, the Guidance Framework was launched as a pioneering approach to resolve air pollution challenges at the local- and national-levels. Centered on identified priority areas of concern in air quality management in the region, the Guidance Framework provides cities and countries with development capacity indicators and recommended steps and actions to improve air quality.

The Guidance Framework serves as a cornerstone document of Clean Air Asia's Integrated Programme for Better Air Quality in Asia (IBAQ Programme), which supports countries and cities in implementing the Guidance Framework through a range of targeted interventions, including knowledge-sharing platforms to strengthen regional collaboration, capacity building activities such as trainings, study tours and city twinning, and technical assistance at both the national and subnational levels.

ABOUT CLEAN AIR ASIA
www.cleanairasia.org

Clean Air Asia is an international NGO established in 2001 as the premier air quality network for Asia by the Asian Development Bank, World Bank and USAID. Its mission is to promote better air quality and livable cities by translating knowledge to policies and actions that reduce air pollution and greenhouse gas emissions from transport, energy and other sectors.

Clean Air Asia became a UN-recognized partnership in 2007, its network spanning 261 organizations in 31 countries in Asia and worldwide, with nine country networks: China, India, Indonesia, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, and Vietnam. It is headquartered in Manila and has offices in Beijing and Delhi. Clean Air Asia leads efforts to enable Asia's more than 1000 cities to reduce both air pollution and CO_2 emissions, and thereby contribute to more livable and healthy cities with blue skies and a low carbon footprint. Clean Air Asia helps to reduce emissions, through policies, plans, programs, and concrete measures that cover air quality, transport and industrial emissions and energy use.

The Better Air Quality (BAQ) Conference is a flagship event of Clean Air Asia covering the key sectors of transport, energy and industry, with a particular emphasis on government policies and measures. Policymakers, practitioners and industry leaders meet at BAQ to network, innovate, learn, and share experiences. The biennial event was first held in 2002 and attracts close to a thousand participants from Asia and the rest of the world.

ABOUT UNEP

www.unep.org

The United Nations Environment Programme (UNEP) is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system and serves as an authoritative advocate for the global environment. UNEP work encompasses assessing global, regional and national environmental conditions and trends; developing international and national environmental instruments; and strengthening institutions for the wise management of the environment. UNEP's mission includes to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations.

CONTENTS

PREFACE

Air pollution is now considered the world's largest environmental health risk. There have been a number of global efforts calling for air pollution actions in recent years. These global calls for action on air pollution strengthen regional and national initiatives and highlight the need to prioritize addressing this issue through a collaborative and integrated approach.

In 2006, the First Governmental Meeting on Urban Air Quality in Asia[1] recognized the need for guidance in implementing a Long Term Vision for Urban Air Quality in Asia, which describes the desired state of urban air quality management in Asian cities. During the Third Governmental Meeting, environment ministries from the region identified key challenges they are facing to improve urban air quality.

To set the way forward in achieving the vision for cleaner air, Clean Air Asia led the development of the Guidance Framework for Better Air Quality in Asian Cities (Guidance Framework) to address the needs and challenges in the region. It aims to provide a recognized guidance on improving urban air quality and is organized around priority areas of concern in the region, which were translated into key guidance areas with roadmaps on how to progress in a step by step manner.

This voluntary, non-binding document consists of seven individually published chapters covering each of the Guidance Areas. Policy and decision makers in Asia, as well as other relevant stakeholders, can use one or a combination of the Guidance Framework chapters to develop local roadmaps or action plans depending on their priority areas of concern.

The Guidance Framework consists of seven main books with these titles:

- Introduction
- Guidance Area 1 - Ambient air quality standards and monitoring
- Guidance Area 2 - Emissions inventories and modeling
- Guidance Area 3 - Health and other impacts
- Guidance Area 4 - Air quality communication
- Guidance Area 5 - Clean air action plans
- Guidance Area 6 - Governance

These guidance areas come with an Information Sourcebook, which is a compilation of resources to support the implementation of Guidance Framework roadmaps. There is also an accompanying training course on Guidance Framework implementation, which is available online in the Clean Air Asia website and Integrated Programme for Better Air Quality (IBAQ Programme) website: www.cleanairasia.org/ibaq

The Guidance Framework was developed together with a team of international and regional experts and practitioners and has undergone an extensive review process through the Governmental Meetings and the involvement of external reviewers. The draft document was also shared in a number of international events, including the Asia Pacific Clean Air Partnership (APCAP) Joint Forum organized by UNEP ROAP in November 2015. The Guidance Framework was welcomed by participants from 24 countries in Asia and the Pacific, involving environment ministries, intergovernmental organizations, non-governmental organizations, and experts.

1 Governmental Meetings on Urban Air Quality in Asia are biennial meetings organized by the United Nations Environment Programme Regional Office of Asia and the Pacific (UNEP ROAP) and Clean Air Asia that convene environment ministries with the aim to harmonize approaches across the region in tackling air pollution and related fields.

ABBREVIATIONS

ACAP	Asia Center for Air Pollution Research
AQM	Air Quality Management
AQSM	Air Quality Simulation Model
BC	Black Carbon
CAAP	Clean Air Action Plan
CAM	Crustal + Alluvial + Marine Constituents
CAMx	Comprehensive Air Quality Model with Extensions
CH_4	Methane
CMAQ	Community Multi-Scale Air Quality
CMB	Chemical Mass Balance
CPCB	Central Pollution Control Board
CO	Carbon monoxide
CUACE	Chinese Unified Atmospheric Chemistry Environment
DEFRA (UK)	Department for Environment, Food, and Rural Affairs
EAGrid	East Asian Air Pollutant Emission Grid Database
EC	Elemental Carbon
EEA	European Environment Agency
EF	Emission Factor
EI	Emissions Inventory
EPD (Hong Kong)	Environmental Protection Division
GAPF	Global Atmospheric Pollution Forum
GHG	Greenhouse Gas
HC	Hydrocarbons
HDV	Heavy Duty Vehicles
HFCs	Hydrofluorocarbons
HTSVE	High-Temporal Spatial Resolutions Vehicle Emissions Inventory
IPCC	Intergovernmental Panel on Climate Change
JTOP	Japan Auto-Oil Program
LDV	Light Duty Vehicles
MM5	Mesoscale Meteorological Model
MOE (New Zealand)	Ministry of Environment
MOEJ	Ministry of the Environment of Japan
NAQPMS	Nested Air Quality Prediction Model System

NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
NMVOCs	Non-Methane Volatile Organic Compounds
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
PATH	Pollutants in the Atmosphere and their Transport over Hong Kong
PM	Particulate Matter
PM_{10}	Particulate Matter (≤ 10 micrometers in diameter)
$PM_{2.5}$	Particulate Matter (≤ 2.5 micrometers in diameter)
PFCs	Perfluorinated Compounds
PMF	Positive Matrix Factorization
PRD	Pearl River Delta
QA	Quality Assurance
QC	Quality Control
REAS	Regional Emissions Inventory in Asia
RIAS	Rapid Inventory Assessment Technique
SA	Source Apportionment
SF_6	Sulfur hexafluoride
SEI	Stockholm Environment Institute
SIA	Secondary Inorganic Aerosols
SMOKE	Sparse Matrix Operator Kernel Emissions Processing System
SOP	Standard Operating Procedure
SO_2	Sulfur dioxide
TC	Total Carbon
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
VKT	Vehicle Kilometers Travelled
WRF	Weather Research and Forecast Model


VIỆT NAM

To develop **emissions inventory** and apply source apportionment and dispersion modeling techniques to **guide clean air action plans** and related environmental policies; **strengthening** air quality management and the **basis** for subsequent evaluation of the **effectiveness** of measures to protect **human health** and the **environment**.

CHAPTER 3

GUIDANCE AREA 2: EMISSIONS INVENTORIES AND MODELING

3.1 Introduction

This guidance area addresses the issues of developing an accurate and reliable emissions inventory (EI) which can be used as input to dispersion models in order to estimate exposure of human populations and the environment. Information from EIs are also important for understanding air pollution sources to draw up control measures to mitigate industrial, transport, and residential emissions and achieve compliance with emission standards. Source apportionment (SA) is a science-based approach to assess the contribution of emissions of specific source types to air pollutant concentrations at receptor sites. The guidance area also discusses the issues and challenges in Asian cities and regions and develops a roadmap and recommendations on how to implement effective approaches to resolve the challenges.

3.1.1 Objective

To develop EI and apply SA and dispersion modeling techniques to guide clean air action plans (CAAPs) and related environmental policies; strengthen air quality management (AQM) and the basis for subsequent evaluation of the effectiveness of measures to protect human health and the environment.

This **guidance area** is **important** in air quality management since only a quantitative **knowledge** of the emissions from **air pollution sources** allows mitigating **air pollutant concentrations** and, correspondingly, **avoiding health and environmental impacts** by reducing emissions via appropriate **control measures**.

3.1.2 Role of emissions inventories, source apportionment and modeling in air quality management framework

3.1.2.1 Emissions inventories and source apportionment

This guidance area is important in AQM since only a quantitative knowledge of the emissions from air pollution sources allows mitigating air pollutant concentrations, and, correspondingly, avoiding health and environmental impacts by reducing emissions via appropriate control measures. Holistically, an effective AQM requires a process of continual improvement in knowing where pollution is coming from and how much each of the sources is contributing to the ambient air pollution. For this reason, in an area of concern (i.e. area of non-attainment of air quality standards), it has to be assessed which sources are the most relevant ones for which the reduction of emissions will lead to a significant decrease of pollutant concentrations. Two approaches used to resolve this task are EI and SA.

An EI is a listing, by source, of the amounts of air pollutants – including criteria pollutants, greenhouse gases (GHGs), volatile organic compounds (VOCs), among others – actually or potentially discharged into the atmosphere of a community during a given time period (Organisation for Economic Co-operation and Development [OECD]), 2001; European Environment Agency [EEA], 2013; Stockholm Environment Institute [SEI], 2008). The EEA considers EI as a valuable tool to help define priorities and set specific objectives for AQM policies and guidance mechanisms, to help assess the potential health and environmental impacts and consequently, to estimate the costs of control and benefits of avoided health and environmental impacts [See *Guidance Area 3 on Health and other impacts*] (EEA, 2013). Emissions inventories facilitate assessment and prioritization of long-term reduction measures for estimated future emissions as well as target emission sources. The compilation of EIs can be accomplished at the national level, or it can be a composite of emissions obtained at smaller geographical scales such as a municipality or city (SEI, 2008).

Information from EIs can be used to establish emission trends (if EIs are routinely compiled) and determine hotspots and exposure areas by simulating air pollutant concentrations via dispersion models (United States Environmental Protection Agency [USEPA], 2014a). Air pollutant concentration maps, along with data on population density and baseline information on health outcomes, could guide policymakers to design and implement regulations and CAAPs [See *Guidance Area 5 on Clean air action plans*].

There are two approaches in establishing EI: top-down and bottom-up approaches. The top-down EI approach uses national- or regional-level emission estimates allocated to a city, area, or grid according to surrogate parameters (i.e. population, employment, energy consumption, resource use, vehicle number, etc.), typically used when local data are not available and resources are limited (SEI, 2008). Activity rate is derived from international, national, regional, or local level statistical information on source and process characteristics. Temporal change is estimated using allocation of the total amount of emissions according to hours of activity and operation of each source. An example of a top-down EI approach is presented in **Annex II-A of the Information Sourcebook.**

The bottom-up EI approach, on the other hand, gathers information from individual sources, processes, activity rates and their levels, and subsequently estimates emission factors (EFs). Emission factors are the average rate of emission of a pollutant per unit of activity for a given source. The process requires more financial resources to implement, but results to more accurate estimates than the top-down approach (SEI, 2008). Available information sources for EFs are tabulated in **Annex II-A of the Information Sourcebook.**

There are significant challenges in EI approaches that have to be taken into account in order to assess an EI's reliability (See Section 3.3). Once a reliable EI has been achieved, dispersion modeling is then used to estimate ambient air pollutant concentrations at receptor sites. The dispersion modeling tool – depending on the model systems used – can provide information on contributions of emission sources to ambient air pollutants measured at a site. Owing to the complexity brought about by physical and chemical properties of air pollutants, coupled with meteorological and geographical characteristics of sampling domains, certain levels of uncertainty of modeling results would be expected.

Emissions inventories provide information on emission loads of primary air pollutants that are directly released from different source categories (shares of pollution loads) in an inventory area. It does not provide information on sources located from outside the domain of emissions nor information on secondary pollutants that are formed in the atmosphere. Emissions inventories could not directly provide information related to contributions from each source category to ambient air pollution at a receptor site.

Source apportionment by receptor modeling, can provide contributions of different source categories to ambient levels of some pollutants. This information is necessary for the development of sector-specific CAAPs [See *Guidance Area 5 on Clean air action plans*]. It involves ambient sampling and measurement of atmospheric particles and/or VOCs, semi-VOCs, followed by laboratory analyses to characterize the chemical composition. Such information could help in the validation and improvement of the available EI data (Environment Canada, 2013). Chemical speciation helps to understand the properties of the pollutants at receptor site(s) and to identify the source types of pollution, including sources that are not readily identified in preliminary EIs.

Three SA approaches or techniques are in use: (1) source emission shares of pollution load in an area based on EI, (2) SA based on dispersion modeling, and (3) SA based on receptor modeling. Source apportionment based on EI provides information on contribution of different source categories (e.g., power plants, vehicles) and sub-categories (e.g., diesel-powered vehicles, two-wheelers, passenger cars within vehicle category) to total emission loads of identified pollutant(s). On the other hand, dispersion models are used to estimate source contribution to ambient air concentration of identified pollutant(s). While dispersion models use emissions data, meteorological data, and chemical transformation to estimate pollutant concentrations, receptor models use chemically-speciated ambient pollutant concentration

data and source profiles to estimate source contribution to ambient levels measured in receptor sites. Receptor models are normally used for SA of pollutants found as mixtures in ambient air with contributions from different sources (i.e. PM, VOCs, or semi-VOCs). In the process, the portion of secondary air pollutants attributed to regional and long-range pollution transport may also be apportioned.

The three approaches mentioned above have their own limitations and challenges, and should therefore be used complementarily. An overview of the properties of the methods is presented in **Annex II-A of the Information Sourcebook.** Each approach can mutually validate outputs and lead to more robust results. As an example, measurements conducted close to the sources can validate EFs while compiling source profiles. Results from SA by receptor modeling can be used to identify the missing sources in an EI.

Figure 3.1 illustrates the links between EI and SA methods. Ambient monitoring data can, in turn, help validate dispersion models by comparing simulated concentrations with measured ones. A combination of these models can therefore facilitate a strong pollution control strategy (Guttikunda, 2011).

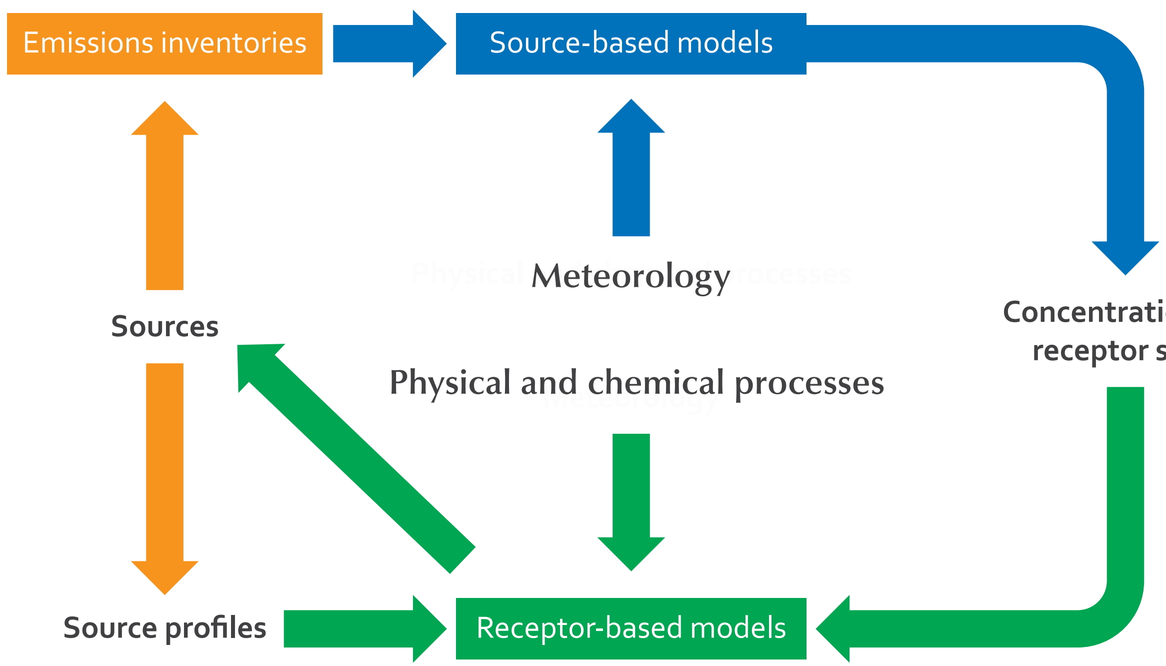


Figure 3.1 Schematic representation of how top-down and bottom-up SA approaches are linked

Adapted from European Commission, 2014

Both emissions inventories and source apportionment **have their own limitations** and challenges, and should therefore be **used complementarily**.

3.1.2.2 Receptor-based and source-based modeling

As Figure 3.1 demonstrates, the linkage between EI results and pollution concentration at receptor sites is provided by source-based (dispersion) models on the one hand and receptor-based models on the other. Prediction of air pollutant concentrations by EI and dispersion modeling are verified by air quality monitoring results [See *Guidance Area 1 on Ambient air quality standards and monitoring*]. Monitoring also comes in when a receptor-based model identifies the types of sources leading to SA. Predicted concentrations also allow the estimation of health and environmental impacts [See *Guidance Area 3 on Health and other impacts*]. The same applies for measuring exposures (concentrations) at receptor sites. Emissions inventories and SA are important ingredients of CAAPs [See *Guidance Area 5 on Clean air action plans*] and their scope must be regulated by legislation. Control measures based on a reliable EI must be implemented by means of appropriate governance [See *Guidance Area 6 on Governance*].

Receptor-based modeling

Receptor-based approaches have been termed "receptor models" (USEPA, 2013a). They are mathematical or statistical procedures that use source profiles as well as physical and chemical characteristics of pollutant gases and particles at sources and receptor sites in a given area to estimate the presence and fraction of source contributions at receptor locations. Unlike dispersion models, receptor-based models do not require pollutant emissions, meteorological data, chemical transformation, and deposition mechanisms to estimate contribution of sources to receptor concentrations (USEPA, 2013a). Receptor-based models cannot identify the contribution of individual sources if several sources of the same type and emission characteristics (e.g. two or more power plants, two or more cement plants) are located in the area considered. Receptor-based models complement dispersion models instead by apportioning concentrations at receptor sites to distinct source types. An overview of receptor-based model types is described in **Annex II-B of the Information Sourcebook.**

Dispersion or source-based modeling

The dispersion model, also known as air quality simulation model (AQSM) or source-based model, is a numerical technique or methodology for estimating air pollutant concentrations in space and time. Data inputs to dispersion models consist mainly of emissions, meteorological, and topographical data. The parameters that constitute a dispersion model include (SEI, 2008): a) emissions sources, including their locations and emissions rates; b) receptor locations; c) meteorological specifications; d) deposition rates, if these will be considered; and e) output specifications or what kind of values are required (e.g., average concentrations).

Dispersion models can provide valuable estimates such as the concentrations of pollutants that are too difficult or expensive to measure, influence of geophysical factors on dispersion, among others. With the wealth of technical estimates they can provide, dispersion models can contribute in designing ambient air monitoring networks [See *Guidance Area 1 on Ambient air quality standards and monitoring*]. They can also be useful in evaluating the impact and efficiency of policy and mitigation strategies [See *Guidance Area 5 on Clean air action plans*]. Lastly, dispersion models can contribute in forecasting air pollution episodes and assessing the risks of and tracking originating sources of accidental hazardous substance releases (New Zealand Ministry of Environment [MoE], 2004). The major objective of dispersion models is to simulate air pollutant concentrations at receptor sites, starting from reliable emission estimates and using monitored or modeled meteorological data. This can be performed at costs much lower than those for air quality monitoring. Figure 3.2 illustrates that dispersion modeling complements air quality monitoring and can even replace monitoring activities provided an accurate and reliable EI exists. A comparison of air quality monitoring and modeling capabilities are provided in **Annex II-A of the Information Sourcebook.**

With the wealth of **technical estimates** they can provide, dispersion models can **contribute** in designing ambient **air monitoring networks**. They can also be **useful** in evaluating the **impact and efficiency** of policy and mitigation strategies.

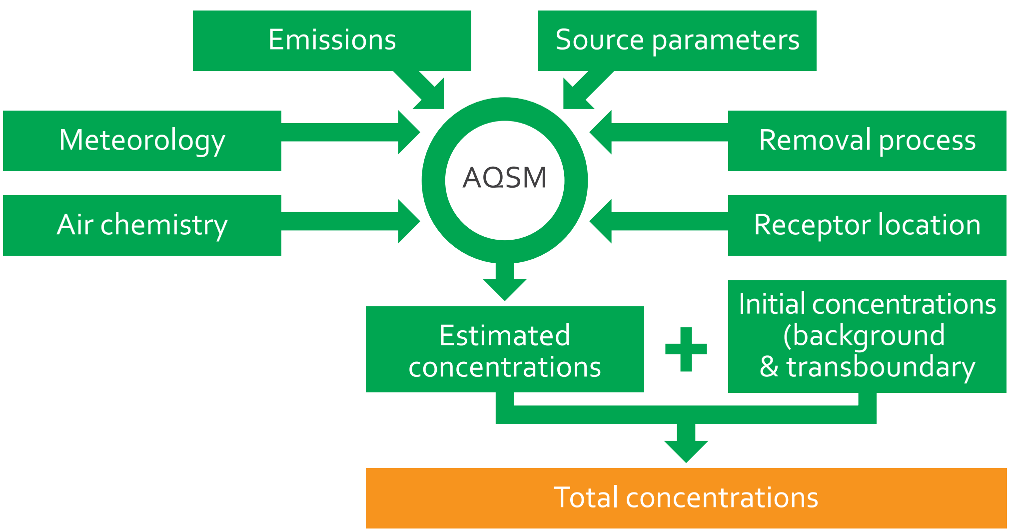


Figure 3.2 Basic components of dispersion modeling

Source: SEI, 2008

3.2 Stages of emissions inventory, source apportionment, receptor and dispersion modeling development

Strengthening the capacity for quantification of pollutants, determination of source contributions, and evaluation of existing and future emissions help shape and define policies for improving air quality. Such capacity also helps in the assessment of compliance with national and international targets, and evaluation of the effectiveness of measures to protect human health and the environment. As a starting point, Table 3.1 presents indicators that would aid cities in identifying their current state of AQM development for EI, SA, and air quality modeling.

The key indicators that should be considered in progressing from underdeveloped to fully developed stage include:

- Capacity for conducting EI (i.e. frequency, scope, and approach)
- Capacity for conducting SA (i.e. availability of source profiles and scope)
- Verifying accuracy and reliability of EI and SA
- Capacity for applying elementary and/or sophisticated dispersion models

"**Strengthening** the capacity for **quantification** of pollutants, determination of **source contributions**, and **evaluation** of existing and future **emissions** help shape and **define policies** for **improving** air quality."

Table 3.1 Stages of emissions inventory, source apportionment, receptor and dispersion modeling

Stages	Indicators
Underdeveloped	No EI has ever been compiled There is no ambient air quality monitoring system. Particulate matter (PM) source profile data are not collected and receptor-based SA is not conducted Pollution dispersion has not been modeled/mapped
Developing	An initial EI or a rapid EI is available for criteria and/or other air pollutants covering major sources (e.g. those using the Global Air Pollution Forum (GAPF) EI Methodology or the WHO Rapid Inventory Assessment (RIAS) approach) An ad hoc EI may have been compiled using a top-down EI approach with default EFs and surrogate activity data EI results are not reviewed nor validated. Quality assurance/quality control (QA/QC) manuals for EI are developed PM source profile data are not collected and receptor-based SA is not conducted Dispersion modeling is not conducted but capacity is being developed for dispersion model applications[2] Ambient air quality monitoring and meteorological monitoring systems are being developed and are being considered for emission-exposure-impacts modeling

2 Applications include exposure estimates and selection of appropriate AQ monitoring sites

Stages	Indicators
Emerging	EI for criteria pollutants covering major sources as well as sources with increasing importance are regularly compiled based on a mixed top-down and bottom-up approach Default EFs and EFs obtained from local academic research are used There are initial plans to use more sophisticated or higher tier EI approaches, such as those by USEPA and EEA EI review process and results are considered and or utilized in AQM policy development, implementation, and evaluation Rapid EIs for toxic pollutants are being planned Initial attempts to validate EIs are made Receptor-based SA for PM and VOCs/semi-VOCs is conducted on an ad hoc basis by research/academic institutions PM source profile from external and local literature/studies are used to describe source profiles for major local sources. Attempts are made to validate receptor-based SA QA/QC procedures for EI and SA are regularly implemented Simple steady-state dispersion models are used to estimate pollutant concentrations using meteorological measurement inputs Non-steady state dispersion models are beginning to be explored/initiated SA and dispersion modeling results sometimes align EI, SA, and dispersion modeling results are used in identifying air quality policies or measures

Stages	Indicators
Maturing	EI for air pollutants are systematically and routinely compiled (with an initial inclusion of toxic pollutants) using a bottom-up approach, local EFs and some actual emissions measurements. All relevant sources (major and emerging) are covered. EI methodologies that are more sophisticated than those of GAPF and WHO RIAS are being applied. EIs make use of higher tier activity data EIs are reviewed and validated regularly. QA/QC procedures are routinely implemented EI results are used as important inputs in air quality policy development, implementation, and evaluation Receptor-based SA for PM and VOCs/semi-VOCs is conducted using different approaches by academe and government agencies/research institutions Receptor-based SA for key toxic pollutants is initiated PM source profile data needed for Chemical Mass Balance (CMB) are collected mostly from local information sources and assumed to describe source profiles for the majority of local sources. Air quality is monitored at several receptor sites during all seasons and receptor-based SA is conducted using CMB, UNMIX and Positive Matrix Factorization (PMF) models, covering both general and episodic conditions. An integrated database on (i) sources in the area, (ii) source profiles, and (iii) ambient receptor site measurements is developed SA is conducted on both general conditions and pollution episodes. Results from receptor-based SA and dispersion model are increasingly aligned[3] Initial attempts to validate SA are made More advanced steady state dispersion models or even non-steady state models are used for exposure estimation using local data[4] Dispersion models incorporate local land use and emissions profile data. Local AQ monitoring and other measured data are used for model verification and performance evaluation The role of EI and SA in air quality management is understood and appreciated by policymakers and the public in general EI, SA, and dispersion modeling results are also used to review or assess progress or achievements of AQ policies or measures Capacity to forecast future emissions and dispersion is being developed

3 If results from both models do not align, cities would go one stage back. This also applies to Maturing and Fully developed stages.
4 Such as land use, topographical data, and meteorological data

Stages	Indicators
Fully developed	EIs for criteria, toxics, and other air pollutants are compiled with a bottom-up approach at predefined intervals (e.g., annually or every two years), covering all types of relevant sources. Emissions are measured cost-effectively and as regularly as possible QA/QC procedures are routinely implemented and regularly reviewed and updated EI validation is performed as a routine procedure without exception EI results are used as important inputs in air quality policy development, implementation, and evaluation Receptor-based SA studies for PM and VOCs/semi-VOCs are routinely performed by academe and government/research institutions Receptor-based SA for key toxic pollutants is routinely performed PM data for SA studies are collected primarily from local information sources to represent more accurately the majority of local pollution source profile Air quality is monitored at several receptor sites during all seasons to cover both general and episodic conditions. Receptor-based SA is conducted using CMB, UNMIX and PMF models. An integrated database on sources in the area, source profiles, and ambient receptor site measurements is in place and updated routinely SA model validation and performance evaluation use local data Results from receptor and dispersion models are run in parallel. Reasons for any divergent results are identified All models (steady state, non-steady state, photochemical) are routinely applied and validated to estimate exposure, using routinely updated meteorological data and local data Dispersion models are developed and used with incorporation of local land use and emissions profile data. Local measurement data is used for model verification and performance evaluation. New dispersion models more appropriate for the local situation are developed if needed. Localized air quality models or locally-developed models when available are updated as regularly as possible EI, SA, and dispersion models are used in an integrated manner Capacity to forecast future emissions and dispersion is well established Dispersion modeling results are used for studies that measure impacts of air pollution on public health and the environment

"One major **institutional problem** in developing emissions inventories, source apportionment and air quality modeling is the **lack of an integrated action plan** and strategy, especially the **poor linkage** among source inventory, emission, air quality monitoring, meteorological situation and receptor-based modeling."

3.3 Issues and challenges

Asian cities are faced with a number of institutional, management and technical, and financial issues and challenges, which differ for each stage of development. As the stage advances from underdeveloped to fully developed, fewer issues and lesser challenges are noted.

Institutional

An institutional framework with specific focus on the development and application of EI and SA techniques is not available. Emissions inventories and SA are used mostly for academic purposes; there is no mechanism to make use of these techniques or available information for policy inputs.

One major institutional problem in developing EI, SA, and air quality modeling is the **lack of an integrated action plan and strategy**, especially the poor linkage among source inventory, emission, air quality monitoring, meteorological situation, and receptor-based modeling. As a result, there is a lack of coordination among different agencies, and data in their custody are not easily available. There is also limited transboundary collaboration to address air pollution dispersed over neighboring municipalities/provinces. Lastly, there is very limited stakeholder capability and participation in development of EI, SA, and air quality modeling. Local stakeholders and the public may not be fully aware of the usefulness of these techniques and often do not show adequate interest in participating in the necessary activities.

Management and Technical

- **Policy and decision making processes are limited** and constrained by lack of reliable EI and sufficient information for SA to guide CAAPs development.

- **Only a limited number of reliable EI and SA studies are extant**. There is also a particular scarcity of studies comparing the results of different receptor-based models.

- **Studies concerning the linkage of air pollution EI to climate change are limited.**

- **Poor data/information availability and transparency on EI and SA**. Input data uncertainty is a problem both for EI and SA. Outliers and anomalous values contribute to input data uncertainty if they are not identified (Karagulian & Belis, 2012). The same is true if there are no established criteria on how to treat values of concentrations below the detection limit in SA. Estimation of values below the detection limit has a high impact on the quality of results since the uncertainty of estimated values is higher than that of measured ones.

- **Difficulty in acquiring reliable local data, especially for source activities**. In bottom-up inventories, it may be difficult to acquire reliable local data due to multiplicity and complexity of emission sources and limited technical resources. Available secondary data also may not be up-to-date. Default EFs are often used, without much analysis on applicability or uncertainty. These practices may not provide reliable estimates.

- **Lack of quality assured data for developing and updating EI**. In most areas, secondary data, particularly on source emission measurements, may not be of acceptable quality, and ascertaining the quality is difficult due to lack of transparency. At point sources, emission measurement are often performed at the bottom of a stack and may not be representative of the emissions at the top of the stack.

- **Some EIs do not include future projections or, if they do, projections are inaccurate** due to lack of understanding of dynamic changes of economy and the development process in a certain area.

- **Complexity of more sophisticated EI calculations** which require technical knowledge of emission sources and processes.

- **Uncertainties in EI and SA and difficulties in their estimation**. Currently, a high-resolution regional emission inventory takes years to develop, which leads to air quality modeling outputs that are based on outdated emission information. Significant uncertainties would henceforth be associated with the simulation results and the derived AQM plans. Factors leading to uncertainties in EI are outlined in **Annex II-A of the Information Sourcebook**. Precision in air quality dataset measured by sample-specific uncertainties are used in various multi-linear receptor models but the expense involved with repetitive field measurements and laboratory analysis for air quality monitoring renders this approach practically infeasible (Hopke, 2003).

- **Model performance uncertainty**. Receptor-based models rely on the mass conservation principle between source and receptor (Karagulian & Belis, 2012). All receptor models make the same assumptions, e.g., on unvaried compositions of source emissions, non-reactivity of chemical species, and other characteristics (Watson et al., 2002).

- **Analytical uncertainty.** Sources of analytical uncertainty in SA modeling include the usual uncertainties of chemical analysis of samples (Eurachem/CITAC, 2012).

- **Lack of local source profiles**. Significant differences in fuel composition and control technology exists, hence, the source profile in Asia has a potentially large difference from those in North America and Europe.

- **Necessity of model validation**. The predicted results from a dispersion model must be validated against monitoring data (U.K. Department for Environment, Food and Rural Affairs [DEFRA], 2009). The predicted results from a dispersion model may differ from measured concentrations for a large number of reasons.

Financial

The development of EI and SA is resource-intensive. Choosing the methodology for the development and implementation of EIs depends on the availability of data, time, manpower, and financial capabilities (British Columbia Ministry of Environment Air Quality, 2013). While the application of air quality models is a relatively cheap option as some of these models have been developed by and tested in some countries in transition such as China and India, they still need reliable EI as well as meteorological data to guide CAAPs and policy measures. With many other pressing demands in developing countries and cities, obtaining adequate financial resources for AQM in general is a major issue. City-level initiatives often need to be aligned with the national development agenda to gain full financial support from the national government.

3.4 Roadmap for emissions inventory, source apportionment, receptor and dispersion modeling

To progress towards a fully developed system of EI, SA and dispersion modeling within an integrated and rational AQM approach, there are a number of management and technical steps at each stage that the city – and if applicable, provincial or national authorities – should follow. These are compiled for each stage in Table 3.2.

Table 3.2 Steps to follow to implement a roadmap for emissions inventory, source apportionment and dispersion modeling

Developmental stages	Steps to follow
Underdeveloped	**Management Process** • Identify potential stakeholders from different levels of government and from other non-government, academe, and private sectors • Ensure buy-in of decision makers from the identified stakeholders through seminars, workshops, and policy papers that encourage awareness on importance of EI and SA studies on AQM • Establish a working group of technical experts and an advisory group of policymakers and decision-makers • Assess existing technical capacity of working group and identify training or resource needs • Research around the region for case studies and approaches that may be adapted for local implementation of EI or SA • Secure funding from internal (in-country) and external (international) sources **Technical Process** • Identify and secure activity data needed using rapid assessment procedures (GAPF, 2012; WHO, 1993) • Determine the objective, design and scope, extent of details and pollutants for EI development and implementation work plans. Refer to basic considerations in Box 3.1 • Build the technical capacity of compiling EI for criteria pollutants for main source categories by top-down approach with statistical information, default EFs, and surrogate activity data • Participate in regional EI networks (i.e. Acid Deposition Monitoring Network in East Asia [EANET]) and assess methods that may be adapted for local EI • Build capacity for dispersion model applications for local air quality simulation using the top-down EI • Develop quality assurance/quality control (QA/QC) guidance manual for EI

Developmental stages	Steps to follow
Developing	**Management Process** • Involve more stakeholders • Establish a cooperation framework by the local or national government among the working group (i.e. technical team, data providers), advisory group, and experts to set up a stable EI system • Develop a sustainable data collection plan with relevant organizations producing data inputs for EI • Develop a review process involving experts and stakeholders for continual improvement in EI for use in AQM policies • Enhance technical capacity for EI through sustainable training **Technical Process** • Build the capacity for compiling mixed top-down and bottom-up EI for criteria and other pollutants • Evaluate the applicability of default EFs and EFs obtained from academic and/or other countries' research • Assess capacity to use more sophisticated EI approaches (i.e. USEPA, EEA) • Adapt applicable methods used in regional EI networks and disseminate results • Develop a review process and conduct regular validation of EI to ensure good data quality • Prepare and implement monitoring plan (sampling locations, schedule, among others) for collection of ambient samples, and arrange for necessary monitoring and analytical instruments. Refer to available literature (e.g., CPCB, 2006; 2007a) • Identify laboratories within the region capable of doing analysis for major PM components, e.g. ions, elements, organic carbon (OC) and elemental carbon • Collect ambient sample(s) and send for analysis for key chemical constituents to laboratories (in-country or abroad) with the appropriate technical capacity • Build capacity for initial SA for PM and VOCs/semi-VOCs on an ad hoc basis or by research/academic institutions • Evaluate applicability of any PM source profiles available (external or from local studies) for major local sources • Initialize characterization of local source profiles and apply in CMB runs • Use CMB model to determine SA, and compare results with similar reported studies • Develop QA/QC procedures for SA • Secure appropriate receptor model software (Box 3.2) and source profiles (e.g., SPECIATE [USEPA, 2014b], CPCB, 2010) • Initialize use of dispersion models for exposure (concentration) simulation • Analyze the correlation of SA results from dispersion and receptor-based models, and provide recommendations to improve their alignment • Develop and propose control measures on the basis of findings from EI, SA and dispersion modeling

Developmental stages	Steps to follow
Emerging	**Management Process** • Set-up a framework for review and continual improvement of the EI and SA estimates, and organize long-term resources for the same • Engage and ensure buy-in of all relevant stakeholders in implementing sustainable data collection plan • Enhance technical capacity through sustainable training • Identify and prioritize resource, equipment and infrastructure investments necessary to establish local capacity for chemical speciation analysis **Technical Process** • Enhance capacity for routine compilation of EI for criteria pollutants (with initial inclusion of toxics and GHGs) • Enhance capacity for bottom-up EI approach using available local EFs and/or utilize actual measurements for several main emission sources • Use EI results as basis for development of AQM policies, implementation and evaluation • Plan for use of rapid EIs for toxic pollutants • Build capacity to contribute to regional EI studies • Continually improve review processes and QA/QC procedures for EI and SA • Enhance capacity for SA using more sophisticated approaches • Conduct SA by at least two receptor models, e.g. CMB and PMF • Conduct SA using available local profiles needed by CMB; use international profiles for other sources • Identify a few key sources and develop local source profiles • Plan for conducting SA for toxic pollutants (i.e. PAHs, dioxins) • Conduct sensitivity analysis using different sets of source profiles available internationally • Conduct PM speciation measurement and analysis in a regular manner • Evaluate model outputs by statistical tools • Develop an integrated database on source and ambient pollution characteristics • Build capacity to use more advanced steady-state models and if possible, non-steady state models for exposure estimation using local data • Incorporate local land use and emission profile data • Validate modeling results by local measurement data • Evaluate alignment of results from receptor-based SA and dispersion models • Ensure use of EI, SA, and dispersion modeling findings to review or assess progress or achievements of air quality policies and measures

Developmental stages	Steps to follow
Maturing	**Management Process** • Set up a comprehensive framework for development of local, regional, and national-level EI and SA using local source profiles, and necessary infrastructure (e.g., laboratory, GIS-based database system) • Set up for review and continual improvement of EI and SA estimates • Make long-term provisions for required resources (i.e. human, financial, infrastructure) • Establish a mechanism for use of EI and SA for policy decisions • Continually enhance technical capacity through sustainable trainings and participation in knowledge sharing platforms **Technical Process** • Build the operations and management system of compiled bottom-up EI for pollutants and GHGs at pre-defined intervals (i.e. annually or every two years) using more refined EI approaches • Ensure capacity to participate in regional EI studies using refined EI approaches • Ensure regular update and review of standard operating procedures (SOPs) and QA/QC procedures for EI and SA • Enhance technical capacity for SA studies; collaborate with academe and other research institutions and explore more advanced methods • Complete local source profiles for majority of sources and maintain database for the same • Conduct receptor-based SA using a variety of models (i.e. CMB, UNMIX, PMF) • Collect PM speciation data covering spatial, seasonal variations and business as usual; as well as episodic scenarios • Use multiple SA techniques, conduct sensitivity analysis and disseminate peer reviewed results • Conduct regular audits of laboratory facilities and data quality checks for ensuring good SA estimates • Develop and continually update an integrated database of speciated data, source profiles, and ambient receptor site measurements • Conduct continuous PM speciation measurement and analysis, and update SA every year • Develop localized dispersion models and apply for SA at least one month per season • With factors leading to diverged results identified and resolved, ensure alignment of SA results from dispersion and receptor models for most of the time • Apply and validate all models (steady state, non-steady state, photochemical) routinely to estimate exposure • Improve local land use and emissions profile data for incorporation into dispersion models • Use EI, SA, and dispersion models in an integrated manner for AQM policymaking or evaluating policies • Build capacity to forecast future emissions and dispersion

Developmental stages	Steps to follow
Fully developed	**Management Process** • Set up an institutional framework for continual improvement of infrastructure including state-of-the-art laboratory facilities, techniques, documentation, and database management systems for EI and SA • Sustain use of EI and SA for policy decisions and feedback for improving EI and SA and specific scientific inputs • Ensure allocation of adequate and sustainable technical and financial resources • Ensure that all stakeholders are regularly involved **Technical Process** • Continually enhance the operations and management system of compiled EI for pollutants, toxics, and GHGs annually or every two years • Build and sustain the capacity for EI of toxic pollutants • Participate in studies that conduct regional EI • Explore capacity building opportunities for more sophisticated SA methods • Conduct SA for selected criteria and toxic pollutants regularly • Collect PM speciation data regularly covering trace and molecular marker species • Upgrade source profiles in CMB applications • Establish and continually assess data quality by EI validation and SA verification • Conduct SA using multiple SA techniques with comprehensive scientific analysis of the data and results • Organize international peer review and dissemination of results • Sustain enforcement of control measures • Sustain capability to apply steady-state, non-steady state and photochemical modeling • Enhance capacity for forecasting emissions and dispersion • Sustain an AQM system using inputs from EI, SA, and dispersion modeling to AQ policymaking and evaluation of effectiveness or impacts of AQ policies and measures

Box 3.1
Basic considerations in emissions inventory development

General planning considerations. The most important step in initiating an EI is determining the objectives from which major planning considerations need to be taken into account. Factors that need to be considered include:

- ultimate use of, background and basis for the inventory;
- identification of point, areas, and mobile source categories;
- responsibility for the inventory;
- staff and budget requirements/constraints;
- geographical coverage;
- selection of base year;
- variation of source emissions: daily, seasonal, annual;
- rule effectiveness;
- minimal source size;
- data collection methods;
- emission estimate approach, including selection of sources for EFs;
- status of existing EIs;
- inventory data handling system;
- QA/QC measures, including naming a QA coordinator; and
- use of the inventory for modeling purposes (e.g., as input to a photochemical dispersion model).

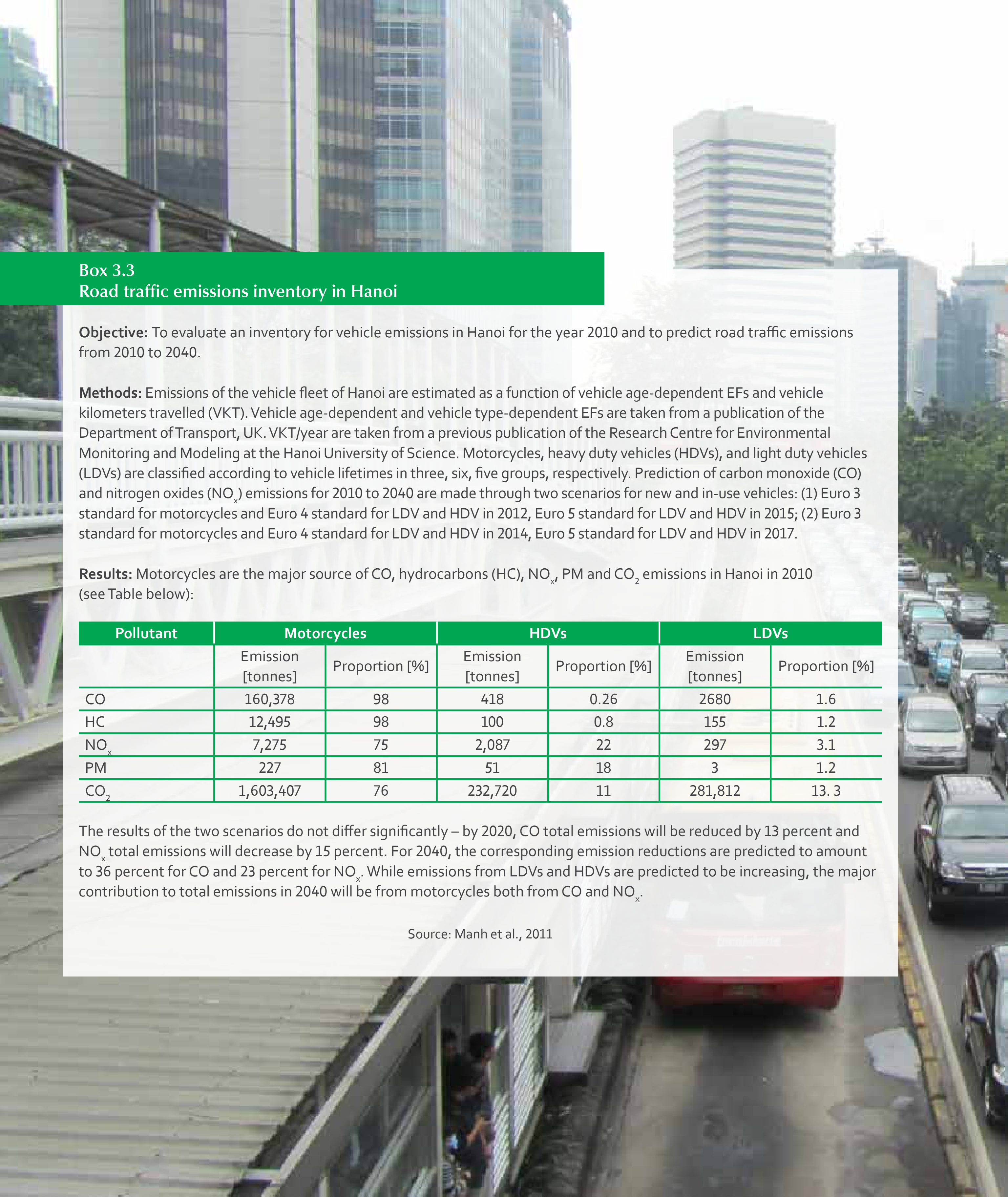
Source: SEI, 2008

Box 3.2
List of reference manuals for emissions inventory

The relevant manuals and guidebooks for EI, some of which provide EFs, are listed in the table below.

Manual/Guidebook	Website
Assessment of sources of air, water, and land pollution – A guide to rapid source inventory techniques and their use in formulating environmental control strategies. Part One: Rapid Inventory techniques in environmental pollution. By Alexander Economopoulos (WHO, 1993).	http://whqlibdoc.who.int/hq/1993/WHO_PEP_GETNET_93.1-A.pdf
Asia Center for Air Pollution Research. Guidelines for Developing Emission Inventory in East Asia (ACAP, 2011).	http://www.acap.asia/publication/pdf/em_inventory/em_guideline.pdf
Global Atmospheric Pollution Forum. Global Air Pollution Forum Emission Manual (GAPF, 2012).	http://sei-international.org/rapidc/gapforum/html/emissions-manual.php
Intergovernmental Panel on Climate Change. IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).	http://www.ipcc-nggip.iges.or.jp/public/2006gl/
New Zealand, Ministry of Environment. Good Practice Guide for Atmospheric Dispersion Modeling (MoE, 2004).	http://www.mfe.govt.nz/publications/air/good-practice-guide-atmospheric-dispersion-modelling
Stockholm Environment Institute. Foundation Course on Air Quality Management in in Asia: Emission, G Haq and D Schwela (eds.) (SEI, 2008).	http://www.sei-international.org/publications?pid=1087
Stockholm Environment Institute. The Forum air pollutant emissions inventory preparation manual. Version 5, November 2012 (SEI, 2012).	http://www.sei-international.org/gapforum/tools.php
United States Environmental Protection Agency. A complication of Air Pollutant Emission Factors (AP-42) (USEPA, 1995).	http://www.epa.gov/ttn/chief/ap42/index.html
India, Central Pollution Control Board. Air quality monitoring, emission inventory and source apportionment study for Indian cities – National Summary Report (CPCB, 2011).	http://cpcb.nic.in/FinalNationalSummary.pdf
India, Central Pollution Control Board. Conceptual Guidelines and Common Methodology for Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Indian Cities (CPCB, 2007b).	http://cpcb.nic.in/sourceapportionmentstudies.pdf

Detailed guidelines "Establishing emissions inventory, source apportionment and modeling for Asian cities" focused on management and technical processes are elaborated in **Annex II-B of the Information Sourcebook**. Case studies that demonstrate different stages of development of cities (Boxes 3.3 to 3.5) are also provided. Initiatives in Japan on general survey of emissions and EI for non-criteria pollutants (e.g. VOCs and GHGs) are described in Box 3.6, while regional EI databases and frameworks are described in Boxes 3.7 and 3.8. A case study on SA conducted by the CPCB in six Indian cities is described in Box 3.9. A comparison of receptor-based models (CMB, UNMIX and PMF for VOCs) in Beijing is described in Box 3.10. The complementary nature of EI and SA techniques, wherein SA results were used to validate EI in Hong Kong and the Pearl River Delta (PRD) Region is shown in Box 3.11.



Box 3.3
Road traffic emissions inventory in Hanoi

Objective: To evaluate an inventory for vehicle emissions in Hanoi for the year 2010 and to predict road traffic emissions from 2010 to 2040.

Methods: Emissions of the vehicle fleet of Hanoi are estimated as a function of vehicle age-dependent EFs and vehicle kilometers travelled (VKT). Vehicle age-dependent and vehicle type-dependent EFs are taken from a publication of the Department of Transport, UK. VKT/year are taken from a previous publication of the Research Centre for Environmental Monitoring and Modeling at the Hanoi University of Science. Motorcycles, heavy duty vehicles (HDVs), and light duty vehicles (LDVs) are classified according to vehicle lifetimes in three, six, five groups, respectively. Prediction of carbon monoxide (CO) and nitrogen oxides (NO_x) emissions for 2010 to 2040 are made through two scenarios for new and in-use vehicles: (1) Euro 3 standard for motorcycles and Euro 4 standard for LDV and HDV in 2012, Euro 5 standard for LDV and HDV in 2015; (2) Euro 3 standard for motorcycles and Euro 4 standard for LDV and HDV in 2014, Euro 5 standard for LDV and HDV in 2017.

Results: Motorcycles are the major source of CO, hydrocarbons (HC), NO_x, PM and CO_2 emissions in Hanoi in 2010 (see Table below):

Pollutant	Motorcycles		HDVs		LDVs	
	Emission [tonnes]	Proportion [%]	Emission [tonnes]	Proportion [%]	Emission [tonnes]	Proportion [%]
CO	160,378	98	418	0.26	2680	1.6
HC	12,495	98	100	0.8	155	1.2
NO_x	7,275	75	2,087	22	297	3.1
PM	227	81	51	18	3	1.2
CO_2	1,603,407	76	232,720	11	281,812	13. 3

The results of the two scenarios do not differ significantly – by 2020, CO total emissions will be reduced by 13 percent and NO_x total emissions will decrease by 15 percent. For 2040, the corresponding emission reductions are predicted to amount to 36 percent for CO and 23 percent for NO_x. While emissions from LDVs and HDVs are predicted to be increasing, the major contribution to total emissions in 2040 will be from motorcycles both from CO and NO_x.

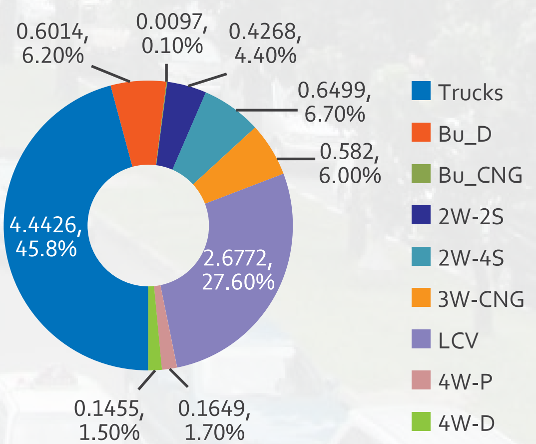
Source: Manh et al., 2011

Box 3.4
Emissions inventory for major cities in India

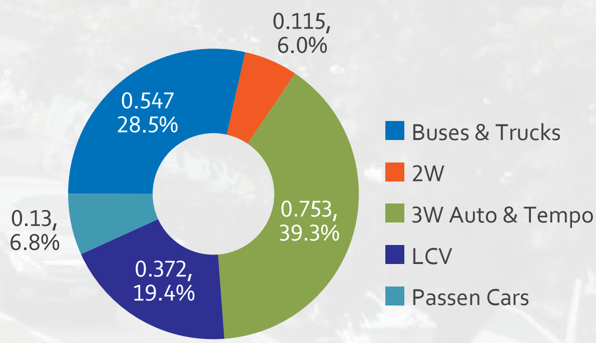
Emissions inventory for six cities were developed in 2007 for sulfur dioxide (SO_2), PM, NO_x, CO, and HC, with future projections for the years 2012 and 2017. It involved estimation of emissions from various activities (vehicular, industrial, residential, commercial, etc.). A combination of top-down and bottom-up approaches was used for identification of all major emission sources, reliable estimates, and adequate representation of various factors influencing emissions (land use, socio-economic structure, and spatial and temporal distribution of source activities vis-à-vis pollutants). In addition to data obtained from secondary sources of information, activity rates were collected through primary surveys including questionnaire surveys, personal interviews, house-to-house surveys, actual traffic counts, among others. While this approach provides reasonable quality of data on emission estimates, resolutions with respect to time and space are limited in view of resources and available timeframe. Important features of methodology are summarized below:

- Detailed in-situ primary surveys within 2x2-km zone of influence around each monitoring location to identify all significant pollution sources (e.g., construction activities, industries fuel use, domestic fuel combustions, size and activities of diesel generator sets, etc.) and also to collect activity rate through personal interviews.
- Diurnal traffic count surveys on different categories of roads along with personal interviews at parking lots/petrol pumps with vehicle owners for obtaining data on age, fuel use, VKT per day, etc.
- Use of local EF for vehicular exhaust emissions and selection of appropriate EF for stationary sources (i.e. roadside dust, domestic fuel combustions, industries, construction activities, etc.);
- Extrapolation of city level EI based on detailed inventories prepared in 2x2-km grids, and city land use plans.
- Future projections of emission scenarios considering developmental plans, changes in the land-use and activities and/or activity levels, (with or without implementation of given pollution control plans), etc.

Results:



Mobile Source - EI: PM_{10}-Delhi



Mobile Source - EI: PM_{10}-Kanpur

Bu_D: Bus (Diesel); Bu_CNG: Bus (compressed natural gas); 2W-2S: Two-wheeler (two stroke); 2W-4S: Two-wheeler (four-stroke): 3W-CNG: Three-wheeler (compressed natural gas); LCV: light commercial vehicle; 4W-P: Four-wheeler (petrol); 4W-D: Four-wheeler (diesel)

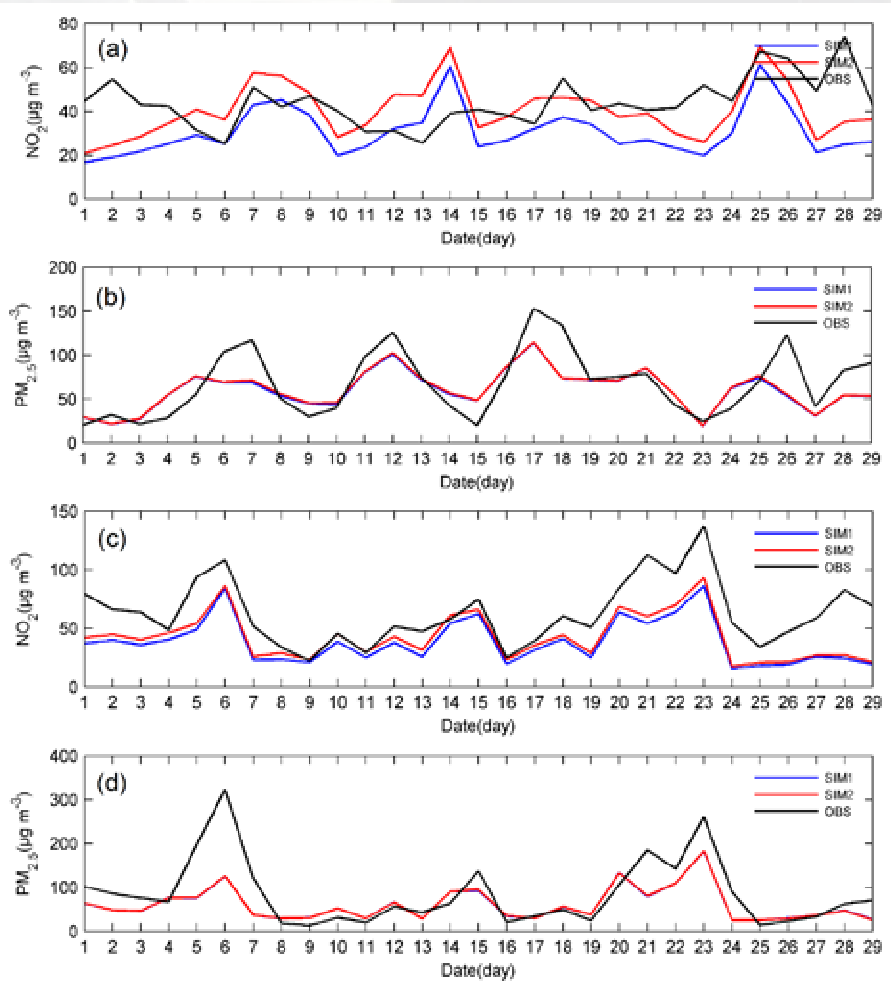
Source: CPCB, 2011

Box 3.5
Impact of vehicle emissions on urban air quality in Beijing

Objective: To estimate the contribution of vehicle emissions to the air pollution exposure in Beijing's main urban areas in July and December 2013.

Methods: Use of a high temporal-spatial resolution vehicle emissions inventory (HTSVE) in the Chinese Unified Atmospheric Chemistry Environment (CUACE) model was used to estimate the wind field and other meteorological parameters. Simulation of nitrogen dioxide (NO_2) and $PM_{2.5}$ (PM ≤ 2.5 micrometers in diameter) was performed with (a) default emissions of CUACE ('SIM1') and (b) the improved emissions of Beijing's HTSVE ('SIM2').

Results: SIM2 estimated concentrations are higher than SIM1 estimates. The mean vehicle emission contribution to outdoor air NO_2 is 55 percent in July 2013 and 49 percent in December; the corresponding percentages for $PM_{2.5}$ are 5.4 percent and 10.5 percent, respectively. The observed concentrations of NO_2 and $PM_{2.5}$ in July 2013 (figures a, b) and December 2013 (figures c, d) are compared with the simulated concentrations in the figures below.



The comparison of site average NO_2 and $PM_{2.5}$ concentrations between SIM1, SIM2, and observation in July (a,b) and December (c,d) 2013.

Source: He et al,. 2015

Box 3.6
Status and recent initiatives in emissions inventory in Japan

General Survey of the Emissions of Air Pollutants

This survey, carried out every three years by Ministry of the Environment of Japan (MOEJ), is conducted to grasp the state of sulfur oxides (SO_x) emissions, NO_x emissions, and soot and dust emissions from business establishments subject under the Air Pollution Control Law. This questionnaire survey requires hourly emission, yearly operation hours, soot and dust concentration, and amount of fuel usage. In the investigation, the amount of emissions of prefecture air pollution became clear via facility and by soot and smoke emissions from factory. The results of the survey can be accessed at http://www.env.go.jp/air/osen/kotei/index.html (in Japanese).

Studies to develop the national emissions inventory for volatile organic compounds

In order to assess the progress of measures to suppress VOCs emission from stationary sources in Japan, the emissions of VOCs from stationary sources have been estimated and compiled into the national "Emissions Inventory for VOC" every year by MOEJ.

The study targeted around 200 kinds of VOCs. Emissions are estimated mainly through (i) multiplying the shipping volume of VOC-containing products (e.g., paints) by emission rates, or (ii) summing up the VOC emissions reported in the voluntary plans related to VOC reduction that are implemented by industry organizations. This survey can be accessed at http://www.env.go.jp/air/osen/voc/inventory.html (in Japanese).

National Greenhouse Gas Inventory

Under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, parties included in Annex I (developed countries and countries with economy in transition) are required to submit an annual national GHG inventory to the secretariat of UNFCCC. A GHGs inventory by the MOEJ is an accounting of the amount of anthropogenic GHGs (CO_2, CH_4, N_2O, and HFCs, PFCs, and SF_6) emissions by sources and removals by sinks in a year. For GHG inventories, the emissions estimates for each gas are conducted by each sector and source category, based on statistics instead of actual measurement data. The inventory can be accessed at http://www-gio.nies.go.jp/index.html.

Japan Auto-Oil Program

Under the Japan Auto-Oil Program (JATOP) conducted by the Japan Petroleum Energy Center, the inventory for the emissions from vehicle and stationary sources are compiled using the top-down approach. The inventory for vehicle emissions estimates the emissions from each operation process. The evaporation fuel and tire wear for FY2000, FY2005, and FY2010 are estimated by the JATOP Emission Inventory Vehicle Emission Estimation Model. The inventory for stationary sources estimates NO_x, SO_x, CO, NMVOC, PM, and NH_3 from combustion sources, as well as NMVOC, and NH_3 from other sources. The inventory of stationary sources will be disclosed as part of the JATOP Emission Inventory-Data Base. Information for this program can be accessed at http://www.pecj.or.jp/english/jcap/index_e.asp.

CO_2 = carbon dioxide; CH_4 = methane, N_2O = nitrous oxide,
HFCs = hydrofluorocarbons; PFCs = perfluorinated compounds; SF_6 = sulfur hexafluoride;
NMVOC = non-methane volatile organic compounds; PM = particulate matter; NH_3 = ammonia

Box 3.7
Overview of East Asian Air Pollutant Emission Grid Database (EAGrid)

The purpose of this original project was to enter emissions data into a long-range atmospheric transport model that incorporated an atmospheric chemical reaction process meant to elucidate the mechanisms by which sulfates and nitrates are formed, transported, and removed. The original East Asian Air Pollutant Emissions Grid Database (EAGrid1995) contained estimates of emissions per grid cell of air pollutants such as SO_2, NO_x, NMVOCs, and NH_3 for China, Taiwan, Japan, the Republic of Korea, the Democratic People's Republic of Korea, and Mongolia. EAGrid2000 includes CO, PM_{10}, and mercury in addition to those that were already included in EAGrid1995.

In order to clarify local domestic contributions to air pollution in simulations of trans-boundary air pollution arriving in Japan from other East Asian countries, EAGrid 2000-Japan is the inventory refined by nesting a sub grid covering Japan. Emission for FY2005 and FY2010 are newly estimated in order to update EAGrid-Japan 2000.

Source: Center for Global Environmental Research, 2007

Box 3.8
Regional Emission Inventory in Asia (REAS)

For the analysis of long-term trends of the Asian atmospheric environment, the first inventory of historical and future projected emissions in Asia, Regional Emission inventory in ASia (REAS) 1.11, has been developed and made available for download since 2007. Recently, the REAS inventory was updated and re-opened as version 2.1. The major role of the REAS is to provide emission input data for atmospheric chemistry models. Data from REAS has the following scope:

- Species: SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, NH_3, CH_4, N_2O, CO_2
- Years: 2000–2008
- Areas: East, Southeast, South, and Central Asia, Asian part of Russia
- Emission Sources: Fuel combustion in power plants, industry, transport and domestic sectors, agricultural activities, and others
- Spatial Resolution: 0.25 degree by 0.25 degree
- Temporal Resolution: Monthly

BC – Black Carbon; OC – organic carbon

Source: Kurokowa, et al., 2013

Box 3.9
Source apportionment studies in Indian Cities

Objective: Ambient air quality monitoring data generated in Indian cities over the last decade reveal that PM concentrations are exceeding the air PM standards at many locations. Air pollution problem becomes complex due to multiplicity and complexity of air polluting sources (e.g. industries, automobiles, generator sets, domestic fuel burning, road side dusts, construction activities, etc.). The CPCB considers a cost-effective approach for improving air quality in polluted areas to involve (i) identification of emission sources; (ii) assessment of extent of contribution of these sources on ambient environment; (iii) prioritizing the sources that need to be tackled; (iv) evaluation of various options for controlling the sources based on feasibility and economic viability; and (v) formulation and implementation of most appropriate action plans. Source apportionment studies help in identifying the sources & extent of their contribution.

Methods: Accordingly, SA studies have been initiated in six major cities viz. (i) Bangalore; (ii) Chennai; (iii) Delhi; (iv) Kanpur; (v) Mumbai; and (vi) Pune. The studies focus on apportionment of PM_{10}, one of the most critical pollutants. Conceptual guidelines for a common methodology and SOPs for sampling and analysis were developed to guide the investigators for each city. In addition, separate projects on the development of EFs for vehicles and emission profiles for vehicular as well as non-vehicular sources have been performed, which would provide necessary inputs to the SA studies.

The scope for SA studies includes the concentrations for various constituents of PM_{10}, such as elemental carbon (EC), organic carbon (OC), total carbon (TC), the sum of ions of sulfate (SO_4^{2-}), nitrate (NO_3^-), and ammonium (NH_4^+) or secondary inorganic aerosols (SIA), and the sum of elements aluminum, calcium, silicon, iron, sodium, paladium, and ions calcium (Ca^{++}), sodium (Na^+), chlorine (Cl^-), representative of Crustal + Alluvial + Marine constituents (CAM) at selected locations (7 – 10 locations covering different land use viz. residential, industrial, and kerbside) and application of receptor (CMB8) and receptor-based models to assess the contribution from various sources, future projections and evaluation of various control options to develop cost-effective action plans.

Results: Results obtained in these studies are numerous. The most relevant are those for PM_{10}, EC, OC, TC, SIA, and CAM concentrations and source apportionment, see table 1-3 below (explanation of acronyms in the text). Industrial and kerbside carbon contents are major contributors to PM_{10}.

Table1: Major components [µg/m³] of PM_{10}, EC, OC, TC, SIA and CAM at residential sites in six Indian cities

City	PM_{10}*	EC	OC	TC	SIA	CAM
Bangalore	98	5.6	14.0	19.6	15.5	26.8
Chennai	123	4.7	14.4	19.1	10.7	17.5
Delhi	419	18.5	100.4	118.8	21.2	27.2
Kanpur	213	19.4	53.7	73.1	29.9	16.1
Mumbai	207	9.2	41.1	50.3	9.8	28.2
Pune	132	4.4	29.6	34.0	14.1	40.6

Table2: Major components [µg/m³] of PM_{10}, EC, OC, TC, SIA and CAM at industrial sites in six Indian cities

City	PM_{10}*	EC	OC	TC	SIA	CAM
Bangalore	137	8.1	21.4	29.5	9.5	23.6
Chennai	142	8.3	27.8	36.1	15.5	14.6
Delhi	519	13.7	73.3	87.1	18.7	33.5
Kanpur	385	38.0	105.3	143.4	30.2	15.2
Mumbai	196	9.1	36.5	45.6	11.4	24.5
Pune	136	4.0	27.8	31.9	9.4	32.6

Table3: Major components of PM_{10}, EC, OC, TC, SIA and CAM at kerbside sites in six Indian cities

City	PM_{10}*	EC	OC	TC	SIA	CAM
Bangalore	164	14.3	34.3	48.6	10.9	25.6
Chennai	170	10.9	27.1	38.0	12.9	10.9
Delhi	576	13.7	64.2	77.9	13.5	25.0
Kanpur	275	24.3	61.6	85.5	27.6	18.3
Mumbai	205	10.3	41.6	51.9	8.9	27.1
Pune	195	10.4	37.1	47.5	8.9	33.9

* Average of 20-day monitoring in each of the seasons (winter, summer, post-monsoon)

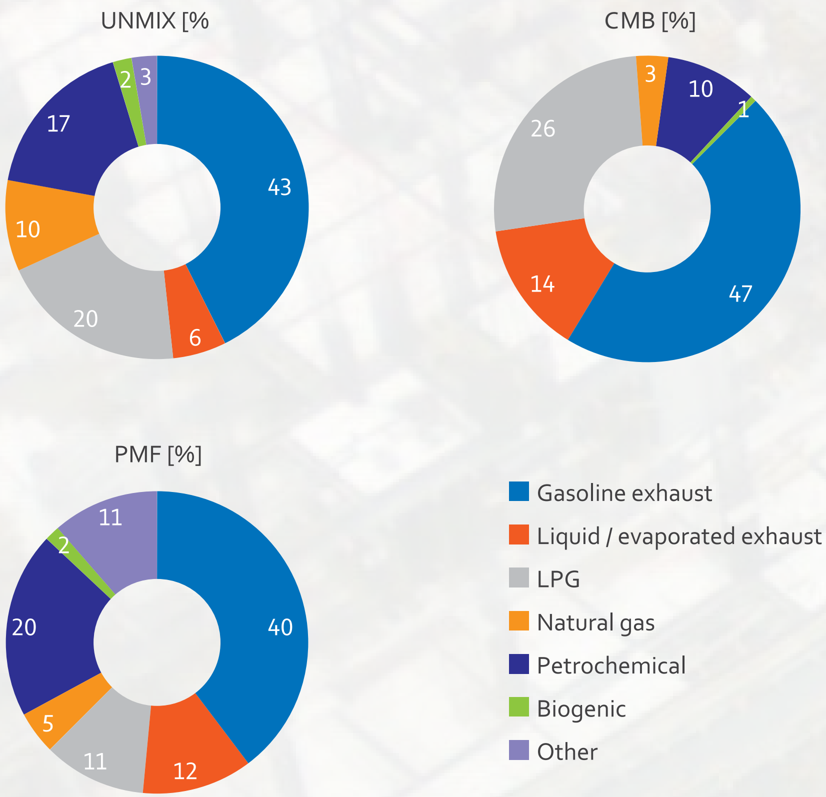
Source: Gargava & Rajagopalan, 2015

Box 3.10
Comparisons of receptor-based models for source apportionment of VOCs in Beijing

Objective: To apply the UNMIX and CMB models to VOC source apportionment based on a data set investigated previously with the PMF model by Song et al. (2008) and compare results.

Methods: Samples were collected on the roof of a five-story building on the campus of Peking University surrounded by heavy traffic intersections. In August 2005, VOC concentrations were quantified by a custom-built Gas Chromatography – Flame Ionization Detector/Mass Spectrograph system, which separated 31 carbon species from 1019 samples. Analysis of samples with the CMB and UNMIX models, and comparison with PMF model results were made.

Results: All three models showed that gasoline-related emissions contributed between 49 percent and 61 percent to VOCs. Petrochemical emissions contributed between 10 percent and 20 percent and liquefied petroleum gas (LPG) between 11 percent and 26 percent, depending on the model. The figures below illustrate the findings.



Source: Song et al., 2008

Box 3.11
Emissions inventory and source apportionment in Hong Kong and the Pearl River Delta of China

The Hong Kong Environmental Protection Department (EPD) is the environmental authority responsible for AQM in Hong Kong. Through more than 20 years of capacity building, Hong Kong has progressed into the fully developed stage in terms of EI and SA. The successful experience in Hong Kong also sheds light on the AQM practice in the nearby Pearl River Delta (PRD), which has progressed into the maturing stage and is envisioned to achieve fully developed stage within three years.

The EI in Hong Kong covers six major air pollutants, namely SO_2, NO_x, respirable suspended particulates (or PM_{10}), fine suspended particulates (or $PM_{2.5}$), VOCs and CO, from six emission categories, namely public electricity generation, road transport, navigation, civil aviation, other fuel combustion and non-combustion sources. Starting from 1997, the EI is updated annually by using the latest compilation methodology and new activity rate and EF and by revising the errors identified in the estimates. Major updates in the recent years include revised emission estimates from marine vessels with new local vessel activity rate and emission compilation methodologies, revised emission estimates from on-road vehicles by means of remote sensing equipment and advanced portable emission measurement systems, and revised VOC emission estimates from regulated VOC-containing products by sales report data submitted by importers (EPD, 2015).

The first Regional Air Pollutant EI in the PRD region was developed in 2006 under the framework of Guangdong/Hong Kong Cooperation. An EI Handbook for Air Pollutants in the PRD Region was compiled to provide the basis for the quantitative evaluations of effectiveness of emission reduction measures. It also provided unified development procedures of EI and the quality assurance system in Hong Kong and Guangdong (Zheng et al., 2009). In 2010, the PRD Regional Atmospheric Environmental Research Center was established with one of the responsibilities of development and update of dynamic air pollutant emission inventory and database systems in the PRD (Zheng et al., 2013). The PRD regional emission inventory is updated once every two to three years by using the latest compilation methodology and new activity rate and EF wherever available.

The EPD has initiated PM_{10} and $PM_{2.5}$ speciations with the aims of understanding the chemical compositions of PM and identifying major contributing sources by SA techniques. With the continuous financial support from the Hong Kong Government, the once-every-six-day PM_{10} sampling has been continuing since 1998 from a network of ten monitoring stations representing different environmental backgrounds. As of February 2015, PM_{10} measurement has been continued for over seventeen years. $PM_{2.5}$ sampling was initiated in 2000 with a 1-year sampling campaign conducted once every four years (2000/2001, 2004/2005, and 2008/2009). Starting from 2011, $PM_{2.5}$ measurement has changed to be in line with the sampling frequency of PM_{10} at six monitoring sites across the territory, which include four collocated sites. As of February 2015, $PM_{2.5}$ measurement has continued for over four years. Collocated measurement is important for QA/QC of results and estimation of measurement uncertainties to be used in receptor modeling analysis (Hyslop & White, 2008).

PM_{10} and $PM_{2.5}$ masses are measured for identifying areas that meet or do not meet the Air Quality Objective and supporting designation of an area as attainment or non-attainment. Apart from mass, major chemical elements, water-soluble ions, OC/EC/total carbon, and non-polar organic compounds in all PM samples are characterized by a set of advanced instruments. Organic carbon, EC, and individual peaks for OC, EC, and pyrolyzed carbon are measured using Thermal Optical Transmittance and Thermal Optical Reflectance by both National Institute for Occupational Safety and Health (NIOSH) and Interagency Monitoring of PROtected Visual Environments (IMPROVE) protocols. The speciation data are analyzed to characterize the composition and temporal and spatial variations of PM concentrations.

The rich PM_{10} and $PM_{2.5}$ speciation dataset has served significantly the identification of major sources and quantification of their contributions by receptor models. The SA analysis is updated bi-annually with the addition of measurement in the recent two years. In the previous stages of analysis, at least three receptor models were conducted, including Principal Component Analysis, PMF, and UNMIX for source identification. Through years of detailed examination and inter-comparisons of the receptor modeling results, it has been concluded that PMF model is the most suitable model for PM source identification and quantification in Hong Kong.

Annual, seasonal, monthly and weekly trends of different sources are discovered by SA. This sheds light on potential contributing sources during different meteorological conditions and pollution episodes. Results have clearly shown the effectiveness of local control on emissions from motor vehicles. Their contributions to both PM_{10} and $PM_{2.5}$ have decreased more than 60 percent during the past decade. However, the successful local control is offset by the increasing regional contribution from Mainland China, mostly in the form of secondary sulfate and biomass burning associated with northerly wind in winter and spring. As a result, the PM pollution level has remained steady in the past five years, however, with a distinct compositional pattern. Regional contribution to PM_{10} in Hong Kong was around 40 to 50 percent in year 2000 and has increased to around 70 percent in 2010 (Yuan et al., 2013).

Hong Kong has established its own AQ modeling system called 'Pollutants in the Atmosphere and their Transport over Hong Kong (PATH). The PATH modeling system is an integrated numerical modeling system with Sparse Matrix Operator Kernel Emissions Processing System (SMOKE) version 2.4 as the emission module, Weather Research and Forecast model (WRF) version 3.6 as the meteorological module, and Community Multi-scale Air Quality (CMAQ) version 4.6 as the chemical transport module. Both emission and chemical transport modules support CB05 and SAPRC chemical mechanisms. The PATH modeling system is setup in a four-nested domain with the coarsest grid size of 27 km cover most part of East Asia down to the finest grid size of 1 km covering Hong Kong and its surrounding cities. Results from PATH are compared with the Comprehensive Air Quality Model with Extensions (CAMx) and the Nested Air Quality Prediction Model System (NAQPMS) to improve the reliability of the simulation results. Currently, CAMx is used for SA in Hong Kong. Hong Kong is considering the development of an SA module in the PATH system.

The SA results were used to validate EI, e.g., for on-road emissions of PM (Yuan et al., 2013). The SA results also contributed directly to the formulation of a series of pollution control measures implemented locally and regionally. For example, the sharp increase of residual oil contribution has resulted in the mandatory switch to low sulfur fuel for ocean going vessels when berthing in Hong Kong waters. Increasing regional contributions from Mainland China also triggered regional collaboration in combating regional pollution between Hong Kong and Guangdong governments under the "one country, two systems" principle. The Hong Kong experience is also utilized in the development of Guangdong-Hong Kong-Macau $PM_{2.5}$ joint speciation network which covers 12 stations and starts operation in December 2014. The Guangdong-Hong Kong-Macau $PM_{2.5}$ joint speciation monitoring network would help improve the scientific understanding of $PM_{2.5}$ emission sources and formation processed in Southern China, and contribute significantly to the policy-making on effectively controlling PM pollution.

Source: EPD, 2015

3.5 References

Asia Center for Air Pollution Research. (2011). *Guidelines for Developing Emission Inventory in East Asia*. Retrieved from http://www.acap.asia/publication/pdf/em_inventory/em_guideline.pdf

Belis, C.A., Larsen, B., Amato F., El Haddad, I., Favez, O., Harrison, R., Hopke, P., Nava, S., Paatero, P., Prevot, A.S.H., Quass, U., Vecchi, R., & Viana M. (2014). *European guide on air pollution source apportionment with receptor models*, (EUR 26080). Retrieved from http://source-apportionment.jrc.ec.europa.eu/Docu/EU_guide_on_SA.pdf

British Columbia Ministry of Environment. (2013). *Emissions: An introduction*. Retrieved from http://www.bcairquality.ca/101/emissions-intro.html

Center for Global Environmental Research. (2007). *East Asian air pollutant emissions grid database (EAGrid2000)*. Ibaraki, Japan: National Institute for Environmental Studies. Retrieved from http://www.cger.nies.go.jp/db/eagrid/eagrid_index_e.html

Central Pollution Control Board, India. (2006). *Model standard operating procedures (SOPs) for sampling and analysis - air quality monitoring, emission inventory & source apportionment studies for Indian cities*. New Delhi, India: Author. Retrieved from http://cpcb.nic.in/SA-Studies%20-SOPs-for-sampling-and-analysis.pdf

Central Pollution Control Board, India. (2007a). *Conceptual guidelines and common methodology for air quality monitoring, emission inventory & source spportionment studies for Indian cities*. New Delhi, India: Author. Retrieved from http://cpcb.nic.in/sourceapportionmentstudies.pdf

Central Pollution Control Board, India. (2007b). *Emission Factor development for Indian vehicles*. New Delhi, India: Author. Retrieved from http://cpcb.nic.in/Emission_Factors_Vehicles.pdf

Central Pollution Control Board, India. (2010). *Source apportionment studies*. New Delhi, India: Author. Retrieved from http://cpcb.nic.in/Source_Apportionment_Studies.php

Central Pollution Control Board, India. (2011). *Air quality monitoring, emission inventory and source apportionment study for Indian cities – National Summary Report*., New Delhi, India: Author. Retrieved from http://cpcb.nic.in/FinalNationalSummary.pdf

Central Pollution Control Board, India. (n.d.). *Source profiles for vehicular sources*. New Delhi, India: Author. Retrieved from http://cpcb.nic.in/Vehicular_Sources_Emission_Profiles.xls

Central Pollution Control Board, India. (n.d.). New Delhi, India: Author. *Source emission profiles for stationary sources*. Retrieved from http://cpcb.nic.in/Stationary_Sources_Emission_Profiles.xls

Department for Environment, Food and Rural Affair. (2009). *Local air quality management*. (Technical Guidance LAQM.TG(09). London, U.K.: Author. Retrieved from laqm.defra.gov.uk/technical-guidance/

European Commission. (2014). *European guide on air pollution source apportionment with receptor models* (EUR 26080 EN). Luxembourg: Publications Office of the European Union. Retrieved from http://source-apportionment.jrc.ec.europa.eu/Docu/EU_guide_on_SA.pdf

European Environment Agency. (2005). *Source apportionment of nitrogen and phosphorus inputs into the aquatic environment* (EEA Report No 7/2005). Retrieved from: www.eea.europa.eu/publications/eea_report_2005_7/download

European Environment Agency. (2013). *EMEP/EEA air pollutant inventory guidebook* 2013. (Technical guidance to prepare national emission inventories, EEA Technical Report No.12/2013). Retrieved from http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

Environment Canada. (2013). *Air quality source apportionment and receptor modeling techniques*. Retrieved from https://www.ec.gc.ca/air-sc-r/default.asp?lang=En&n=13A7E1D0-1

EURACHEM/CITAC. (2012). Quantifying uncertainty in analytical measurement. *Co-operation on international traceability in analytical chemistry (EURACHEM/CITAC Guide CG 4)*. Retrieved from https://www.eurachem.org/index.php/publications/guides/quam

Gargava, P. & Rajagopalan, V., (2015). Source apportionment studies in six Indian cities – drawing broad inferences for urban PM10 reductions. Air Quality, Atmosphere and Health DOI 10.1007/s11869-015-0353-4.

Global Atmospheric Pollution Forum. (2012). *The Global Atmospheric Pollution Forum Air Pollutant Emission Inventory Manual* (Version 5). Retrieved from http://www.sei-international.org/gap-the-global-air-pollution-forum-emission-manual

Guttikunda, S. (2011). *A primer on source apportionment*. Retrieved from http://urbanemissions.info/images/stories/Comics/What_is_Source_Apportionment.pdf

Guttikunda, S.K.. (2015). *What is SIM-air – Overview of the family of the tools*. Retrieved from http://urbanemissions.info/contact.html

Handbook Emission Factors for Road Transport. (2014). Website was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria; additional countries (Sweden, Norway, France) as well as the JRC (European Research Center of the European Commission) are now supporting it as well. Retrieved from http://www.hbefa.net/e/index.html

He, J.J., Wu, L., Mao, H. J., Liu, H.L., Jing, B. Y., Yu, Y., Ren, P.P., Feng, C., & Liu, X. H. (2015) Development of a high temporal–spatial resolution vehicle emission inventory based on NRT traffic data and its impact on air pollution in Beijing – Part 2: Impact of vehicle emission on urban air quality. *Atmospheric Chemistry and Physics Discussions* 15: 19239-19273.

Hopke, P.K. (2003). Recent developments in receptor modeling. *Journal of Chemometrics*, 17: 255–265.

Hyslop, H. & White, W. (2008). An empirical approach to estimating detection limits using collocated data. *Environmental Science and Technology*, 42: 5235–5240.

Intergovernmental Panel on Climate Change (2006). Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds) Published: IGES, Japan

Japan Petroleum Energy Center. *JATOP: Japan Auto-Oil Program*. Retrieved from http://www.pecj.or.jp/english/jcap/index_e.asp

Johnson, T.M., Guttikunda, S., Wells, G.J., Artaxo, P., Bond, T.C., Russell, A.G., Watson, J.G. & West, J. (2011). *Tools for improving air quality management – a review of top-down source apportionment techniques and their application in developing countries*. Retrieved from http://www.esmap.org/node/1159

Karagulian, F. & Belis, C.A. (2012). *Enhancing source apportionment with receptor models to foster the air quality directive implementation. International Journal of Environment and Pollution*, 50: 190-199.

Kurokawa, J., Ohara, T., Morikawa, T., Hanayama, S., Janssens-Maenhout, G., Fukui, T., Kawashima, K., & Akimoto, H. (2013). Emissions of air pollutants and greenhouse gases over Asian regions during 2000-2008: Regional emission inventory in Asia (REAS) version 2, *Atmospheric Chemistry and Physics Discussions* 13: 10049–10123.

Manh, V.V., Thuy, B.P., & Duy, D.H., (2011). Emission inventory and predict from road traffic sources. *Enviroinfo Ispra 2011: Innovations in sharing environmental observations and information*. Shaker Verlag, Aachen, Germany: Karlsruhe Institute of Technology. Retrieved from http://www.iai.kit.edu/ictensure/site;jsessionid=1191DE0EE0E6EEE2342AA6DB49E675EB?mod=litdb&subject=art&pid=XB9A94295&action=detail.

Ministry of Environment of Japan. (2007). *What is an emission inventory?*. Retrieved from http://www.acap.asia/publication/pdf/emissioneng.pdf

Ministry of Environment of Japan. (n.d). *Studies to develop the national emissions inventory for volatile organic compounds*. Retrieved from http://www.env.go.jp/air/osen/voc/inventory.html

Ministry of Environment of Japan. (2015). *General survey of the emissions of air pollutants*. http://www.env.go.jp/air/osen/kotei/index.html

National Institute for Environmental Studies, Japan. (2007). *East Asian Air Pollutant Emissions Grid Database (EAGrid2000)*. Retrieved from http://www.cger.nies.go.jp/db/eagrid/eagrid_index_e.html

New Zealand Ministry for the Environment. (2004). *Good practice guide for atmospheric dispersion modelling*. Retrieved from http://www.mfe.govt.nz/publications/air/good-practice-guide-atmospheric-dispersion-modelling

Organisation for Economic Co-operation and Development. (2001). *Glossary of statistical terms – emissions inventory*. Retrieved from https://stats.oecd.org/glossary/detail.asp?ID=762

Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K., Yan, X., & Hayasaka, T. (2007). An Asian emission inventory of anthropogenic emission sources for the period 1980–2020. *Atmospheric Chemistry and Physics*, 7: 4419–4444.

Regional Emission inventory in Asia data download site. (n.d.). Website developed for the analysis of long-term trends of the Asian atmospheric environment, the first inventory of historical and future projected emissions in Asia. Retrieved from https://www.nies.go.jp/REAS/

Song, Y., Dai, W., Shao, M., Liu, Y., Li, S.-H., Kuster, W., & Goldan, P. (2008). Comparison of receptor models for source apportionment of volatile organic compounds in Beijing, China. *Environmental Pollution*, 156: 174-183.

Stockholm Environment Institute. (2008). Emission. In Haq, G. & Schwela, D. (Eds.) *Foundation course on air quality management in Asia*. Retrieved from http://www.sei.se/cleanair/modules.html

Stockholm Environment Institute. (2012). *The Forum air pollutant emissions inventory preparation manual* (Version 5). Retrieved from http://www.sei-international.org/gapforum/tools.php

United States Environmental Protection Agency. (1995). *A compilation of air pollutant emission factors (AP-42)*. Retrieved from https://www3.epa.gov/ttn/chief/ap42/index.html

United States Environmental Protection Agency. (2007). *Unmix 6.0 fundamentals & user guide*. Retrieved from https://www.epa.gov/sites/production/files/2015-02/documents/unmix-6-user-manual.pdf

United States Environmental Protection Agency. (2013a). *Receptor modeling*. Research Triangle Park, NC: Author. Retrieved from https://www3.epa.gov/ttn/scram/receptorindex.htm

United States Environmental Protection Agency. (2014a). *Emissions Inventory*. Research Triangle Park, NC: Author. Retrieved from https://www3.epa.gov/otaq/invntory.htm

United States Environmental Protection Agency. (2014b). *SPECIATE Version 4.4*. Research Triangle Park, N.C.: USEPA Technology Transfer Network Clearing House for Emission Inventories & Emission Factors. Retrieved from https://www3.epa.gov/ttnchie1/software/speciate/

United States Environmental Protection Agency. (2015) *AP – 42 Emission factors* (Vol. 1). Research Triangle Park, NC: Author. Retrieved from https://www3.epa.gov/ttnchie1/ap42/c00s00.pdf

United States Environmental Protection Agency. (n.d.). *Dispersion modeling*. Research Triangle Park, NC Author. Retrieved from https://www3.epa.gov/ttn/scram/dispersionindex.htm

United States Environmental Protection Agency. (n.d.). *EPA Positive Matrix Factorization (PMF) Model*. Research Triangle Park, NC: Author. Retrieved from https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses

Watson, J.G., Zhu, T., Chow, J.C., Engelbrecht, J., Fujita, E.M. & Wilson, W.E. (2002). Receptor modeling application framework for particulate source apportionment. *Atmospheric Environment* 49: 1093-1136.

World Health Organization. (1993). Part One: Rapid Inventory Techniques in Environmental Pollution.. *Assessment of sources of air, water, and land pollution: A guide to rapid source inventory techniques and their use in formulating environmental control strategies*. WHO/ PEP/GETNET 93.1-A. Geneva, Switzerland: Author. Retrieved from http://whqlibdoc.who.int/hq/1993/WHO_PEP_GETNET_93.1-A.pdf

Yuan, Z.B., Yadav, V., Turner, J.R., Louie, P.K.K. & Lau, A.K.H. (2013). Long-term trends of ambient particulate matter emission source contributions and the accountability of control strategies in Hong Kong over 1998-2008. *Atmospheric Environment*, 76: 21-31.

Zheng, J.Y., Zhang, L.J., Che, W.W., Zheng, Z.Y. & Yin, S.S. (2009). A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment. *Atmospheric Environment*, 43: 5112-5122.

Zheng, J.Y., Liu, H., Lu, Q. & Ou, J.M. (2013). *Air quality management in Guangdong Province and implications from the California Air Resources Board Experience*. Hong Kong: Civic Exchange. Retrieved from www.civic-exchange.org/en/publications/164986967

IBAQ

Integrated Programme for Better Air Quality in Asia

WWW.CLEANAIRASIA.ORG/IBAQ

ISBN 978-621-95434-0-8

9 786219 543408