ATMOSPHERIC BROWN CLOUDS

EMISSION INVENTORY

MANUAL

UNEP

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FOREWORD

Atmospheric brown clouds (ABCs) are widespread layers of regional scale plumes of air pollution consisting of a mixture of anthropogenic sulfate, nitrate, organics, black carbon, dust, and fly ash particles. Recent scientific findings suggest that the impacts of ABCs, which include short-lived climate pollutants (SLCPs) such as black carbon and tropospheric ozone, have reached a critical point that raises the need for urgent action. An Atmospheric Brown Clouds (ABC) study published in 2010 (Ramanathan and Xu, 2010) showed that mitigation of all four SLCPs (black carbon, methane, ozone precursors, and HFCs) using maximum available technologies will reduce global warming by 0.6 degree C by 2050. Prompted by this finding and other scientific studies, UNEP commissioned a global assessment of black carbon and tropospheric ozone. The UNEP report was published in 2011. It confirmed the ABC study and suggested that widespread and swift implementation of a small number of already available mitigation measures targeting black carbon and methane emissions will decrease global warming by 0.5 degree C. The report also showed that measures to control SLCPs can prevent crops losses of 30 to 140 million tons and some 0.7 to 4.6 million premature deaths globally. Those regions that cut down significant levels of emissions will benefit most.

The main sources of ABCs are industrial emissions, vehicular exhausts, burning of residential fuels including fossil and biofuels, and open biomass burning. Emissions from contained burning of fuels are still uncertain by a factor of 2-6. Emissions from open burning are even more uncertain. This poses a big challenge in designing sector- and source-based mitigation measures and technological, financial, or policy measures.

In order to address this challenge, UNEP commissioned a group of experts to prepare a comprehensive emission inventory manual that is user friendly, and can be used both as a guide in compiling emission inventories in developed and developing countries, and as a training material for human resource development. The Emission Inventory Manual is accompanied by an Excel-based workbook, which can be used for compilation and estimation of ABCs emissions from different sources.

We would like to express our gratitude to all of those who contributed to the compilation of this Emission Inventory Manual. This manual will provide governments, research institutions, and academia with a tool for compilation and identification of ABCs sources and a reliable reference for science- based decision making.

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LIST OF ABBREVIATIONS

ABC	Atmospheric Brown Clouds
AIT	Asian Institute of Technology
AIRPET	Improving Air Quality in Asian Developing Countries
AIT-UNEP RRC. AP	AIT-UNEP Regional Resource Centre for Asia and the Pacific
AP-42	Common Name for the US EPA's Compilation of Air Pollutant Emission Factors
ATSR	Advanced Thermal Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
Btu	British thermal unit
BC	Black Carbon
CEC	Commission of the European Communities
CGRER	Center for Global and Regional Environmental Research
CNG	Compressed Natural Gas
CORINE	Coordination d'information Environmentale
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EANET	Acid Deposition Monitoring Network in East Asia
EDGAR	Emission Database for Global Atmospheric Research
EC	Elemental Carbon
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme of the Convention on Long-range Transboundary Air Pollution
EPA	(US) Environment Protection Agency
EEATF	European Environment Agency Task Force
ESP	Electrostatic Precipitator
FAO	United Nations Food and Agriculture Organization
FGD	Flue Gas Desulfurization
g	Gram
GAPF	Global Atmospheric Pollution Forum
GEIA	Global Emissions Inventory Activity
GIS	Geographical Information System
GJ	Giga Joule (one billion Joules)
Gt	Giga tonne
ha	Hectare
HFO	Heavy Fuel Oil (also called Residual Fuel Oil (RFO))
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
INDOEX	Indian Ocean Experiment
ISO	International Standards Organization
K	Kelvin
kg	Kilogram (1000 grams)
kt	Kilotonne (1000 tonnes)
LPG	Liquefied Petroleum Gas
LPS	Large Point Source
LTO	Landing and Take-off Cycle (for aircraft)

LIST OF ABBREVIATIONS

Mg	Megagram (10^6 grams, equal to one "metric tonne" (t))
MODIS	Moderate Resolution Imaging Spectrometer
MSW	Municipal Solid Waste
Mt	Megatonne (1,000,000 tonnes)
Mtoe	Megatonne Oil Equivalent
MW	Megawatt (1,000,000 watts)
MW_e	Megawatt (electricity)
MW_{th}	Megawatt (thermal)
m^3	Cubic meter
μm	Micrometer (10^{-6} meter)
N	Nitrogen
NAPAP	National Acid Precipitation Assessment Program
NAPSEA	Nomenclature for Air Pollution Socio-economic Activity
NCV	Net Calorific Value (= lower heating value, LHV)
NGL	Natural Gas Liquids
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NMHC	Non-Methane Hydrocarbon
NO_x	Nitrogen Oxides ($NO + NO_x$)
OECD	Organization for Economic Co-operation and Development
OFA	Over-fire Air (a form of NO_x emission control)
O_3	Ozone
OC	Organic Carbon
P	Pascal
PC	Passenger Car
PM	Particulate Matter
PM_{10}	Particulate Matter with less than or equal to 10 micrometers in aerodynamic diameter
$PM_{2.5}$	Particulate Matter with less than or equal to 2.5 micrometers in aerodynamic diameter
ppm	Parts Per Million
QA/QC	Quality Assurance/Quality Control
RAINS-Asia	Regional Acidification Information and Simulation Model for Asia
RAPIDC	Regional Air Pollution in Developing Countries
REAS	Regional Emission Inventory in Asia
RFO	Residual Fuel Oil (also called 'Heavy Fuel Oil')
S	Sulfur
SCR	Selective Catalytic Reduction
SEI	Stockholm Environment Institute
Sida	Swedish International Development Cooperation Agency
Sm^3	Standard Cubic Metre
SNAP	Selected Nomenclature for Air Pollution
SoE	State of Environment
SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides

LIST OF ABBREVIATIONS

SPM	Suspended Particulate Matter
SWFDs	Solid Waste Final Disposal Facilities
t	Tonne (metric tonne = 1000 kg = 10^6 g)
toe	Tonne of Oil Equivalent (an amount of fuel equal in energy content to one tonne of oil = 10^7 kcal)
TSP	Total Suspended Particulate Matter (particles up to about 45 micrometers in aerodynamic diameter)
USGS	United States Geological Survey
VOC	Volatile Organic Compounds

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UNITS AND CONVERSIONS

Units

The SI system of units is generally used for emission inventories in order to ensure international compatibility. The basic unit of weight is the gram (g) and the basic unit of energy is the joule (J).

Symbol	Prefix	Multiple
P	peta	10^{15}
T	tera	10^{12}
G	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
h	hecto	10^{2}

Conversion Factors for Energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	**Multiply by:**				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

Conversion Factors for Mass

To:	kg	t	lt	st	Lb
From:	**Multiply by:**				
Kilogramme (kg)	1	0.001	9.84×10^{-4}	1.102×10^{-3}	2.2046
Tonne (t)	1000	1	0.984	1.1023	2204.6
Long ton (lt)	1016	1.016	1	1.120	2240
Short ton (st)	907.2	0.9072	0.893	1	2000
Pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5×10^{-4}	1

Atmospheric brown clouds (ABCs), a frequently occurring phenomenon in many regions of the world, are a regional scale plume of air pollution that consists of a mixture of anthropogenic sulfate, nitrate, organics, black carbon, dust and fly ash particles and natural aerosols, such as sea salt and mineral dust. Greater awareness of the ABCs problem was generated by the 1999 Indian Ocean Experiment (INDOEX) initiative over the North Indian Ocean region. Global concern came about following the first preliminary report on ABCs, which was based on INDOEX. The global implications of ABCs were highlighted by the United Nations Environment Programme in 2002 (UNEP and C[4], 2002). *In-situ* measurements revealed that the main sources of ABCs are anthropogenic (for example, biomass open burning, biofuels and fossil fuel combustion). ABCs are believed to have potentially serious regional and global implications for climate change, the hydrological cycle and water resources, agricultural crops and public health (UNEP and C[4], 2002; Ramanathan and Crutzen, 2003; Ramanathan 2008).

Many studies state that there are complex inter-linkages among air pollution, haze, smog, ozone and climate change. The most visible impact of air pollution is haze, a brownish layer of pollutants and particles from biomass burning and industrial emissions that pervades in many regions of the world, including Asia. The Indian Ocean Experiment has revealed that this haze is transported far beyond the source region, particularly during the dry seasons. At present, biomass open burning, biofuel and fossil fuel combustions are major sources of air pollution, especially particulate (aerosol) pollution in the atmosphere (UNEP and C[4], 2002). Significant reductions in solar radiation reaching the surface, precipitation efficiency, and agricultural productivity were observed during the brownish haze phenomenon (UNEP and C[4], 2002; Ramanathan 2008).

Estimates of ABCs emissions from different sources are required to design effective emission reduction measures. However, published data on sources of primary and secondary aerosols from different sectors and regions are very limited. Emission data with reasonably good spatial and temporal resolutions rarely exist. There is thus a need to characterize the relative strengths of biomass burning and fossil fuel combustion in a spatially and temporally disaggregated manner to aid policy actions, as highlighted in the UNEP Assessment Report, 2002. A detailed and reliable emission inventory of emissions of ABCs precursors is important in order to develop strategic plans for multi-spatial air pollution control. The purpose of the manual is to provide a framework for ABCs emissions inventory that is suitable for use in different countries especially in Asia.

The content of the ABCs emission inventory manual (ABC EIM) has been developed after reviewing the structure and content of other major emission inventory manuals, such as the EMEP/CORINAIR Guidebook, IPCC Guidelines, Air Pollutant Emissions Inventory Manual of the Global Atmospheric Pollution Forum (GAPF), EMEP/EEA revised guideline and the art of emission inventorying (TNO 2010 available at www.tno.nl/emissioninventorybook). The ABC EIM places added emphasis on biomass open burning emissions to highlight the importance of this source as well as uncertainties involved in its estimation. This manual also presents methods for temporal and spatial distribution of emissions. It specifically includes emission estimations of black carbon (BC) and organic carbon (OC), which are not addressed in detail by existing manuals. An Excel-based tool has been developed, building upon existing tools, such as the one developed by GAPF.

Introduction

This manual attempts to provide greater details of the BC inventory in line with the emission inventory templates provided by the IPCC Guidelines and the EMEP/CORINAIR Guidebook (that is, cooperation of temporal and spatial distribution templates), but with necessary modifications suitable for regional/local application. The manual has also been tested in two case studies of emission inventories developed for Indonesia and Thailand, using the Excel-based tool which can also be applied in emission inventories in other Asian countries. With this experience, the manual encourages inventory compilers to make use of local activity data and emission factors. There is, however, a provision in the ABC EIM that allows use of best available default data, as it has tried to include, to the extent possible, updated emission factors relevant to the region. As new information becomes available, the manual intends to provide future updates and modifications to contribute towards developing better emission inventories.

Furthermore, spatially and temporally disaggregated regional emission inventories of ABC pollutants by source and/or sector are expected to be established in the future. The results can be further elaborated with modeling tools to

1. Develop national/regional level emission scenarios under various socio-economic development and land use scenarios in the medium- and long-term.
2. Assess ABCs impacts at national/sub-national levels.
3. Identify major cost effective mitigation options and technological and policy measures for ABCs emissions and analyze their potential for emission abatement at national/sub-national levels in Asia.
4. Identify major adaptation options and measures and analyze their costs and benefits.
5. Develop national capacity for the above activities.

ABCs INVENTORY METHODS AND COVERAGE

An emission inventory (EI) is a comprehensive listing by source of air pollutant and /or GHG emissions in a geographic area during a specific time period. Emission inventories are one of the fundamental components of Air Quality Management Plans to measure progress/changes over time to achieve cleaner air and to determine compliance with environmental regulations. Emission inventories are also very useful in air quality model applications and for understanding long-range transport of pollutants. As generally accepted objectives that have also been adopted by other major EI preparation manuals, EIs should be transparent, accurate, complete, consistent and comparable.

2.1 EMISSION INVENTORY CHARACTERISTICS

An inventory can be conducted for a certain period (single or multiple years), showing the estimated strength of emissions in a particular geographical area. The inventory base year provides a benchmark for comparison with previous and future inventories compiled for different years. This base year is selected depending on the purpose of the inventory, regulatory requirements and data availability. In Asia, an inventory of SO_2, NO_x, CO, NMVOC, black carbon (BC) and organic carbon (OC) from fuel combustion and industrial sources has been available since 2000 under the Regional Emission Inventory in Asia (REAS) (Ohara et al., 2007). However, in the case of biomass burning, which is believed to be one of the major sources of ABCs, the systematic development of emission inventories has been started only recently.

The variability of emissions over short periods can be described using temporal resolution. Depending on the purpose of the EI, the resolution can be annual, seasonal, monthly, daily, hourly, or for a shorter period. For example, current urban chemical transport modeling requires hourly temporal resolution, whereas global modeling is typically confined to applying monthly mean information. Currently, most of the existing emission databases have aggregated annual energy/emission data, which do not allow a study of the role of seasonal variations in emissions.

A geographic domain needs to be established for an inventory in order to determine the sources to be included in the inventory, based on their location. The sources can be determined based on administrative boundaries (that is, city, provincial, or national borders), air shed boundaries, or other considerations (for example, model grid boxes). Depending on the purpose of an inventory, the geographic domain can be defined at city, district, provincial or national levels. Spatial allocation can be based at a national-level analysis, which represents single national estimates for each major source type and pollutant. For purpose-specific allocation (for example, modeling), emissions can be allocated to grids (usually ranging from 1km x 1km to 50 km x 50 km in size), based on location coordinates, population density and other relevant spatial data. Existing anthropogenic emission databases for Asia generally often have 1° x 1° grid resolution (Streets et al., 2003; Zhang et al., 2009). For ABCs-specific pollutants, Streets et al. (2001) showed the distribution of BC emissions in China (provincial) at a resolution 10 min x 10 min (approximately 0.16° x 0.16°).

Quality assurance/quality control (QA/QC) is very important to ensure that appropriate methods and data are used, errors in calculations or data transcriptions are minimized, and the

documentation is adequate to reconstruct the estimation. The QA/QC principles developed by IPCC (2006) are also generally applicable to other inventories. The Emission Inventory Improvement Program (USEPA, 2007) provided several QA/QC methods, such as reality checks, peer review, sample calculations, computerized checks, sensitivity analysis, statistical checks, independent audits and emissions estimation validation.

2.2 EMISSION INVENTORY DEVELOPMENT APPROACHES

The top-down approach uses general emission factors combined with high-level (national) activity data (for example, emission factor x national fuel consumption) to estimate emissions for a country or region. Furthermore, national or regional level emission estimates can be scaled down to a smaller inventory domain based on surrogate data (geographic, demographic, economic data, and so on). They are typically used when local data are not available and the cost of gathering local information is high. This approach requires minimum resources, but the emissions generally have a high level of uncertainty and potential loss of accuracy in emission estimates (USEPA, 2007). This approach is also known as the rapid emission inventory method and serves as an excellent tool for preliminary estimation of pollution generation, which could be used in decision making (Economopoulos, 1993).

The bottom-up approach uses source-specific data (for point sources) and category-specific data at the most refined spatial level (for non-point and mobile sources). Emission estimation for individual sources (and source categories) is summed up to obtain a domain-level inventory. It is typically used when source/category-specific activity or emission data are available. It produces better spatial distribution of emissions but requires resources to collect site-specific information.

2.3 EMISSION ESTIMATION METHODS

There are several estimation methods to calculate emissions, as summarized by USEPA in Table 2.1.

Table 2.1: Summary of Estimation Methods

No.	Source Categories	Estimation Methods
1	Point Source	Continuous Emission Monitor (CEM)
		Source tests
		Material balance
		Emission factor x activity factors
		Fuel analysis
		Emission estimation models
		Engineering judgement
2	Non-Point Source	Surveys and questionnaires
		Material balance
		Emission factor x activity factor
		Emission models
3	Mobile Source	Emission factor x activity factor
		Emission models

Source: USEPA (2007)

The most common emission estimation method is to multiply an emission factor by activity rate. This method estimates the rate at which a pollutant is released to the atmosphere as a result of certain processes. Uncontrolled emission factors are those where no control devices are in place. Emission factors can also be derived from data obtained from facilities with control devices, and these are called 'controlled emission factors'. Emission calculation can be expressed by using the following equation:

$$Em = EF \times AR \times \frac{(100\text{-}CE)}{100} \qquad \text{(eq. 2.1)}$$

where,

Em = Emission load
EF = Emission factor
AR = Activity data (can be also expressed in terms of production rate)
CE = Overall control efficiency (%).

Another common estimation method related to the energy sector is based on fuel analysis. This method is used to predict emissions based on conservation laws. Emission calculation can be estimated by using the following equation:

$$Em = Q_f \times P_f \times \frac{(MW_p)}{(MW_f)} \qquad \text{(eq. 2.2)}$$

where,

Em = Emission load
Q_f = Mass rate of fuel consumption f (g/hr)
P_f = Pollutant in fuel f (g/g)
MW_p = Molecular weight of pollutant emitted (g/g-mole)
MW_f = Molecular weight of relevant species in fuel (g/g-mole).

Equation 2.2 should be used when emissions are directly related to the amount of pollutants in the fuel. Examples are sulfur dioxide, particulate matter emissions resulting from mineral matter in the fuel, and heavy metals. A capture or retention efficiency may be applied to account for material that is left behind or removed with controls.

Equation 2.1 is necessary when emissions are process-dependent, that is, they vary with the nature of the combustion or manufacturing process. Examples of such pollutants are carbon monoxide, nitrogen oxides, and black and organic carbon.

2.4 DATA COLLECTION

The manual gives information about data that need to be collected and some possible default sources. Suitable and realistic emission factors in the region are presented in this manual. The IPCC (2006) describes methodological principles of data collection that are applicable for this manual.

- Focus on the collection of data needed to improve estimates of key categories, which are large, have high potential to change, or have high uncertainty,
- Choose data collection procedures that iteratively improve the quality of the inventory in line with data quality objectives,
- Put in place data collection activities (resource prioritization, planning, implementation, documentation, and so on) that lead to continuous improvement of data sets used in the inventory,
- Collect data/information at a detailed level appropriate to the method used,
- Review data collection activities and methodological needs on a regular basis, and
- Introduce agreements with data suppliers to support consistent and continuing information flows.

This manual also gives suggestions on activity data collection. Often, most of the compiled activity data will be available from national statistics, international organizations, or government offices. Specific data, especially for biomass burning, will be provided in detail with explanation, including how to get satellite hotspot data for temporal variation, how to get burning area data, and so on. Detailed methods of data collection are discussed in relevant chapters.

2.5 POLLUTANTS

An inventory of key ABC pollutants will focus on primary gaseous and particulates pollutants, such as PM_{10}, $PM_{2.5}$, particulate black carbon (BC) and organic carbon (OC), as well as gaseous pollutants (SO_2, CO_2, NO_x, NH_3, CO, NMVOC and CH_4) and other greenhouse gases (GHGs).

The pollutants listed above should be included in any inventory in order to obtain an overall picture of atmospheric processes that will be useful in atmospheric modeling studies. Thus, important precursors are included to allow evaluation of the effects of secondary air pollutants, such as ozone, and secondary aerosols through photochemical reactions. For example, tropospheric ozone formed in the atmosphere is a GHG that can also cause toxic effects on human health and on plants. A general overview of each key pollutant and its relation to ABCs is presented below.

2.5.1 PARTICULATE MATTER (PM)

Aerosols may be emitted directly as particles (primary aerosol) or formed in the atmosphere by gas-to-particle conversion processes (secondary aerosol). Particulates in the atmosphere arise from natural sources, such as windblown dust, sea spray and volcanoes, as well as from anthropogenic activities like combustion processes.

Tropospheric aerosols may contain sulfate, ammonium, nitrate, sodium, chloride, carbonaceous materials, crustal elements, and water. The carbonaceous fraction of aerosol consists of both elemental and organic carbon. Elemental carbon, also called black carbon (BC), is emitted directly to the atmosphere, predominantly from incomplete combustion processes. Particulate organic carbon (OC) is emitted directly by source or can result from the condensation of low-volatility organic gases in the air, sometimes after oxidation reactions. Particles less than 2.5 μm in diameter are referred to as "fine" and those greater than 2.5 μm as "coarse". In Asia, current BC and OC inventories by TRACE-P and REAS in Asia estimate BC emission levels at

2,020to 2,699 kt/yr and at 7,038 to 8,872 kt/yr for OC emissions. Future changes in economic growth, environmental policy and implementation of emission controls can influence the status of these pollutants.

Significant sources of natural particles include soil, rock debris, volcanic action, sea spray and reactions between natural gaseous emissions. Particles from human activities arise primarily from four source categories: fuel combustion, industrial processes and non-industrial fugitive sources (for example, roadway dust from paved and unpaved roads, wind erosion, and so on) and transportation sources. Biomass burning is also a major source of particulate matter (PM), especially fine PM. A source apportionment study of PM pollution at a suburban site in Thailand suggests that biomass burning contributes over 30% to $PM_{2.5}$ mass (Kim Oanh et al., 2006), highlighting the role of biomass burning in atmospheric haze. The routes of incorporation of chemical species into atmospheric particulate matter are presented in Figure 2.1.
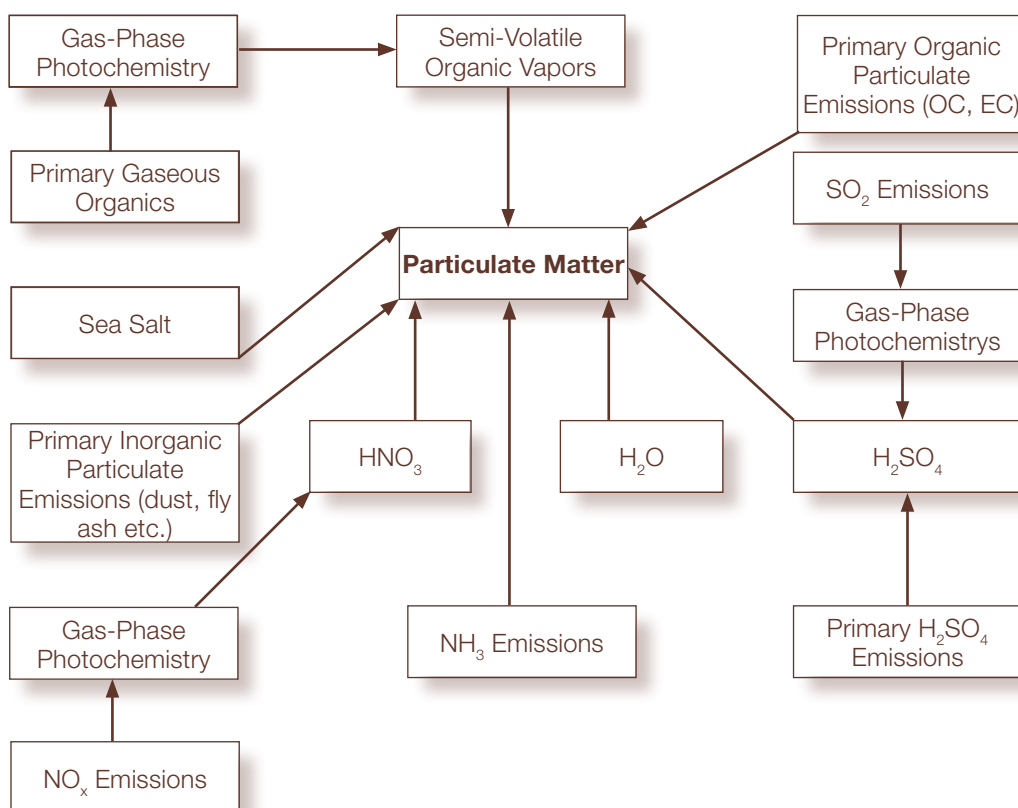
Figure 2.1: Routes of Incorporation of Chemical Species into Atmospheric   Particulate Matter (Meng et al., 1997)

2.5.2 SULFUR DIOXIDE (SO$_2$)

Sulfur occurs in five oxidation states in the atmosphere. Sulfur dioxide (SO$_2$) is the predominant anthropogenic sulfur-containing air pollutant. According to the USEPA definition, sulfur dioxide is one of the criteria pollutants that can harm human health and the environment. Asia has been a leading sulfur-emitting continent since about 1981 (>20 Tg (S)/yr compared with <15 Tg(S)/yr for North America), largely (Seinfeld and Pandis, 1998) due to increasing coal combustion in China and other Asian countries. Sulfur dioxide in the atmosphere contributes to secondary aerosol formation through gas-to-particle conversion.

2.5.3 CARBON DIOXIDE (CO$_2$)

Carbon dioxide (CO$_2$) is a naturally occurring gas and a by-product from the burning of fossil fuel or biomass, as well as from land use changes and industrial processes. CO$_2$ has the largest radiative forcing impact of any trace constituent. Atmospheric levels of CO$_2$ increase at a rate of about 1.9 ppm/yr as a result of the combustion of fossil fuels, cement production and land use. Other dominant sources are deforestation and land use changes. An estimation based on combustion statistics showed increased value of CO$_2$ emissions from 5.5 Gt(C) in 1980 to 6.2 Gt(C) in 1991 (Seinfeld and Pandis, 1998).

2.5.4 NITROGEN OXIDES (NO$_x$) AND NITROUS OXIDE (N$_2$O)

Nitric oxide (NO) and nitrogen dioxide (NO$_2$), collectively known as NO$_x$, are among the most important molecules in air pollution. NO$_2$ is also a criteria pollutant. Estimates of NO$_x$ global emissions show an increasing trend over the past few decades. Kato and Akimoto (2007) report an increase in fossil fuel combustion of NO$_x$ from 9.4 Tg/yr in 1975 to 15.5 Tg/yr in 1985. In Canada and the United States, 40 to 45% of all NO$_x$ emissions are estimated to come from transportation, 30 to 35% from power plants, and about 20% from industrial sources. In Asia, current inventories identify major NO$_x$ contributors as coal-burning power plants (34%), followed by transport and industry (Ohara et al., 2007). Together with VOC, NO$_x$ is one of the main ozone (O$_3$) precursors. NO$_2$ has a role in the dominant termination reaction with OH, a radical in the photochemical O$_3$ system that produces nitric acid. Nitric acid has a potential to react with ammonia to produce ammonium sulfate in the particulate-phase.

Another nitrogen-containing compound is N$_2$O, which is emitted predominantly in the atmosphere by biological sources in soil and water. Although it exists in lower concentration compared to CO$_2$ and H$_2$O, it is an important greenhouse gas. Anthropogenic sources include cultivated soils, biomass burning, industrial sources, cattle and feedlots, while natural sources include oceans, tropical soils and temperate soils. Tropical soils contributed around 4 Tg(N)/yr to the total N$_2$O emission estimated in the last decade (IPCC, 1995).

2.5.5 AMMONIA (NH$_3$)

Ammonia is the main alkaline gas in the atmosphere and is the most abundant nitrogen-containing compound in the atmosphere (Seinfeld and Pandis, 1998) after N$_2$ and N$_2$O. Natural sources of ammonia, such as wild animals, vegetation and oceans, contribute around 45% of total global emissions. Agricultural practices (livestock manure management and N-containing

fertilizer application) are the most significant anthropogenic sources of NH_3. Ammonium ion is an important component of continental tropospheric aerosol. Ammonia provides a route for the formation of particulate-phase nitrate through reversible reactions between ammonia and nitric acid that form ammonium nitrate in the particulate phase. The residence time of NH_3 in the atmosphere is expected to be quite short (10 days or less) because NH_3 gas is readily absorbed by surface water and soil and also because ammonium aerosols are semi-volatile and evaporate into the gas phase when NH_3 gas is consumed by absorption. Wet and dry deposition is the main atmospheric removal mechanism for NH_3 and ammonium.

2.5.6 CARBON MONOXIDE (CO)

Carbon monoxide (CO) is produced in large quantities by incomplete combustion of fossil fuels (especially in the transport sector) and of other organic matter (for example, biomass and biofuel burning). It is also emitted as a by-product of some industrial processes, such as those in steel production. Natural sources of CO include volcanic eruptions, photolysis of certain naturally occurring VOCs (such as methane and terpenes), chlorophyll decomposition, forest fires, and microbial action in oceans. IPCC (1995) noted that about two-thirds of carbon monoxide comes from anthropogenic activities. The major sink for CO is the reaction with OH radicals, while minor sinks are soil uptake and diffusion into the stratosphere. The chemical lifetime of CO is about 30 to 90 days on a global scale. The maximum concentration of CO is usually observed during the local spring. Current inventories conducted by several inventory projects describe CO emissions in Asia within the range of 75,442 to 141,700 kt/yr. China and India are cited as major contributors.

2.5.7 NON-METHANE VOLATILE ORGANIC COMPOUND (NMVOC)

Non-methane volatile organic compounds (NMVOCs) are not direct greenhouse gases, but together with NO_x, CO and CH_4, they increase the formation of tropospheric (ground level) ozone and thus contribute indirectly to radiative forcing. The emission of NMVOC plays a key role in the formation of ground level ozone, and the resulting by-products can be transported over long distances. Some NMVOCs also act as aerosol precursors. The major anthropogenic sources of NMVOC emissions are industrial activities, as for example, industrial coating process, industrial solvent use, dry cleaning, large point sources (oil refineries, large combustion plants, chemical manufacture and production processes), transport sector (motor vehicles), and other combustion sources, such as residential biomass burning. NMVOCs from refineries originate from four main sources:

- fugitive emissions from piping associated with nearly all process steps in a refinery,
- flaring, which is used to ensure safety and environmental control of discharges of undesired or excess combustibles and for surges of gases in emergency situations or upsets,
- waste water treatment plants (those used in refineries, including neutralizers, oil/water separators, settling chambers, clarifiers, dissolved air flotation systems and activated sludge ponds), and
- storage tanks and refinery dispatch stations.

Natural biogenic sources of NMVOCs may also be important, especially isoprene and terpenes, as well as those emitted from trees and other vegetation. Biogenic NMVOC emissions are highest in the summer and may exceed anthropogenic emissions in certain regions. Estimates of natural NMVOC emissions, although not covered in this manual, are crucial input parameters for air quality models.

2.5.8 METHANE (CH$_4$)

Methane is the most abundant hydrocarbon in the atmosphere. As its natural source, methane is predominantly derived from wetlands, while its anthropogenic sources are mainly fossil fuel combustion, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning and waste management. IPCC (1995) estimated the total global annual emission of anthropogenic methane at 375 Tg(CH$_4$)/yr source and around 160 Tg(CH$_4$)/yr for methane from natural sources.

2.6 SOURCES AND SECTORS

2.6.1 CHAPTERS

Fossil fuel, biofuel and biomass open burning are believed to be the main sources of ABC precursors. Emission source categories used in this manual are adopted from key categories given by IPCC (2006). Brief descriptions of the processes included in each sector are provided in respective chapters.

Chapter 1 mainly describes the background and main output of the project. Chapter 2 highlights methods and coverage of the manual, including source sector categories and types of pollutants. Chapter 3 includes fuel combustion activities in the energy sector (namely in power generation, manufacturing and construction, transportation, residential and commercial sectors.

Chapter 4 covers emissions from non-combustion activities related to the extraction, processing, storage, distribution, and use of fuels. Chapter 5 covers processes that generate by-product emissions (process emissions). However, it excludes all combustion emissions from industry as these are already covered in Chapter 3. Chapter 6 includes rice straw and other crop residue burning in the field or other open areas. Chapter 7 includes on-site burning of forests and natural grasslands which is human-induced (due to prescribed burning for management purpose or conversion to other land uses). Chapter 8 includes open burning of solid waste (normally on-site in the community where the wastes are generated) and landfill open burning. Chapter 9 covers the use of solvents and other products. This chapter includes emissions from the application of paint, varnish, glue and adhesives; metal degreasing and dry cleaning of fabrics; manufacture of certain chemical products; pesticides and pharmaceuticals, and use of solvents in the printing industry. Chapter 10 covers non-combustion emissions from the agriculture sector (including livestock management and application of nitrogen-containing fertilizer) and emissions from combustion in waste incinerators (for example, thermal incineration of solid waste, including municipal solid waste, industrial waste, medical waste incineration, and methane emission from landfill). However, this chapter excludes emissions from agricultural field burning activities as these

are already considered in Chapter 6. Waste incineration activity is excluded as it is considered in Chapter 10. A summary of the sectoral structure of sources used in this manual is presented in Table 2.2.

Table 2.2: Summary of Emission Inventory Using a Sectoral Structure

Chapter	Sector	Description
Chapter 3	Combustion in Energy Industry and Energy Using Sectors	Includes emissions related to fuel combustion in power generation, manufacturing and construction, residential, commercial services and transport sectors
Chapter 4	Fugitive Emissions from Fuels	Includes emissions from coal mining and handling, oil and gas exploration, treatment and loading, oil refinery, gasoline distribution and flaring in oil and gas production facility
Chapter 5	Process Related Emissions in Manufacturing/Process Industries	Includes by-product emissions from processes and excludes industrial combustion emissions
Chapter 6	Crop Residue Open Burning	Includes emissions from agricultural field burning (includes land clearing and crop residue burning)
Chapter 7	Forest Fires	Includes total emissions from on-site burning of forest (and other vegetation) and land clearing
Chapter 8	Municipal Solid Waste Open Burning	Includes emissions from solid waste open burning; excludes solid waste incineration emission
Chapter 9	Solvents and Other Products Use	Includes emissions resulting from the use of solvents and other products
Chapter 10	Other sectors	Includes other sources, such as agricultural emissions from non-burning activities (that is, domestic livestock and fertilizer application and emissions from waste treatment and disposal.

2.6.2 LARGE POINT SOURCES (LPS)

A large point source (LPS) is any emission source greater than a particular size source at a fixed location. The exact definition of a large point source is study-specific and depends on data availability in a given situation as well as on the aim of the study. Examples of LPS include large power stations, waste incineration plants and major industrial plants, such as metal smelters and oil refineries. The number of LPSs included in an inventory depends on the availability of individual plant data and on the definition of "large".

In the Regional Air Pollution Information and Simulation-Asia (RAINS-ASIA) Program, a large point source is defined as an emitting complex with:
- total electric output capacity greater than or equal to 500 MW_{el} (electric power plants), or
- total thermal input capacity greater than or equal to 1500 MW_{th} (industrial plants), or
- unabated annual SO_2 emissions greater than 20,000 metric tonnes, or
- unabated annual NO_x emissions greater than 5000 metric tonnes.

In the European Monitoring and Evaluation Programme/Core Inventory of Air Emissions (EMEP/CORINAIR) Emission Inventory Guidebook (2007), the criteria for large point sources include the following considerations:

- power plants with thermal input capacity > 300 MW
- refineries
- sulfuric acid production
- nitric acid production
- iron and steel plants with production capacity > 3 Mt/year
- production of paper pulp with capacity > 1 Mt/year
- vehicle painting units > 10^6 vehicles/year
- airports > 10^6 LTO cycles per year, and
- any activity emitting > 1kt of SO_2, NO_x or NMVOC or > 3 Mt CO_2/year.

Most countries have expanded the above mentioned criteria. Generally, it is recognized that the definition of "large" varies from country to country. It is therefore recommended that preparation of a country's inventory should include a review of the above mentioned criteria.

In our Excel workbook, LPSs are categorized under two main groups, as follows:
- large point sources of combustion activities, and
- large point sources of non-combustion activities and fugitive emissions.

For LPS combustion activities, the following data are required:
- locational information, such as province, latitude, longitude, and so on,
- stack details, such as stack height and emitted stack gas volume and temperature,
- fuel details, such as type, annual consumption, net calorific value (NCV), Sulfur content, Sulfur retention in ash and ash content (for particulate matter),
- emission controls, such as type and efficiency of each pollutant, and
- measured pollutant emissions depending upon availability.

For non-combustion and fugitive emissions, data requirements are similar except that relevant process activity rates are needed instead of fuel details. Default emission factors are used in case measured or plant-specific emission factors are not available.

2.6.3 AREA SOURCES

Area sources are sources of pollution that emit a substance from a specific area. These include small pollution sources, such as dry cleaners, gas stations, and auto body paint shops. They generally emit less than 10 tonnes per year of criteria or hazardous air pollutants or less than 25 tonnes per year of a combination of pollutants. However, their definition should be harmonized with that of LPS so that all sources are covered. The category also includes commercial buildings (heating and cooling units, surface coatings), residential buildings (fire places, surface coatings), fuel combustion in non-road machinery, boats, railroads, and even the family lawnmower or barbecue grill. Open burning, landfills and wastewater treatment as forms of waste disposal are significant area sources.

Although emissions from individual area sources are relatively small per unit, collectively their emissions can be of concern, particularly where large numbers of sources are located in heavily populated areas. Area sources can be responsible for over 50% of particulate matter emissions, exceeding point or mobile sources for volatile organic compound (VOC) emissions.

2.6.4 MOBILE SOURCES

Mobile sources include both on-road vehicles (such as cars, trucks and buses) and off-road vehicles and machinery (such as ships, airplanes, and mobile agricultural and construction equipment).

2.7 TEMPORAL EMISSION DISTRIBUTION

Temporal distribution of emissions over time intervals within a year can be accomplished at many different time scales, including seasonal, monthly, weekly, day-of-week, day/night (diurnal) and hourly scales. For LPS and area source, the disaggregation of annual emissions into monthly, daily or hourly emissions can be done according to the following steps (EMEP/CORINAIR, 2006):

a. Calculation of monthly emission,

$$EM_n = Em_A \times FM_n \qquad \text{(eq. 2.3)}$$

where,

n	= Month (1-12)
EM_n	= Monthly emission
Em_A	= Annual emission rate
FM_n	= Monthly fraction.

b. Calculation of daily emission,

$$ED_{n,d} = EM_n \times FD_d \qquad \text{(eq. 2.4)}$$

where,

n,d	= Month, day
$ED_{n,d}$	= Daily emission
EM_n	= Monthly emission
FD_d	= Daily fraction.

c. Calculation of hourly emission,

$$EH_{n,d,h} = ED_{n,d} \times FH_{,h} \qquad \text{(eq. 2.5)}$$

where,

n,d, h	= Month, day, hour
$EH_{n,d,h}$	= Hourly emission
$ED_{n,d}$	= Daily emission
$FH_{,h}$	= Hourly fraction.

The factors for month FM_n, day FD_d and hour FH_h can be constructed by relating monthly activity data to total fuel consumption (e.g. net electricity production for power generation, hotspot counts for forest fire, and fuel sold for the residential sector, etc).

2.8 SPATIAL EMISSION DISTRIBUTION

Besides distribution over time, emissions are also distributed over space, that is, location or area (for example, 1° x 1° grid squares as often found in existing global inventories) within the country from where the emissions come. Spatial emission distribution is calculated based on following equation:

$$ES_m = Em_A \times FS_m \qquad \text{(eq. 2.6)}$$

where,

ES_m	= Sub-national level emission
Em_A	= Annual emission rate
FS_m	= Spatial fraction at sub-national level m.

The spatial fraction of FS_m can be constructed by relating sub-national level activity data to the national level activity data. An example of related activity data used to determine national emission distribution is given in each chapter.

CHAPTER 3

COMBUSTION IN ENERGY INDUSTRY AND ENERGY USING SECTORS

3.1 ENERGY INDUSTRY

This chapter deals with the estimation of emissions from fuel combustion in the energy industry as well as that from manufacturing and construction, transport, residential and commercial sectors.

3.1.1 OVERVIEW

This section covers activities in combustion plants for the generation of electricity, production of heat, and extraction/processing of fossil fuels. The activities include:

- **Electricity Generation and Heat Production:** Emissions are produced by the combustion of fuel(s) for the production of electricity or heat. Both public and private power generation utilities are included.
- **Petroleum Refining:** Emissions are produced by the combustion of fuels during the petroleum refining process mainly because of process heaters.
- **Solid Fuels and Other Energy Industries:** Emissions are produced by the combustion of fuel(s) during the manufacture of secondary or tertiary products from solid fuels. The emissions are mainly from the production of coke, patent fuel, brown coal briquettes (BCB) and gas work gas, gas from coal, and charcoal from wood. Emissions also come from 'own use' of fuels (i.e., fuel combustion) in various energy industries, such as coal combustion in the course of coal mining, and oil/gas use in oil and gas extraction.

Emissions considered in this sector are released by contained combustion processes (boiler emissions, furnace emissions, emissions from gas turbines or stationary engines) and are mainly characterized by the type of fuel used. In particular, based on source category, combustion plants are treated either a large point source (LPS) as area source. In general, LPS is any emission source at a fixed location, for which individual data are collected. The criteria for large point sources are described in sub-section 2.6.3 of Chapter 2.

The aforementioned activities may emit air pollutants related to ABCs, such as PM_{10}, $PM_{2.5}$, BC, OC, SO_2, NO_x, NH_3, CO, and NMVOC. Emissions of sulfur dioxide (SO_2) are directly related to the sulfur content of the fuel.

3.1.2 EMISSION ESTIMATION METHOD

Large Point Source (LPS) (Refer to section 2.6.3 for a definition of LPS).

a. Simple Method

The simple method proposed by EMEP/CORINAIR (2006) is used in this manual. It refers to the calculation of emissions based on emission factors and activities. This should only be used when measured data are not available. A combustion plant can be treated either as an area source (many boilers within one plant, irrespective of type/size of individual boilers) or point source (consider each individual boiler). The emission can be estimated using the following equation.

$$Em_i = AR_i \times EF_i \qquad \text{(eq. 3.1)where,}$$

i = Type of pollutant
Em_i = Emission of pollutant i
AR_i = Activity rate related to emission of pollutant i, in energy input or fuel consumption in GJ
EF_i = Emission factor for pollutant i (g/GJ).

b. Detailed Method

This method makes use of continuous monitoring data of major pollutants which are normally found in plants that have installed abatement technologies. This method should be used when measured data are available. For example, periodically measured data are often available in large size combustion installations. Pollutants normally measured in power plants are SO_2, NOx, CO and particulate matter. Temperature and O_2 concentration are also normally measured.

For gaseous emissions, the emission calculation is expressed in the following equation.

$$Em_{i,t} = V_t \times C_{i,t} \qquad \text{(eq. 3.2)}$$

where,
t = Period of operation (h)
$Em_{i,t}$ = Emission of pollutant i in the period of operation t (mg/h)
V_t = Flue gas volume flow rate in period t (m³/h)
$C_{i,t}$ = Flue gas concentration of pollutant i in period t (mg/m³).

Area Source (Refer to section 2.6.4 for a definition of area source)

The emission estimation methodology for area source is similar to that of LPS (refer to the previous section). For area source emissions, the detailed method is not applicable as only few sources are monitored directly.

3.1.3 DATA ON ACTIVITY LEVELS
Listed below are activity data needed for estimation of emissions from this sector:
- Size of combustion plants in thermal capacity unit (MW).
- Energy input or fuel consumption of combustion plants in GJ.
- Installed abatement technologies in combustion plants (type and efficiency of each pollutant).
- Fixed geographical location of combustion plants (for LPS) for spatial distribution.
- Continuous emission monitoring data of pollutants (concentration, mg/m³), flue gas flow rate (m³/h), period of operation to calculate emissions by using detailed method for LPS.
- Stack detail data which may be needed for other purposes (that is, modeling, and so on).
- Fuel details (type, annual consumption, Net Calorific Value (NCV), sulfur content, sulfur retention in ash, and ash content).

The stack data should be obtained from a relevant national authority. Listed below are several possible sources of the above mentioned data, which are important for data comparison or as a starting point to update the data:

- For Asia, RAINS-ASIA provides 355 LPS data identified at 332 locations
  http://webarchive.iiasa.ac.at/Research/TAP/rains_asia/docs/
- Country-wise total transformation of heat and electricity is also available at
  http://www.iea.org/stats/prodresult.asp?PRODUCT=Electricity/Heat
- National reports on the power generation sector in individual countries, where available.

3.1.4 EMISSION FACTORS

Emission factors are mainly taken from EMEP/CORINAIR (2006) for SO_2, NOx, CO, NMVOC and NH_3, from USEPA (1995) for PM_{10} and $PM_{2.5}$, and from Bond et al., (2004) for BC and OC and other information sources. The compiled values presented in Tables 3.2 to 3.5 are mostly general uncontrolled emission factors. Representative pollutant emission control reductions for power stations are presented in Table 3.3. The emission factor for SO_2 is calculated using the expression in eq. 3.3 (IPCC, 1996), while the values of some parameters are presented in Table 3.1:

$$EF_{SO2} = 2 \; x \left(\frac{CS_{fuel}}{100}\right) x \left(\frac{100 - \alpha_s}{100}\right) x \frac{1}{H_u} x \; 10^6 \; x \left(\frac{100 - \eta_{cd}}{100}\right) \qquad \text{(eq. 3.3)}$$

where,

EF_{SO2} = Specified emission factor for SO_2 (kg/TJ)
CS_{fuel} = Sulfur content in fuel (% weight)
α_s = Sulfur retention in ash (%)
H_u = Lower heating value of fuel (TJ/ktonne)
η_{cd} = Reduction efficiency of control device (%).

Table 3.1: Parameters to Calculate SO_2 Emission Factor and Existing SO_2 EF

Fuel Type	CS_{fuel}[a] in %	α_s[d] in %	Hu (TJ/ktonne)[a]	Existing SO_2 EF (kg/TJ)[h,b]
Other Bituminous Coal and Anthracite	0.5 - 3.00, 0.2 – 3.65[b]	5[a]	26.12[k]	746 CS_{fuel}[i,1], 74.7CS_{fuel}
Sub-bituminous Coal	0.5 - 3.0, 0.2 – 3.65[b]	25[a]	20-21[e]	905 CS_{fuel}[i,1], 92.9 CS_{fuel}
Lignite	0.5 - 3.0, 0.48 – 3.65[b]	25[a]	-	1000 CS_{fuel}[i,1], 130 CS_{fuel}
Coke Oven Gas	1.35 x coal S%[b]	0	28[f]	9 CS_{fuel}
Blast Furnace Gas	0.00064	0	2.2[f]	0.24
Gas Works Gas	0.00064	0	28[g]	0.24
Natural Gas	0.00064[b,c]	0	50.81[g]	0.19[i], 0.22
Crude Oil	1.2[g]	0	42.68[i]	46.9 CS_{fuel}
Natural Gas Liquid	0.00064	0	48.63[i]	0.3
Refinery Gas	0.00064	0	48.15	0.3
Liquefied Petroleum Gas	0.02[c]	0	47.31	0.2
Motor Gasoline	0.1, 0.2[c], 0.005-0.18[b]	0	44.8	44.6 CS_{fuel}
Kerosene	0.05, 0.2[c], 0.004-0.2[b]	0	44.75	44.6 CS_{fuel}
Diesel Oil	0.3 - 1.0, 1.0-1.8[c]	0	43.33	46.2 CS_{fuel}
Heavy Fuel Oil	1.0 - 4.0, 4.0[c]	0	40.19	49.8 CS_{fuel}
Petroleum Coke	6	5[a]	31	32.3 CS_{fuel}
Other Petroleum Products	0.05[b]	0	40.19	24.9 CS_{fuel}
Wood	0.04[c]	0	15[g]	10.7[i,3]
Vegetable Materials and Waste	0.04[c]	0	12[g]	-
Others (e.g. animal products/wastes)	0.07[c]	0	15[g]	-
Unspecified Primary Solid Biomass	0.07[c]	0	15[g]	-
Municipal Waste	0.003	0	11[g]	-
Industrial Waste	0.2	0	11[g]	-
Charcoal	0.036[b]	0	30.81[g]	-

Source/Remarks

CSfuel: Sulfur content in fuel, % weight.
α_s: Sulfur retention in ash (in %).
H_u: Lower heating value of fuel, TJ/ktonne
A = % ash content (e.g. if ash content is 10%, multiply the factor by 10).
[a] Default value suggested by IPCC 1997 and 2006, unless otherwise indicated.
[b] Kato and Akimoto, 1992. Variability of sulfur content (wt %) of fuels used in 25 Asian countries showing min and max values.
[c] Reddy and Venkataraman, 2002a. These values are compiled for India.
[d] Sulfur retention in ash assumed to be zero for gaseous and liquid fuels, biomass and waste.
[e] http://en.wikipedia.org/wiki/Sub-bituminous_coal.
[f] EMEP/CORINAIR, 1992. Presented values are average values.
[g] OECD/IEA, 1998. Taken from OECD/IEA Energy Statistics and Balances for non-OECD Countries.
[h] If parameters required to calculate SO_2 EF (eq. 3.3) are not available, use available SO_2 EF (as a function of sulfur content) compiled from various sources.
[i] USEPA, 1995. [i,1] Mean value for pulverized coal-fired boilers (uncontrolled); [i,2] Converted to kg/TJ by using density of natural gas of 0.9 kg/m³; [i,3] Mean value for uncontrolled dry wood-fired boiler.

Table 3.2: General Emission Factors for Power Generation

Fuel Type	Emission Factors in kg/TJ unless indicated otherwise										
	NO_x[a]	CO[a]	NMVOC[a]	PM_{10}[b]	$PM_{2.5}$[b]	NH_3[f]	BC[c]	OC[c]	CO_2[a]	CH_4[a]	N_2O[a]
Other Bituminous Coal and Anthracite	300, 345[b,1], 381[d]	20, 11.5[b,7]	5, 5.74[b,7]	47 x A[b,1]	19.9 x A[b,1], 42.11[h]	0.00028	0.11[j], 0.25[c,1], 2.94[h]	0.0-0.04[c,1], 12.63[h], 1.8-2.8[k]	94600	0.6	0.8
Sub-Bituminous Coal	300, 524[b,1], 474[d]	20, 12[b,1]	5, 2[b,1]	24.7 x A[b,1]	24.7 x A[b,1], 52.4[h]	0.00028	0.14[j], 0.3[c,2], 3.66[h]	0.0-0.04[c,2], 15.71[h], 1.8-2.8[k]	96100	1	1.5
Lignite	300, 564[d], 433[b,1]	20, 8.3[b,1]	5, 2.6[b,1]	68.6 x A[b,2]	22 x A[b,2], 124[h]	0.00028	1.0[c,3]	2.66[c,3], 12.66[h], 1.8-2.8[k]	101000	1	1.5
Coke Oven Gas	77.8[d]	20	5	-	-	-	-	-	44400	1	0.1
Blast Furnace Gas	10.5[d]	20	5	-	-	-	-	-	260000	1	0.1
Gas Works Gas	10.5[d]	20	5	-	-	-	-	-	44400	1,	0.1,
Natural Gas	105[d], 98[b,8]	20, 29.5[b,8]	5, 1.9[b,8]	25	2.5, 39[h]	1.31	0.002[c,4]	0.019[c,4]	56100, 41979[b,8]	1, 0.78[b,8]	0.1, 0.78[b,8]
Crude Oil	200, 170[d]	15	5	-	-	-	-	-	73300	3	0.6
Natural Gas Liquid	200, 127[d]	15	5	-	-	-	-	-	64200	3	0.6
Refinery Gas	16[d]	15	5	-	-	-	-	-	57600	1	0.1
Liquefied Petroleum Gas	79[d]	15	5	-	-	-	-	-	63100	1	0.1
Motor Gasoline	373[d]	15	5	-	-	-	-	-	69300	3	0.6
Kerosene	485[d]	15	5	-	-	-	0.59[c,5], 0.25[h]	0.17[c,5]	71900	3	0.6
Diesel Oil	632[d]	15	5	7.7[b,3]	5.6[b,3], 15.4[h]	-	0.61[c,6], 0.25[h]	0.18[c,6]	74100	3	0.6
Heavy Fuel Oil	249[d]	15	5	7.8[l], 22.4[b,4]	16.4[b,4], 3.92[l], 8.9[h]	0.101	0.7[g], 0.98[c,7], 8.9[j]	0.37[c,7], 0.33[g], 6.71[i]	77400	3	0.6
Petroleum Coke	300[e]	20	5	39.7 x A[b,5]	16.7 x A[b,5]	0.00028	-	-	97500	3	0.6

Fuel Type	Emission Factors in kg/TJ indicated otherwise										
	NO_x^a	CO^a	$NMVOC_x^a$	PM_{10}^b	$PM_{2.5}^b$	NH_3^f	BC^c	CO^c	CH_2^a	CH_4^a	N_4O^a
Other Petroleum Products	200	-	5	-	-	-	-	-	73300	3	0.6
Wood	100, 211[b,6]	1000, 258[b,6]	50, 7.3[b,6]	155[b,6]	133[b,6]	-	2.93	12	112000, 83850[b,6]	30	4, 5.6[b,6]
Vegetable Materials and Waste	100	1000	50	248[c,8]	25[c,8]	-	0.86	0.13	106000	1	1.5
Others (e.g. animal products/ wastes)	100	1000	50	-	-	-	-	-	100000	30	4
Unspecified Primary Solid Biomass	100	1000	50	-	-	-	-	-	100000	30	4
Municipal Waste	100	1000	50	-	-	-	-	-	91700	30	4
Industrial Waste	100	1000	50	-	-	-	-	-	143000	30	4

Source/Remarks

The emission factors presented here are for common technology used and alternative EFs sources; for other technology-wise EFs details, refer to Emission Factor Data Base EXCEL tool, which is a part of this ABC EIM.

[a] IPCC 1997 and 2006, unless otherwise indicated. Uncontrolled emission factors. Default values are presented for GHGs.

[b] USEPA, 1995. [b,1] Mean value for pulverized coal-fired boilers (uncontrolled), TNMOC EF instead of NMVOC; [b,2] Mean value for tangentially (uncontrolled), wall-fired pulverized lignite boilers; [b,3] Uncontrolled EF for filterable plus condensable PM_{10} for utility boilers firing no 2 grade distillate oil (diesel); [b,4] Uncontrolled EF for utility boilers firing no 5 grade residual fuel oil; [b,5] Assume= EF of other bituminous coal and anthracite; [b,6] Applicable for dry wood/bark-fired boilers, estimated from cumulative particle size distributions graph, [b,7] Applicable for stoker-fired boiler, for NMVOC it represents TOC EF; [b,8] Applicable for large wall-fired boiler (NOx and CO), all Efs are converted from $lb/10^6$ scf to g/kg by using natural gas density of 0.9 kg/m^3.

[c] Bond et al., 2004. Uncontrolled central values which have been converted from g/kg to kg/TJ by using NCV values. [c,1] Derived from PM (12 g/kg) for pulverized coal technology with $F_{1.0}$ is 0.09, F_{BC} is 0.006, and F_{OC} is 0, the range of OC Efs show variability in central values due to regional variations because of technology mix; [c,2] Assume using similar factors with other bituminous coal; [c,3] Derived from PM (29 g/kg) for pulverized coal technology with $F_{1.0}$ is 0.09, F_{BC} is 0.006, OC EF is 0.04 g/kg; [c,4] Derived from filterable PM (0.002 g/kg) for all technologies with $F_{1.0}$ is 1.0, F_{BC} is 0.06, OC EF is 0.5 g/kg; [c,5] Derived from PM (0.49 g/kg) for all technologies with $F_{1.0}$ is 0.18, F_{BC} is 0.30, OC EF is 0.09 g/kg; [c,6] Assume using similar factors applied for [c,5]; [c,7] Derived from PM (1.1 g/kg) for all technologies with $F_{1.0}$ is 0.45, F_{BC} is 0.08, OC EF is 0.03 g/kg; [c,8] Solid waste for all technologies.

[d] Kato and Akimoto, 1992. Derived by assuming average calorific values, as given in the IEA Energy Statistics and Balances for non-OECD Countries (IEA, 1998).

[e] Assumed emission factors are similar to other bituminous coal and anthracite.

[f] Batye et al., 1994. No NOx control.

[g] Kupianen and Klimont, 2007. Values presented are central values.

[h] Reddy and Venkataraman, 2002a. Most values are applicable for Indian case. 50% control scenario lower value.

[i] Streets et al., 2003.The unit has been converted from g/kg to kg/TJ by using NCV values.

[j] Streets et al., 2001. Uncontrolled central value. For coal, technology involved is pulverized coal. The unit has been converted from g/kg to kg/TJ by using NCV values.

[k] Hangebrauck et al., 1964. Applicable for pulverized coal based on sampling of stack data.

[l] APEG, 1999. For public power generation, PM_1/PM_{10} ratio is 0.18.

- Not available.

Table 3.3: Representative Emission Control Reductions (SO$_2$, NO$_x$, PM$_{2.5}$, BC, OC) in %

Technology	SO$_2$ Reduction[a] (%)	NO$_x$ Reduction[a] (%)	PM$_{2.5}$ Reduction[b] (%)	BC Reduction[g] (%)	OC Reduction (%)
Lime/Limestone Wet Scrubber (WS)	90	-	-	-	-
Spray Dryer Absorption (SDA)	90	-	-	-	-
Dry Sorbent Injection (DSI)	70	-	-	-	-
Wellman Lord (WL)	97	-	-	-	-
Walther Process (WAP)	88	-	-	-	-
Low NOx Burner	-	10-30[c]	-	-	-
Staged Air Supply (SAS)	-	20[d]	-	-	-
Overfire Air (OFA)	-	10-40[e]	-	-	-
Flue Gas Recirculation (FGR)	-	15-20[f]	-	-	-
Selective Non-Catalytic Reduction (SNCR)	-	80	-	-	-
Selective Catalytic Reduction (SCR)	-	90	-	-	-
Activated Carbon Process	95	70	-	-	-
DESONOX Process	95	95	-	-	-
Electrostatic Precipitators (ESP)	-	-	99.2	98	96[h]
Multiple Cyclones	-	-	11[h]	11[h]	11[h]
Scrubber	-	-	94	76	90
Baghouse	-	-	99.8	95	-
ESP + Others	-	-	99.8	>98	99.5
Fabric filters			99.9[h]	99.9[h]	99.9[h]

Source/Remarks
[a] EMEP/CORINAIR, 2006.
[b] USEPA, 1995. Values are derived from PM reduction, actual values may be less.
[c] Applicable for coal-fired boilers.
[d] Applicable for oil-fired boilers.
[e] Applicable for oil- and coal-fired boilers.
[f] Applicable for gas- and oil- fired boilers.
[g] Streets et al., 2001. Central value applied for each type of control device.
[h] Kupiainen and Klimont, 2004. Removal efficiencies for PM$_{2.5}$ (refer to PM$_1$), black carbon (BC), and organic carbon (OC) assumed in RAINS.
- Not available.

Table 3.4: Emission Factors for Petroleum Refining Process

Fuel Type	NO_x[b]	CO[a]	NMVOC[a]	NH_3[c]
Coking Coal	-	-	-	-
Other Bituminous Coal and Anthracite	-	-	-	-
Sub-Bituminous Coal	-	-	-	-
Lignite	-	-	-	-
Coke	-	-	-	--
Gas Coke	-	-	-	-
Brown Coal Briquettes BKB	-	-	-	-
Coke Oven Gas	-	-	-	-
Blast Furnace Gas	-	-	-	-
Gas Works Gas	7.4	20	5	-
Natural Gas	53, 1.4-140[i]	20, 1.3-280[i]	5, 0.3-7[i]	1.31
Crude Oil	200[a]	15	5	-
Refinery Gas	11, 30-150[i]	15, 10-280[i]	5, 0.3-10[i]	-
Liquefied Petroleum Gases	56	15, 45[i]	5, 14[i]	-
Motor Gasoline	-	15	-	-
Kerosene	167	15	5	-
Diesel Oil	222	15	5	-
Heavy Fuel Oil	145, 100-210[i]	15, 7-350[i]	5, 1-41[i]	-
Petroleum Coke	300[a]	20	5	-

Source/Remarks
[a] IPCC, 2006. Technology applied is combustion plants (boilers) with dry and wet bottom boiler, unless indicated otherwise.
[b] Kato and Akimoto, 1992. Assuming average calorific values given in IEA energy statistics (1998).
[c] Batye et al., 1994.
[d] Applicable for boilers with grate firing/spreader stoker.
[e] Applicable for gas turbine/simple cycle.
[f] Applicable for gas turbine/combined cycle.
[g] Applicable for process furnace.
[h] USEPA, 1995. Refer to PM_{10} emission.
[i] EMEP/CORINAIR, 2006. These values are applicable for process heaters in refinery.
[j] Muhlbaier and Williams, 1982. These values are converted to kg/TJ from g/kg by using NCV value of 0.0508 TJ/tonne.
[k] Bond et al., 2004. These values are converted to kg/TJ from g/kg by using NCV value of 0.0310 TJ/tonne for coke and 0.0402 TJ/tonne for HFO, PM_{10} values refer to PM EF while $PM_{2.5}$ values refer to $PM_{1.0}$. [k.1] Derived from PM EF with $FPM_{1.0}$ is 0.28, F_{BC} is 0.28 and F_{OC} is 0.05; [k.2] Derived from PM EF with $FPM_{1.0}$ is 0.45, F_{BC} is 0.08 and F_{OC} is 0.03.
- Not available.

Emission Factor in (kg/TJ)						
$CO_2{}^a$	$CH_4{}^a$	N_2O^a	PM_{10}	$PM_{2.5}$	BC	OC
94600	0.6, 0.7[d]	0.8	-		-	-
94600	0.6, 0.7[d]	0.8	-	-	-	-
96100	0.6, 0.7[d]	0.8	-	-	-	-
101000	0.6, 0.7[d]	0.8	-	-	-	-
107000	-	-	12.8[k,1]	3.6[k,1]	1[k,1]	0.18[k,1]
107000	-	-	-	-	-	-
97500	-	-	-	-	-	-
44400	-	-	-	-	-	-
260000	-	-	-	-	-	-
-	-	-	-	-	-	-
56100, 3000-55000[i]	0.1, 5.9[e], 6.1[f], 0.3-4[i]	2.4, 1.5-22[i]	0.104[h]	0.104[h]	0.004[j]	0.008[i]
73300	-	-	-	-	-	-
57600, 60000[i]	0.3[g], 0.3-4[i]	0.44[g], 1.5[i]	-	-	-	-
63100, 64000[i]	6[i]	1.5[i]	-	-	-	-
69300	-	-	-	-	-	-
71900-	-	-	-	-	-	-
74100	-	-	-	-	-	-
78000i	0.7, 0.1-3.5[i]	46.5, 2-22[i]	35.3[k,2]	15.9[k,2]	1.3[k,2]	0.5[k,2]
97500, 101000[i]	-	-	-	-	-	-

Table 3.5: Emission Factors for the Manufacture of Solid Fuels and Other Forms of Energy (in kg/TJ unless indicated

Fuel type	Coke ovens			Gas works			
	NOx	CO[a]	NMVOC[a]	NOx	CO[a]	NMVOC[a]	NH$_3$
Coking Coal	-	-	-	-	-	-	-
Other Bituminous Coal and Anthracite	300[a]	20	5	300[a]	20	5	-
Coke Oven Coke	300[a]	20	5	300[a]	20	5	
Coke Oven Gas	55[b]	20	5	55b	20	5	-
Blast Furnace Gas	7.4[b]	20	5	-	-	-	-
Gas Works Gas	7.4[b]	20	5	7.4[b]	20	5	-
Natural Gas	-	-	-	53[b]	20	5	1.31[d]
Crude Oil	-	-	-	-	-	-	-
Refinery Gas	-	-	-	-	-	-	-
Liquefied Petroleum Gas	-	-	-	-	-	-	-
Kerosene	-	-	-	-	-	-	-
Gas/Diesel Oil	-	15	5	-	-	-	-
Heavy Fuel Oil	-	15	5	-	-	-	-
Petroleum coke	-	-	-	-	-	-	-
Other Petroleum Products	-	-	-	-	-	-	-
Wood for charcoal production	-	-	-	-	-	-	-

Source/Remarks
[a] IPCC, 2006. GHG values are applicable for all energy industries as default values, [b] Taken from Kato and Akimoto, 1992, assuming average calorific values as given in the IEA Energy Statistics and Balances of non-OECD Countries (International Energy Agency, 1998)., [c] EF obtained from Bertschi et al., 2003, for charcoal production., [d] EFs are taken from Battye et al., 1994., [e] Uncontrolled EFs are derived from USEPA, 1995, [f] Derived from Smith et al., 1999 for PM value (PM$_{2.5}$ is assumed 35% from PM). [g] Type of fuel wood refers to charcoal production process. [h] Bond et al., 2004. Units (g/kg) have been converted to kg/TJ by using NCV value of 15 TJ/Ktonne.

otherwise)

	Other own use[g]								GHGs		
NOx	CO[a]	NMVOC[a]	NH$_3$	PM$_{10}$	PM$_{2.5}$	BC	OC	CO$_2$[a]	CH4[a]	N$_2$O[a]
-	-	-	-	-	-	-	-	94600	1	1.5
300[a]	20	5	-	-	-	-	-	107000	1	0.5
300[a]	20	5	-	-	-	-	-	107000	1	1.5
55[b]	20	5	-	-	-	-	-	44400	1	0.1
-	-	-	-	-	-	-	-	260000	1	0.1
-	-	-	-	-	-	-	-	44400	1	0.1
53[b]	20	5	1.31[d]	-	-	-	-	56100	1	0.1
200[a]	15	5	-	-	-	-	-	73300	3	0.6
11[b]	15	5	-	-	-	-	-	57600	1	0.1
56[b]	15	5	-	-	-	-	-	63100	1	0.1
167[b]	15	5	-	-	-	-	-	71900	3	0.6
222[b]	15	5	-	-	-	-	-	74100	3	0.6
145[b]	15	5	-	-	-	-	-	77400	3	0.6
300[a]	20	5	-	-	-	-	-	97500	3	0.6
145[b]	15	5	-	-	-	-	-	73300	3	0.6
12.3	6453	2190	24.6[c]	280[f]	98[f]	13.3[h]	86.7[h]	94600	30	4

3.1.5 TEMPORAL AND SPATIAL DISTRIBUTION

Spatial disaggregation of annual emissions data (top down approach) can be carried out as follows:

- For monthly variation, use monthly fuel consumption data. For daily and hourly variation, plant-wise daily and hourly fuel consumption data are required. Figure 1 provides monthly profiles applicable for Europe and Thailand. (Refer to Section 2.7).
- For spatial distribution, number of industrial employees in industrial areas or number of industries (EMEP/CORINAIR, 2006) and Industrial Gross Domestic Product (GDP) or industrial output (Wang et al., 2005) can be used.
- For LPS, spatial distribution will be based on exact geographical locations (longitude/ latitude coordinates).
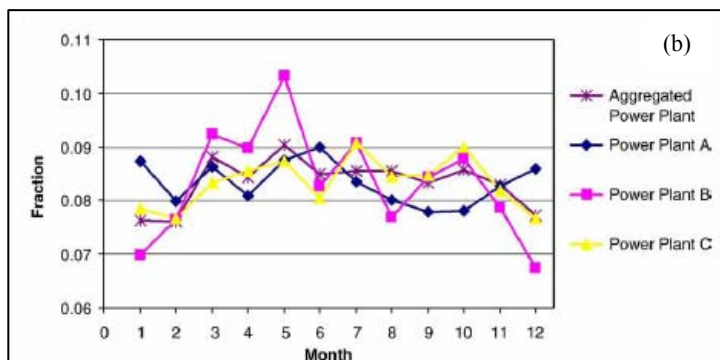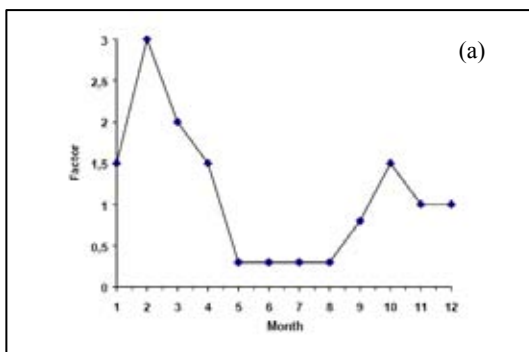
Figure 3.1: Examples of Monthly Factors (FM_n)
(a) EMEP/CORINAIR, (2006), applicable for Europe and
(b) Pham TBT et al., (2008), applicable for Thailand

The calculation procedure for emissions from power generation is presented in Table 3.6.

Table 3.6: Summary of Calculation Procedure for Emissions from Power Generation

Step	Calculation Procedure
1	**Emission Calculation** • Identify the power generation plants as an area source or a large point source (LPS) by using the given criteria. • Obtain data on energy input or fuel consumption in GJ, where possible. • For LPS, typical information from the Continuous Emission Monitoring (CEM) data is needed. If this is not available, obtain energy input or fuel consumption to calculate emissions by using the simple method. • Calculate total emissions using eq. 3.1.
2	**Temporal Variation** • Obtain the total fuel consumption or net electricity production in public power plants, to construct monthly, daily (FM_n and FD_d) and hourly emission variation factor (FH_h) (refer to section 2.7). Calculate monthly emission from annual emission using eq. 2.3. • Calculate daily emission from monthly emission using eq. 2.4. • Calculate hourly emission from daily emission using eq. 2.5.
3	**Spatial Distribution** • For LPS, distribute the emission by using information in the longitude/latitude coordinates of each power generation station. • For area source, industrial GDP and industrial output can be used to surrogate the emission.

3.2 MANUFACTURING AND CONSTRUCTION

3.2.1 OVERVIEW

This sector covers fuel combustion activities in the manufacturing and construction industries, such as:

- Iron and steel manufacture,
- Non-metallic minerals (cement, ceramic and brick) manufacture,
- Non-ferrous metals (alumina) production,
- Pulp and paper production,
- Mining and quarrying,
- Construction,
- Food and beverage production, and
- Textile production.

In addition to the above, there are other industries in some countries that involve fuel-consuming activities. These can be included under the 'Other Manufacturing' sub-category in the Excel workbook accompanying this manual. A separate sub-category for construction is also provided in Annex 1 of this manual. Typical sources that are associated with fuel combustion are boilers, gas turbines, stationary engines, flare stacks, furnaces, palletizing sinter plants, and so on. These may emit combustion pollutants, such as particulate matter (PM_{10}, $PM_{2.5}$), particulate BC, OC, NO_x, CO, CO_2, SO_2, NMVOC, NH_3, and CH_4.

A source can be considered as an area source or a point source. EMEP/CORINAIR provides guidelines on how to consider a source as a point source:

- Refinery sector, flare stack,
- Integrated iron/steel works with production capacity > 3 Mt/year,
- Pulp and paper industry with production capacity > 100 kt/year, and
- Other plants emitting ≥ 1,000 t/yr of SO_2 and NO_x.

3.2.2 EMISSION ESTIMATION METHOD

a. Area Source

The proposed emission estimation method in this manual is the simple method that is based on activity rate and emission factor. This method is considered as an overall approach where activity data refer to fuel consumption (kJ). The detailed method corresponds to a plant-specific approach, which takes plant-specific information into account as far as possible. Emissions are calculated based on the following equation.

$$Em_{i,j,k} = AR_{j,k} \times EF_{i,j,k} \qquad \text{(eq. 3.4)}$$

where,

j, k	= Fuel type j and sub-sector k
$Em_{i,j,k}$	= Emission of pollutant i, from fuel type j and sub-sector k
$AR_{j,k}$	= Activity rate of fuel type j and sub-sector k (fuel consumption in kJ)
$EF_{i,j,k}$	= Emission factor specific to pollutant i, fuel type j and sub-sector k.

b. Large Point Source (LPS)

Emissions from a large point source can be calculated using the simple method, a method similar to that for an area source. In the detailed method, emission is calculated using the Continuous Emission Monitoring (CEM) data of each plant. For further details, refer to the emission estimation methodology for power generation.

3.2.3 DATA ON ACTIVITY LEVELS

The simple method requires annual fuel consumption (kJ) per sub-sector and national energy balance data at the required level of detail. Annual fuel consumption data are reported by the IEA at http://www.iea.org/stats/. Annual country industrial statistics may provide production capacity data. The data on Net Calorific Value (NCV) for each type of fuel can be obtained from CORINAIR, OECD/IEA and other data sources.

For emission calculation from LPS using the detailed method, several plant-specific data are needed, such as:

- Measured pollutant concentrations in the emissions,
- Stack details (flue gas flow rate, volume and stack height),
- Emission control data (type and removal efficiency for each pollutant),
- Additional information, such as location information (coordinates) and time of operation, which may be useful for temporal and spatial distribution.

3.2.4 EMISSION FACTORS

Most of the emission factors are compiled from the IPCC Guidelines (CO and NMVOC), AP-42 (USEPA, 1995) (PM), Battye et al., 1994 (NH_3), Bond et al., 2004 (BC, OC), Kato and Akimoto, 1992 (for NO_x), and other publications. The compiled values are mostly uncontrolled EFs. The EFs are presented in Table 3.7. Emission factors of SO_2 are calculated based on the following equation:

$$EF_{SO2} = 2 \times \left(\frac{CS_{fuel}}{100}\right) \times \left(\frac{100 - \alpha_s}{100}\right) \times \frac{1}{H_u} \times 10^6 \times \left(\frac{100 - \eta_{cd}}{100}\right) \qquad \text{(eq. 3.5)}$$

where,

EF_{SO2}	= Specified emission factor for SO_2 (kg/TJ)
CS_{fuel}	= Sulfur content in fuel (% weight)
α_s	= Sulfur retention in ash (%)
H_u	= Lower heating value of fuel (TJ/ktonne)
η_{cd}	= Reduction efficiency of control device (%).

Reduction efficiencies of particular pollutants, SO_2 and NO_x, due to the introduced abatement methods are provided in Table 3.3. For $PM_{2.5}$, BC, OC, emission reduction efficiencies in the manufacturing industry are presented in Table 3.8.

3.2.5 TEMPORAL AND SPATIAL DISTRIBUTION

For LPS and area source, the disaggregation of annual emissions can be done as monthly or daily emissions by using fuel consumption data or net production data. Refer to the power generation sector to construct the temporal variation of emissions.

Spatial disaggregation of annual emission data (top down approach) can be carried out by using:
- Number of industrial employees in industrial areas (EMEP/CORINAIR, 2006),
- Industrial Gross Domestic Product (GDP) or industrial output (Wang et al., 2005),
- Industrial land use (industrial estate and so on), and
- Exact geographical locations (longitude/latitude coordinates), in the case of LPS.

Table 3.7: Emission Factors from Combustion in Manufacturing and Construction

Fuel Type	Emission Factor (in kg/TJ unless otherwise indicated)				
	NO$_x$[a]	CO[a]	NMVOC[a]	PM$_{10}$[c,e]	
Coking Coal	300	150	20	241.6	84.6
Other Bituminous Coal and Anthracite	300	150	20	51.8-167.3(478), 168.5[j,1]	7.8-55.2 (43),
Coal	300	150	20	438[h]	54.2[f,1], 131.5-
Lignite	300	150	20	250A[j,1], 937.5[l]	120[f,1], 270[i],
Patent fuel	300	150	20	-	-
Coke Oven Coke	300	15	20	14.3	4
Gas Coke	300	15	20	-	-
BKB	300	15	20	-	-
Coke Oven Gas	55[b]	20	20	-	-
Gas Works Gas	7.4[b]	150	5	-	-
Natural Gas	53[b]	2000	5	0.04	0.04
Crude Oil	200	4000	5	-	-
Natural Gas Liquid	200	4000	5	-	-
Refinery Gas	11[b]	4000	5	-	-
Liquefied Petroleum Gas	56[b]	10	5	-	-
Motor Gasoline	373[b]	10	5	22.9[f,2]	22.9[f,2]
Kerosene	167[b]	15	5	10.8, 3.3[j,2], 20[h]	1.9, 10[h], 0.82[j,2]
Gas/Diesel Oil	222[b]	15	5	3.3[j,2]	0.83[j,2], 4.37[f,2]
Heavy Fuel Oil	145[b]	15	5	27.4, 27.12[j,3], 32.3[h]	12.3, 16.17[h],
Petroleum Coke	300	20	5	136[j,4]	58[j,4]
Other Petroleum Products	145[b]	15	5	-	-
Wood	100	2000	50	666-146,	240[h], 566-126,
Vegetable Materials and Waste	100	4000	50	666-146	240[h], 566-126,
Unspecified Primary Solid Biomass	100	4000	50	666-146	240[h], 566-126,
Industrial Wastes	100	4000	50	-	-
Charcoal	100	4000	100	-	-

Source/Remarks
[a] IPCC, 2006. Values for CO_2, CH_4 and N_2O represent default values.
[b] Kato and Akimoto, 1992.
[c] Bond et al., 2004. Values are converted from g/kg to kg/T by using NCV value for each type of fuel. For brown coal (anthracite), high values in the range refer to stoker technology; low values in the range refer to cyclone technology, while values in parentheses refer to pulverized coal technology. For biofuel, low values in the range refer to stoker technology, while high values refer to traditional technology. For coke, technology applied is blast furnace, which is mostly used in the iron and steel industry. Single value shows central value.
[d] Batye et al., 1994.
[e] PM$_{10}$ values refer to PM EFs.
[f] Reddy and Venkataraman, 2002a. [f,1] Central value from plant-wise values for 50% control scenario, OM/OC is assumed as 1.3; [f,2] PM emissions from petroleum fuel combustion are mostly in the smaller particle size range, with PM$_{2.1}$ mass accounting over 90%, PM$_{2.5}$ value refers to PM$_{2.1}$, applicable for industrial IC engine, BC/PM ratio is 0.085 and OC/PM ratio is 0.055.
[g] EMEP/CORINAIR, 1992.
[h] Streets et al., 2001. The unit has been converted from g/kg to kg/TJ by using NCV value. For coal, high values in the range refer to stoker technology, while low values refer to pulverized coal technology.

PM$_{2.5}$ [c]	NH$_3$ [d]	BC [c]	OC [c]	CO$_2$ [a]	CH$_4$ [a]	N$_2$O [a]
	-	40.6	28.7	94600	10	1.5
358.5[i], 71.7[j,1]	0.0003	0.04-11(0.26), 179.3[i], 3.7[k]	0-2.2, 143.4[i], 1.2[k]	94600	10	1.5
26.3[h], 486[i]	-	0.37[f,1], 1.3-0.13[h], 73[i]	0.16[f,1], 404[i]	96100	10	1.5
25A[j,1], 112.5[l]	-	0[f,1], 10.6[l], 2,25[l]	11.2[f,1], 229.4[i], 5[l]	101000	10	1.5
	-	-	-	97500	10	1.5
	-	1.1	0.26	107000	10	1.5
	-	-	-	107000	1	0.1
	-	-	-	97500	10	1.5
	-	-	-	44400	1	0.1
	-	-	-	44400	1	0.1
	1.31	0.002	0.02	56100	1	0.1
	-	-	-	73300	3	0.6
	-	-	-	64200	3	0.6
	-	-	-	57600	1	0.1
	-	-	-	63100	1	0.1
	0.005[g]	0.44[f,2]	5.35[f,2]	69300	3	0.6
	-	0.06, 5.5[h]	1.7	71900	3	0.6
	0.007[g]	3.9[f,2]	0[f,2]	74100	3	0.6
17.6[j,3]	0.101	0.9, 8.9[h]	0.37	77400	3	0.6
	0.0003	-	-	97500	3	0.6
	-	-	-	73300	3	0.6
12[m,1], 120[m,2]	-	60[h], 56.6-6.3, 1.2[m,1], 9.6[m,2]	340-25.2, 1.2[m,1], 14.4[m,2]	112000	30	4
12[m,1], 120[m,2]	-	60[h], 56.6-6.3, 1.2[m,1], 9.6[m,2]	340-25.2, 1.2[m,1], 14.4[m,2]	100000	30	4
12[m,1], 120[m,2]	-	60[h], 56.6-6.3, 1.2[m,1], 9.6[m,2]	340-25.2, 1.2[m,1], 14.4[m,2]	100000	30	4
	-	-	-	143000	30	4
	-	-	-	112000	200	4

[i] Values are applicable for the brick kiln industry. Coal and lignite EFs are taken from [f], while anthracite and other coal EFs are taken from [c]. The units have been converted from g/kg to kg/TJ by using NCV value.
[j] USEPA, 1995. [j,1] Applicable for stoker boiler, PM$_{2.5}$/PM$_{10}$ is 10% (taken from APEG, 1999); [j,2] Applicable for firing distillate oil; [j,3] Applicable for no 5 grade residual oil; [j,4] Assumed to be similar to sub-bituminous coal.
[k] Ge et al., 2001. Applicable for hard coal burned in an industrial boiler.
[l] Bond et al., 1999. Lignite, small combustion plant (2MW), with condensable PM, the BC to OC ratio is assumed to be similar to that for brown coal burned in industrial (grate) boilers of around 0.5, while PM$_{2.5}$/PM$_{10}$ ratio is around 0.12.
[m] Kupiainen and Klimont, 2004. [m,1] Applicable for fluidized bed combustion (FBC); [m,2] Applicable for grate combustion.
- Not available.

Table 3.8: Removal Efficiencies for PM$_{2.5}$, BC, OC (%)

Technology	PM$_{2.5}$ Reduction (%)	BC Reduction (%)	OC Reduction (%)
Multicyclone	11	11	11
Wet Scrubbers	95	73.36	90
Fabric Filters	99.9	99.9	99.9
ESP	91.96	91.1	96
Wet ESP	98.86	98	99.7
Oil-fired Boilers, Regular Maintenance	21.52	5	10
New Biomass-fired Boilers	89	89	89

Source: Kupiainen and Klimont, 2004

3.2.6 SUMMARY

Step-wise calculation of emissions from non-electric energy conversion is described below.

Table 3.9: Summary of Calculation Procedure for Emissions from Non-electric Energy Conversion

Step	Calculation Procedure
1	Emission Calculation • Identify manufacturing plants/refineries as an area source or a large point source (LPS), using given criteria. • Obtain data on energy input or fuel consumption in kJ applicable to the source, where possible. • For SO$_2$, calculate EFs by taking parameters from Table (3.1), Table (3.3) (for emission reduction efficiency) and use eq. 3.5. • Take EFs from Table (3.7). • For LPS, typical information from the Continuous Emission Monitoring Data (CEM) is needed. If it is not available, obtain energy input or fuel consumption to calculate emission by using the simple method. • Calculate total emissions by using eq. 3.4 and Table (3.8) for emission reduction efficiency.
2	**Temporal Variation** • Obtain the total fuel consumption to construct monthly, daily (FM_n and FD_d) and hourly emission variation factor (FH_h) (refer section 2.7). Calculate monthly emission from annual emission by using eq. 2.3. • Calculate daily emission from monthly emission by using eq. 2.4. • Calculate hourly emission from daily emission by using eq. 2.5.
3	**Spatial Distribution** • For LPS, distribute emissions by using information in the longitude/latitude coordinates of each power generation station. • For area sources, industrial GDP and land use can be used to surrogate the emission.

3.3 EMISSIONS FROM THE TRANSPORTATION SECTOR

3.3.1 OVERVIEW

This sector covers on-and off-road transportation. On-road transportation includes all types of light duty vehicles (automobiles and light trucks), heavy duty vehicles (buses and large trucks), and on-road motorcycles, including mopeds, scooters, and three-wheelers. Off-road transportation covers civil aviation, railways, shipping, off-road vehicles, and various types of mobile equipment used in agriculture, industry, forestry and households. Off-road mobile activities in agriculture, industry, forestry and households are categorized in this manual under 'Other Transportation'. The focus of this manual is on the internal combustion of many types of gaseous and liquid fuels in mobile sources, excluding evaporation loss emission.

In general, vehicles are powered by internal combustion engines, which use fossil fuels (gasoline, diesel, LPG, and so on). The combustion process produces CO_2 and harmless H_2O as main products. Unfortunately, combustion also produces several by-products that, originate from incomplete fuel oxidation (CO, hydrocarbons, particulate matter) or from the oxidation of non-combustible species present in the combustion chamber (NO_x from N_2 in the air, SO_x from S in the fuel and lubricant, and so on). The pollutants covered in this sector include particulate matter (PM), including BC and OC, ozone precursors (CO, NO_x and NMVOC), greenhouse gases (CO_2, CH_4 and N_2O) and acidifying substances (NH_3, SO_2).

3.3.2 EMISSION ESTIMATION METHOD

There are two methods for calculating emissions in the transportation sector, i.e., the simple method and the detailed method (IPCC, 2006; EMEP/CORINAIR, 2006). The choice of method depends mainly on the availability of data. The two methods are described below:

3.3.2.1 ON-ROAD TRANSPORT

Simple Method

The simple method is based on vehicle type and fuel consumption. Aggregated sectoral fuel consumption data are considered as basic requirements. Although this method is suitable for all sub-sectors included in this chapter, it is also recommended for the off-road transport sub-sector (agriculture, industry, households, forestry). Uncontrolled bulk emission factors for each type of fuel used are obtained in order to calculate emissions. Total emissions for each pollutant species and type of fuel are calculated based on the following equation.

$$Em_{i,j} = \sum_j Fc_j \times EF_{i,j} \qquad \text{(eq. 3.6)}$$

where,

j = Type of vehicle

$Em_{i,j}$ = Emission of pollutant i from vehicle type j

Fc_j = Fuel consumption of vehicle type j

$EF_{i,j}$ = Emission factor of pollutant i for vehicle type j.

The simple method is recommended for estimating all transport related SO_2 emissions that depend only on the fuel's sulfur content. For other pollutants, the simple method only gives very approximate estimates of emissions and should only be used in countries lacking data required for the detailed method described below. In some cases, the simple method is expected to overestimate emissions, since it does not take into account implementation of catalytic converters and other technologies to reduce emissions from vehicles.

Detailed Method

Total emissions are calculated by considering activity data for each vehicle category and appropriate emission factors. These emission factors vary according to input data (driving situations, climatic conditions, and so on). Data on emission factors, number of vehicles and mileage per vehicle need to be provided specific to each vehicle class and category. The emission equation is expressed as:

$$Em_{i,j,r} = Nv_j \times Mv_{j,r} \times e_{i,j,r} \qquad \text{(eq. 3.7)}$$

where,

j,r = Vehicle class j and road type r (urban, rural)

$Em_{i,j,r}$ = Emission of pollutant i in gram (g), produced in the reference year by vehicle class j driven on road type r

Nv_j = Number of vehicles (veh.) of class j in circulation in the reference year

$Mv_{j,r}$ = Annual mileage per vehicle (km/veh.) driven on road type r by vehicles class j

$e_{i,j,r}$ = Average fleet representative baseline emission factor in g/km for pollutant i, relevant for vehicle class j, operated on road type r.

Emission inventory for on-road transportation will take into account emission per vehicle distance or emission per fuel mass. The first method is suitable for finer spatial distribution and is useful in identifying specific source groups (that is, heavy duty or light duty diesel engines). However, this may require detailed information on vehicle fleets, which is generally not available in most developing countries. On the other hand, emissions per fuel mass require far fewer variables than the previous method and may remove dependence on engine size. However, fuel consumption statistics pose larger uncertainties as compared to total distance driven. If data are available, the 'total distance driven' method is strongly suggested. Otherwise, this manual also provides guidance on how to calculate emissions using the fuel mass based approach.

3.3.2.2 AIR TRAFFIC

The method proposed in this manual is based on EMEP/CORINAIR (2006) under the category of 'very simple method' which is the simplest tier method in the manual. The standard activity data required are the landing and take-off (LTO) cycle and aviation fuel sold. Estimations are made without considering the actual aircraft types used, whereas in the simple methodology it is assumed that information is available on the types of aircraft that operate in the country. This method is applied, when the number of LTO cycles carried out on a per aircraft type basis is not known. In this case, information on a country's total number of LTOs is needed, preferably with

information on the destination (long and short distance) for international LTOs, together with general information about the aircraft type carrying out these aviation activities. Data on LTO cycles and fuel consumption are used in eq. 3.8 to estimate the emissions:

$$Em_j = LTO_j \times EF_j \qquad \text{(eq. 3.8)}$$

where,

j = Type of flight, either domestic or international
Em_j = Emission from flight type j
LTO_j = Number of landing and take-off cycles (LTOs) of flight type j
EF_j = Emission factor (kg/LTO) of flight type j

For cruise activity, the method is described below.

$$Em_j = Fc_j \times EF_j \qquad \text{(eq. 3.9)}$$

where,

Fc_j = Aviation fuel consumption (kt) per flight type j
EF_j = Emission factor (g/kt of fuel consumption) of flight type j.

3.3.2.3 WATER/SHIPPING

Ships are among the world's highest polluting combustion sources per unit of fuel consumed (Corbett and Fischbeck, 1997). This sub-sector includes all shipping activities, whether at sea, in port, or on inland waterways. Emissions are mostly generated from combustion in marine diesel engine boilers used for steam turbine propulsion and other purposes and from combustion in gas turbines. The emission calculation is classified as follows: national sea traffic, national fishing and international sea traffic. Existing inventory manuals suggest two methods: the simple method (based on fuel consumption) and the detailed method (based on ship movement) (EMEP/CORINAIR, 2006). According to the U.S. Environmental Protection Agency (USEPA), the estimation methodology for shipping emissions is based on two methods: Method A and Method B. Method A produces an inventory of emissions from commercial flag vessels with compression ignition marine engines, by considering engine type, duty cycles and other operational factors. Method B estimates emissions from foreign and domestic ships transporting cargo, by estimating emissions per tonne-mile of cargo moved and deriving the pollution emitted from cargo transport. This method provides an estimate of emissions from foreign shipping as well as the regional characteristics of ship emissions. Thus, by combining the inventory of emissions from Methods A and B, an estimate of total nationwide emissions from commercial ships can be obtained.

This manual proposes the following simple method based on data availability:

$$Em_j = Fc_j \times EF_j \qquad \text{(eq. 3.10)}$$

where,

j = Type of fuel, classified as residual bunker fuel oil (heavy fuel oil) or distillate fuel (gas oil and marine diesel oil)

Em_j = Emission from fuel type j (g)

Fc_j = Shipping fuel consumption/sold (ktonne)

EF_j = Emission factor (g/ktonne of fuel consumption/sold).

3.3.2.4 RAILWAYS AND OTHER MODES OF TRANSPORTATION

The methodology for emission calculation involving railways (locomotives, rail cars) and other mobile machinery used in agriculture, industry, forestry and households is similar to that described in EMEP/CORINAIR (2006). The method consists of the simple method, which is fuel consumption based, and the detailed method, which is based on more detailed engine type. This manual makes use of the simple method.

The simple method is based on total fuel consumption data, which are then multiplied by appropriate bulk emission factors. The formula used to estimate emissions is:

$$Em_i = Fc \times EF_i \qquad \text{(eq. 3.11)}$$

where,

Em_i = Emission of pollutant i

Fc = Fuel consumption of other modes in the transportation sub-sector

EF_i = Average emission factor of pollutant i per unit of fuel used.

This method needs data on the fuel consumption of each specific sub-sector which can be obtained from country reports on the transportation sector.

3.3.3 DATA ON ACTIVITY LEVELS

3.3.3.1 ON-ROAD

The simple method only requires data on the fuel consumption of all road vehicles combined. Relevant activity data can be found in national energy balances, e.g., as reported by the IEA. However, these data are not disaggregated by vehicle category. National statistics are needed. In the detailed method, the number of vehicles in the reference year for each vehicle type, mileage per vehicle driven on roads, and driving patterns are considered as key data. In general, vehicle statistics are available in national statistical reports and in international statistical organizations, such as the International Road Federation (IRF) World Road Statistics 2005 (http://www.irfnet. org/statistics.php). However, these statistics are not vehicle-specific (that is, they refer to fleet data) and provide information about general aggregate categories only (for example, passenger cars, trucks, buses, and motorcycles). In addition, more detailed traffic survey data are required to generate mileage per vehicle driven on roads and road type data.

3.3.3.2 AIR TRAFFIC

LTO cycle data are key activity data needed for calculating emissions using the simple method. The LTO cycle consists of one take-off and one landing activity and includes idle engine running, taxi in and out, and climbing and descending under 914 meters. This can be obtained from national statistics. For individual aircraft at a specific airport, data can be obtained from the airport authority. Cruise activity includes all activities that take place at altitudes above 3000 feet (1000 m). The key data cover aviation fuel consumption. Detailed fuel statistics can be obtained from a relevant local authority. General data on aviation fuel consumption per country are also available at IEA. A distinction between national and international aviation is established and follows this rule of thumb. All traffic between two airports in a country is considered domestic, regardless of the nationality of the carrier. Air traffic is considered international if the activity takes place between airports in two different countries.

3.3.3.3 WATER/SHIPPING

The activity data required will depend on the method chosen. In the simple method, national statistics for fuel used by ships and categorized under fisheries, national traffic and international bunker are necessary. The statistics should also make a distinction between residual fuel oil and distillate fuel. All countries report these data annually to the IEA (published in the 'Energy Statistics of OECD Countries').

As for the detailed methodology, LMIS (Lloyd's Maritime Information Service) provides database records of all ship movements worldwide (www.llplimited.com/lmis.shtml www.llplimited. com/lmis.shtml). The database provides information on ship size, destination, approximate time of arrival and departure, engine type and number, and so on. Ferries and fishing vessels are typically not included. In one study of international shipping emissions inventory, the vessels are registered by using radar (De Meyer et al., 2008). The main shipping routes are given in the IMO (International Maritime Organization) publication on ships routing (IMO, 1987).

3.3.3.4 RAILWAYS AND OTHER MODES OF TRANSPORTATION

In the simple method, the fuel consumption of each specific sub-sector (railways, agriculture, industry, forestry and households) is considered as key data. In the detailed method, additional input data are required for the application of this approach (for example, usage and population data). Therefore, special investigations have to be carried out so that reasonable estimates can be made based on general technical experiences.

3.3.4 EMISSION FACTORS

3.3.4.1 ON-ROAD

In most emission inventory manuals and publications (EMEP/CORINAIR, The Global Atmospheric Pollution Forum (GAPF), and Streets et al., 2003), bulk emission factors differ from country to country. The EFs for the simple method are presented in Table 3.10, while those for the detailed method are presented in Table 3.11.

The SO_2 emission factor calculation can be based either on the method given in equation 3.8 or on the fuel economy method (JICA, 1997), which is expressed as follows:

$$EF_{SO_2} = Fc \times \frac{CS_{fuel}}{100} \times S_g \times \frac{64}{32} \times 1,000 \qquad \text{(eq. 3.12)}$$

where,

EF_{SO_2} = Specified emission factor for SO_2 (g/km)
Fc = Fuel economy (liter/km)
CS_{fuel} = Sulfur content in fuel (%)
S_g = Specific gravity of fuel (g/cm³).

The parameters for calculating SO_2 EFs are presented in Table 3.12.

Table 3.10: Vehicle Bulk Emission Factors in g/kg for the Simple Method

Fuel type	Category	CO[a]	NOx[a]	NMVOC[a]	CH4[b]
Gasoline	Gasoline PC	550, 220[b]	27, 31.7[i]	63	1.7, 1.5[j]
	Gasoline LDV	360[a,1], 243[b]	29[a,1], 31.5[i]	59[a,1]	1.24, 1.5[j]
	Motorcycle	730[a,2], 530[a,3], 570[b]	2.7[a,2], 7.9[a,3]	530[a,2], 105[a,3]	5.2
Diesel	Diesel LDV	18[a,1], 11.7[b]	16[a,1], 27.4[i]	4.6[a,1]	0.08, 0.17[j]
	Diesel HDV	36[a,1], 9.2[b]	42[a,1], 27.4[i]	8[a,1]	0.25, 0.17[j]
	Diesel PC	12[a,1], 8.9[b]	11[a,1], 27.4[i]	3[a,1]	0.13, 0.17[j]
LPG	General	67.5	17.7, 18.1[i]	29.5	2.9[j]
CNG	General	36.1	19, 2.7[i]	4.5	4.7[j]
Ethanol	Passenger cars (advanced control)	28	4.5	5.9	0.2
	HDV (advanced control)	6.1	6.1	2.3	0.2

Source/Remarks
[a] IPCC, 1996. Uncontrolled emission factors. [a,1] Moderate control emission factors; [a,2] Uncontrolled emission factor for motorcycle >50 CC 2 stroke; [a,3] Uncontrolled emission factor for motorcycle >50 CC 4 stroke.
[b] EMEP/CORINAIR, 2006. Average value of EU-15 countries bulk emission factors. The production of the emission factor is based on a large number of assumptions concerning vehicle technology mix (e.g. share of passenger cars according to different Euro standards), driving conditions (travelling speeds, etc) and even climatic conditions (temperature).
[c] Williams et al., 1989b. Australian diesel (models 1978-1986) and leaded gasoline car (model 1965-1983).
[d] Cooke et al., 1999. BC/PM ratio is 66%; it is assumed that the non-BC fraction is OC.
[e] Kirchstetter et al., 1999. BC/PM$_{2.5}$ ratio is around 32% for unleaded gasoline vehicles and 52% for diesel vehicles. US tunnel measurements.
[f] Reddy and Venkataraman, 2002a. Assume PM$_{10}$ value is similar to PM with PM$_{2.5}$/PM ratios are similar to Durbin et al., (1999). BC/PM ratio used is 52% and OC/PM ratio is 30% (taken from Williams et al., 1989). For gasoline PC, BC/PM ratio is 8.1% and OC/PM ratio is 65.5% (taken from Hildeman, 1991).
[g] Miguel et al., 1998. Derived from PM$_{1.3}$ from US tunnel measurement.

PM$_{2.5}$	CO$_2$[b]	BC	OC	N$_2$O[j]
0.88[f], 0.34[h], 0.64[c]	3060[j], 2720	0.07[f], 0.03[c], 0.035[e], 0.04[l], 0.02[m]	0.6[f], 0.2[c], 0.053[e], 0.14[l], 0.02[m]	0.14
0.88[f], 0.34[h],	3060[j], 2590	0.07[f], 0.03[c], 0.035[e], 0.04[l], 0.02[m]	0.6[f], 0.2[c], 0.053[e], 0.14[l], 0.02[m]	0.14
28[n], 6.9[o]	3060[j], 1710	1.4[n]	27[n]	0.14
2.2[k], 3.3[f], 4.1[h], 3.3[c]	3211[j], 3090	1.4[k], 2.18[c], 1.7[f], 2[d], 0.52[e], 2.75[l]	0.4[k], 0.89[c], 0.9[f], 0.5[e], 0.85[l]	0.17
8.4[k], 6.7[f], 4.1[h],	3211[j], 3090	5.5[k], 3.5[f], 2[d], 1.3[e], 1.4[g], 2.75[l]	1.7[k], 2[f], 0.5[e], 0.85[l]	0.17
2.2[k], 3.3[f], 4.1[h],	3211[j], 3090	1.4[k], 1.7[f], 2[d], 1.3[e], 2.75[l]	0.4[k], 0.9[f], 0.5[e], 0.85[l]	0.17
-	2985[j]	-	-	0.009
-	2850[j]	-	-	0.15
-	1632	-	-	-
-	1375	-	-	-

[h] Durbin et al., 1999. PM$_{2.5}$/PM$_{10}$ ratio used is 0.85 (mean value) for gasoline vehicle and 0.95 for diesel vehicle.
[i] Kato and Akimoto 1992. Bulk uncontrolled emission factors based on fuel type only.
[j] IPCC 2006. Values represent 100 percent oxidation of fuel carbon content and default values.
[k] Subramanian et al., 2009. BC/PM ratio used is 60%, and OC/PM ratio is 21%.
[l] Muhlbaier and Williams, 1982 and Muhlbaier and Cadle, 1989. Uncontrolled emission
[m] Muhlbaier and Williams, 1982 and Muhlbaier and Cadle, 1989. Catalytic device is installed.
[n] Faiz et al., 1996. Average emission from 167 Thai motorcycles, BC is assumed to be 5% of the particulate matter, and that the remainder is OM.
[o] Patschul and Roth, 1995. Single cylinder two-stroke motorcycle.

Table 3.11: Vehicle Emission Factors (g/km) for the Detailed Method

Vehicle /Fuel Type	Pollutants in g/km [a]			
	NO_x	CO	NMVOC	NH_3
Gasoline				
Passenger cars (Uncontrolled)	2.2,1.8[c]	46, 9.8[c]	5.3, 1.7[c]	0.002
Passenger cars (Moderate control)	1.4, 1.1[c]	7.5, 3.9[c]	1.4, 0.8[c]	0.002
Passenger cars (Good control-EURO I & II)	0.5, 0.2[c]	2.9, 2[c]	0.5, 0.25[c]	0.1
Motorcycles (2-stroke) (Uncontrolled)	0.05, 0.03[c], 0.02[n]	10, 6.5[c], 2.7[n]	6.5, 3.9[c], 3.8[n]	0.001
Motorycles (2-stroke with control)	0.06[c]	4[c],	3.3[c]	0.002
Motorcycles (4-stroke) (Uncontrolled)	0.3, 0.31[c], 0.17[n]	20, 3c, 1.6[n]	3.9, 0.8[c], 0.54[n]	0.002
Motorcycles (4-stroke with control)	0.3[c]	2.2[c]	0.7[c]	0.002
3-Wheelers (2-stroke) (uncontrolled)	0.09, 0.05[c]	24, 14[c]	16, 8.3[c]	0.002
3-Wheelers (2-stroke with control)	0.09[c]	8.6[c]	7[c]	0.002
Diesel				
3-Wheelers (Uncontrolled)	13 [b]	2.25	-	0.001
Passenger cars (Uncontrolled)	2.77[c]	7.3[c]	0.37[c]	0.001
Passenger cars (Moderate control)	0.66, 2.77[c]	0.71, 1.2[c]	0.19, 0.37[c]	0.001
Passenger cars (Good control-EURO I & II)	0.66, 2.77[c]	0.9[c]	0.13[c]	0.001
Light duty vehicles (Uncontrolled)	3.15[c]	8.7[c]	0.34[c]	0.001
Light duty vehicles (Moderate control)	1.43, 2.49[c]	1.58, 6.9[c]	0.42, 0.28[c]	0.001
Light duty vehicles (Good control-EURO I & II)	1.28[c]	5.1[c]	0.14[c]	0.001
Heavy duty vehicles (Uncontrolled)	6.54[s]	5.5[c], 4.96[s]	1.78[c], 1.88[s]	0.003
Heavy duty vehicles (moderate control)	10.4, 12.6[c]	8.98, 4.5[c]	1.95, 1.21[c]	0.003
Heavy duty vehicles (Good control- EURO I & II)	9.15[c]	3.6[c]	0.87[c]	0.003
LPG				
Passenger cars (Uncontrolled)	2.1[c]	8[c], 4.1[r]	3.5, 0.18[r]	-
Passenger cars (Good control-EURO I)	2.16, 0.05[c]	7.1, 0.3[c]	1.49, 0.25[c]	-

PM$_{2.5}$	BC	OC	CO$_2$	CH$_4$	N$_2$O
			Pollutants in g/kg[a,f]		
0.06[c], 0.073[p], 0.059[u], 0.59[v]	0.025[p], 0.020[c], 0.005[u], 0.05[v]	0.026[p], 0.021[c], 0.04[u], 0.4[v]	3180	1.7, 1.5[e]	0.14[e]
0.05[c], 0.0035[y], 0.011[u]	0.017[c], 0.0022[y], 0.0009[u]	0.018[c], 0.0012[y], 0.007[u]	3180	1.7, 1.5[e]	0.14[e]
0.03[c], 0.007[v], 0.014[l]	0.010[c], 0.0067[l], 0.0005[v]	0.011[c], 0.0022[l], 0.004[v]	3180	1.7, 1.5[e]	0.14[e]
0.05, 0.23[c]	0.01[c]	0.18[c]	38.8	1.24, 1.5[e]	0.14[e]
0.1[c]	0.005[c]	0.08[c]	38.8	1.24, 1.5[e]	0.14[e]
0.032, 0.07[c]	0.0035[c]	0.05[c]	36.65	1.24, 1.5[e]	0.14[e]
0.05[c]	0.0025[c]	0.04[c]	36.65	1.24, 1.5[e]	0.14[e]
0.6, 0.35[c],	0.017[c]	0.3[c]	3180	1.24, 1.5[e]	0.14[e]
0.15[c]	0.007[c]	0.12[c]	3180	1.24, 1.5[e]	0.14[e]
1.54[b]	0.8[t]	0.24[t]	3140	0.08	0.17[e]
0.84[c]	0.23[p], 0.44[t]	0.13[t]	3140	0.08	0.17[e]
0.15, 0.42[c]	0.2[t]	0.06[t]	3140	0.08	0.17[e]
0.07[c]	0.04[t]	0.01[t]	3140	0.08	0.17[e]
0.8[c], 0.324[g], 0.26[m], 0.15[n], 0.73[x]	0.13[m], 0.4[p], 0.16[g], 0.51[t], 0.5[x]	0.067[m], 0.15[g], 0.24[t], 0.17[x]	3140	0.08, 0.17[e]	0.17[e]
0.25, 0.5[c], 0.26[m]	0.07[m], 0.32[t]	0.012[m], 0.15[t]	3140	0.08, 0.17[e]	0.17[e]
0.2[c], 0.052[o], 0.15[m]	0.04[m], 0.13[t], 0.034[o]	0.012[m], 0.014[o], 0.06[t]	3140	0.08, 0.17[e]	0.17[e]
2.25[c], 3.3[m], 1.34[n], 1.3[w]	2.6[m], 2[p], 0.74[t], 0.54[w]	0.3[m], 1[t], 0.47[w]	3140	0.25, 0.17[e]	0.17[e]
1, 1.2[c], 0.185[k], 0.76[m]	0.41[m], 0.056[k], 0.4[t]	0.036[m], 0.036[k], 0.54[t]	3140, 1411[q]	0.25, 0.076[q], 0.17[e]	0.17[e], 0.09[q]
0.42[c], 0.047[j], 0.72[m]	0.27[m], 0.041[j], 0.14[t]	0.036[m], 0.008[j], 0.19[t]	3140, 1411[q]	0.25, 0.076[q], 0.17[e]	0.17[e], 0.09[q]
0.06[c]	-	-	3030	2.9[e]	0.009
0.064	-	-	3030	2.9[e]	0.009

Vehicle /Fuel Type	Pollutants in g/km [a]			
	NO$_x$	CO	NMVOC	NH$_3$
Light duty vehicles (Uncontrolled)	2.1	8.0, 8[c]	3.5, 3.5[c]	-
Light duty vehicles (Good control- EURO I)	0.05[c]	5.1[c]	0.25[c]	-
Heavy duty vehicles (Uncontrolled)	5.7	24	8	-
Heavy duty vehicles (Good control)	2.6[c]	1[c]	0.7[c]	-
CNG				
Passenger car (Uncontrolled)	2.1[d]	4[d]	0.5[d]	-
Passenger car (Good control-Euro 1)	0.5[d]	0.3[d]	0.05[d]	-
Bus/trucks	5.7	12	1.4	-
Methanol				
Passenger car (advanced control)[d]	0.5	3.14	0.66	-
Heavy Duty Vehicle (advanced control)[d]	4	4	1.5	-

Source/Remarks

All units are expressed in g/km, unless otherwise indicated.

[a] EMEP/CORINAIR, 2006.

[b] Shrestha and Malla, 1996.

[c] CPCB, 2000 , India. Applicable for Indian cars 1995-2005 model. BC/PM ratio used is 34 % while OC/P ratio used is 36%
for gasoline vehicles (Gillies and Gertler, 2000). For 2-stroke motorcyle and 2-stroke 3-wheelers, BC/PM ratio used is
5% while OC/PM ratio is 79% (Sakai et al., 1999 and Kojima et al., 2000). Values are recommended for other Asian countries.

[d] IPCC, 1996.

[e] IPCC, 2006.

[f] Using fuel economy values to convert to g/km.

[g] Norbeck et al., 1998a ; Durbin et al., 1999. US models mainly from 1980s cars.

[h] Cooke et al., 1999.

[i] Kirchstetter et al., 1999.

[j] Norbeck et al., 1998b. Models 1994-1996, with oxidation catalyst.

[k] Schauer et al., 1999. Derived from PM$_{1.8}$, 1995 model cars.

[l] Lappi et al., 2001b. Average value for EURO III cars.

[m] Kim Oanh et al., 2009. Values are applicable for LD and HD Bangkok vehicles, Thailand from 1985-2005 model.

[n] Paw-amart, 2004. Values are applicable for LD and HD Bangkok vehicles, Thailand with fewer car samples.

[o] Kerminan et al., 1997. Diesel car with oxidation catalyst with sulfur content of around 400 ppm.

[p] Williams et al., 1989b. Values are taken from Chassis dynamometer study. BC/PM fraction used is 34% while OC/PM
ratio is 36%.

[q] Graham et al., 2008.

[r] Ning and Chan, 2007. Values are obtained from on-road remote sensing observation.

[s] Chen et al., 2007. Values are obtained from 'real-world' emission measurement.

[t] BC and OC Efs are derived fro PM$_{2.5}$ values (CPCB, 2000) by using BC/PM ratio of 53% and OC/PM ratio of 16% for gasoline
passenger cars (taken from Williams et al., 1989). For diesel LDV cars BC/PM ratio is 64% and OC/PM ratio is 30%
while for diesel HDV cars BC/PM ratio is 33% and OC/PM ratio is 45% (Williams et al., 1989).

[u] Hildemann et al., 1991. BC/PM ratio of 8% and OC/PM ratio of 65% are used for uncontrolled 1965-1976 non-catalyst
gasoline cars and catalyst gasoline cars (moderate control).

[v] Schauer et al., 2002. BC/PM ratio of 8% and OC/PM ratio of 65% are used for uncontrolled 1995 non-catalyst gasoline cars
and 1995 catalyst gasoline cars (good control).

[w] Watson et al., 1998. BC/PM ratio of 42% and OC/PM ratio of 36% are used for uncontrolled diesel HDV 1981-1995 cars.

[x] Caddle et al., 1999. BC/PM ratio of 67% and OC/PM ratio of 24% are used for uncontrolled diesel LDV 1996 cars.

- Not available.

PM$_{2.5}$	BC	OC	Pollutants in g/kg[a,f]		
			CO$_2$	CH$_4$	N$_2$O
0.06[c]	-	-	3030	2.9[e]	0.009
0.03[c]	-	-	3030	2.9[e]	0.009
-	-	-	3030	2.9[e]	0.009
-	-	-	3030	2.9[e]	0.009
0.06[d]	-	-	2750	4.7[e]	0.15
0.03[d]	-	-	2750	4.7[e]	0.15
-	-	-	2750, 1170[q]	4.7[e], 6.26[q]	0.15, 0.06[q]
-	-	-	183	0.02	-
-	-	-	908	0.1	-

Table 3.12: Parameters for Calculating SO$_2$ Emission Factors

Fuel Types	Sulfur Content (CS_{fuel})[a]	Sulfur Retention in Ash (α_s)[c]	Hu (TJ/ktonne)[d]
Natural Gas (CNG)	0.00064[b]	0	50.82
LPG	0.00054[b]	0	47.31
Motor Gasoline	0.1, 0.005-0.18[b]	0	44.80
Kerosene	0.05, 0.004-0.2[b]	0	44.75
Gas/Diesel Oil	0.3, 0.16-1.16[b]	0	43.33
Heavy Fuel Oil	1.0 - 4.0	0	40.19

Source/Remarks
a IPCC, 1996.
b Kato and Akimoto, 1992. Typical range of values for Asian countries.
c Assumption of zero value
d Lower heating value of fuel. Compiled from OECD/IEA, 1998.

3.3.4.2 AIR TRAFFIC

Most of the emission factors are taken from EMEP/CORINAIR, with additional EFs of PM, BC, and OC compiled from several sources. The emission factors are presented in Table 3.13.

Table 3.13: Emission Factors in the 'Simple' Method

Fleet Categories	In (kg/LTO)[a]							In (g/kg fuel)[b]	
	SO_2	CO_2	CO	NOx	CH_4	N_2O	$PM_{2.5}$[d]	BC	OC
Domestic									
LTO (kg/LTO)-Average fleet (B737-400)	0.8	2600	11.48	8.3	0.1	0.1	0.2	0.1	0.03
LTO (kg/LTO)-Old fleet (B737-100)	0.9	2900	4.8	8	0.1	0.1	0.2		
Cruise (kg/tonne)- Average fleet (B737-400)	1.0	3150	2.0	10.3	0	0.1	0.2		
Cruise (kg/tonne)- Old fleet (B737-100)	1.0	3150	2.0	9.4	0	0.1	0.2		
International									
LTO (kg/LTO) Average fleet(B767)	1.6	5094	6.1	26	0	0.2	0.15	0.1	0.03
LTO (kg/LTO) Average fleet (short distance, B737-400)	0.8	2600	11.8	8.3	0.1	0.1	0.07		
LTO (kg/LTO) Average fleet (long distance, B747-400)	3.4	10717	19.5	56.6	0.2	0.3	0.07		
LTO (kg/LTO) Old fleet (DC-10)	2.4	7500	61.6	41.7	2.3	0.2	0.32		
LTO (kg/LTO) Old fleet (short distance, B737-100)	0.9	2900	4.8	8	0.1	0.1	0.1		
LTO (kg/LTO) Old fleet (long distance, B747-100)	3.4	10754	78.2	55.9	3.7	0.3	0.47		
Domestic Cruise Emission[c]									
Cruise (kg/tonne)-Average fleet (B767)	1.0	3150	2.0	10.3	0.0	0.1	0.2	0.1	0.03
Cruise (kg/tonne)-Old fleet (DC10)	1.0	3150	2.0	9.4	0.0	0.1	0.2	0.1	0.03
International Cruise Emission[c]									
Cruise (kg/tonne)- Average fleet (B767)	1.0	3150	1.1	12.8	0.0	0.1	0.2	0.1	0.03
Cruise (kg/tonne)- Old fleet (DC10)	1.0	3150	1.0	17.6	0.0	0.1	0.2	0.1	0.03

Source/Remarks

[a] EMEP/CORINAIR, 2006. Values are based on type of aircraft.

[b] Bond et al., 2004. Values do not have the range of technologies applicable for aviation fuel.

[c] Units are presented in kg/tonne of fuel consumed.

[d] In case users want to estimate PM_{10} emission, assume $PM_{10} = PM_{2.5}$ emission factor.

3.3.4.3 WATER/SHIPPING

The compiled emission factors for the different methods are mainly from the EMEP/CORINAIR Guidebook. The EFs for the simple method (fuel use method) and detailed method are presented in Table 3.14.

Table 3.14: Emission Factors for Fuel Use-Based Method

Pollutants	EFs (kg/tonne fuel)[a]
CO_2[c]	3170
SO_2[c]	20xS
NO_x[d]	57
CO[d]	7.4
CH_4[d]	0.05
N_2O[d]	0.08
NMVOC[d]	2.4
$PM_{2.5}$[f]	1.38[e,1], 1.58[e,2], 0.102[e,3], 1.1 (diesel), 6.7 (heavy fuel oil)
BC	1.02[b]
OC	0.49[b]

Source/Remarks
S: Sulfur content (%), in the absence of this value, use 2.7% (by wt) - residual fuel oil, and 0.5% (by wt) - distillate fuel.
[a] EMEP/CORINAIR, 2006.
[b] Bond et al., 2004. Values are applicable for diesel and heavy oil.
[c] Fuel composition-dependent emission.
[d] Engine-dependent emission.
[e] APEG, 1999; Berdowski et al., 1997. [e,1] APEG: Fuel oil, PM_1 23% of PM_{10}; [e,2] Diesel, PM_1 85%; [e,3] Gasoline, PM_1 85%.
[f] In case users want to estimate PM_{10} emission, assume $PM_{2.5}$=PM_{10} emission factor.

A comparison of compression ignition marine engine emission factors with USEPA emission factors are presented in the Annex in Table A.1.

3.3.4.4 RAILWAYS AND OTHER MODES OF TRANSPORTATION

For railways and other modes of transportation, the simple method utilizing bulk emission factors is considered sufficient in this manual. EFs are mainly taken from EMEP/CORINAIR (2006) and are presented in Table 3.15.

Table 3.15: Bulk Emission Factors for Other Mobile Sources and Machinery, Based on Fuel Type (in g/kg fuel)

Fuel type/ Sub-sector[a]	NO_x	NMVOC	CH_4	CO	NH_3	N_2O	$PM_{2.5}$	PM_{10}	BC[b]	OC[b]
Diesel engines										
Agriculture	50.3	7.27	0.17	16.0	0.007	1.29	3.7	3.93	2.27	0.72
Forestry	50.3	6.50	0.17	14.5	0.007	1.32	2.27	2.42	3.12	0.99
Industry	48.8	7.08	0.17	15.8	0.007	1.30	2.15	2.29	3.12	0.99
Households	48.2	10.4	0.17	22.9	0.007	1.23	7.65	7.65	-	-
Railways	39.6	4.65	0.18	10.7	0.007	1.24	4.83, 3.4[c]	5.14	1.53, 0.29[c]	0.49, 0.28[c]
Inland waterways	42.5	4.72	0.18	10.9	0.007	1.29	3.87	4.12	-	-
Gasoline engines										
Agriculture	7.56	73.6	3.68	1486	0.005	0.07	-	-	-	-
Forestry	-	-	-	-	-	-	-	-	-	-
Industry	9.61	43.4	2.17	1193	0.005	0.08	-	-	-	-
Households	8.0	110	5.50	2193	0.005	0.07	-	-	-	-
Railways	-	-	-	-	-	-	3.59[c] (2.47)	-	0.07[c] (0.06)	0.65[c] (0.29)
Inland waterways	9.70	34.4	1.72	1022	0.005	0.08	-	-	-	-

Source/Remarks
[a] EMEP/CORINAIR, 2006. PM_{10} emission factors refer to PM.
[b] Bond et al., 2004. Applicable for diesel fuel.
[c] Reddy and Venkataraman, 2002a. Values in parentheses are applicable for fuel oil.

3.3.5 TEMPORAL AND SPATIAL DISTRIBUTION

3.3.5.1 ON-ROAD

The temporal resolution of road transport emissions is an important input in mesoscale air quality models or for local air pollution assessment. In this case, patterns of traffic load, in conjunction with variation over time of average vehicle speed, should be used for the calculation of temporal variation of emissions. This means that traffic counting and speed recording data should be available.

For countries, where the required data are not available at the lower level (bottom up), the top down approach is suggested. This approach implies starting to calculate emissions at the national level and allocating the national level emissions at the lower levels, using available surrogate data. The surrogate data can include population density (urban and rural), geographical location of road (road mapping), etc.

3.3.5.2 AIR TRAFFIC

Temporal variation data may be obtained from flight timetables (airport authority). The schedule will give diurnal variations as well as variations over months and weekdays.

The emissions for LTO activity can be disaggregated by noting exactly the geographical location of specific airports. For cruise activity, these can be associated with the appropriate territorial unit (for example, country/regional), which can be shown by using specific flight routes.

3.3.5.3 WATER/SHIPPING

Although EMEP/CORINAIR suggests that seasonal variation throughout the year is insignificant, there may be exceptions in certain areas and for certain vessel types. A greater proportion of emissions from fishing as well as cruise ships is noted in late summer months (in Europe) as these activities are more popular during this time of the year.

Spatial disaggregation of emissions can be constructed based on ship routing data, especially for the simple and fuel-based methodology.

3.3.5.4 RAILWAYS AND OTHER MODES OF TRANSPORTATION

EMEP/CORINAIR (2006) provides the following guidelines on the spatial allocation procedure:

- Railway emissions should be disaggregated as a line source along tracks in a way similar to that used for road emissions, or railways can be treated as an area source by using railway track distribution.
- Agricultural, forestry and military emissions should be disaggregated using land use data.
- Industrial, household and gardening emissions should be disaggregated using general population density data.
- Inland waterways can be allocated to the appropriate water body and land use.

In general, it is difficult to categorize emissions according to seasonal, monthly and daily variations. For European countries, seasonal and hourly disaggregation profiles (in %) have been proposed in EMEP/CORINAIR (2006). However, the values will greatly depend on conditions in individual countries.

The steps for calculating total emissions from the transportation sector are presented in Table 3.16.

Table 3.16: Summary of Calculation Procedure for Transportation Sector Emissions

Step	Calculation Procedure
1	**Calculating Emissions from On-road Transport** **Simple Method:** • Obtain fuel consumption of each vehicle category (or derived from total energy consumption for the transportation sector). • Take emission factor from Table 3.10. • For SO_2 EFs, take values of CS_{fuel}, α_s, Hu; calculate the EFs by using eq. 3.12. • Calculate emissions by using eq. 3.6. **Detailed Method:** • Obtain data on the number of vehicles (Nv_j) in the country during a reference year. • Obtain mileage per vehicle driven on roads ($Mv_{j,r}$). • Take emission factor from Table 3.11. • Calculate emissions by using eq. 3.7.
2	**Calculating Emissions of Air Traffic:** • Obtain LTO data from the airport authority for specific airports. • Obtain aviation fuel used from the national report (kt). • Take emission factor for LTO activity from Table 3.13 (fleet category is needed). • Calculate emissions from LTO activity by using eq. 3.8. • Calculate emissions from cruise activity by using eq. 3.9.
3	**Calculating Emissions of Water/Shipping:** • Obtain shipping fuel sold (kt) data. • Obtain the EFs from Table 3.14 for the simple method. • Calculate emissions by using eq. 3.10.
4	**Calculating Emissions of Railways and Other Modes of Transportation:** • Obtain data on fuel consumption of railways and others in the machinery sub-sector (kt) data. • Pick the bulk EFs from Table 3.15. • Calculate emissions by using eq. 3.11.
5	**Temporal Variation:** • On road: traffic counting • Air traffic: flight schedule • Shipping: seasonal variation • Railways and other machinery: apply seasonal and hourly factors from EMEP/CORINAIR (2006).

3.4 EMISSIONS FROM THE RESIDENTIAL AND COMMERCIAL SECTORS
3.4.1 EMISSIONS FROM THE RESIDENTIAL SECTOR
3.4.1.1 OVERVIEW

This sector covers all fuel combustion activities in households, including domestic cooking and use of fireplaces. Household stoves, although small, are numerous and thus have the potential to contribute further to decreasing the air quality. Developing countries account for a significant share of total fuel use (Zhang et al., 2000). The type of fuel used is largely dependent on locality. In rural households, for example, common types of fuel are crop residue, wood, kerosene and coal, while in urban households, gaseous fuel, coal and kerosene are more common. Residential fireplaces are used primarily for aesthetic effects and secondarily as a supplemental source of heat in houses and other dwellings that do not have very efficient sources of heat. Heating stoves are more efficient heat sources than fireplaces.

Pollutants associated with fuel combustion in the residential sector are PM, BC, OC, SO_2, CO_2, NO_x, CO, NMVOC and CH_4.

3.4.1.2 EMISSION ESTIMATION METHOD

The proposed emission estimation method in this manual is the simple method, which is based on fuel consumption and fuel type. Uncontrolled bulk emission factors for each type of fuel used are normally used to calculate emissions. Total emissions for specific species and types of fuels are calculated based on the following equation:

$$Em_{i,j} = \sum_j Fc_j \times EF_{i,j} \qquad \text{(eq. 3.13)}$$

where,
j = Type of fuel
$Em_{i,j}$ = Emission of pollutant i from fuel type j
Fc_j = Consumption of fuel type j (kg/yr)
$EF_{i,j}$ = Emission factor specific to pollutant i from fuel type j.

3.4.1.3 DATA ON ACTIVITY LEVELS

Annual fuel consumption is the most important data for the estimation of residential sector emissions. In general, three types of fuel are used, namely solid fuel, liquid fuel and gaseous fuels. It is reported that domestic burning of solid fuels results in a large percentage of total emissions (Streets et al., 2001). This may be due to low thermal and combustion efficiencies of solid fuel. Fuel consumption data can be obtained from national level data sources. However, if they are not available, the International Energy Agency (IEA) provides sectoral data on different types of fuel use in 138 countries (http: //www.iea.org/Textbase/stats/). Detailed energy balance data (in TOE units) for different years are available for a fee from IEA.

The residential sector energy data are often not disaggregated by end use devices, such as household stoves and fire places/heating stoves. Kerosene, liquefied petroleum gas (LPG) and natural gas are used for cooking, while kerosene is used for lighting in the residential sector in many regions. Coal is used mostly for domestic cooking and heating stoves. In rural China, coal is commonly used for cooking. Biomass fuels, such as wood, are only used for heating stoves and fireplaces, when electricity or natural gas is unavailable (urban population). However, the choice of fuel is greatly dependent on locality, as described by Bond et al., (2004). In the USA, 25% of wood burned is used to heat fireplaces and the remainder for heating stoves. In Europe, 25% of wood burned is used for heating stoves, 5% for heating fireplaces, and the remainder is used for boilers. For Eastern Europe and the former USSR, wood is burned mostly for heating stoves, while in Asia, Africa and Central America, wood is burned largely for cooking stoves. The latter assumption should be used if local/country-specific data are not available.

3.4.1.4 EMISSION FACTORS

Compiled emission factors of PM, CO_2, CO, CH_4, NMVOC, NO_x, SO_2 and N_2O from household stoves have been obtained from specific studies in Asian countries (Zhang et al. (2000); Oanh et al., 1999; Bhattacharya et al., 2002; Venkataraman and Rao, 2001). The EFs were generated from a systematic measurement of 56 fuel/stove combinations in India and China. These combinations represent a large portion of worldwide use (Zhang et al., 2000). However, when stove-specific fuel data are not available, the mean values of all stove types tested are compiled, as presented in Table 3.18. The emission factors of BC and OC are compiled for specific types of fuel from Bond et al. (2004). Ammonia emission factors for wood and charcoal-based cooking are compiled from Bertschi et al. (2003). Considering that combustion processes and emissions from cooking fires may differ across heating stoves/fireplaces, a compilation of fireplace EFs from certain sources is presented in Table 3.17.

Table 3.17: Compiled Emission Factors of Pollutants for the Residential Sector

Pollutants	Emission Factors as g/kg fuels			
	Cooking/Household Stoves			
	Wood	Coal	Kerosene	Gases/LPG
PM [a]	3.82, 2-5 (3.5)[d], 4.2-8.2[o]	1.3, 7[d], 12.2[n]	0.13, 1.9[n]	0.26, 0.33[n]
SO_2 [a]	0.008	2.67	0.025	0.33
CO_2 [a]	1520, 1560-1620 (1550)[h]	2280	3130	2980
CO [a]	69.2, 19-136 (77.5)[h],	71.3, 300[j]	7.39	3.72
NO_x [a]	1.2, 0.05-0.2 (0.125)[h]	0.914	1.1	1.76
NH_3 [c]	1.29	-	-	-
CH_4 [a]	5.06, 6-10(8)[h]	2.92, 6.7-66 (36.6)[m]	0.025, 0.09-1 (0.56)[m]	0.14, 0.04-1.1 (0.56)[m]
N_2O	0.06[l]		0.05-0.08 (0.07)[m]	0.03-0.16 (0.09)[m]
C_{TNMVOC} [a]	4.34, 6-9 (7.5)[h]	0.664	0.39	1.6 (89.7)
BC [b]	0.3-1.4 (0.85), 0.38-0.62[g], 1.1-2[o]	0.76-5.4 (3.1), 1.8[n]	0.9, 0.16[n]	0.2, 0.01[n]
OC [b]	1.7-7.8(4.75), 0.17-4.69[g]	0.4-4.3 (2.3), 7.8[n]	0.09 0.16[n]	0.05 0.03[n]

Source/Remarks

Values in parentheses are central values from certain ranges.

[a] Zhang et al., 2000.

[b] Bond et al., 2004, for fireplace, BC/PM and OC/PM ratio is taken from Houck and Tiegs (1998) which is around 0.15 and 0.6. PM EF is a central value taken from Houck and Tiegs (1998).

[c] Bertschi et al., 2003.

[d] Oanh et al., 1999 (for charcoal only). For others refer to Oanh et al, 2005. EFs are derived from hood monitoring of 12 selected cooking stoves in Asia, using wood, rice husk briquettes and anthracite coal as fuel.

[e] Smith et al., 2000.

[f] USEPA, 1996.

[g] Venkataraman et al., 2005.

[h] Bhattacharya et al., 2002; Study was conducted on a number of traditional and improved cooking stoves collected from different Asian countries, using wood and charcoal as fuel.

[i] Andreae and Merlet, 2001.Values are applicable for a traditional one-pot stove, estimated in India for varying burn rates.

[j] Zhang et al., 2000. EFs are determined by using a carbon balance approach for 56 types of fuel/stove combinations in China and India.

[k] Values are compiled by Bhattacharya, et al., 2002, from various EF works in India and Nepal for improved biomass cooking stove.

[l] Ventakaraman and Rao, 2001. Values are applicable for traditional cooking stoves.

[m] IPCC 2006. Compiled from various sources.

[n] Values have been estimated and used by Reddy and Venkataraman, 2002a, from various sources. For domestic coal, BC and OC fractions of PM for domestic coal combustion were 15% and 64%, respectively (Mumford et al., 1987).

[o] Roden et al., 2009. Lower values in the range refer to well-designed/improved cooking stove with chimney, while high values refer to traditional cooking stove. Black carbon of PM is found to be about 25% for both kinds of stoves.

[p] Muhlbaier and Williams, 1982. Residential fireplace using softwood.

[q] Purvis et al., 2000. Fireplaces using wet/seasoned oak.

[r] Fine et al., 2002. In $PM_{2.5}$, fireplace combustion, hardwoods with thermal methods with an optical correction based on reflectance or transmittance of light (TO).

Crop Residues	Charcoal	Dung and other wastes	Fireplaces
			Wood
8.05, 5[d], 10[l]	3.9-7.5[d]	4.1-20 (12)[k], 3.9-4.9 (4.2)[l]	17.3[f], 12[b], 6.7[q]
0.216, 6[l]	0.3-0.69 (0.49)[k]	6[k]	0.2[f]
1130	2611[i], 2155-2567 (2361)[h]	1060[k]	1700[f]
86.3, 75[l]	275[e], 35-198, 280[j] (116.5)[h]	26-83 (54.5)[k]	126.3[f]
0.7	6.0[i], 0.03– 0.42 (0.22)[h]	0.7 – 7 (3.85)[k]	1.3[f]
-	0.97		-
4.56, 3.8-69 (36.4)[m]	6.2[i], 6.7-7.8 (7.25)[h], 8.4-11.8 (10.2)[m]	3.9[l], 3.7[m]	-
0.06[l], 0.16[m]	0.03[l], 0.05-0.3 (0.17)[m]	0.053[l], 0.36[m]	0.15[m]
4.35	6-10 (8)[h]	-	-
1, 0.12-0.17[g]	1	0.53	1.8, 1.3[p], 0.23[r]
3.3	1.3	1.8	7.2, 5.27[r], 2.8[p]

3.4.1.5 TEMPORAL AND SPATIAL DISTRIBUTION

Domestic cooking and fireplace/heating have different temporal use patterns. Cooking is a daily routine that may vary within a day (hourly). Peak hour may occur in the early morning (breakfast), mid-day (lunch) and late afternoon (dinner). Fireplace/heating, on the other hand, is largely associated with seasonal variations. Seasonal/monthly variation can be constructed based on the monthly consumption of each type of fuel. Therefore, country-specific fuel consumption data need to be obtained. The seasonal (or monthly) factor is calculated by using the following equation. To obtain the monthly emission, this factor is multiplied with the annual average emission.

$$FM_n = \frac{Fc_n}{\sum_n Fc}$$

(eq. 3.14)

where,
n = Month (1-12)
FM_n = Monthly fraction
Fc_n = Fuel consumption in month n
$\sum Fc$ = Total fuel consumption in a year.

Although fuel use data are extracted from country level sources, spatial distribution of emissions can be carried out based on total population. For example, a space (grid cell) with 5% of a country's total population would be allocated 5% of total emissions. Populous urban regions are expected to have more fuel alternatives than rural areas, thus using more fossil fuel-based energy (for example, kerosene and gas). In rural areas, it is common practice to use fire wood, coal and agricultural residue as fuel for fireplaces and cooking.
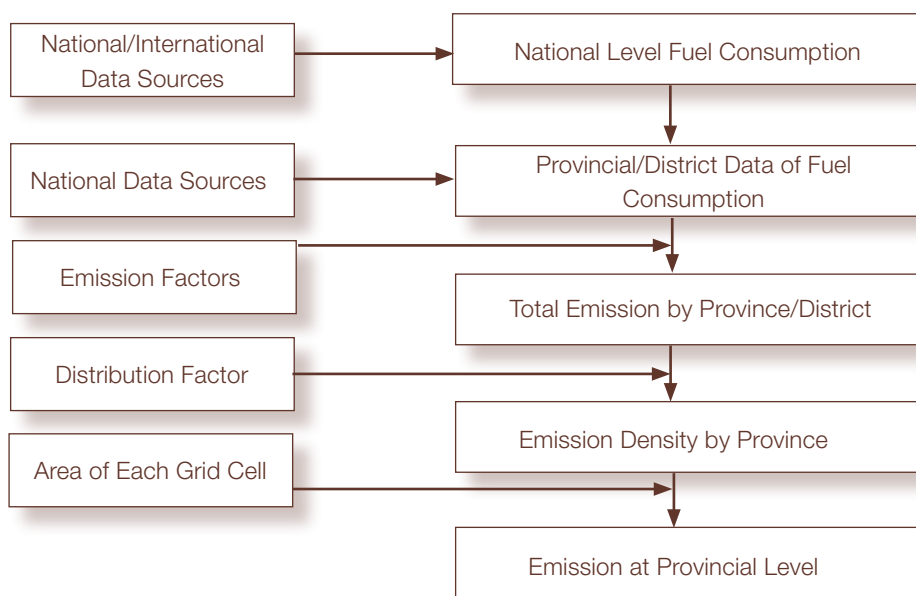
Figure 3.2: Flowchart for Spatial Distribution of Emissions in the Residential Sector

The calculation procedure for residential sector emissions is presented in Table 3.18.

Table 3.18: Summary of Calculation Procedure for Residential Sector Emissions

Step	Calculation Procedure
1	**Calculating Fuel Consumption Rate** • Obtain residential sector fuel consumption rate for each type of fuel in a specific country from national/international data sources. • For all fuels (in TJ/yr), use consumption rate for calculating emissions, or convert it to mass unit (ktonne/yr) by using their Net Calorific Values (NCVs).
2	**Calculating Total Emissions** • Take the EFs of each fuel type from Table 3.17. • Calculate emissions by using eq. 3.13.
3	**Temporal Distribution** • Obtain fuel consumption data from all sources (monthly data). • Calculate the respective monthly factor by using eq. 3.14. • Calculate monthly emissions by multiplying annual emission with the monthly factors.
4	**Spatial Distribution** Use fuel consumption data for each province/district. (Refer to Figure 3.2).

3.4.2 EMISSIONS FROM THE COMMERCIAL SECTOR

3.4.2.1 OVERVIEW

This sector covers all fuel combustion activities in hotels or offices (other public services), such as cooking, heating, boiler operation, and captive power generation. Since these facilities are available in urban areas, typical urban types of fuel combustion are considered. These are gaseous fuels, coal, oil and kerosene. These may emit combustion pollutants, such as PM, BC, OC, SO_2, CO_2, NO_x, CO, NMVOC, and CH_4.

3.4.2.2 EMISSION ESTIMATION METHOD

The proposed emission estimation method in this manual is the simple method, which is based on fuel consumption and type, similar to that in the residential sector. Uncontrolled bulk emission factors for each type of fuel used are normally used in order to calculate emissions. Total emissions for specific species and types of fuel are calculated based on the following simple equation.

$$Em_{i,j,k} = \sum_j Fc_{j,k} \times EF_{i,j,k} \qquad \text{(eq. 3.15)}$$

where,

$Em_{i,j,k}$ = Emissions of pollutant i from fuel type j and sub-sector k

$Fc_{j,k}$ = Fuel consumption for fuel type j and sub-sector k (kg/year)

$EF_{i,j,k}$ = Emission factor specific to pollutant i, fuel type j and sub-sector k.

3.4.2.3 DATA ON ACTIVITY LEVELS

The activity rate is normally the rate for annual fuel consumption for cooking, heating, boiler operation, and captive power generation. Data can be obtained from national level data sources. If these are not available, the International Energy Agency (IEA) provides data on sectoral fuel use in 138 countries (http: //www.iea.org/Textbase/stats/). Data on 'total final consumption' for commercial and public services are available by fuel type. However, there are no disaggregated sub-sectoral data (e.g., data for cooking, heating, boiler operation, and captive power generation) for commercial and public services. Therefore disaggregated sub-sectoral data need to be collected. Nevertheless, assumptions need to be made based on the type of fuel. Kerosene, LPG and gas are used for cooking; with the use of LPG and natural gas depending on their availability (supply). Residual fuel oil, natural gas, LPG, and coal are used for boilers and space heaters.

3.4.2.4 EMISSION FACTORS

Compiled emission factors of PM, SO_2, CO_2, NO_x, CO, CH_4 and N_2O for the commercial cooking activity are adapted from those for the household cooking stoves (Zhang et al., 2000); the emission factors are presented in Table 3.18. The emission factors of commercial boilers and space heaters using different types of fuel are compiled from USEPA (1995) and are presented in Table 3.19.

Table 3.19: Compiled Emission Factors of Pollutants for the Commercial Sector

Pollutant	Emission Factors[a]								
	Stationary Combustion Device					Space Heating			
	LPG (g/kg)	Heavy Fuel Oil (g/kg)	Middle Distillate Fuel Oil (g/kg)	Natural Gases (g/kg)	Coal (g/kg)	Heavy Fuel Oil (g/kg)	Middle Dist. Fuel Oil (g/kg)	Natural Gases (g/kg)	Coal (g/kg)
PM	0.1, 0.52[b]	1.1[b]	1.10, 6[b]	0.18	12, 4.2[b]	0.36A, 1.1[b]	6[b]	0.18	4.2
$PM_{2.5}$ [b, c]	0.52	6.12, 0.5	5.16	0.0004	1.4	0.5	5.16	0.0004	1.4
SO_2	0.02S	18.97S	23.85S	0.014	19.5s	12.90S	21.57S	0.014	19.5s
CO_2	2958.62	2838.71	-	2857	2840	2838.71		2857	-
CO	0.43	0.65	0.76	2	0.3	0.22	0.76	0.95	-
NO_x	3.10	2.45	7.14	2.4	9	1.42	8.35	2.2	1.5
CH_4	0.04	-	0.07	0.055	-	-	0.27	0.055	4
N_2O	0.19	-	-	0.052	-	-	-	0.052	-
BC[b,d]	0.07	0.04	3.4	0.00003	0.3	0.04	3.4	0.00001	0.3
OC[b,e]	0.05	0.015	1.1	0.00001	0.05	0.015	1.1	0.00001	0.05

Source/Remarks

[a] USEPA, 1995. Units are all converted to g/kg (except for natural gases) by using density value; LPG = 580 kg/m³, HFO = 930 kg/m³, kerosene = 790 kg/m³, natural gas = 0.9 kg/m³, and coal = 800 kg/m³. The values are applicable for uncontrolled small boilers for stationary combustion and residential furnace for space heating. For small wall-fired boilers with SNCR control, apply a 24% reduction to the appropriate NOx emission factor. PM emission factors presented here can be used to estimate PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ emissions.
[b] Compiled by Bond et al., 2004 from various sources.
[c] $PM_{2.5}$ here refers to $PM_{1.0}$ with $PM_{1.0}$/PM ratio of around 1 (natural gas and LPG), 0.45 (heavy fuel oil), 0.86 (middle distillate oil), and 0.33 (coal).
[d] BC/$PM_{1.0}$ ratio used are 0.06 (natural gas), 0.08 (heavy fuel oil), 0.13 (LPG), 0.66 (middle distillate oil), and 0.2 (coal).
[e] OC/$PM_{1.0}$ ratio used are 0.5 (natural gas), 0.03 (heavy fuel oil), 0.1 (LPG), 0.21 (middle distillate oil) and 0.04 (coal).
S = sulfur content in gr/1000 ft³; s = sulfur content in %; A = ash content in %.

3.4.2.5 TEMPORAL AND SPATIAL DISTRIBUTION

Seasonal/monthly variations in emissions in the commercial sector can be constructed from the monthly fuel consumption. These data may not be available in international reference sources but can be obtained from national reports. To obtain the monthly emission, the monthly fraction factor is multiplied with the annual average emission. The monthly fraction is calculated as follows:

$$FM_n = \frac{Fc_n}{\sum_n Fc} \qquad \text{(eq. 3.16)}$$

where,
k = Month (1-12)
FM_n = Monthly fraction
Fc_n = Fuel consumption in month n
$\sum_n Fc$ = Total fuel consumption in a year.
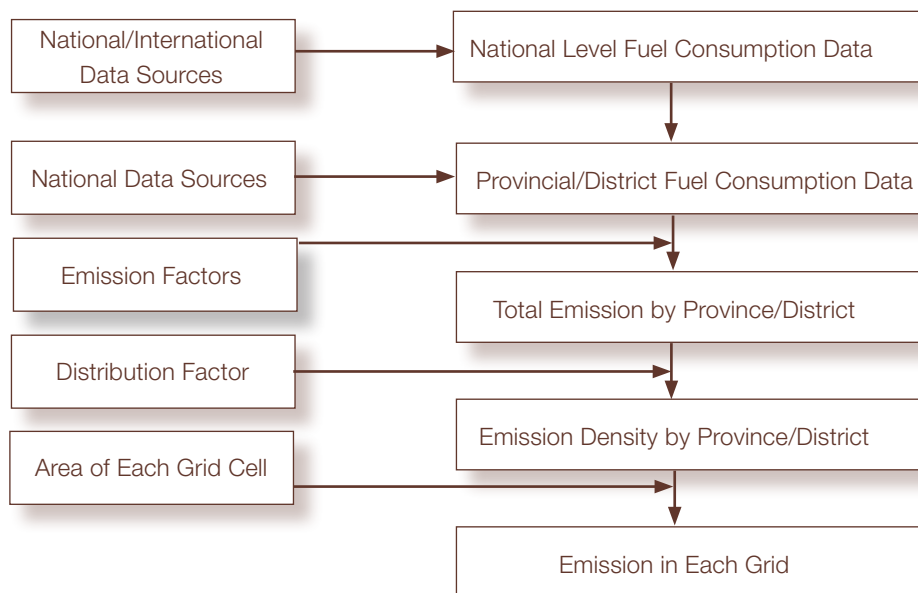
Figure 3.3: Flowchart of Spatial Distribution of Emissions for the Commercial Sector

In general, data on fuel use in the commercial sector are extracted from national sources. In order to spatially distribute emissions, data on provincial/district level fuel consumption are needed. Total emissions per province/district can be calculated by using the EFs and corresponding fuel consumption. Total emission per province/district is calculated based on data for each province. When the domain is set up into grid cell resolutions, total emission per grid can be calculated by multiplying total emission per area (i.e., province or district) with area of each grid cell. The flowchart is presented in Figure 3.3.

The calculation procedure for commercial sector emissions is presented in Table 3.20.

Table 3.20: Summary of Calculation Procedure for Commercial Sector Emissions

Step	Calculation Procedure
1	**Calculate Fuel Consumption Rate per Sub-sector** • Obtain annual total consumption of each type of fuel in a specific country from national and international data sources. • Aggregate the data into several sub-sectors, such as cooking, boiler operation and heating, based on fuel type and local-specific data.
2	**Calculate Total Emissions of Commercial Sector** • Take the EFs of each fuel type from Table 3.19 for each sub-sector. • Calculate the emissions by using eq. 3.15. • Sum up the total emissions from all sub-sectors.
3	**Temporal Distribution** • Obtain fuel consumption data from all sources (monthly format). • Calculate the respective monthly factor by using eq. 3.16. • Calculate monthly emission by multiplying monthly factor with annual emission.
4	**Spatial Distribution** Use fuel consumption data for each province/district. (Refer to Figure 3.3).

4.1 OVERVIEW

This sector covers all non-combustion activities related to the extraction, processing, storage, distribution and non-combustion use of fossil fuels. In this manual, this sector includes fugitive emissions from the following:

- Coke production processes, including fugitive NMVOC and particulate matter,
- Coal mining and handling, including fugitive NMVOC and PM_{10} which may arise from coal extraction and processing activities,
- Oil and gas exploration, treatment and loading, including fugitive NMVOC, CH_4 and CO_2 losses, which may result from maintenance (venting, and so on) and leakage,
- Oil refinery, including fugitive NMVOC from storage facility,
- Gasoline distribution, including fugitive NMVOC which evaporates, and
- Flaring in oil and gas production facility.

From the extraction of fossil fuels up to their final use, there may occur an escape or release of gaseous fuels or volatile components of liquid fuels. Fugitive emissions from the refining, transport and distribution of oil products are a major component of national NMVOC emissions in many countries. In addition to NMVOC, fugitive emissions of particulate matter arise from the production of coke. SO_2, NO_x and CO emissions are released while refining oil from catalytic cracking and sulfur recovery as well as flaring during oil and gas extraction. Emissions from the use of oil and gas or derived fuel products to provide energy for internal (own) use in fuel extraction and processing, and evaporative emissions from vehicles, are excluded from consideration as fugitive emissions.

4.2 EMISSION ESTIMATION METHOD

The method proposed in this manual for the estimation of fugitive emissions is adopted from EMEP/CORINAIR (2006). Two methodologies -simple and detailed – are used. The simple methodology involves the application of a general emission factor to appropriate activity statistics, while the detailed methodology requires a specific emission factor for more detailed activity data type. As an example, for coal mining the first methodology utilizes default emission factors for mining and post mining activities (in m^3/Mg coal produced) and requires production data only (EMEP/CORINAIR, 2006). The second method requires country-/field-specific activity data where the emission factors are based on country-/field-specific data (available for European countries).

Given the limited availability of activity specific emission factors and detailed activity data, the proposed estimation methodology is the simple methodology whereby the general emission factor is multiplied by the level of activity. Total emission of specific species from each type of fuel is calculated using the following equation.

$$Em_{i,j,k} = \sum_j Fc_{j,k} \times EF_{i,j,k} \qquad \text{(eq. 4.1)}$$

where,

i, j, k	= Pollutant i, fuel type j and sub-sector k
$Em_{i,j,k}$	= Emission from pollutant i, fuel type j in sub-sector k
$\sum Fc_{j,k}$	= Consumption of fuel type j and sub-sector k (tonne/yr)
$EF_{i,j,k}$	= Emission factor specific to pollutant i fuel type j and sub-sector k.

4.3 DATA ON ACTIVITY LEVELS

For the simple method, the following activity statistics are required:

- Mass of coke produced in each type of production process.
- Oil and gas production, which can be obtained from national statistics offices in individual countries or from various international sources
- Volume of gas processed through a gas terminal. This is normally available from national sources.
- Mass of crude oil loaded into tankers (ships or trucks). In many cases, the mass will be equal to national oil production.
- Frequency of drilling operations (number of wells drilled per year or total number of drilling days per year).
- Volume of gas or oil transported through a given pipeline. This volume is measured for economical reasons; in many cases, it might be equal to the combined production from a number of fields.
- Volume of gasoline distributed. In many cases, national statistial offices may report this as volume of gasoline sold.
- Coal production data which can be obtained from national statistics offices or ministries of energy and resources.

4.4 EMISSION FACTORS

Compiled emission factors are taken from EMEP/CORINAIR (1999) and USEPA (1995), which are presented in the following tables.

Table 4.1: Compiled Emission Factors for Coke Production

Activity	NMVOC	PM$_{10}$	PM$_{2.5}$	BC	OC
	g/tonne coke	kg/tonne coke[b]	kg/tonne coke[b]	kg/tonne coke[j]	kg/tonne coke[j]
Coking process	29 - 400[a]	4.9[j]	1.53[j]	0.68	0.49
COG purification	210[a]	-	-	-	-
Coal crushing	-	0.055 [b]	-	-	-
Coal preheating	-	1.7[c]	1[g]	-	-
Oven charging	-	0.24[d]	-	-	-
Oven door leaking	-	0.27[b]	-	-	-
Oven pushing	-	0.25[e]	0.1[h]	-	-
Quenching	-	0.6[f]	0.51[i]	-	-

Source/Remarks

[a] EMEP/CORINAIR, 1999. Values for COG purification is the sum of benzene, toluene and xylene EFs.

[b] USEPA, 1995. Most of the values presented are uncontrolled emission factors.

[c] For coal preheating controlled with venturi scrubber, use PM$_{10}$ emission factor = 0.12 kg/t.

[d] For oven charging controlled with sequential charging, use PM$_{10}$ emission factor = 0.004 kg/t.

[e] For oven pushing with venturi scrubber control device, use PM$_{10}$ emission factor = 0.08 kg/t; - with mobile scrubber car emission factor = 0.012 kg/t.

[f] If quenching uncontrolled (clean water) is involved, use PM$_{10}$ emission factor = 0.17 kg/t; if controlled with baffles (dirty water) is involved, use = 0.21 kg/t; and if controlled with baffles (clean water), the EF is = 0.03 kg/t.

[g] If coal preheating is equipped by venturi scrubber PM$_{2.5}$ use emission factor of 0.11 kg/t.

[h] If the process is equipped by venturi scrubber, use PM$_{2.5}$ emission factor of 0.07 kg/t; - with mobile scrubber car - 0.011 kg/t.

[i] For quenching uncontrolled (clean water), use PM$_{2.5}$ emission factor of 0.06 kg/t; controlled with baffles (dirty water) = 0.13 kg/t; controlled with baffles (clean water) = 0.02 kg/t.

[j] Kupiainen and Klimont, 2004. Applicable for coke production, TSP (refer to PM$_{10}$, PM$_{2.5}$ refer to PM$_1$) emission factors from Klimont et al., 2002.

- not available.

Table 4.2: Compiled Emissions Factors for Oil and Gas Exploration, Treatment and Loading

Activity	Units (U)	Emission Factor (kg/U)		
		NMVOC	CH$_4$	CO$_2$
Venting in gas production facility	Gg/yr of gas produced	190 - 600[a]	330 - 6,700[a]	200[a]
Venting in oil production facility	Gg/yr of oil produced	240 - 900[a]	440 - 9,300[a]	300[a]
Venting in gas terminal	Number of terminals/yr	30,000 - 760,000[b]	50,000 - 470,000[b]	-
Oil loading and transport				
Marine vessels	Crude oil loaded (kt/yr)	71[c]	-	-
Rail tank cars and tank trucks	Crude oil loaded (kt/yr)	564[c]	-	-
Pipeline (oil and gas distribution)				
Crude oil	Gg crude oil transported/yr	72[d]	130[d]	-
Natural gas	Gg gas transported/yr	54[d]	95[d]	-
Drilling	No. of wells drilled/year	700[e]	-	-

Source/Remarks
[a] EMEP/CORINAIR, 2006. Values are taken from UK, Canada and Netherlands.
[b] EMEP/CORINAIR, 20067. Values are taken from UK, Canada and Norway.
[c] USEPA, 1995. Typical emission factor assuming an RVP (Reid vapor pressure) of 34 kPa, an average crude oil density of 874 kg/m^3
[d] EMEP/CORINAIR, 2006.
[e] EMEP/CORINAIR, 2006. Value is taken from Norway.
 - not available.

Table 4.3: Compiled Emission Factors for Oil Refinery

Process	Emission Factor (kg/ m³ fresh feed)								
	SO_2	NO_x	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$[c]	BC[c]	OC[c]
Fluid catalytic cracking unit (FCCU)									
Uncontrolled	1.413	0.204	39.2	0.63	0.155	0.695	0.05	0	0
ESP and CO boiler[d]	1.413	0.204	-	-	-	0.071	-	0	0
Moving bed catalytic cracking unit									
Uncontrolled	0.171	0.014	10.8	0.25	0.017	0.0387	0.05	0	0
Fluid coking unit									
Uncontrolled	-	-	-	0.046	-	0.765	0.05	0	0
ESP and CO boiler[d]	-	-	-	-	-	0.01	-	0	0
Storage (in g/kg)	-	-	-	4.9[b]	-	-	-	0	0
Blowdown system (uncontrolled (kg/m³ refinery feed)	-	-	-	1662	-	-	-	-	-

Source/Remarks
[a] USEPA, 1997 unless otherwise indicated. Units are presented in kg/m³ fresh feed of input.
[b] USEPA, 1995. Unit is presented in g/kg of volatile products stored.
[c] Kupiainen and Klimont, 2004. Units are expressed in kg/ton crude oil throughput.
[d] ESP and CO boiler refers to a steam-generating boiler where the carbon monoxide in the flue gas is burned as fuel to provide steam for use in the refinery and the flue gas from the CO boiler is further processed through an electrostatic precipitator (ESP) to remove residual particulate matter.- not available.

Fugitive Emissions
from Fuels

Table 4.4: Compiled Emission Factors for Gasoline Distribution

Activity	Units (U)	NMVOC Emission Factor (kg/U)
Refinery dispatch station	ktonne gasoline produced	310[a]
Transport and depot	ktonne gasoline consumed	740[a]
Service station	ktonne gasoline consumed/sold	2880[a]
Filling underground tank		
Splash filling	tonne of gasoline sold	2.24[b]
Submerged filling	tonne of gasoline sold	1.48[b]
Balanced vapor filling	tonne of gasoline sold	0.24[b]
Vehicle refueling		
Uncontrolled	tonne of gasoline sold	2.1[b]
Balanced vapor filling	tonne of gasoline sold	0.31[b]

Source/Remarks
[a] EMEP/CORINAIR, 2007. Uncontrolled emission factors are also applied to gasohol (gasoline/ethanol mixture usually at a ratio of 90:10).
[b] Economopoulos, 1993. Unit has been converted from ton to tonne by applying a factor of 0.907.

Table 4.5: Flaring in Oil and Gas Production Facility

Activity	Unit (U)	Emission Factor (kg/U)						
		NOx	CO	NMVOC	PM_{10}[b]	$PM_{2.5}$[b]	BC[b]	OC[b]
Flaring	Volume of flared gas (1000 Sm³/year)	12[a]	0.08[a]	0.53[a]	0.064	0.064	0.05	0.01

Source/Remarks
a EMEP/CORINAIR, 2007. CO emission factor represents emission from fluid catalytic cracker only; NMVOC represents fugitive and process emission.
b Kupiainen and Klimont, 2004. Units are presented in kt/PJ of gas flared. *Note that Sm³ denotes a standard cubic metre; one standard cubic metre of gas is that amount of gas, which occupies one cubic metre at standard temperature and pres sure (0 degree Celsius and one atmospheric pressure).

The following section covers emissions from the mining and handling of coal, excluding peat and other solid fuels. Table 4.6 presents emission factors recommended for use in a simple method, assuming average emission factors that account for emissions from combination of

different sub-processes within the coal mining and handling process.

Table 4.6: Coal Mining and Handling

Activity	Unit (U)	Emission Factor (kg/U)[a]		
		NMVOC	PM_{10}	CH_4[b]
Coal mining and handling	Coal produced (in Mg)	0.8	0.003	2[b,1], 25[b,2]
Coal storage			4.1[c]	

Source/Remarks
a EMEP/CORINAIR, 2006. Uncertainty of NMVOC is assumed to be large because it is based on measurements of methane emissions.
b EMEP/CORINAIR, 2006. b,1 Applicable for opencast mine; b,2 applicable for deep-mine coal.
c Unit is in kg/ha/year.

4.5 TEMPORAL AND SPATIAL DISTRIBUTION

Seasonal/monthly variation of fugitive emissions of fuel can be estimated on the basis of monthly fuel production data. The activity data will be based mainly on the type of fuel produced. Such data may not be available in international data sources. It is therefore necessary to extract monthly production data from national sources. To estimate monthly emissions, multiply the monthly fraction factor by the annual average emission. Fuel production activities are considered as daily routine activities that may vary within a day (hourly). Monthly fraction is calculated by using the following equation.

$$FM_n = \frac{Fc_n}{\sum_j Fc} \qquad \text{(eq.4.2)}$$

where,
n = Month (1-12)
FM_n = Monthly fraction
Fc_n = Fuel consumption in month n
$\sum_j Fc$ = Total fuel consumption in a year.

Spatial distribution of emissions should be based on information about territorial units, where the processes occur, for example, information on coal production in a given territorial unit/ administrative level.

4.6 SUMMARY

Calculation procedure for fugitive emissions from the fuel sector is presented in Table 4.7.

Table 4.7: Summary of Calculation Procedure for Fugitive Emissions from the Fuel Sector

Step	Calculation Procedure
1	**Calculate Fuel Consumption Rate by Sub-sector** • Obtain total annual consumption per type of fuel for each sub-sector in specific countries, from national and international data sources.
2	**Calculate Total Emissions** • Take the EFs of each fuel type from Tables 4.1 to 4.5 for each sub- sector. • Calculate emissions by using eq. 4.1. • Sum up total emissions from all sub-sectors.
3	**Calculate Temporal Variation** • Obtain monthly fuel production data (e.g. coal production data for coal mining and handling). • Construct monthly fraction using eq. 4.2 and taking the total annual fuel production as basis. • Calculate emission per month by multiplying total annual emission with the monthly factor.
4	**Calculate Spatial Distribution** • Obtain provincial fuel production data (e.g. coal production data for coal mining and handling). • Construct provincial fraction based on annual national fuel production. • Calculate monthly emission per province by multiplying annual national emission with constructed provincial factor.

PROCESS-RELATED EMISSIONS IN THE MANUFACTURING AND PROCESS INDUSTRIES

5.1 OVERVIEW

This sector covers non-fuel combustion emissions from the manufacturing and process industries and some processes that involve combustion, mainly in metal production (smelting process and so on). Trace gases (e.g., SO_2) can be emitted from the copper smelting process, with the sulfur content coming from the copper ore and not from the fuel used for smelting (SEI, 2007). Particulate emissions are released during the conveyance, loading and handling of materials as well as from the metal melting process in the furnace. Emissions may contain submicron particles (Kupiainen and Klimont, 2004). Air pollutants, that fall under this category include PM_{10}, $PM_{2.5}$, BC, OC, SO_2, CO_2, NO_x and NMVOC. The manufacturing and process industries covered in this manual are the following:

- Non-metallic mineral production,
- Metal production,
- Chemical industry,
- Pulp and paper industry,
- Food processing industry,
- Food and beverage industry, and
- Other industrial processes.

5.2 EMISSION ESTIMATION METHOD

The emission estimation method proposed in this manual is the simple method, whereby emissions are calculated by multiplying the activity rate (tonne of output or product) by the corresponding emission factor. That is:

$$Em_{i,j} = \sum_j AR_{i,j} \times EF_{i,j} \qquad \text{(eq. 5.1)}$$

where,
i, j = Pollutant i and process j
$Em_{i,j}$ = Emission of pollutant i from process j
$AR_{i,j}$ = Activity rate related to emission of pollutant i and process j (kg/yr)
$EF_{i,j}$ = Emission factor specific to pollutant i and process j.

5.3 DATA ON ACTIVITY LEVELS

The activity rate data needed in the simple method are the annual outputs of each sub-sector/process. The Global Atmospheric Pollution Forum (GAPF) Inventory Manual (2007) suggests several international data sources, such as following:

- United States Geological Survey(USGS),
- Mineral Yearbooks (http://minerals.usgs.gov/minerals/pubs/country/),
- Steel Statistical Yearbook (http://www.worldsteel.org/statistics/statistics-archive.html),
- United Nations Industrial Commodity Statistics Yearbooks,
- FAOSTAT (http://faostat.fao.org/faostat/) data base for pulp and paper, and
- National reports that may also contain output data.

5.4 EMISSION FACTORS

Emission factors are taken mainly from the GAPF Inventory Manual, which provides a compilation of EFs from several sources, such as USEPA (1995), IPCC (1996), EMEP/CORINAIR (2005), and other publications. In some of the compiled EFs, it is assumed that no emission control technologies are involved. Where relevant, use of alternative EFs that take into account control technologies is also suggested. Table 5.1 presents compiled emission factors for the manufacturing and process industries.

5.5 TEMPORAL AND SPATIAL DISTRIBUTION

Temporal variation of emissions depends on the type of process, that is, whether it is continuous or intermittent. For most of the continuous processes, temporal disaggregation can be carried out by using the operation time data. For some processing plants, daily material balance is obtained, which may enable disaggregation of emissions in an hourly basis. As the processes for most of the metal industries are neither continuous nor intermittent, temporal disaggregation would depend on the production rate. However, this quantitative information is difficult to obtain.

Spatial distribution of emissions from manufacturing and industrial processes could be carried out using several methods. For sources that are treated as point sources, the longitude/latitude (location, geographical coordinates) coordinates of each point source can be used. For those that are treated as an area source, industrial output data, which are widely available, can be used as spatial distribution proxy factor (Wang et al., 2005). Industrial Gross Domestic Product (GDP) can also be used, if provincial data are available.

Table 5.1: Emission Factors for Manufacturing and Process Industries (Mineral Products)

Sub-sector/ Process	Emission Factor (kg/tonne product output)									
	SO_2	NO_x	CO	NMVOC	CO_2[a]	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Cement Production										
Wet process kiln (uncontrolled)	0.3[a]	-	-	-	520	-	16[b], 54.6[h,1]	4.64[b], 6.5[h,1]	0-0.15[h,1]	0.73-3.25[h,1]
Wet process kiln with ESP	0.3[a]	-	-	-	520	-	0.33[b]	0.25[b]	-	-
Dry process kiln with fabric filter	0.3[a]	-	-	-	520	-	0.084[b]	0.045[b]	-	-
Lime Production										
Coal-fired rotary kiln (uncontrolled)	-	-	-	-	750	-	22[b], 12[h,2]	2.57[b], 0.46[h,2]	0.22[h,2]	1.54[h,2]
Coal-fired rotary kiln (with ESP)	-	-	-	-	750	-	2.2[b]	0.62[b]	-	-
Asphalt Roofing Production	-	-	0.0095[c]	0.046[c]	-	-	0.6[c]	-	-	-
Asphalt Blowing	-	-	0.014[b]	0.66[d]	-	-	0.33[e]	-	-	-
Road Paving										
Asphalt plant-batch mix hot mix, (uncontrolled)	0.12[c]	0.084[c]	0.035[c]	0.023[b]	-	-	2.25[b]	0.14[b]	-	-
Asphalt plant-batch mix hot mix, (fabric filter PM control)	-	-	-	0.018[b]	-	-	0.0135[b]	0.0042[b]	-	-
Asphalt plant-drum mix hot mix, (uncontrolled)	-	-	-	0.016[b]	-	-	3.25[b]	0.75[b]	-	-

Sub-sector/ Process	Emission Factor (kg/tonne product output)									
	SO_2	NO_x	CO	NMVOC	CO_2[a]	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Asphalt plant-drum mix hot mix, (fabric filter PM control)	-	-	-	0.016[b]	-	-	0.0115[b]	0.0015[b]	-	-
Liquefied asphalt-rapid cure (RC)	-	-	-	170[f]	-	-	-	-	-	-
Liquefied asphalt-medium cure (MC)	-	-	-	140[f]	-	-	-	-	-	-
Liquefied asphalt-slow cure (SC)	-	-	-	50[f]	-	-	-	-	-	-
Brick Manufacturing										
Grinding and screening (uncontrolled)	-	-	-	-	-	-	0.26[b]	-	-	-
Kiln (uncontrolled)	0.23-2.68 (1.46)[g]	-	2.8 – 5.6 (4.2)[g]	-	-	-	0.68[b], 0.29–0.63 (0.46)[g]	0.44[b],	-	-

Source/Remarks

[a] IPCC, 1996. Presented values are mostly applicable for non-combustion processes.

[b] USEPA, 1995. PM emission factors include combustion emissions (apart from grinding and screening in brick manufacture).

[c] EMEP/CORINAIR, 2005. EFs of CO, NMVOC (TOC), and PM are mostly applicable for uncontrolled dip saturator. For dip saturator with ESP control device, the values are 0.049 (TOC), 0.016 (PM).

[d] USEPA, 1995. EFs of NMVOC (TOC) are applicable for saturant asphalt without control. With afterburners=0.14 kg/t asphalt blown.

[e] USEPA, 1995. Value of PM is filterable PM without control. With afterburners, the value is 0.14 kg/t asphalt blown. Values for coating asphalt are 12 (uncontrolled) and 0.41 (with afterburner) kg/t asphalt blown.

[f] EMEP/CORINAIR, 2005. Assumed that 25% by volume diluent content.

[g] Le and Kim Oanh, 2009. In parenthesis are central values. Particulate matter EF are estimated from size distribution of SPM emitted from stack. PM_{10}/SPM = 0.96; $PM_{2.1}$/PM_{10} ratio is 0.33. Weight of brick is 2.2 kg/piece.

[h] Kupiainen and Klimont, 2004. h,1 Since there were no studies reporting emission characteristics from heavy fuel fired cement kilns, BC and OC data of large scale combustion of heavy fuel were used; h,2 the BC shares are derived from the SPECIATE database and the shares in PM_{10} from Engelbrecht et al. (2002); values are used in RAINS. Unit has been converted from ton to tonne by applying a factor of 0.907.

Table 5.1 (continued): Compiled Emission Factors for Manufacturing and Industrial Processes (Metal Production and Pulp and Paper Industries)

Sub-sector/ Process	Emission Factor (kg/tonne product output)								
	SO_2	NO_x	CO	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC	CO_2[e]
Metal Production									
Pig iron production	3[a]	0.076[d]	1.34[c]	0.12[c]	0.05[i]	0.04[q,1]	0.019[q,1]	0[q,1]	1350
Aluminium production	15.1[e]	2.15[e]	135[d]	0.02[d]	47[b], 11.9[q,3]	8.46[q,2], 1.48[q,3]	0[q,2], 0.013[q,3]	0[q,2], 0.014[q,3]	1600
Copper smelting (primary)	2120[f]	-	-	0.03[d]	230[f]	193[f]	0	0	-
Lead smelting (primary)	320[g]	-	-	-	0.43[k], 15[q,4]	3.6[q,4]	0	0	520
Lead smelting (secondary)	40[h]	-	-	-	162[h], 15[q,4]	3.6[q,4]	0	0	520
Zinc smelting (primary)	1000[g]	-	-	-	293[j], 15[q,4]	3.6[q,4]	0	0	1720
Pulp and Paper Industries									
Kraft or Alkaline soda pulping	3.8[l]	1.5[m]	5.6[m]	3.7[m]	92[p], 103.6[q,4]	81[p], 41.4[q,4]	2.2[q,4]	11[q,4]	-
Acid sulphite pulping	30[m]	-	-	-	1.5[o]	1.3[o]	-	-	-
Neutral sulphite semi-chemical (NSSC)	-	0.5[n]	-	0.15[n]	-	-	-	-	-

Source/Remarks

[a] IPCC, 1996. Emission factors are provided in a range of 1-3 kg SO_2/tonne iron. 3 kg/t is used.
[b] USEPA, 1995. Value is applicable for non-controlled prebake cell process.
[c] IPCC, 1996. Values are applicable for blast furnace charging and pig iron tapping combined.
[d] IPCC, 1996.
[e] IPCC, 1996. Values are applicable for electrolysis and anode baking combined.
[f] USEPA, 1995. Value is applicable for multiple hearth roaster followed by reverberatory furnace and copper converter. Adjust SO_2 emission factor according to S recovery rate, for particulate matter assume 20-80% efficiency for ESP.
[g] Kato and Akimoto, 1992. Values are applicable for uncontrolled.
[h] USEPA, 1995. Those presented are uncontrolled for reverberatory smelting, if PM_{10} and $PM_{2.5}$ are controlled, assume 99% efficiency.
[i] EMEP/CORINAIR, 2000. For blast furnace charging, dust emission factor is 0.02 kg/t, pig iron tapping is 0.03 kg/t (un controlled) and for fabric filters use, the EF is 0.0128 kg/t.
[j] USEPA, 1995. Uncontrolled PM emission factor for multiple hearth roaster and sinter plant (assume zinc=60% of zinc ore concentrate).
[k] USEPA, 1995. Uncontrolled EF's for primary lead blast furnace.
[l] USEPA, 1995. Uncontrolled EF's for kraft pulp, assume that alkaline soda has same EF.
[m] IPCC, 1996. Uncontrolled emission factor.
[n] Stockton and Steling, 1987. Uncontrolled emission factor.
[o] USEPA, 1995. Uncontrolled emission factor for sodium carbonate scrubber recovery system assuming PM_{10} is 0.75 of TSP and $PM_{2.5}$ is 0.67 of TSP emission.
[p] USEPA, 199). Uncontrolled emission factor for Kraft pulp. If PM emission control is applied, use EF=1 for PM_{10} and 0.8 for $PM_{2.5}$. Assume alkaline soda pulping has same emission factor.
[q] Kupiainen and Klimont, 2004, all $PM_{2.5}$ EFs refer to PM_1 while PM_{10} EFs refer to TSP; [q,1]Applicable for pig iron production ; [q,2] Applicable for primary aluminium production, where emission factor for $PM_{2.5}$ (PM_1) is based on US EPA (1998) for prebake cells (see Klimont et al., 2002); [q,3] Secondary aluminium production; [q,4] other non-ferrous metal production; [q,4] applicable for kraft pulping (sulfate method), units are expressed in kg/tonne of air dried pulp.
- not available.

Table 5.1 (continued): Compiled Emission Factors for Manufacturing and Industrial Process Emissions (Chemical Industry)

Sub-sector/ Process	Emission Factor (kg/tonne product output)											
	SO_2	NO_x	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CO_2[k]	CH_4	N_2O[k]
Ammonia	0.022[i], 0.03[a]	2.7[f]	7.9[a]	4.7[b]	2.1[a]	0.072[f]	-	-	-	2104[k,2]	-	-
Nitric acid	-	12[c], 22[i]	-	-	0.01[d]	-	-	-	-	-	-	2-9[k,2]
Adipic acid	-	8.1[a]	34.4[a], 58[i]	9[a], 20[i]	-	0.5[a]	-	-	-	-	-	300[k,3]
Carbon black	3.1[e]	0.28[e], 0.4[i]	10[e]	40[i], 75[e]	-	6.56[a]	1.2[l]	1.2[l]	0[l]	2620[k,5]	-	-
Urea	-	-	-	-	11.8[f]	0.71[f]	-	-	-	2-7	-	-
Ammonium nitrate	-	-	-	-	29 – 63[g]	4.7-9.0[g]	-	-	-	-	-	-
Ammonium phosphate	0.04[h]	-	-	-	0.07[h]	0.15[i], 0.34[h]	-	-	-	-	-	-
Sulfuric acid	0[i], 48[i]	-	-	-	-	-	-	-	-	-	-	-
Titanium dioxide	14.6[e]	-	-	-	-	-	-	-	-	1430[k,4]	-	-

Source/Remarks

[a] USEPA, 1995. Values are applicable for uncontrolled process.

[b] USEPA, 1995. Expressed in kg total organic/tonne ammonia.

[c] IPCC, 1996. Factors range from 0.1-1.0 kg NOx/tonne nitric acid for the direct strong acid process to 10-20 NOx/tonne for the low pressure process. IPCC (1996) suggests a default of 12.0 kg NOx/tonne nitric acid where process details are not known. Higher range is provided by Economopoulos (1993), applicable for uncontrolled weak acid tail gas.

[d] EMEP/CORINAIR, 1996.

[e] IPCC, 1996. For NMVOC and NOx from black carbon, higher and lower ranges are provided by Economopoulos (1993) which are based on uncontrolled oil furnace process.

[f] USEPA, 1995 Value assumes use of fluidized bed prilling and wet scrubber control.

[g] USEPA, 1995. Values are provided in range for uncontrolled emission factors assuming use of high density prill towers for fertilizer.

[h] USEPA, 1995. Values are average controlled emission factors. For PM_{10} from ammonium phosphates, lower range is provided by Economopoulos (1993).

[i] Economopoulos, 1993. For SO_2 from ammonia, lower range (0.022) is provided by Economopoulos (1993) applicable for de-sulfurized natural gas feedstock. For CO and NMVOC from adipic acid, higher ranges are provided by Economopoulos (1993) which may come from Cyclohexane oxidation.

[j] USEPA, 1995. Values are provided in range of 0 - 48 kg SO_2/tonne sulfuric acid depending on SO_2 to SO_3 conversion efficiency (single absorption plant : 95-98%). Assume 17 kg/tonne for single contact process and 3.4 kg/tonne fofr double contact process.

[k] IPCC, 2006. [k,1] Derived from European average values for specific energy consumption (mix of modern and older plants), average value – natural gas; [k,2] Values vary according to the process/control device involved, lower value refers to plants with NSCR (all processes), while upper value refers to high pressure plants, [k,3] Nitric acid oxidation process; [k,4] For synthetic rutile; [k,5] Furnace Black Process for total feedstock.

[l] Kupiainen and Klimont, 2004. It is assumed that the submicron fraction is composed totally of BC.

- not available.

Table 5.1 (continued): Compiled Emission Factors for Manufacturing and Industrial Process Emissions (Food and Beverage Industries)

Sub-sector/Process	Emission Factor of NMVOC[a]
Food and Beverage	
Alcoholic Beverage (kg/hectolitre)	
Beer	0.035
Red wine	0.08
White wine	0.035
Wine (unspecified)	0.08 - 0.35
Malt whiskey	15
Grain whiskey	7.5
Brandy	3.5
Other spirits (unspecified)	15
Food Production (kg/tonne)	
Meat, fish and poultry (cooked only)	0.18 - 0.3
Sugar	10
Margarines and solid cooking fats	10
Cakes, biscuits and breakfast cereals	1
Bread	4.5
Animal feed	1
Coffee roasting	0.55

Source/Remarks
[a] EMEP/CORINAIR, 2004. Most values are applicable for uncontrolled processes. For food production, a control rate is assumed at 90%.

5.6 SUMMARY

Table 5.2 summarizes the procedure for calculating emissions from manufacturing and industrial process sector.

Table 5.2: Summary of Calculation Procedure for Emissions from the Manufacturing and Industrial Process Sector

Step	Calculation Procedure
1	**Calculating Emissions from Each Sub-sector:** • Obtain data on annual production output per sub-sector (tonne/yr) from related sources. • Choose EFs from Table 5.1 for each type of pollutant and sub- sector. • Calculate emissions from each sub-sector by using eq 5.1. • Sum up all emissions.
2	**Spatial Distribution:** • Obtain industrial output data for each province/district. • Surrogate (proxy) factor is developed by calculating the ratio of industrial output data per province/district in relation to national industrial output data. • Distribute total national emissions by using this ratio.
3	**Temporal Distribution:** • Determine if the process to be considered is continuous or intermittent. • For sources included in a continuous process, operation time data are used to surrogate the emissions temporally. • For sources included in an intermittent process, production rate, where available, is used.

CHAPTER 6

CROP RESIDUE OPEN BURNING

6.1 OVERVIEW

Post harvest field burning is a common practice in many countries, particularly in developing countries that have an agriculture-based economy with simple production technologies. Large quantities of crop residues are produced annually and are burned openly in the field. This activity can release emissions that are directly related to ABCs, such as particulate matter (PM_{10}, $PM_{2.5}$), particulate BC, OC and gaseous emissions (CO, CO_2, NO_x, NMVOC, CH_4, SO_2 and NH_3).

To prevent double counting, residue burning is classified under two types, on-site and off-site. This manual defines crop residue open burning as any deliberate burning of various types of crop residues, that occur on-site or in an open field. Off-site burning (biofuel combustion) of some crop residues removed from the fields and burned as a source of energy is excluded because this is already covered in other sectors (emissions from power generation, industry and residential sectors) in this manual.

6.2 EMISSION ESTIMATION METHOD

Emission inventory is developed based on a compilation of a wide variety of data taken from research publications. The bottom up approach is adopted in this manual. Emission is estimated based on data on the type of crops and burning activity in specific countries/regions. It is noted that estimates of burning activities tend to vary widely in various publication sources. Thus, comprehensive data have to be compiled from several sources that include peer-reviewed literatures, FAO statistics, national communications to IPCC, and government and nongovernmental sources in individual countries.

In general, agricultural emissions are calculated by multiplying activity rate by emission factor. Activity rate requires information on crop production, amount of residue produced per unit of crop production, amount of residues burned, burned area, and emission factors. The emission estimation can be expressed in the following equation:

$$Em_{i,j} = \sum_j M_j \times EF_{i,j} \qquad \text{(eq. 6.1)}$$

Where,

i, j = Pollutant i and crop type j

$Em_{i,j}$ = Emission of pollutant i from crop type j

M_j = Amount of burned biomass from crop type j (kg/yr)

$EF_{i,j}$ = Emission factor of pollutant i from crop type j (g/kg of dry matter).

Normally, data on the actual amount of biomass burned (M_j), if available, can be used directly to calculate emissions. However, only data on crop production or crop cultivation area are commonly provided in current literature. The approaches presented below (Streets et al., 2003) can be used to convert these data to the amount of burned biomass (M_j).

Approach 1: Estimation of the amount of burned biomass/crop residues based on total crop

production data.

$$M_j = P_j \times S_j \times D_j \times B_j \times \eta_j \qquad \text{(eq. 6.2)}$$

Where,

P_j = Crop production (kg/yr)
S_j = Crop-specific residue-to-production ratio (fraction)
D_j = Dry matter-to-crop residue ratio (fraction)
B_j = Fraction of dry matter residue, that are urned in the field
η_j = Crop-specific burn efficiency ratio (fraction oxidized during combustion).

Approach 2: Estimation of amount of burned biomass/crop residues based on harvested area data.

$$M_j = Y_j \times S_j \times D_j \times B_j \times A_j \times \eta_j \qquad \text{(eq. 6.3)}$$

Where,

Y_j = Annual yield (kg/ha)
A_j = Harvested area of crop (ha/yr).

6.3 DATA ON ACTIVITY LEVELS

In the first approach to estimate the amount of biomass burned (M_j), data on national crop production are provided by FAOSTAT (http://faostat.fao.org/site/567/DesktopDefault.aspx). It also provides data on total area harvested (ha) and yield per hectare (kg/ha) for various commodities. Various research publications provide typical values for crop-specific production-to-residue ratio, dry matter-to-crop ratio, fraction of dry matter residues burned in the field, and crop-specific burn efficiency ratio, such as those presented in Streets et al. (2003) and the Global Atmospheric Pollution Forum (GAPF) Air Pollutant Emissions Inventory Manual. Values for major crops are presented in Table 6.1. However, country-specific values should be used, if available.

In the second approach to estimate the amount of biomass burned (M_j), data on cultivated area can be obtained from country-specific sources, such as national statistics yearbooks or state of the environment (SoE) reports. Data on harvested areas burned may also be directly obtained from relevant institutions. The term 'harvested area' differs in meaning from 'cultivated area'. The former takes into account the cycle of crop harvest in a year. If crops are harvested two times yearly, the harvested area in a year will be counted twice from its cultivated area. Caution should be observed when using literature data, including those provided in Table 6.1. Data on country-specific yield per hectare typical for each type of crop can be obtained from the FAOSTAT (http://faostat.fao.org/site/567/DesktopDefault.aspx). Use of suitable factors obtained from local agricultural research stations and/or rural colleges and universities is also suggested.

Table 6.1: Compiled Parameters for Estimating Amount of Crop Residues Burned (M)

Parameter	Rice	Maize & Sorghum	Soybean	Potato	Jute & Cotton	Groundnut & Mung bean	Sugarcane	Root/Tubers (cassava)
Available data								
Residue to crop ratio (S)	1.19[a] 1.76[c] 1.2[e]	0.19[a] 2.0[c] 1.85[e] 1.4[f]	1.5[b] 0.21[c] 2.1[f]	0.5[b]	3.0[b] 2.1[f]	1.5[b] 2.1[f]	0.24[a] 0.3[c] 0.5[e] 1.6[f]	0.12[a] 0.2[c]
Dry-matter-to-crop residue ratio (D)	0.85[c]	0.4[c]	0.71[c]	0.45[g]	0.8[d]	0.8[d]	0.71[c]	0.71[c]
Fraction burned in field (B)	0.48[h] 0.90[i] 0.30[j]	0.61[j]	0.76[k]	≤ 1.0	1.0[k]	≤ 1.0	0.55[j]	0.41[j]
Burn efficiency ratio (η)	0.89[c] 0.85[e]	0.92[c] 0.35[e]	0.68[c]	0.9[g]	0.9[g]	0.9[g]	0.68[c] 0.35[e]	0.68[c]

Remarks:
[a] DEDE, 2007. Biomass potential for energy production in Thailand.
[b] Yang et al., 2008. Primary data on crop residue burning in China.
[c] Street et al., 2003. Data were likely obtained from various area sources.
[d] GAPF EI Manual, 2007. Primary data for India.
[e] Penner et al., 1996. Data selected for developing countries estimated from various literatures.
[f] Jingura and Matengaifa, 2008. Primary data for Zimbabwe .
[g] IPCC, 1996. Default value from IPCC EI manual.
[h] DEDE, 2003. Non-exploited rice straw in Thailand.
[i] Tipayarom and Kim Oanh, 2004. Survey data on rice straw burning in Central Thailand.
[j] EFE, 2009. Non-exploited crop residues in Thailand in 2007.
[k] Sajjakulnukit et al., 2005. Surplus availability of crop residues in Thailand.

6.4 EMISSION FACTORS

For biomass burning, normally an emission factor is expressed in grams of released pollutant per kilogram of burned dry matter. Area- or region-specific emission factors for specific types of crops are not widely available. Some publications provide emission factors for crop residues only without specific information on types of crops. Compiled values of emission factors and their reference sources are presented in Table 6.2.

Table 6.2: Compiled Emission Factors of Pollutants from Crop Residue Burning

Pollutant	Crop Residue Type (g/kg dry mass of residue)									
	Rice	Wheat	Soybean	Maize	Potatoes	Jute	Oil crops	Groundnut	Sugarcane	Root/tubers
PM	13[a] 6.28[i]	4[c] 8.75[i]	13[a]	13[a] 4.92[i]	13[a]	13[a]	13[a]	13[a]	4[c]	13[a]
$PM_{2.5}$	3.2[e], 8.3[k]	3.7[c]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.7[c]	3.9[a]
PM_{10}	3.5[e], 9.1[k]	3.9[c]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.9[a]	3.9[c]	3.9[c]
SO_2	0.4[a] 0.18[i]	0.4[a] 0.04[i]	0.4[a]	0.4[a] 0.04[i]	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]
CO_2	1216[d] 1674[i] 791.3[j], 1200[k]	1613[a] 1378[i] 1558[j]	1613[a]	1613[a] 1836[i] 1262[j]	1613[a]	1613[a]	1613[a]	1613[a]	1613[a]	1613[a]
CO	180[d] 67.98[i] 64.2[j], 93[k]	28[b] 57.78[i] 141.2[j]	36.4[c]	36.4[c] 86.73[i] 114.7[j]	36.4[c]	36.4[c]	36.4[c]	36.4[c]	34.6[c]	34.6[c]
NO_x	0.62[d] 3.43[i] 1.81[j]	1.7[b] 2.28[i] 1.12[j]	1.7[b]	1.7[b] 3.05[i] 1.28[j]	1.7[b]	1.7[b]	1.7[b]	1.7[b]	2.6[c]	1.7[b]
NH_3	4.1[d]	0.95[c]	1.3[a]	1.3[a]	1.3[a]	1.3[a]	1.3[a]	1.3[a]	0.95[c]	1.3[a]
CH_4	9.6[d]	3.55[b]	2.7[a]	2.7[a]	2.7[a]	2.7[a]	2.7[a]	2.7[a]	0.4[c]	2.7[a]
NMVOC	7[a]	2.16[c]	7[a]	7[a]	7[a]	7[a]	7[a]	7[a]	2.16[c]	7[a]
BC	0.73[f], 0.69[a], 0.49[i],	0.73[f], 0.52[c], 0.42[i]	0.73[f], 0.69[a],	0.73[f], 0.69[a],, 0.35[g] 0.87[i]	0.73[f], 0.69[a],	0.73[f], 0.69[a],		0.73[f], 0.69[a],	0.73[f], 0.69[a],	0.73[f], 0.69[a],
OC	0.7[h], 2.8[k], 3.3[a] 2.01[i]	0.7[h], 1.26[c] 3.46[i]	0.7[h], 3.3[a]	0.7[h], 3.3[a], 2.04[i]	0.7[h], 3.3[a]	0.7[h], 3.3[a]	0.7[h], 3.3[a]	0.7[h], 3.3[a]	0.7[h], 3.3[a]	0.7[h], 3.3[a]

Remarks:
[a] Andreae and Merlet, 2001. Values are best guess and are applicable for any combination of crop residue. Those presented are average values.
[b] Sahai et al., 2007. Values are suitable for the burning of wheat straw residue and mostly applicable in India.
[c] Dennis et al., 2002. Values are specific for corn, sugarcane, and wheat, while the rest is assumed to be similar to sugar cane. Units are converted from lb/tonne to g/kg. The emission factor study was developed in the USA.
[d] Christian et al., 2003. Values are taken from the Open-path Fourier Transform Infrared Spectrometry (OP-FTIR). Most of the values are applicable for rice straw in Indonesia.
[e] Jenkins et al., 1996. Values are applicable for rice straw open field burning which has been generated in wind tunnel experiments.
[f] Streets et al. , 2001.
[g] Li et al., 2007. EFs for the burning of wheat straw and corn stover in China
[h] Reddy and Venkataraman, 2002a. OM/OC ratio assumed as 1.3.
[i] Cao et al., 2008. Average emission factors from crop residues, such as wheat, rice, and corn, were carried out in a burning tower in China.
[j] Zhang et al., 2008. Laboratory study of crop residue combustion of wheat, rice and corn in China.
[k] Kim Oanh et al., 2010. Values are taken from field burning of rice straw in Thailand.

6.5 TEMPORAL AND SPATIAL DISTRIBUTION

Temporal and spatial distribution of crop residue burning is strongly correlated with agricultural practices, such as harvesting cycles, types of crops and climate conditions (dry or wet seasons). These factors correspond with the region's classification. According to IPCC (1996), the world's regions are grouped into eight: North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Near East and the Mediterranean, and Asia.

Where data are available, temporal and spatial distribution can be calculated based on the quantity of crop production, such as monthly and sub-national basis. However, using this approach to estimate crop residue burning could be influenced by the economic situation of farmers. Poor farmers would save crop residues as much as possible for use as livestock feed or for other purposes. Relatively better off farmers are not necessarily interested in this and could just burn the residues. There is a need to specify the fraction of crop residues burned based on crop production. Crop residue field burning tends to increase as living conditions among the rural population are improved.

In addition, satellite information plays an important role in detecting and analyzing open fire trends. Interest in using satellite remote sensing to monitor fires began more than two decades ago. Later, several methods were developed using data from the Advanced Very High Resolution Radiometer (AVHRR) (Stroppiana et al., 2000; Streets et al., 2003), Along Track Scanning Radiometer (ATSR) (Arino et al., 2001; Kasischke et al., 2003), and the Moderate Resolution Imaging Spectrometer (MODIS) (Justice et al., 2002; Roy et al., 2007) to analyze global and temporal distribution of biomass open burning. However, there have been very few studies conducted to calibrate those satellite fire products through direct comparison to the burned areas (Kasiscke et al., 2003).

More importantly, crop residue field burning fire is short-lived and sporadic in nature; hence it presents a major challenge to satellite monitoring as satellites pass specific locations only at certain time in a day. For example, rice straw field burning in Thailand normally covers small areas of a few thousand square meters and happens over short periods (around one hour for a rice paddy). Hence, not all fires can be detected by MODIS satellite which normally passes the Southeast Asia region twice a day. Thus, using hotspot counts poses high uncertainty and can only provide preliminary information on burning activities/intensities. Also, given the coarse scale of MODIS, the burned area is likely to be overestimated, if estimation is based solely on fire counts. Furthermore, fire counts alone cannot provide information on crop type (j), if there is no information on land use and available crop types. Besides, satellite observations have inherent uncertainties related to meteorology and surface factors that should be taken into account.

6.5.1 TEMPORAL EMISSION DISTRIBUTION

a. Calculation of monthly emission

To calculate temporal variation, total annual emission should be disaggregated monthly, daily and hourly. As mentioned earlier, two approaches are used to temporally allocate emissions, depending on the availability of data. These are presented below.

Approach 1: Temporal distribution based on monthly crop production data.

A survey of crop residue field burning practices is conducted. Total annual emission can be estimated based on crop production data and the fraction of burned residues. Monthly emission is calculated as follows:

$$EM_{j,n} = Em_A \times FM_{j,n} \qquad \text{(eq. 6.4)}$$

where,

n = Month (1-12)

$EM_{j,n}$ = Emission from burning crop residue type j in a month n

Em_A = Annual emission rate

$FM_{j,n}$ = Monthly fraction (fraction of crop residue type j burned in month n).

This is calculated as follows:

$$FM_{j,n} = \frac{P_{j,n}}{TP_{j,year}} \qquad \text{(eq. 6.5)}$$

where,

$P_{j,n}$ = Production of crop type j in month n

$TP_{j,year}$ = Production of crop type j during a year (12 months)

Approach 2: Temporal distribution based on satellite data

When monthly data on crop production are not available, the hotspot counts from satellite images can be used. However, a large uncertainty is involved in this approach, as mentioned above. As a way of illustration, calculation can be made using eq. 6.1. The fraction of biomass type j burned in month n is calculated as follows ($FM_{j,n}$):

$$FM_{j,n} = \frac{HS_{j,n}}{THS_{j,year}} \qquad \text{(eq. 6.6)}$$

where,

$HS_{j,n}$ = Hotspots counted for burning specific crop residue type j in month n

$THS_{j,year}$ = Total hotspots counted for burning specific crop residue type j in a year (12 months).

When this approach is used, it is important to overlay daily satellite hotspots maps with land use maps of the concerned region in order to determine the type of crop(s) burned in specific days in a month. If several crop residue types are burned in the same area, it is not possible to separate crop types by using satellite hotspot maps only.

b. Calculation of daily emission

In principle, daily emission can be derived from hotspot counts using the following equation.

$$ED_{j,n,d} = EM_{j,n} \times FD_{j,d} \qquad \text{(eq. 6.7)}$$

where,
$ED_{j,n,d}$ = Emission from burning crop residue type j in day d and month n
$EM_{j,n}$ = *Emission from burning crop residue type j in month n*
$FD_{j,d}$ = Daily fraction (fraction of crop residue type j burned in day d). This is calculated as follows:

$$FD_{j,d} = \frac{HS_{j,d}}{THS_{j,n}} \qquad \text{(eq. 6.8)}$$

where,
$HS_{j,d}$ = Hotspots counted for burning of specific crop residue type j in day d
$THS_{j,n}$ = Total hotspots counted for burning of specific crop residue type j in month n.

Due to unavailability of 24-hour hotspot counts, hourly emission rates cannot be estimated based on hotspot counts alone. Local knowledge and additional monitoring data are required to estimate hourly emission rates.

Thus, seasonal/monthly data can be generated for large domains using hotspot counts with caution. For urban scale and smaller domains, daily and hourly emission rates can be incorporated, mainly for modeling purposes. However, a detailed survey should be conducted for this purpose.

Daily data on fire counts can be analyzed in order to produce temporal patterns of monthly, seasonal and annual variations typical for each region. Active fire counts data are available at:

-   AVHRR, World Fire Web, http://ptah.gvm.sai.jrc.it/wfw/
-   ATSR, http://dup.esrin.esa.int/wfa/
-   MODIS, http://modis-fire.umd.edu/Burned_Area_Products.html & http://www.geoinfo.ait.ac.th/

Secondly, not all satellite-based hotspots may be actual fire or burning. Depending on the availability of computer facility, accessibility to these web-based data can be a limitation in some cases.

6.5.2 SPATIAL EMISSION DISTRIBUTION

Similar to temporal emission distribution, there are two approaches to allocate spatial emissions, depending on availability of data.

Approach 1: Spatial distribution based on sub-national crop production data.

If crop specific production data are available, calculation of spatial distribution at the sub-national level can be done as follows:

$$ES_{j,m} = Em_A \times FS_{j,m} \qquad \text{(eq. 6.9)}$$

where,

$ES_{j,m}$ = Emission from burning of crop residue type j at sub-national level m
Em_A = Annual emission rate
$FS_{j,m}$ = Spatial fraction (fraction of crop residue type j burned at sub-national level m).
This is calculated as follows:

$$FS_{j,m} = \frac{P_{j,m}}{TP_{j,country}} \qquad \text{(eq. 6.10)}$$

where,

$P_{j,m}$ = Production of crop type j at sub-national level m
$TP_{j,country}$ = Production of crop type j in the whole country

Approach 2: Spatial distribution based on satellite data.

The spatial distribution method derived from fire counts data is adopted from Streets et al. (2003). The factor for allocating the emission into each grid cell is expressed in the following equation:

$$FC_{j,p,m} = \sum_{p} LC_{j,p,m} \times FC_{p,m} \qquad \text{(eq. 6.11)}$$

where,

p = Number of grids in a sub-nation level m
$FC_{j,p,m}$ = Sum of fire counts of burning type j (crop type) within grid p at sub-national level m
$LC_{j,p,m}$ = Area fraction of crop j within grid p at sub-national level m
$FC_{p,m}$ = Fire counts in grid p at sub-national level m.

In summary, it is important to highlight the following issues when using satellite fire products:

1. Not all hotspot identified in satellite data are showing fire occurrence.
2. To define the burning type corresponding to the hotspots, overlay with a land cover map is necessary.
3. Clouds interfere with satellite hotspot data. Hence, fires below clouds cannot be detected in optical satellite data. It is difficult to estimate and the average value may be used as desirable in such situation. There are times when observed data are not available because of problems with the satellite on-board system.
4. Non-biomass burning hotspots (for example, oil/gas, and flares) which can be detected by satellites should be removed by analyzing ground information.
5. Satellite data over the Asian region are normally available for a short period within a day (i.e., MODIS, twice per day), while crop residue burning normally lasts for an hour or less. Thus, there is a high chance that agro-residue open burning is not detected by MODIS.

The application of satellite data to monitor crop residue burning, as presented above, suggests that hotspot counts can be used to provide preliminary information. Detailed analysis of local agricultural practices and land use pattern should be made when estimating the spatial and temporal distribution of emissions. Of importance in particular is whether or not the common burning hours of agro-residues within a day coincides with the satellite passing over the region.

6.6 SUMMARY

The calculation procedure for emissions from agricultural residue burning is summarized in Table 6.3.

Table 6.3: Summary of Calculation Procedure for Emissions from Crop Residue Burning

Step	Calculation Procedure
1	**Calculate Amount of Residue** • Specify important types of crops in individual countries. • Obtain annual production data (in metric tonnes) from FAOSTAT which is available for 1961-present. • Take value of S from Table 6.1 for each type of crop. • Multiply annual production by S to calculate amount of residue for each type of crop.
2	**Calculate Amount of Dry Residue** • Take value of D from Table 6.1 for each type of crop. • Multiply amount of residue (obtained from Step 1) by D to obtain amount of dry residue matter.
3	**Estimate Total Amount of Residue Burned** • Take values of B and η from Table 6.1 for each type of crop. • Multiply amount of dry residual matter (obtained in Step 2) with B and η to obtain total amount of residue burned.

Step	Calculation Procedure
4	**Estimate Pollutant Emissions** • Take values of emission factors for each pollutant for each type of crop from Table 6.2. • Emission factor (*EF*) is in g/kg of dry matter burned. Therefore, the total amount of residue burned needs to be converted to kg instead of metric tonnes. • Multiply the *EF* by the amount of residue burned to obtain the emission in g/yr • Convert the unit into teragrams (Tg) by multiplying it by 10^{-12}
5	**Temporal Distribution of Emission** **Approach 1** • Obtain monthly specific crop production data from government sources. • Calculate monthly factor ($FM_{j,n}$) by using eq. 6.5. • Calculate monthly emission by using eq. 6.4. **Approach 2** • Use land use map and information on agricultural practices in the concerned area. • Obtain daily or annual hotspot counts (as appropriate) over the area from mentioned data sources. • Calculate monthly factor ($FM_{j,n}$) and daily factor ($FD_{i,d}$) by using eq. 6.6 and 6.8. • Calculate monthly and daily emissions by using eq. 6.4 and 6.7.
6	**Spatial Distribution of Emission** **Approach 1** • Obtain specific sub-national crop production data from government sources. • Calculate sub-national factor ($FS_{j,m}$) by using eq. 6.10. • Calculate sub-national level emission by using eq. 6.9. **Approach 2** • Use land use map and information on agricultural practices in the concerned area. • Allocate grids within the study area. • Obtain hotspot count in each grid (annual, monthly, and so on). • Determine fraction of area of agricultural land cover in each grid. • Calculate emissions in each grid by using eq. 6.11.

7.1 OVERVIEW

Forest fires include all on-site burning of forest vegetation as a result of a natural occurrence or due to human-induced burning to clear land or to serve other purposes. This section covers savanna/grassland fires arising from prescribed burning, natural fires and grassland conversion. Forests and savannas have different biomass/vegetation composition and structure. These differ according to forest type and affect the level or intensity of burning.

Forest fires may release emissions that are directly related to ABCs, such as particulate matter (PM_{10}, $PM_{2.5}$), particulate BC, OC and gaseous emissions (CO, CO_2, nitrogen oxides, NMVOC, CH_4, SO_2 and NH_3).

It should be noted that only on-site burning is considered . Forest products that have been removed and used as fuelwood are excluded. Biogenic emissions that are naturally emitted from live vegetation area also excluded.

7.2 EMISSION ESTIMATION METHOD

Particulate matter and trace gas emissions from forest fires can be estimated through a series of simple calculations using locally available data. Estimation depends on best estimated data available for a given region. Hao and Liu (1994) provides a method to estimate forest fire emissions, as shown below. Eq. 7.1 is applied to estimate the emission of each pollutant,

$$Em_{i,j} = \sum_{j} M_j \times EF_{i,j} \times 10^{-3} \qquad \text{(eq. 7.1)}$$

where,
$Em_{i,j}$ = Emission of pollutant i from land cover type j (tonne/yr)
M_j = Amount of burned biomass on land cover type j (tonne/yr)
$EF_{i,j}$ = Emission factor of pollutant i from land cover type j (g/kg of dry matter).

First, the quantity of biomass actually burned each year from savanna and forest fires is calculated by multiplying the area of savanna/forest burned by the fraction of total area burned, above ground biomass densities, and burning efficiency. This is expressed in the following equation.

$$M_j = A_j \times f_j \times \rho_j \times \eta_j \qquad \text{(eq. 7.2)}$$

where,
A_j = Area of land cover type j (ha)
f_j = Fraction of total area burned annually of land cover type j
ρ_j = Dry matter density (tonne/ha)
η_j = Burning efficiency (oxidized in the combustion).

Under normal open burning condition, not all biomass subjected to burning is actually burned. The burning efficiency (η_j) is applied to derive the amount of dry matter that is actually oxidized during combustion. Generally, in the case of savanna fires, this value ranges between 0.80 and 0.85 of biomass. The value may be higher in very dry regions. For forest fires, a lower η_j of 0.6 is considered. However for some conditions, the values of A_j and f_j can be directly substituted with the actual burned area (A_{ba}), if data are available. The mass of dry matter burned can be calculated as:

$$M_j = A_{ba} \times \rho_j \times \eta_j \qquad \text{(eq. 7.3)}$$

where,
A_{ba} = Actual burned area (ha/yr).

Several methods are discussed to determine A_{ba} in the activity levels section.

7.3 DATA ON ACTIVITY LEVELS

At present, published data on burned savannas and forest areas are not widely available. Data on burned areas are available in only a few countries in Asia. Some possible approaches to estimate burned areas are presented here. It should be noted that data on burned areas are believed to be highly uncertain as several factors influence the burning process.

7.3.1 ACTUAL BURNED AREA ESTIMATION

The proposed methods for estimating burned area are as follows:

1. IPCC Method

Following the IPCC method, the simplest method to calculate the area burned is by using fraction of total area burned (f_j) as default factor. This method poses the highest level of uncertainty. In this method, the total area of land cover type (A_j) is needed. This is commonly available in many countries. Largest uncertainty is f_j, for which default values from the IPCC are adopted and is only available for savanna/grassland (f_j ranges between 0.05 and 0.7). The calculation for the actual area burned is expressed as:

$$A_{ba} = A_j \times f_j \qquad \text{(eq. 7.4)}$$

where,
A_{ba} = Actual burned area (ha)
A_j = Area of land cover type j (ha)
f_j = Fraction of total area burned annually for land cover type j.

2. Ground/Field Level Data

This is a simple method that uses ground monitoring data that are provided by local forestry agencies. While provincial or national data are available on a monthly basis in some countries, many countries do not have such data or, if available, these maybe of a coarse scale. Also, the data provided may only be for forests or combined for savanna/grassland and crop residue burning. This should be clarified with the data provider in each country.

3. Remote Sensing-based Active Fire Counts (Hotspot Pixel)

Some coarse resolution satellite instruments (for example, SPOT-VEGETATION, AVHRR, MODIS, and ERS-ATSR) provide daily global observations of fire activity, such as active fire hotspots. Unlike burned area data, long-term observations of active fire hotspots made with space-borne sensors are readily available. In this manual, the approach is to assume that the burned area is proportional to simple counts of fire pixels, as reported by Giglio et al. (2006), that is:

$$A_{ba(p,t)} = \alpha \, Np_{(p,t)} \qquad\qquad \text{(eq. 7.5)}$$

where,

$A_{ba(p,t)}$ = Actual burned area within a particular region labeled by index p – a grid cell, t – during a fixed time period (ha).

$Np_{(p,t)}$ = Number of fire pixels observed within the same region and same time period.

α = A constant representing the effective burned area per fire pixel (ha/pixel).

This method requires long-term observation of active fire hotspots ($Np_{(p,t)}$) at the national level. Such active fire hotspots are accessible from data providers via the Internet (for example, http://maps.geog.umd.edu/firms/shapes.htm, http://www.geoinfo.ait.ac.th/modis/) These can be superimposed with the respective land cover of a country to identify the type of cover burned. Given the coarse resolution (1000 m x 1000 m) of MODIS products, there is a chance of overestimating the burned area as the complete pixel area may not burn in reality. Available information on actual area burned per pixel can be useful for relatively precise estimates of burned area. Table 7.1 presents area fraction burned per pixel in different regions.

Table 7.1: Average Value of α Representing the Effective Burned Area per Fire Pixel (km²/pixel)

Region	α (km²/pixel)[a]	Coefficient Correlation (r)[b]
Boreal North America	1.4	0.69
Temperate North America	0.84	0.94
Central America	0.43	0.73
NH South America	1	0.78
SH South America	0.29	0.35
Europe	3.1	0.91
Middle East	0.4	0.34
NH Africa	5.2	0.86
SH Africa	2.9	0.6
Boreal Asia	1.3	0.9
Central Asia	6.6	0.85
South Asia	2.9	0.75
Equatorial Asia	0.49	0.71
Australia	3.4	0.82

Source: Giglio et al. (2006)
[a] α is a constant representing the effective burned area per fire pixel. MODIS active fire observations (1 km²) were cali brated to burned area estimates derived from 500-m MODIS imagery for 14 different global regions. α values increased as cluster size increased.
[b] Correlation (r) between predicted (based on active fire counts) and observed burned area (based on 500-m burn scars) within each region.

4. Remote Sensing-based Burned Area Product

Processed and aggregated burned area products from remote sensing satellite observations are also available for use, such as MODIS 500 m x 500 m resolution, which has a relatively larger resolution compared with the previous method (Roy et al., 2008). In this method, the burned area can be estimated as:

$$A_{ba} = Np \times Rp \times 10^{-4}$$

(eq. 7.6)

where,
A_{ba} = Actual burned area (ha)
Np = Number of hotspot pixels of burned area product
Rp = Resolution of product (i.e. 500 x 500 m²)

This method poses some uncertainty as results could be overestimated since the actual burned area might be less than what is shown in the image resolution. However, if finer resolution of fire activity data is available, use of this method is recommended. To differentiate between each type of land cover (forest or savanna), hotspots can be superimposed with the land cover map. Figure 7.1 illustrates the methodology used in case studies in this manual.

```
┌──────────────────────────────────┐
│   Download monthly MODIS burned   │
│            area product           │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│  Extract the approximate Julian day of │
│  burning and their image coordinates  │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│   Image to geographical coordinates   │
│              conversion               │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│      Overlay with GIS land use map     │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│  Monthly annual burned area for each  │
│           type of land use            │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│     Burned area estimation algorithm    │
└──────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────┐
│    National annual burned area maps    │
└──────────────────────────────────┘
```
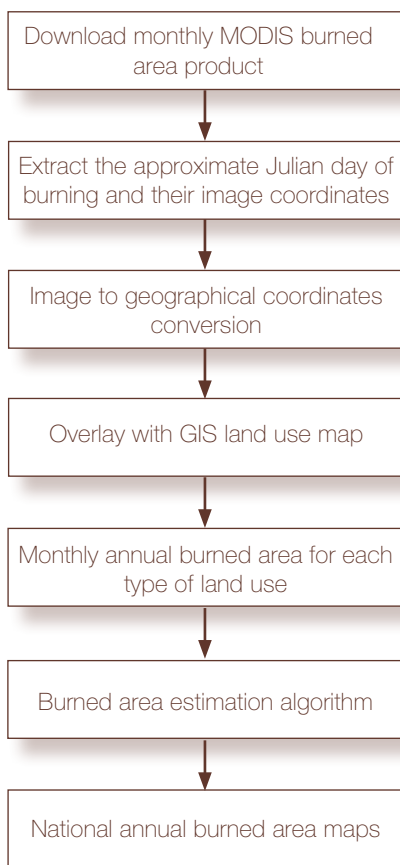
Figure 7.1: Steps in Estimation of Burned Area

7.3.2 OTHER ACTIVITY DATA

Savanna/Grassland Burning

Data for savanna/grassland area (ha) are available in the FAO Forest Resource Assessment 1990: Tropical Countries (FAO, 1993). Such data area available for 1980, 2000 and 2010 at http://www.fao.org/forestry/fra/24691/en/ The fraction of total savanna burned annually is also provided by IPCC (2006). This is presented in Table 7.2 and can be used in eq. 7.4 to estimate A_{ba}. The mass of dry matter burned (M_j) can be estimated by using eq.7.2. The compiled values of some components of the activity data are presented in Table 7.2.

Forest Fire

Country-wise forest area data are available in the State of the World Forest (FAO, 2003). Unlike savanna/grassland, there is no available information on region-specific forest burned area fraction (f_j), making the IPCC approach using eq. 7.4 less preferable.The mass of dry matter burned (M_j) can be derived from the area data by using eq. 7.2. Burning efficiency (η_j) and average above ground biomass estimates (ρ_j) are presented in Table 7.2.

Table 7.2: Default Values for Activity Data of Savanna/Forest Burning

No	Vegetation Type	Fraction of Total Area Burned Annually (f_j)[a]	Dry Matter Density (ρ_j) (ton/ha)[a]	Burning Efficiency (η_j)[c]
1	Primary tropical forest	-	84 – 160, 93.6[b]	0.5
2	Secondary tropical forest	-	8 - 46	0.5
3	Boreal forest	-	27 - 87	0.5
4	Other temperate forest	-	50, 169[b]	0.5
5	Shrub land	-	6 - 27	-
6	Savanna/grassland	0.05 - 0.7	2.1	0.6 - 0.85
7	Others (peatland, tundra)	-	10 - 41	-

Remarks:
[a] IPCC 2006. Values are taken from maximum and minimum values presented by sub-category.
[b] Prashad et al., 2001. Values for primary tropical forest represent tropical dry deciduous forest in India and values for other temperate forest represent Himalayan moist temperate forest type.
[c] Hoelzemann et al., 2004. Values are available for several types of ecosystem.
- : not available.

7.4 EMISSION FACTORS

Most of the emission factors for savanna and forest burning provided in this manual are taken from Andreae and Merlet (2001). These are presented in Table 7.3.

Table 7.3: Emission Factors of Savanna/Forest Burning

Pollutant	Savanna/Grassland (g/kg)[a]	Tropical Forest (g/kg)[a]	Extra Tropical Forest (g/kg)[a]
$PM_{2.5}$	5.4	9.1	13
PM	8.3	6.5-10.5	17.6
SO_2	0.35	0.57	1
CO_2	1613	1580	1569
CO	65	104	107
NO_x	5.98	2.45	4.6
NH_3	1.05	1.3	1.4
CH_4	2.3	6.8	4.7
NMVOC	3.4	8.1	5.7
BC	0.48	0.66	0.56
OC	3.4	5.2	9.15

Remarks:
[a] Andreae and Merlet. (2001).

7.5. TEMPORAL AND SPATIAL DISTRIBUTION
Temporal distribution

In general, forest fires last longer than crop residue burning, making the use of hotspot data suitable to aggregate emissions. To account for temporal variation, emissions should be aggregated as monthly emissions. The following approach to calculate emissions is proprosed .

a. Calculation of Monthly Emission

$$EM_{j,n} = Em_A \times FM_{j,n}$$ (eq. 7.7)

where,
n = Month (1-12)
$EM_{j,n}$ = Emission from burning of land cover type j in a month n
Em_A = Annual emission rate
$FM_{j,n}$ = Monthly fraction (fraction of land cover type j burned in month n).

The fraction of land cover type j burned in month n is calculated by using proxy factors for monthly ground monitoring of burned area or hotspots, as follows:

$$FM_{j,n} = \frac{HS_{j,n}}{THS_{j,year}} \qquad \text{(eq. 7.8)}$$

where,

$HS_{j,n}$ = Proxy factor of monthly ground monitoring of burned area/hotspots counted for respective biomass burning type j in month n

$THS_{j,year}$ = Total ground monitoring of burned area/hotspots counted for respective biomass burning type in a year

Monthly ground monitoring data of burned area can be obtained from national forestry agencies, depending on individual countries. In many countries such data are not commonly available. Daily data of fire counts can be analyzed to produce temporal patterns of monthly, seasonal and annual variations typical for each region. Internet sites that provide active fire counts data are as follows:

- AVHRR, World Fire Web, http://ptah.gvm.sai.jrc.it/wfw/

- ATSR, http://dup.esrin.esa.int/ionia/wfa/index.asp

- MODIS, http://modis-fire.umd.edu/MCD45A1.asp, http:///www.geoinfo.ait.ac.th/mod14/

Spatial distribution

The spatial distribution method derived from fire counts data is adopted from Streets et al. (2003). When using hotspots, land cover is superimposed to aggregate emissions from forest type or savanna/grassland. The factor for allocating emissions into each grid cell is expressed in the following equation.

$$FC_{j,p,m} = \sum_{p} LC_{j,p,m} FC_{p,m} \qquad \text{(eq. 7.9)}$$

where,

p = Number of grids at sub-nation level m
$FC_{j,p,m}$ = Sum of fire counts of burning type j (forest type, grassland) within grid p at sub-national level m
$LC_{j,p,m}$ = Area fraction of burning type j within grid p at sub-national level m
$FC_{p,m}$ = Fire counts in grid p at sub-national level m

7.6 SUMMARY

The procedure for calculating emissions from savanna and forest fires is described in Table 7.4.

Table 7.4: Summary of Calculation Procedure for Forest Fire Emissions

Step	Calculation Procedure
1	**Estimate Total Biomass** • For savanna fire emissions, obtain available data on total area of savanna, multiply by f_j and η_j and ρ_j from Table 7.2, or estimate area burned by using ground monitoring or satellite data. Then apply eq. 7.2 to estimate total biomass burned. • For forest fire emissions, obtain area of forest burned by using ground monitoring data or satellite products; multiply by ρ_j taken from Table 7.2 for the selected region. Then apply eq. 7.2 to estimate total biomass burned. • Use of country-/region-specific data, if available, is encouraged.
2	**Estimate Emissions** • Select the emission factor for specific type of vegetation and pollutant from Table 7.3. • Multiply the total biomass actually burned (obtained in step 1) by the emission factor, to obtain the emission in tonne/year.
3	**Temporal Distribution** • Obtain the monthly hotspot count data. • Estimate the monthly factor ($FM_{j,n}$) from accumulated hotspot counts in a year (refer to eq 7.8). • Calculate monthly emissions (refer to eq. 7.7).
4	**Spatial Distribution of Emission** • Obtain hotspot counts for each sub-national level (annual or monthly). • Determine fraction of forest land cover for each sub-national level. • For finer resolution assigned to province/grid, calculate emissions in each province/grid (refer to eq. 7.9).

CHAPTER 8
MUNICIPAL SOLID WASTE (MSW) OPEN BURNING

8.1 OVERVIEW

Municipal solid waste (MSW) open burning practices are common, especially in developing countries with inadequate system for solid waste management (SWM). Open burning can be done in open drums or baskets, fields and yards, solid waste disposal facilities (SWDFs), and pits. Waste incineration, a part of the solid waste management treatment process, is excluded in this chapter as it is considered a non-open burning process and is covered in Chapter 10.

MSW open burning normally occurs under relatively low temperature, releasing large emissions of pollutants, such as PM (PM_{10}, $PM_{2.5}$), particulate BC and OC, and gaseous pollutants like NOx, CO, CH_4 and NMVOC.

8.2 EMISSION ESTIMATION METHOD

A simple method that involves use of a single emission factor for each pollutant, representing the emission per amount of open-burned MSW can be used for the estimation of emissions. This requires prior knowledge of the amount of MSW generated by a community and the fraction of MSW burned. The emission calculation is expressed in the following equation:

$$Em_i = M_s \times EF_i \quad \text{(eq. 8.1)}$$

where,
Em_i = Emission of pollutant i
EF_i = Emission factor of pollutant i (g/kg of dry matter burned)
M_s = Amount of MSW burned (kg/yr)

The most important activity data are the amounts of open-burned waste (M_s). However, these data may not be available in most countries. While it is preferable to use country-specific data, an alternative method is adopted from IPCC (1996), in case of data unavailability. This method uses population data and a solid waste generation factor as drivers to calculate the total amount of open-burned MSW. There are two kinds of burning activities: burning at source (i.e.,community that generates the solid waste) and burning at disposal sites.

a. Solid Waste Open Burning at Source

$$M_s = Pc \times P_{frac} \times MSW_{GR} \times \delta \times \eta \times 365 \quad \text{(eq. 8.2)}$$

where,
M_s = Amount of open-burned MSW (kg/yr)
Pc = Population (capita)
P_{frac} = Fraction of population burning waste
MSW_{GR} = Per capita MSW generation factor (kg waste/capita.day)
δ = Fraction of combustible MSW
η = Burning/oxidation efficiency (fraction)

b. Solid Waste Open Burning at Disposal Site

$$M_s = Pc \times MSW_{GR} \times \varepsilon \times \delta \times \eta \times 365 \qquad \text{(eq. 8.3)}$$

where,

M_s	= Amount of open-burned MSW (kg/yr)
Pc	= Population (capita)
MSW_{GR}	= Per capita MSW generation factor (kg waste/capita.day)
ε	= MSW collection efficiency (fraction that is dumped/land filled per total waste generated)
λ	= Fraction of waste actually burned relative to total amount of waste disposed at disposal site
δ	= Fraction of combustible MSW
η	= Burning/oxidation efficiency (fraction)

8.3 DATA ON ACTIVITY LEVELS

Table 8.1 presents typical country-specific data on MSW_{GR} (per capita generation rate) provided by IPCC (1996) from around 28 countries and additional references. It is noted that all values in the reference sources can be prepared based on certain assumptions. Hence, updated national data, where available, should be used. For example, updated population data of individual countries can be collected from different sources, such as national statistics and other demographical documents.

Table 8.1: Country Waste Generation (MSW_GR) Values

Region/Country	MSW_{GR} (kg/capita.day)[a]	Region/Country	MSW_{GR} (kg/capita.day)
North America		Luxembourg	1.34
USA	2.0	Netherlands	1.58
Canada	1.81	Norway	1.40
Oceania		Portugal	0.90
Australia	1.26	Spain	0.99
New Zealand	1.33	Sweden	1.01
UK/Scandinavia/Western Europe		Switzerland	1.1
UK	1.9	**Eastern Europe**	
Ireland	0.85	Russia	0.93
Austria	0.92	**Asia**	
Belgium	1.10	Japan	1.12
Denmark	1.26	India[b]	0.6
Finland	1.70	China[b]	0.9
France	1.29	Sri Lanka[b]	0.8
Germany	0.99	Thailand[b]	1.0
Greece	0.85	Indonesia[c]	1.0
Italy	0.94		

Remarks:
[a] IPCC, 1996.
[b] ARRPET, 2004.
[c] NSE, 2004.

In a developed country, P_{frac} can be assumed to be a rough estimate of the rural population. In a region where the urban population exceeds 80 percent of the total population, it can be assumed that no open burning of waste occurs. In a developing country with a poor SWM system, the situation is more complicated. In urban areas, P_{frac} can be roughly estimated based on the number of people whose wastes are not collected (by the municipality) and the number of people, whose waste is collected but disposed in open dumps and subsequently burned (IPCC, 1996). Data provided by international organizations, such as the United Nations Human Settlements Programme (http://www.unhabitat.org, 2000), which has reported the fraction of waste burned in a number of cities, can also be used. However, use of country- and region-specific data is encouraged whenever these are available.

IPCC (1996) defines η as the fraction of waste whose carbon content is oxidized and converted to CO_2 and other gases. When complete combustion occurs, η equals 1.0. For waste incinerators in general, it is assumed that η is close to 1.0, while in open burning it is substantially lower and a value of 0.58 is suggested by IPCC (1996). In some cases, mainly when a substantial quantity of waste in open dumps is burned, a relatively large part of waste is left unburned. In open dumps, the fraction that is not compacted often burns. In this situation, it is suggested that η (also λ and δ) should be estimated by using survey results or available research data or expert judgment, to be applied in eq. 8.1 and eq. 8.2.

8.4 EMISSION FACTORS

Emissions of MSW open burning are significantly affected by many variables, such as ambient temperature, waste composition, moisture content, and local meteorological conditions. Most of the emission factors in Table 8.2 are taken from USEPA (1995) and various international literature. It would be extremely useful if regional- or country-specific emission factors could be developed for use in emission inventory.

Table 8.2: Emission Factors for MSW Open Burning

| Species	Emission factor (g/kg)[a]
SO_2	0.5
NO_X	3
CO	42
NMVOC	15
PM_{10}	30[b]
$PM_{2.5}$	9.8[b]
NH_3	0.94[b]
BC	0.65[b], 5.5[c]
OC	5.27[b], 5.5[c]
CH_4	6.5
CO_2	1,453[b]

Remarks:
[a] US EPA (1995)..
[b] Akagi et al. (2010).
[c] Bond et al. (2004).

8.5 TEMPORAL AND SPATIAL DISTRIBUTION

MSW open burning is likely to be linked with daily MSW generation and can be expected to take place seven days a week. However, it is characterized by seasonal variations (weather conditions), with burning activity less frequent during the rainy season and more frequent in the dry season. In most developed countries, the legal aspect is also very important. As a rule, open burning is banned during the dry season. Thus, if the law is strictly enforced, the emission inventory for open MSW burning during a dry period should result in an emission rate that is much lower than normal. The preferred method for allocating open burning emissions is to use local season-specific activity data. An alternative is to collect estimates of seasonal activity from local experts.

Spatial allocation of burning activity data is necessary for the spatial distribution of emission. In general, spatial allocation is the assignment of an activity level or emission estimate to a specific geographical area. In addition, it is preferable to scale or extrapolate emissions or activities from one area to another within the inventory area only. When the method uses a spatial surrogate, the preferred and alternative surrogates are described as part of the method. In general, the distribution of rural population (developed countries) and total population density (developing countries) can be used as surrogate for spatial distribution of MSW open burning emission. The flowchart for spatial allocation is presented in Figure 8.1. which is more applicable for solid waste open burning at source. For the spatial distribution of burning at disposal sites, the location of the latter is required .
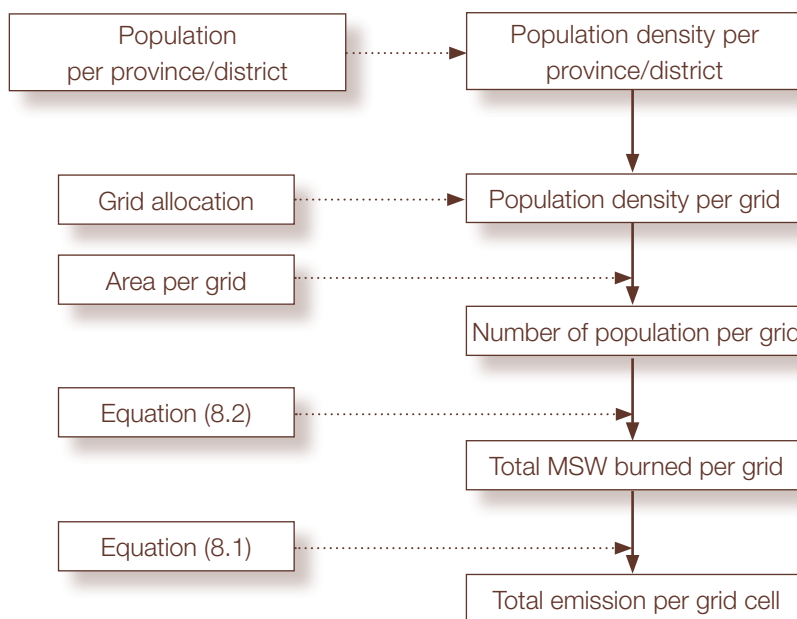
Figure 8.1: Spatial Allocation of Emission

8.6 SUMMARY

The procedure to calculate emissions from MSW open burning is described in Table 8.3.

Table 8.3: Summary of Calculation Procedure for MSW Open Burning Emissions

Step	Calculation Procedure
1	**Estimate Total Generation of MSW** • Take value of MSW_{GR} from Table 8.1 for a specific country. • Take data on population (Pc) from updated statistics in the inventory year. • Calculate total generation of MSW by multiplying MSW_{GR} by Pc (kg/day).
2	**Estimate Total MSW Actually Burned** • Search for P_{frac}, ε, λ, δ, η values from country-specific literature. • Multiply by total MSW generation to calculate total MSW actually burned (kg/day).
3	**Estimate Emissions** • Select the emission factor for each pollutant from Table 8.2. Note that the unit is in g/kg which is equal to kg/tonne of burned MSW. • Select combustion efficiency value (typical $\eta = 0.58$). • Convert unit of total MSW actually burned from kg to tonne by dividing it by 10^3. • Multiply by the emission factor to obtain the emission in kg/day.
4	**Temporal Distribution** Consider seasonal variation (climate condition, local legal aspect (banning), lifestyle, etc.).
5	**Spatial Distribution** Use land use map showing population density and waste disposal areas. Use population data (rural and urban); refer to Figure 8.1.

9.1 OVERVIEW

Solvents and other products containing light hydrocarbon (HC) compounds are potentially major sources of emissions of non-methane volatile organic compounds (NMVOCs). EMEP/ CORINAIR (2006) suggests that anthropogenic emissions of NMVOC from solvents and other products vary from country to country and account for 15% to 30% of total NMVOC emissions. Apart from NMVOC emissions of European countries, solvent use contributes to emissions of some heavy metals, such as zinc, cadmium, copper, and lead. Most solvents are part of a final product, for example, paint, that eventually evaporates. Evaporation of solvents is a major source of NMVOC emission.

Following EMEP/CORINAIR (2006), this manual categorizes the use of solvent and other products containing light HC compounds, as follows:

- **Paint (all applications):** Including emissions from paint application in automobile manufacture, car repair, building and construction, domestic use, coil coating, boat building, wood, other industrial paint application (agricultural, aircraft, cans and drums, military vehicles, motor vehicle components, including engines), office equipment, paper and plastics, toys, and other non-industrial paint applications (structural steel, concrete, and others, such as road marking paints and non-decorative floor paints).
- **Industrial degreasing:** Including emissions from metal degreasing. Degreasing is a process for cleaning products using water-insoluble substances, such as grease, fats, oils, waxes, carbon deposits, fluxes and tars.
- **Dry cleaning:** Including emissions from the dry cleaning of fabrics. Dry cleaning refers to any process to remove dirt or contamination from furs, leathers, down leathers, textiles or other objects made of fibers, using organic solvents.
- **Graphic arts (ink):** Including emissions from the application of ink in graphic arts.
- **Chemical industries:** Including emissions from manufacturing or processing industries, such as pharmaceuticals, polyester processing, polyvinyl chloride processing, rubber processing, and the manufacture of paints, inks, glues adhesives, magnetic tapes, films and photographs, textile finishing, leather tanning, polystyrene foam, asphalt blowing, and others.
- **Vegetable oil extraction:** Including emissions from solvent extraction of edible oils from oilseeds.
- **Pesticides:** Including emissions from the manufacture and use of pesticides.
- **Other solvent use:** Including emissions from domestic solvent use (other than paint application), electronic components manufacture and other industrial cleaning, glass wool enduction, mineral wool enduction, application of glues, and adhesives, domestic use of pharmaceutical products, printing industry, preservation of wood, vehicles dewaxing, under seal treatment, and maintenance of vehicles and others.

As with most other products, there are three stages in the use of the solvents during which emissions occur. These are during production, actual use and disposal. The method considered in this manual deals with the second stage as the first stage is dealt with in Chapter 5, which is a process-related chapter, while the third stage is covered in Chapter 10, which is about emissions from waste treatment and disposal.

9.2 EMISSION ESTIMATION METHOD

Two major method in estimating emissions from solvents are the simple and detailed methods (EMEP/CORINAIR, 2006). These are described in the following section.

Simple Method

The NMVOC emission from solvent use is calculated based on per capita data for several source categories. This is the first step for country which does not have solvent use activity data. Users should select a per capita factor provided in the EMEP/CORINAIR guidebook which resembles the situation in their respective countries as close as possible, and multiply the factor by the population number. Emission factors for this method are presented in Table 9.1. The emission calculation is expressed as:

$$Em_j = \sum AR \times EF \qquad \text{(eq. 9.1)}$$

where,
Em_j = Total emission from product use category j
AR = Activity rate expressed in terms of population number (capita)
EF = Emission factor for NMVOC emission per capita (in kg/cap./year).

Detailed Method

The detailed method as proposed by EMEP/CORINAIR (2006) is based on mass balance per solvent. The sum of all solvent mass balances equals the NMVOC emission due to solvent use. The solvent mass balance can be obtained by using the following equation.

$$C_j = P_j + I_j - E_j - D_j - H_j \qquad \text{(eq. 9.2)}$$

where,
C_j = Consumption of solvent-containing product for product use category j.
P_j = Production of solvent-containing product for product use category j.
I_j = Import of solvent-containing product for product use category j.
E_j = Export of solvent-containing product for product use category j.
D_j = Destruction or disposal of solvent for product use category j.
H_j = Hold-up (this is the difference in the amount in stock at the beginning and at the end of the inventory year).

For each solvent use category, the NMVOC emission can be calculated by multiplying consumption by the fraction emitted that represents ratio between amount of emitted NMVOC and consumption of solvent; that is:

$$\textit{NMVOC component emission} = C_j \text{ (from eq. 9-2)} \times \textit{fraction emitted} \qquad \text{(eq. 9.3)}$$

As stated in EMEP/CORINAIR (2006), when information on the fraction emitted in eq. 9.3 is not available, it can be assumed to be 1.0. It is estimated that this assumption will lead to an error of less than 10%. Thus, the total NMVOC emission due to solvent use can be calculated as the sum of component emissions, that is:

$$TNMVOC = \sum_i NMVOC \qquad \text{(eq. 9.4)}$$

$TNMVOC$ = Total NMVOC emission (tonne/year)
$NMVOC$ = Individual NMVOC component i emission (tonne/year)

Despite of lacking data of fraction emitted, emission factors for various activity data from sub-activity sources are provided in Table 9.2. Solvent data collected for eq. 9.2 can be used to estimate total NMVOC emission of each sub-activity source. Equation 9.1 then can be applied to estimate emission with EFs from Table 9.2

9.3 DATA ON ACTIVITY LEVELS

The simple method requires annual activity data (in tonnes) on consumption or production per year and emission factors. The detailed method requires the following:

- List of the most important solvents, accounting for at least 90% of all solvent emissions,
- Data on import, export, disposal and destruction, feedstock, hold-up and production of each solvent and solvent-containing product, and
- Data on solvent content of products.

Annual industrial statistics from individual countries may provide production capacity data. Data on the solvent content of products can be obtained from EMEP/CORINAIR (2006) and other possible data sources.

9.4 EMISSION FACTORS

Emission factors are mainly taken from EMEP/CORINAIR (2006). The compiled values of emission factors for NMVOC in the simple and detailed methods are presented in Table 9.1 and Table 9.2.

Table 9.1: Emission Factors for Simple Method

Sub-activity Source	Emission Factor in kg/cap./year[a]
	NMVOC
Paints	4.1-4.9 (4.5)
Industrial degreasing	0.55-1.15 (0.85)
Graphic arts	0.4-0.9 (0.65)
Glues and adhesives	0.15-1.05 (0.6)
Household products	1.35-2.25(1.8)
Total	8.6-15.4(12)

[a] EMEP/CORINAIR, 2006. In bracket are average values for European countries.

Users should consider the applicability of emission factors that are suitable for European countries. There is less certainty if the sub-activity source in the users' country resembles the country where the per capita factor has been taken.

Table 9.2: Emission Factors for Solvents and Other Products Use

Sub-activity Source	Activity Units	Emission Factor in kg/tonne NMVOC
Paint Application		
Automobile manufacture	Tonnes paint sold	500
Industry	Tonnes paint sold	750
Decorative	Tonnes paint sold	300
Degreasing		
Metal degreasing	Tonnes solvent consumed	1000
Dry Cleaning	Tonnes solvent consumed	125
Chemical Product Manufacturing/Processing		
Polyester resin processing	Tonnes resin	40
Polyvinyl chloride processing	Tonnes product	40
Rubber processing	Tonnes product	15
Paints manufacturing	Tonnes product	15
Polystyrene foam	Tonnes product	15
Adhesive tape	Tonnes product	60
Ink	Tonnes product	30
Glue	Tonnes product	20
Adhesive tape	m² product	60
Other Uses of Solvents		
Printing industry	Tonnes ink consumed	350
Domestic solvent use	Tonnes solvent used	1.9
Glass/mineral wool enduction	Tonnes product	0.8
Fat, oil extraction	Tonnes oil produced	18
Application of glues and adhesives	Tonnes product used	600

Remarks:
EMEP/CORINAIR, 2006. All values are uncontrolled emission factors.

EMEP/CORINAIR (2006) reported that the uncertainty will differ per solvent. In products where more solvent is present, the certainty is higher. The overall uncertainty will depend on completeness of mass-balance data and quality of production, import, export, disposal, destruction and hold-up data.

9.5 TEMPORAL AND SPATIAL DISTRIBUTION

Depending on source category, emissions can be distributed spatially based on:

- Sub-national gross domestic product
- Number of industries at sub-national level

Spatial disaggregation of emissions from, for example, use of paints in the residential sector can be disaggregated based on population distribution, assuming a constant value for per capita paint consumption.

For temporal variation of emissions from sectors other than the residential sector, monthly production statistics can be used. Emissions from the residential use of paints can be equally distributed over a week as these can occur on working days as well as on holidays. However, according to EMEP/CORINAIR (2006), in the absence of specific surveys, a reasonable assumption is that emissions on Saturdays are twice as high as those on other days of the week. In addition, seasonal conditions can also be considered in the case of temporal distribution, as most painting activities tend to occur in the spring and summer in Europe and probably in Asia too and other regions (EMEP/CORINAIR, 2006).

9.6 SUMMARY

The calculation procedure for emissions from solvents and other products use is presented in Table 9.3.

Table 9.3: Summary of Calculation Procedure for Emission from Solvents and Other Products Use

Step	Calculation Procedure
1	**Calculate Emission** • Select method based on activity data availability • Obtain activity data on population (if using simple method) or consumption or production in tonnes from a relevant source in a particular country (if using detailed method). • Consider emission factors for NMVOC from Tables 9.1 and 9.2. • Calculate emissions using eq. 9.1 or eq. 9.2 - 9.4
2	**Temporal Variation** • Obtain monthly production statistics from country-specific reports and publications. • Calculate monthly emission from annual emissions.
3	**Spatial Distribution** Emissions can be distributed spatially based on • Sub-national gross domestic product. • Number of industries at sub-national level.

This chapter deals with emissions from agriculture, livestock, manure management, fertilizer application, and solid waste treatment (covering methane emission from disposal sites and solid waste incinerators). These activities emit NH_3, CH_4 and N_2O that are indirectly related to ABCs, while solid waste incinerators emit combustion pollutant products including PM_{10}, $PM_{2.5}$, BC, OC, SO_2, NO_x, CO, NMVOC and also GHGs (CO_2 and N_2O).

10.1 EMISSIONS FROM AGRICULTURE SECTOR

10.1.1 OVERVIEW (MAN MADE ACTIVITIES)

In addition to field burning activities, the agriculture sector accounts for other activities that can emit air pollutants, including activities dealing with domestic livestock and fertilizer application. Domestic livestock activities, such as enteric fermentation and manure management, can potentially emit CH_4, N_2O and NH_3 while fertilizer application in agriculture potentially emits NOx and NH_3. NH_3 pollutants in the atmosphere produce secondary particulate species, including ammonium sulfates and ammonium nitrate. These are the main constituents of ambient $PM_{2.5}$, which is associated with ABCs. The main species considered in this section are NH_3, CH_4 and N_2O. Note that natural emissions of NH_3 (e.g. natural landscape) and N_2O (e.g. soils, oceans and rivers) are not included.

10.1.2 EMISSION ESTIMATION METHOD

In general, agricultural emissions are calculated by multiplying activity rate by the corresponding emission factor. IPCC (2006) suggests two types of methodology to calculate emissions from livestock: a) Tier 1 which is based on basic characterization for livestock populations, such as livestock categories and their annual population, and b) Tier 2 which is based on enhanced characterization for livestock populations such as feed intake, body weight, etc. Basic characterization for Tier 1 is likely to be sufficient for the majority of animal species in most countries.

Emissions are calculated by applying the relevant emission factor to the number of animals belonging to each livestock type in a country, to obtain total emissions from enteric fermentation. The most important source for livestock emission is cattle. The same basic method (for CH_4 and NH_3) is used to estimate emissions from manure management and fertilizer application (NH_3).

$$Em_{i,} = \sum Na_i \times EF_{i,j} \qquad \text{(eq. 10.1)}$$

where,
$Em_{i,j}$ = Emission of pollutant i (CH_4 and NH_3) and livestock (animal) type j
Na_i = Number of animals (head/year) or amount of nitrogen fertilizer used (tonnes)
$EF_{i,j}$ = Emission factors (kg/head) or in % NH_3-N volatilized per unit fertilizer-N.

To estimate N_2O emissions from animal waste (AW), the following equation is used:

$$N_2O_{(AW)} = \sum \left(N_{ex(AW)} \times EF_{(AW)} \right) \qquad \text{(eq. 10. 2)}$$

where,

$N_{ex(AW)}$ = N excretion per animal waste (kg/year)

$EF_{(AW)}$ = N_2O emission factor for *AW* (kg N_2O-N/kg of N_{ex} in animal waste).

$N_{ex(AW)}$ is calculated as follows:

$$N_{ex(AW)} = \sum \left(Na_j \times N_{ex\,(j)} \times AW_j \right) \qquad \text{(eq. 10. 3)}$$

where,

Na_j = Number of animal type *j* in the country (head)

$N_{ex\,(j)}$ = N excretion of animal type *j* in the country (kg N/animal/year)

AW_j = Fraction of $N_{ex\,(j)}$ that is managed in particular waste management systems.

IPCC (2006) has divided Na_j into 12 main categories: mature dairy cow or buffalo, other mature cattle or mature non-dairy buffalo, growing cattle or growing buffalo, mature ewes, other mature sheep, growing lambs, mature swine, chickens, turkeys, ducks and others.

10.1.3 DATA ON ACTIVITY LEVELS

In general, data needed to estimate emissions from this sector cannot be found in a single or a strictly limited source. Use of national reports on animal headcounts is the preferred alternative, whenever possible. The FAOSTAT database provides national level activity data, such as the number of livestock (http://faostat.fao.org/site/569/compiled.aspx) and the amount of fertilizer (as *Na*) applied (http://faostat.fao.org/site/568/compiled.aspx). Livestock data cover beef, cows, dairy cows, buffalo, swine, goat, sheep, and other cattle. If there are no locally available data, information from this website may be used. For N_2O estimation, more technical data, such as nitrogen excretion of animals in the country $(N_{ex(j)})$, are presented in Table 10.1. The percentage of manure N produced in different animal waste management systems (AW_j) can be obtained from IPCC (2006).

Table 10.1: Nitrogen Excretion per Head of Animal per Region ($N_{ex(j)}$) in kg/animal/year

Region	Type of Animal					
	Non-dairy cattle	Dairy cattle	Poultry	Sheep	Swine	Others
North America	70	100	0.6	16	20	25
Western Europe	70	100	0.6	20	20	25
Eastern Europe	50	70	0.6	16	20	25
Oceania	60	80	0.6	20	16	25
Latin America	40	70	0.6	12	16	40
Africa	40	60	0.6	12	16	40
Near East and Mediterannean	50	70	0.6	12	16	40
Asia and Far East	40	60	0.6	12	16	40

Remarks: IPCC, 2006.

10.1.4 EMISSION FACTORS

NH_3 emission factors (EFs) for livestock and fertilizer application are taken from Battye et al., (1994) and USA National Emission Inventory (NEI) activity (USEPA, 2003), which are presented in Tables 10.2 and 10.3. Soil profile constitutes very important data when choosing NH_3 EFs from fertilizer application. The CH_4 EFs for livestock enteric fermentation are taken from the IPCC (2006) workbook and are presented in Table 10.4. N_2O EFs from animal waste are also taken from the IPCC (2006) workbook and are presented in Table 10.5.

Table 10.2: Emission Factors of NH_3 from Livestock Source

Livestock Type	(Kg /head-year)	
	NEI (2002)	Battye et al., (2004)
Dairy cow	38.3	28
Beef cow	11.0	10.2
Poultry	0.27	0.37
Swine	6.5	11.4
Horses	12.3	8
Sheep	3.4	1.34
Goats	6.4	na

na: not applicable

Table 10.3: Compiled Emission Factors of NH$_3$ from Fertilizer Application

Fertilizer Type	(kg NH$_3$/tonne fertilizer N)[a]	
	Group I	Group II
Anhydrous ammonium	48	48
Aqua ammonium[b]	12	
Nitrogen solutions	97	97
Urea	242	182
Ammonium phosphates[b]	48	
Diammonium phosphate	61	61
Monoammonium phosphate	61	61
Liquid ammonium polyphosphate	61	61
Aqueous ammonia	97	97
Ammonium nitrate	36	24
Ammonium sulfate	182	121
Calcium ammonium nitrate	36	24
Ammonium thiosulfate	30	30
Other straight nitrogen	30	
N-P-K	48	
Potassium nitrate	12	12
Miscellaneous	97	73
Mix	36	24

Remarks:
Group I: warm, temperate areas with a large proportion of calcareous soils.
Group II: temperate and warm-temperate areas with some calcareous soils (or managed with soil pH>7), but with large areas of acidic soils.
[a] USEPA, 2003.
[b] Battye et al., 1994.

Table 10.4: Compiled Emission Factors of CH$_4$

Livestock Type	Enteric Fermentation (kg CH$_4$/head-year)[a]		Manure Management (kg CH$_4$/head-year)[a]					
	Developed Countries	Developing Countries	Developed Countries			Developing Countries		
			Cool	Temp	Warm	Cool	Temp	Warm
Buffalo	55	55	-	-	-	-	-	-
Sheep	8	5	0.19	0.28	0.37	0.10	0.16	0.21
Goats	5	5	0.12	0.18	0.23	0.11	0.17	0.22
Camels	46	46	1.59	2.38	3.17	1.28	1.92	2.56
Horses	18	18	1.39	2.08	2.77	1.09	1.64	2.18
Mules and asses	10	1.0	0.76	1.14	1.51	0.60	0.90	1.19
Swine	1.5	1.0	-	-	-	-	-	-
Poultry	-	-	0.078	0.117	0.157	0.012	0.018	0.023

Remarks:
 [a] IPCC (2006).
-: not available.

Table 10.5: Compiled Emission Factors of N$_2$O from Animal Waste ($EF_{(AW)}$)

Animal Waste Management System	(Kg N$_2$O-N /kg Nitrogen Excreted)[a] Emission Factor
Anaerobic lagoon	0.001
Liquid system	0.001
Daily spread	0.0
Solid storage and dry lot	0.02
Pasture range and paddock	0.02
Other systems	0.005

Remarks:
[a] IPCC, 2006.

10.1.5. TEMPORAL AND SPATIAL DISTRIBUTION

Temporal variations of NH$_3$ emissions can be assigned based on monthly estimates of fertilizer usage at the county level, taking into account crop calendars and fertilizer sales (CMU, 2001). Since direct emissions from fertilizer application mostly occur within a few days of application, emissions in a given month can be estimated based on fertilizer application during that month. Therefore, national monthly data on fertilizer usage are needed to construct seasonal variation of NH$_3$ emissions from fertilizer application. However, there is less knowledge about the temporal variation of methane from livestock and N$_2$O from animal waste. The fraction of monthly NH$_3$ emission can be expressed in the following equation. To obtain monthly emission, the obtained fraction should be multiplied by the annual average emission.

$$FM_n = \frac{Fc_n}{\sum Fc}$$

(eq. 10.4)

where,
n　　= Month (1-12)
FM_n =Monthly fraction
Fc_n　= Fertilizer consumption in month n
$\sum Fc$ = Total fertilizer consumption in a year.

Spatial allocation of livestock emissions can be calculated by using animal population data by province or district. Such data can be obtained mainly from national sources. The total emission per province/district can be calculated by using EFs. Emission per area can be calculated using district area information. A specific grid net in a specified area is used to calculate the emission of each grid. The method is presented in Figure 10.1.

Fertilizer emission can be spatially distributed as a function of land use type. National land use data can be classified. Emissions will be distributed to fertilizer consumption or amount of crop production for each land use type, such as paddy fields and crop and vegetable farms.
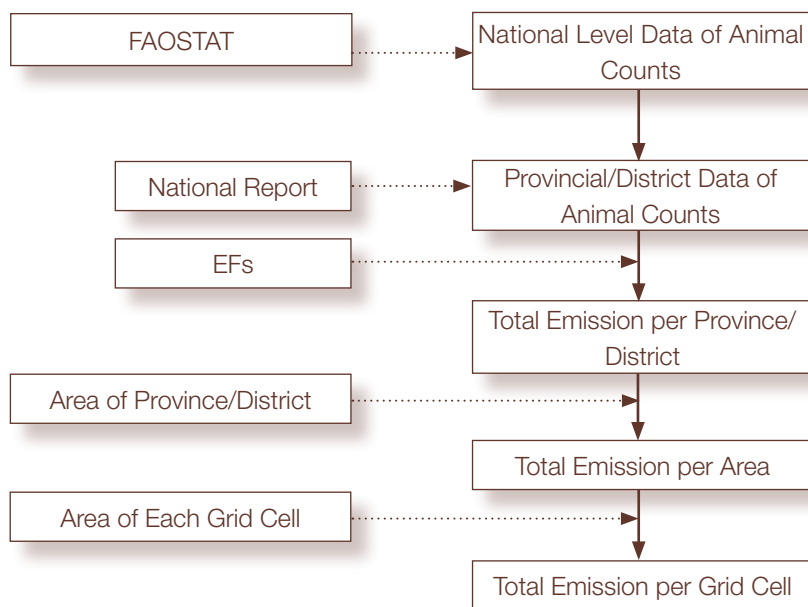
Figure 10.1: Calculation Procedure for Spatial Distribution of Emissions

10.1.6 SUMMARY

The calculation procedure for emissions in the agriculture sector is presented in Table 10.6.

Table 10.6: Summary of Calculation Procedure for Emissions in the Agriculture Sector

Step	Calculation Procedure
1	**Calculate NH$_3$ Emission from Domestic Livestock** • Obtain annual number of each type of livestock from national statistic whenever available, otherwise data from FAOSTAT can be used (head count/year). • Choose EFs from Table 10.2. • Calculate emission by using eq. 10.1.
2	**Calculate NH$_3$ Emission from Fertilizer Application** • Obtain annual fertilizer consumption from national statistics or other national sources whenever available, otherwise data from FAOSTAT can be used. • Choose EFs from Table 10.3. • Calculate emissions by using eq. 10.1.
3	**Calculate CH$_4$ Emission from Enteric Fermentation and Manure Management** • Obtain annual number of each type of livestock from national statistics whenever avail able or from FAOSTAT (head count/year). • Choose EFs from Table 10.4 for both enteric fermentation and manure management sources. • Calculate emission by using eq. 10.1.

Step	Calculation Procedure
4	**Calculate N$_2$O Emission from Manure Management** • Obtain annual number of each type of livestock from national statistics or from FAOSTAT (head count/year) representing N_j. • Obtain data of N ($N_{ex(j)}$) excretion of animals in the country (kg N/animal/year) from Table 10.1. • Take the fraction of $N_{ex(j)}$ that is managed in one of the different/ distinct animal waste management system AW_j. (Take the region-specific value from IPCC 1996 workbook module 4, Table 4.7). • Calculate $N_{ex(AW)}$ from eq. 10.3. • Choose EFs from Table 10.5. • Calculate N$_2$O emission by using eq. 10.3.
5	**Temporal Distribution** • NH$_3$ emission can be temporally distributed by using monthly fertilizer consumption. • For others, temporal variation can be made based on measured temperature.
6	**Spatial Distribution** Fertilizer emission can be spatially distributed as a function of land use type. For livestock, data of livestock population at the provincial level can be used.

10.2 WASTE TREATMENT AND DISPOSAL

10.2.1 OVERVIEW

This sector covers thermal incineration of solid waste, including municipal solid waste (MSW), industrial waste and medical waste and methane emission from solid waste final disposal sites. The pollutants to be considered include PM_{10}, $PM_{2.5}$, BC, particulate EC OC, SO_2, NO_x, NMVOC, CO, CO_2, N_2O, CH_4 and NH_3.

10.2.2 EMISSION ESTIMATION METHOD

Emission is calculated based on the simple method proposed by EMEP/CORINAIR (2006). This makes use of a single emission factor for each pollutant species combined with national waste incineration statistics, as shown in the following equation.

$$Em_{i,j} = M_j \times EF_{i,j} \qquad \text{(eq.10.5)}$$

where,

i,j = Pollutant i and waste type j (MSW, medical waste, etc.)

$Em_{i,j}$ = Emission of pollutant i for waste type j

M_j = Mass of waste type j (tonnes)

$EF_{i,j}$ = Emission factor of pollutant i from waste type j (kg/tonnes of waste)

The method suggested by IPCC (2006) to calculate methane emission from solid waste disposal sites (SWDs) is, as follows:

$$Em = (MSW_t \times MSW_f \times \text{MCF} \times DOC \times DOC_f \times F \frac{16}{12} - R) \times (1\text{-}OX) \qquad \text{(eq. 10.6)}$$

where,

Em = Emission of methane
MSW_t = Total MSW generated (Gg/year)
MSW_f = Fraction of MSW disposed in solid waste disposal sites
MCF   = Methane Correction Factor
DOC = Fraction of degradable organic carbon
DOC_f = Fraction of DOC dissimilated (portion of DOC converted to landfill gas (LFG))
F = Fraction of CH_4 in landfill gas (suggested value is 0.5)
R = Recovered CH_4 (Gg/year)
OX = Oxidation factor (default value is 0). It accounts for methane that is oxidized in the upper layer of waste mass where oxygen is present.

10.2.3 DATA ON ACTIVITY LEVELS AND EMISSION FACTORS

Activity data needed to calculate the amount of MSW incinerated and disposed in landfill are as follows:

- Population data, which can be obtained from country statistics and other documents on demography.
- MSW generation factor (refer to Table 8.1 , Chapter 8), fraction of MSW disposed in landfill, and fraction of degradable organic carbon (DOC) (see Table 10.7).

Table 10.7: Typical Values of MSW_f and DOC

Region/Country	MSW_f[a]	DOC[a]
North America		
USA	0.62	0.18-0.21
Canada	0.75	-
Oceania		
Australia	1.00	0.15
New Zealand	1.00	0.19
UK/Scandinavia/Western Europe		
UK	0.9	0.1
Ireland	1.00	-
Austria	0.40	-
Belgium	0.43	-
Denmark	0.20	-
Finland	0.77	-
France	0.46	-
Germany	0.66	-
Greece	0.93	-
Italy	0.88	-
Luxembourg	0.35	-
Netherlands	0.67	0.14
Norway	0.75	-
Portugal	0.86	-
Spain	0.85	-
Sweden	0.44	-
Switzerland	0.23	-
Eastern Europe		
Russia	0.94	0.17
Asia		
Japan	0.38	-
India	0.6	0.18
China	0.58	0.09
Sri Lanka	0.85	0.17
Thailand	0.65	0.10
Indonesia	0.4	-

Remarks:
[a] IPCC, 2006.
-: not available.

Emission factors of several types of solid waste incinerators are presented in Table 10.8.

Table 10.8: Emission Factors of Solid Waste Incinerators

Pollutant	Municipal Solid Waste (MSW) (kg/tonne)[a]	Medical Waste (kg/tonne)[a]	Industrial Waste (kg/tonne)[a]
SO_2	1.7	0.07	0.07
NO_x	1.8	2.5	2.5
NMVOC	0.02	7.4	7.4
CO	0.7	0.125	0.125
CO_2	985[b]	-	-
N_2O	0.1	-	-
PM	18.3	2.33[b]	-
BC[c]	0.044	0.044	0.044
OC[c]	0.0013	0.0013	0.0013

Remarks:
[a] EMEP/CORINAIR, 2007.. General EFs from incinerators used for PM control only.
[b] USEPA, 1995. Type of incinerator is uncontrolled water wall combustors for MSW and controlled air incinerator for medical waste.
[c] Bond et al., 2004.
- : not available.

10.2.4 TEMPORAL AND SPATIAL DISTRIBUTION

Temporal variations of emissions from solid waste incineration can be surrogated from the period of operation of the incinerator. Large incinerators operate on an uninterrupted basis and should be treated as 24-hour 7-day per week emitters. Smaller incinerators operating at less than 5 tonnes per hour should be treated as 8-hour 5-day per week emitters (i.e. in batch/intermittent operation). For larger scale incineration, monthly data on incinerated provincial solid waste are needed.

Spatial distribution of emission is largely dependent on whether the incinerator is treated as an area or a point source. As mentioned in EMEP/CORINAIR (2006), all sources with a capacity to handle burned waste exceeding 5 tonnes per hour are considered as a point source. For area sources, spatial distribution of an emission may use the provincial population data.

USERS' GUIDE TO THE ABCs EMISSION INVENTORY MANUAL EXCEL WORKBOOK

11.1 OVERVIEW

The ABC EIM Excel Workbook is designed as a tool to implement various emission estimation methods discussed in the ABC EIM. The Excel Workbook has adapted the format of the Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual and, EMEP/CORINAIR (2006) and the IPCC Guideline (2006). However, this workbook includes additional pollutant species and source sectors related to ABCs. The emission inventory template consists of approximately 60 work sheets. Link facilities (in macro records) are provided inside the worksheets and users can access the desired sheet by using the tab scrolling buttons. Users are required to complete the blanks in the activity data cells (sky blue in color). Some energy source sectors require activity data conversion (from mass based to energy data). One sheet is provided for this purpose. Errors due to blank input data or errors in formulation have been automatically converted as text and defined as "NA". To start a new task, the document should first be saved under another file name. A distinctive feature of this workbook compared with others is the use of low, central, and high estimates, rather than single estimate of emission.

11.2 STRUCTURE OF ABC EMISSION INVENTORY TEMPLATE

11.2.1 MENU BOX

The first page of the emission inventory template is the Menu Box, which will appear as soon as the user opens the template file. There are some details in this box that have to be completed. These are as follows:

- Base year of emission inventory (scroll down to choose)
- Administrative level
- Name of the administrative level
- Country name (scroll down to choose)

There are 12 sections/pages in the Menu Box and the user can directly enter specific pages by clicking the access button GO. Sections 1-8 contain the ABCs emission worksheets for all source sectors. Section 9 gives the total emission compilation from all source sectors, while Sections 10-12 deal with the temporal and spatial distribution of emissions. The total emission sheet is directly linked to the emission results from each source sector. Emission share tables and graphs are also linked to this page. Changes in this sheet are expected when the user changes the activity data or emission factor input. This includes the summary table and graphs. The graphs show total emission shares per type of pollutants by sector (in %).
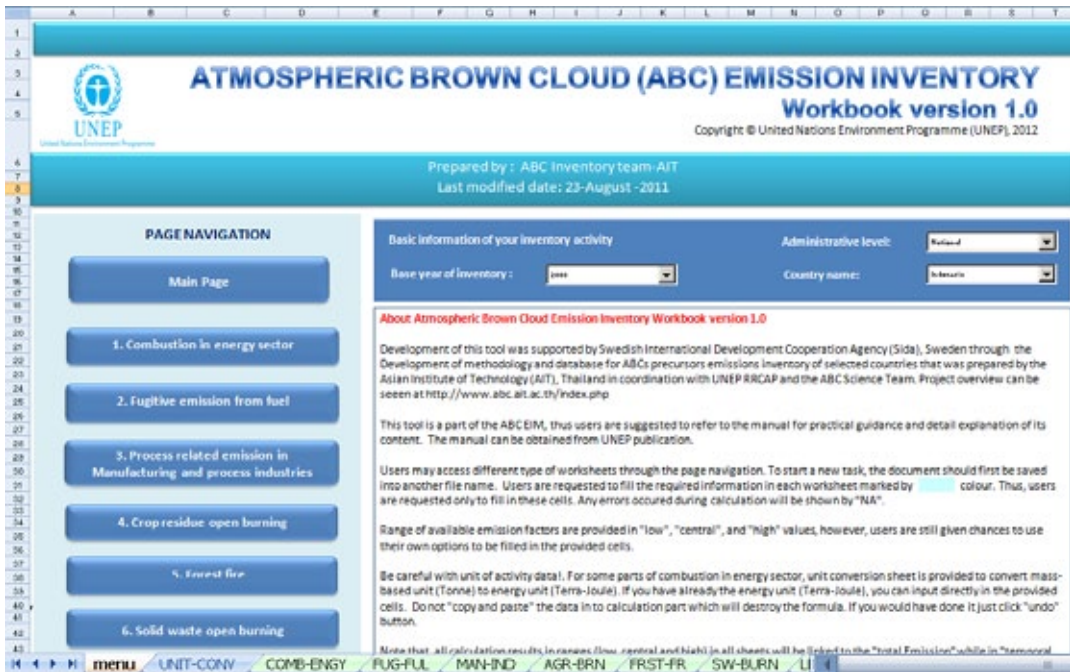
Figure 11.1: Menu Box of ABCs Emission Inventory Template

Figure 11.2: General Structure of Combustion in Energy Sector

Figure 11.2 shows the general structure of combustion in the energy sector. Each sub-sector can be accessed by clicking the access button GO. Other pages are presented in Figure 11.3. These panels provide easy access to all sectors/sub-sectors included in the workbook. Figure 11.3 displays several source sectors. These are designed to help users navigate in order to reach the working emission calculation template, which involves many source sectors, as fast as possible. However, users who are not familiar with macros may use the scroll button at the bottom of the Excel sheet.
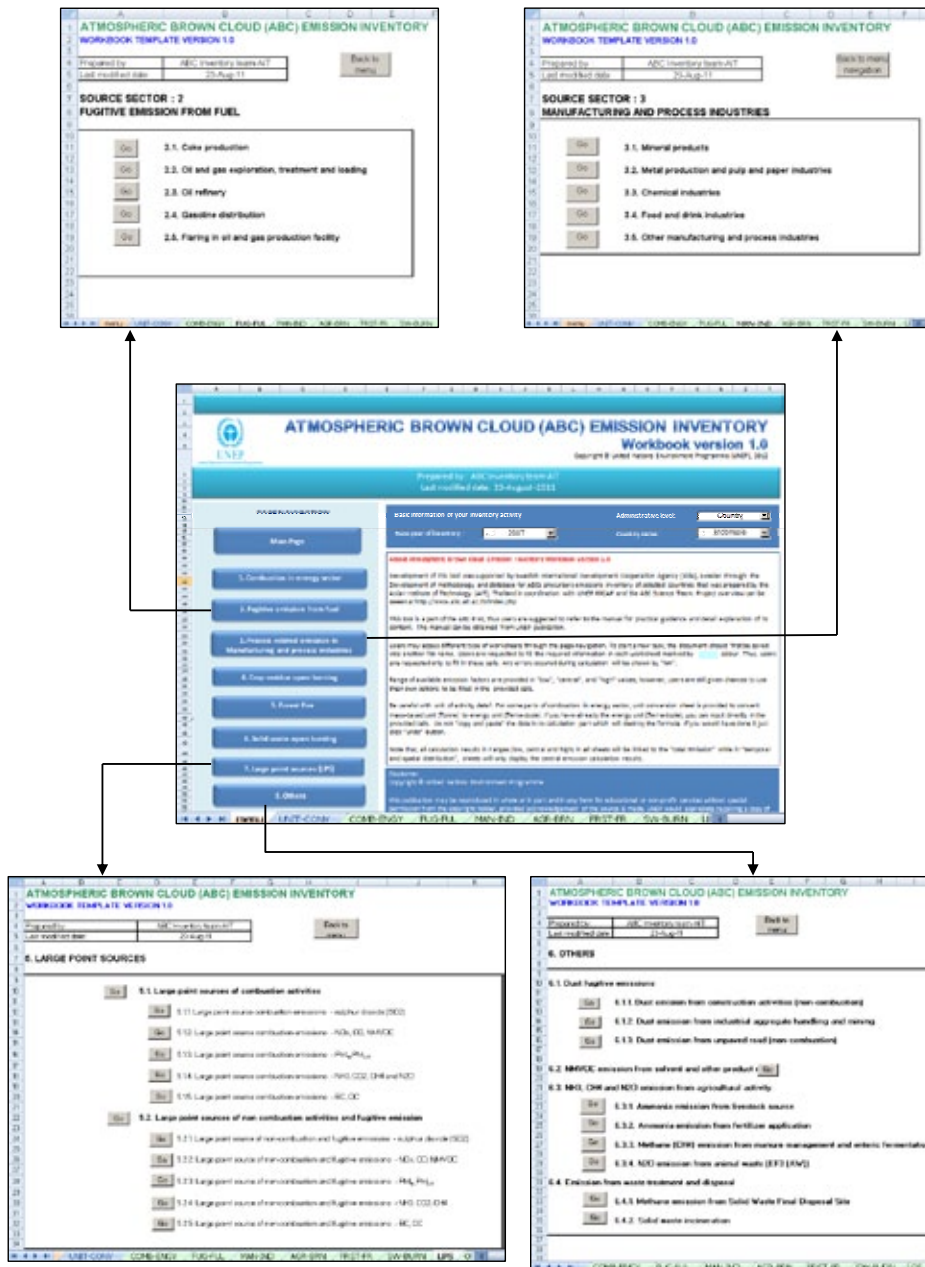
Figure 11.3: Several Displays of the Menu Box

When the user clicks GO in source sector 1 (combustion in the energy sector) in the Menu Box, the following figure will appear:

Figure 11.5

Figure 11.6

Figure 11.7

Figure 11.4: Page 1, Sub-menu of Combustion in Energy Sector

Users are required to input data only in areas that are blue in color. Input data that are in kg or kt (in mass-based) will have to be converted first to tonne yr^{-1} and then entered in the input data unit conversion sheet. Fuel consumption will then be linked to the respective calculation sheets.

Figure 11.5: Input Data Unit Conversion Template

After the activity data are entered, the user will go directly to the energy industry sector. The section is divided based on the type of pollutants; that is, SO_2 from all sub-sectors, and other pollutants. The emission factor for SO_2 is calculated by using several parameters, such as sulfur content (%), sulfur retention in ash (%), emission control efficiency and Net Calorific Value (NCV) or existing SO_2 emission factors. Default values are provided, but the user may use different values and enter these under the column 'chosen values'.

Figure 11.6: SO₂ Emissions from All Sub-sectors

For other pollutants, a different template in a different sheet has been prepared, as shown in Figure 11.7. In every template, the user only needs to fill in the blue-colored cells (activity data, chosen emission factors). Low, central, and high values are provided for the emission factors. The user can fill in the chosen value in the blue-colored cells.

Figure 11.7: Template Calculations for Other Pollutants

In general, information and templates are similar for other source sectors. These contain the activity data to be filled, choice of emission factors, and the emission calculations.

11.2.4 TOTAL EMISSION WORKSHEET

The total emission worksheet is linked to the calculated emissions from all associated sources. If there is a calculation error somewhere in the worksheet, the error will appear in this sheet as well. This is shown in Figure 11.11. The summary of all calculations contains the emission share table and charts to indicate the contribution of each source sector to total emission. The values (percentages) are linked to the total emission table, which may help users to check if errors occur.

Figure 11.8: Total Emission Worksheet

11.2.5 TEMPORAL AND SPATIAL DISTRIBUTION

The temporal and spatial worksheets are provided separately so that the emissions can be aggregated accordingly. The temporal distribution worksheet has been developed based on the aggregation factor for each type of source sector. This manual has prepared the monthly temporal aggregation factor as the aggregation factor is based on monthly activity data (data used to surrogate emissions temporally). The user needs to modify the temporal monthly variation factor since this is given in average values (average aggregation for each month which is 100/12 = 8.33%). The value is applicable only when the temporal monthly variation factor is not available. The template is shown in Figure 11.9 -11.10. A monthly variation graph of the emissions is also provided.

Figure 11.9: Temporal Variation Template

The case is similar for the spatial variation factor, which is associated with the lower administrative level. For example, for a national emission inventory, the spatial variation will be based on second national administrative level, that is the provincial level.

Figure 11.10: Spatial Variation Template

11.2.6 COMBINATION OF TEMPORAL AND SPATIAL DISTRIBUTION

In practice, emissions need to be temporally distributed at the same time in order to obtain the spatial distribution at a specific time. Thus, when the user pushes button 12 in the Menu Box for temporal and spatial distribution, a display as shown in Figure 11.11 will appear. The user needs to access a monthly-based sheet to see the spatial distribution in a particular month.
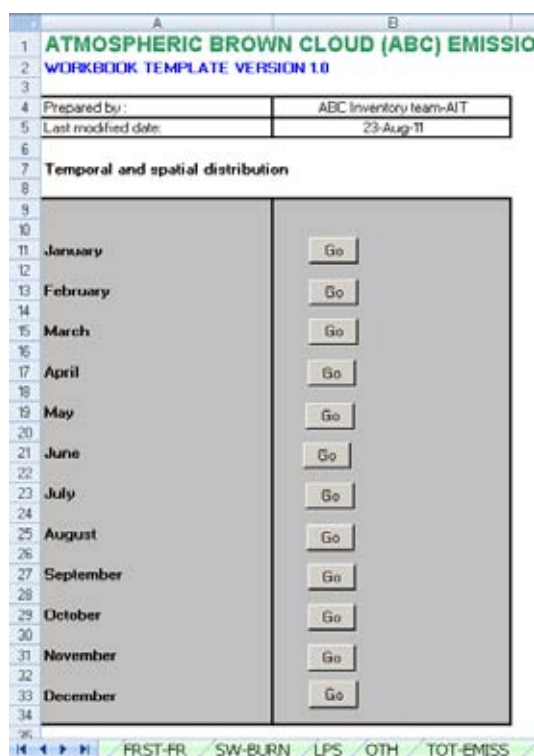
Figure 11.11: Temporal and Spatial Distribution

11.3 SUMMARY AND OUTLOOK

The ABC EIM Excel Workbook version 1.0 is an implementation tool for ABC EIM inventory compilers (users). A single-tier method is provided in this tool (following the general EI equation), taking into account data availability in most developing countries. To the extent possible, the most recent emission factors have been provided. The flexibility of this tool lies in the fact that the user can incorporate or update the emission factors and input these in the tool. This is the first EXCEL tool that includes one EI template the carbonaceous emissions (BC, OC) together with PM (PM_{10}, $PM_{2.5}$), gaseous species (NO_x, SO_2, NH_3, CO), and GHGs (CO_2, CH_4 and N_2O). The emission estimation takes into account the variability of emission factors (technology-based and region-based) to produce low, central and high estimates. This approach will help users in analyzing uncertainties in their emission estimates. For further improvements of this workbook, users are urged to provide feedback and inputs.

REFERENCES

AIRPET (Regional Research Network for Improving Air Quality in Asian Developing Countries), http://www.serd.ait.ac.th/airpet (downloaded on 2nd November 2008).

Alfaro, S.C. and Gomes, L., 2001, Modeling Mineral Aerosol Production by Wind Erosion: Emission Intensities and Aerosol Size Distributions in Source Areas, Journal Geophysical Research-Atmospheres, 106, 18075: 18084.

Andreae, M.O. and Merlet, P., 2001, Emissions of Trace Gases and Aerosols from Biomass Burning, *Global Biogeochem. Cycles*, 15, 955-966.

Arellano, A. F., Kasibhatla, P. S., Giglio, L., Van Der Werf, G. R. and Randerson, J. T., 2004, Top-Down Estimates of Global CO Sources using MOPITT Measurements, Geophysical Research Letters, 31 (1), L01104, doi:10.1029/2003GL018609.

Arino, O. and Plummer, S., 2001, The Along Track Scanning Radiometer World Fire Atlas – Detection of night-time fire activity, IGBP-DIS Working Paper #23. Postdam, Germany.

APEG (The Airborne Particle Expert Group), 1999, Source apportionment of airborne particulate matter in the United Kingdom. Prepared on behalf of the Department on the Environment, Transport and Regions, the Welsh Office, the Scottish Office and the Department of the Environment (Northern Ireland).

Arellano, A. F., Kasibhatla, P. S., Giglio, L., Van Der Werf, G. R., Randerson, J. T. and Collatz, G. J., 2006, Time-Dependent Inversion Estimates of Global Biomass-Burning CO Emissions using Measurement of Pollution in the Troposphere (MOPITT) Measurements, Journal of Geophysical Research-Atmospheres, 111 (D9), D09303, doi:10.1029/2005JD006613.

ARRPET, 2004, Municipal Solid Waste Management in Asia, Asian Institute of Technology, Thailand.

Battye, R., Overcash, C., and Fudge, S., 1994, Development and Selection of Ammonia Emission Factors, US EPA, Washington, D.C., EPA/600/R-94/190.

Bhattacharya, S.C., Albina, D.O., Abdul Salam, P., 2002, Emission factors of wood and charcoal-red cookstoves, Biomass and Bioenergy, 23, 453 – 469.

Bertschi, I.T., Yokelson, R.J., Ward, D.E., Christian, T.J. and Hao, W.M., 2003, Trace Gas Emisions from the Production and Use of Domestic Biofuels in Zambia Measured by Openpath Fourier Transform Infrared Spectroscopy, Journal of Geophysical Research- Atmospheres, 108, Art. No. 8469.

Berdowski, J.J.M., Mulder, W., Veldt, C., Visschedijk, A.J.H. & Zandveld, P.Y.J., 1997, Particulate matter emissions (PM_{10} – $PM_{2.5}$ – $PM_{0.1}$) in Europe in 1990 and 1993, TNO Institute of Environmental Sciences, Energy Research and Process Innovation. TNO report, TNO-MEP – R 96/472.

Bond, T.C., Wehner, B., Plewka, A., Wiedensohler, A., Heintzenberg, J. and Charlson, R.J., 2006, Climate-Relevant Properties of Primary Particulate Emissions from Oil and Natural Gas Combustion, Atmospheric Environment, 40, 3574-3587.

Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J.-H. and Klimont, Z., 2004, A Technology-based Global Inventory of Black and Organic Carbon Emissions from Combustion, Journal of Geophysical Research, 109, D14203, doi: 10.1029/2003JD003697.

Bond, T.C., Bussemer, M., Wehner, B., Keller, S., Charlson, R.J. & Heintzenberg, J., 1999, Light Absorption by Primary Particle Emissions from a Lignite Burning Plant, Environmental Science & Technology, 33(21), 3887-3891.

Cai, H., and Xie, S., 2007, Estimation of Vehicular Emission Inventories in China from 1980 to 2005, Atmospheric Environment, 41, 8963–8979.

Cadle, S.H., Mulawa, P.A., Hunsanger, E.C., Nelson, K.,Ragazzi, R.A., Barrett, R., Gallagher, G.L., Lawson, D.R., Knapp, K.T., Snow, R., 1999, Composition of light-duty motor vehicle exhaust particulate matter in the Denver, Colorado Area, Environmental Science and Technology, 33, 2328–2339.

Cao, G., Zhang, X. and Zheng, F., 2006, Inventory of Black Carbon and Organic Carbon Emissions from China, Atmospheric Environment, 40, 6516–6527.

Cao, G.L., Zhang, X.Y., Gong, S.L., Zheng, F.C., 2008, Investigation on Emission Factors of Particulate Matter and Gaseous Pollutants from Crop Residue Burning. Journal of Environmental Sciences, 20, 50-55.

Center for Global and Regional Environmental Research (CGRER), 2007, http://www.cgrer.uiowa.edu/EMISSION_DATA/index_16.htm, (downloaded on 17th May 2007).

Chan, T.L., and Ning, Z., 2005, On-road remote sensing of diesel vehicle emissions measurement and emission factors estimation in Hong Kong, Atmospheric Environment, 39, 6843–6856.

Chen, C., Huang, C, Jing, Q, Wang, H, Pan, H., Lia, L., Zhao, J., Dai, Y., Huang, H., Schipper, Y., Streets, D.G., 2007, On-road emission characteristics of heavy-duty diesel vehicles in Shanghai, Atmospheric Environment, 41, 5334–5344.

Chitijan, M., Tonnesen, G., and Mansell, G., 2003, An Improved Ammonia Inventory for The WRAP Domain: Technical Description of the Modeling System, Prepared for WRAP Emissions Forum.

Christian, T.J., Kleiss, B., Yokelson, R.J., Holzinger, R., Crutzen, P.J., Hao, W.M., Saharjo, B.H., Ward, D.E., 2003, Comprehensive laboratory measurements of biomass-burning emissions: 1. Emissions from Indonesian, African, and other fuels. *Geophysical Research,* 108(D23), 4719-4732.

CMU, 2001, Carnegie Mellon University (CMU) inventory, http://www.envist.cmu.edu/nh3.

Cooke, W. F., et al., 1999, Construction of a 1deg x 1deg Fossil Fuel Emission Data Set for Carbonaceous Aerosol and Implementation in the ECHAM4 Model, Journal of Geophysical Research- Atmospheres, 104, 22,137–22,162.

Cowherd, C., 2006, Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Dust Emission Factors, Prepared by Midwest Research Institute for Western Governors Association, Western Regional Air Partnership, Denver, CO, February 1, 2006.

CPCB, 2000, Transport Fuel Quality for Year 2005, Central Pollution Control Board, Delhi, India.

Danutawat, T., and Kim Oanh, N.T., 2007, Effects from open rice straw burning emission on air quality in the Bangkok metropolitan region, Science Asia, 33, Vol. 3, 2007.

Dennis, A., Fraser M., Anderson, S. and Allen, D., 2002, Air Pollutant Emissions Associated with Forest, Grassland and Agricultural Burning in Texas, Atmospheric Environment, 36, 3779-3792.

De Meyer, P., Maes, F. and Volckaert, A., 2008, Emissions from International Shipping in the Belgian Part of the North Sea and the Belgian Seaports, Atmospheric Environment, 42, 196–206.

DEDE, 2003. *Rice in Thailand*. Department of Alternative Energy Development and Efficiency (DEDE), Bangkok, Thailand.

DEDE, 2007, *Biomass energy*. Department of Alternative Energy Development and Efficiency (DEDE), Bangkok, Thailand.

Durbin, T.D., Norbeck, J.M., Smith, M.R. & Truex, T.J., 1999, Particulate Emission Rates from Light-Duty Vehicles in the South Coast Air Quality Management District, Environmental Science & Technology, 33(24), 4401-4406.

EFE., 2009, *Final report: Study on biomass resources management for alternative energy in macro level*. Energy for Environment Foundation (EFE), Bangkok, Thailand.

EMEP/CORINAIR, 2002, EMEP/CORINAIR Emission Inventory Guidebook, Third Edition, 2002, European Environment Agency, 2002. http://www.eea.europa.eu/publications/ EMEPCORINAIR3.

EMEP/CORINAIR, 2006, EMEP/CORINAIR Emission Inventory Guidebook, 2006, European Environment Agency, 2008.
http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html.

EMEP/CORINAIR, 2007, EMEP/CORINAIR Emission Inventory Guidebook – 2007, European Environment Agency (EEA), http://www.eea.europa.eu/publications/EMEPCORINAIR5.

Economopoulos A.P., 1993, Assessment of Sources of Air, Water and Land Pollution, Part One: Rapid Inventory Techniques in Environmental Pollution, WHO, Geneva.

Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. & Egami, R.T., 2002, The comparison of source contributions from residential coal and low-smoke fuels, using CMB modeling, in South Africa, Environmental Science & Policy, 5(2), 157-167.

FAO, 2003, State of world's forest, 2003, Food and Agriculture Organization of the United Nations (downloaded from http:////rmportal.net/library/l/A/2/b/fao-2003-state-of-the worlds-forests/fao-2003-state-of-the-world-s-forests/view).

Faiz, A., C. S. Weaver, and M. P. Walsh, 1996, Air Pollution From Motor Vehicles: Standards and Technologies for Controlling Emissions, World Bank, Washington, D. C.

Fine P.M., Cass G.R. & Simoneit, B.R.T., 2002, Chemical Charactrization of Fine Particle Emissions from the Fireplace Combustion of Woods Grown in the Southern United States, Environmental Science & Technology, 34(11), 1442-1451.

GAPF, 2007, The global atmospheric pollution forum air pollutant emissions inventory manual (Version 1.3), Global Atmospheric Pollution Forum (GAPF), Stockholm Environment Institute.

Ge, S., Bai, Z., Liu, W., Zhu, T., Wang, T., Qing, S. & Zhang, J., 2001, Boiler Briquette Coal versus Raw Coal: Part I – Stack Gas Emissions. Journal of the Air & Waste Management Association, 51, 524 - 533.

Giglio, L., Van Der Werf, G. R., Randerson, J. T., Collatz, G. J. and Kasibhatla, P., 2006, Global Estimation of Burned Area using MODIS Active Fire Observations, Atmospheric Chemistry and Physics, 6, 957-974.

Gillies, J.A. & Gertler, A.W., 2000, Comparison and Evaluation of Chemically Speciated Mobile Source PM2.5 Particulate Matter Profiles. Journal of the Air & Waste Management Association 50, 1459-1480.

Gillette, D.A., Adams, J., Endo, E. and Smith, D., 1980, Threshold Velocities for Input of Soil Particles into the Air by Desert Soils, Journal of Geophysical Research, 85(C10), 5621-5630.

Graham, L.A., Rideout, G., Rosenblatt, D., and Hendren, J., 2008, Greenhouse gas emissions from heavy-duty vehicles, Atmospheric Environment, 42, 4665–4681.

Hao, W.M., Liu, M.H., 1994, Spatial and Temporal Distribution of Tropical Biomass Burning, Global Biogeochemical Cycles, 8, 495 – 503.

Hangebrauck, R.P., von Lehmden, D.J & Meeker, J.E. 1964, Emissions of Polynuclear Hydrocarbons and other Pollutants from Heat-Generation and other Pollutants from Heat-Generation and Incineration Processes, Journal of the Air Pollution Control Association, 14(7), 267-278.

Hoelzemann, J.J., Schultz, M.G., Brasseur, G.P., and Grainer, C., 2004, Global Wildland Fire Emission Model (GWEM): Evaluating the Use of Global Area Burnt Satellite Data, Journal of Geophysical Research, Vol. 109, D14S04.

Houck, J. E., and P. E. Tiegs, 1998, Residential wood combustion technology review, Rep. EPA-600/R-98-174a, U.S. Environ. Prot. Agency, Washington, D. C.

Hildemann, L. M., G. R. Markowski, and G. R. Cass., 1991, Chemical composition of emissions from urban sources of fine organic aerosol, Environ. Sci. Technol., 25, 744– 759.

Intergovernmental Panel on Climate Change (IPCC), 1995, Climate Change1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios, Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC), 1997, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reporting Instructions (Vol. 1), Workbook (Vol. 2), Reference Manual (Vol. 3), Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC), 2006, IPCC Guidelines for National Greenhouse Gas Inventories, (downloaded from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html).

International Maritime Organization, 1987, Information can be accessed at http://www.imo.org/.

Jenkins BM, Turn SQ, Williams RB, Goronea M, Abd-el-Fattah H., 1996, Atmospheric pollutant emission factors from open burning of agricultural and forest biomass by wind tunnel simulations, Volume 1. California State Air Resources Board, 1996.

JICA, 1997, Project of "The Study on the Integrated Air Quality Management for Jakarta Metropolitan Area", conducted by Japan International Cooperation Agency (JICA).

Jingura, R.M., & Matengaifa, R. , 2008, The potential for energy production from crop residues in Zimbabwe. *Biomass and Bioenergy*, 32(12), 1287-1292.

Justice, C.O., Giglio, L., Korontzi, S., Owens, J., Morisette, J.T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F. and Kaufman, Y., 2002, The MODIS Fire Products, Remote Sensing Environment, 83, 244-262.

Kasischke, E. S., Hewson, J. H., Stocks, B., Van Der Werf, G. and Randerson J., 2003, The Use of ATSR Active Fire Counts for Estimating Relative Patterns of Biomass Burning - A Study from the Boreal Forest Region, Geophysical Research Letters , 30, 18.

Kannari, A., Tonooka, Y., Baba, Y., and Murano, K., 2007, Development of Multiple-Species 1 Km×1 Km Resolution Hourly Basis Emissions Inventory for Japan, Atmospheric Environment, 41, 3428 – 3439.

Kato, N., and Akimoto, H., 1992, Anthropogenic Emissions of SO_2 and NOx in Asia: Emission Inventories, Atmospheric Environment, 26A, 2997 – 3017.

Kerminen, V-M, Mäkelä, T.E., Ojanen, C.H., Hillamo, R.E., Vilhunen, J.K., Rantanen, L., Havers, N., von Bohlen, A. & Klockow, D., 1997, Characterization of the Particulate Phase in the Exhaust from a Diesel Car. Environmental Science & Technology, 31, Vol. 7, 1883-1889.

Kirchstetter, T.W., Harley, R.A., Kriesberg, N.M., Stolzenburg, M.R. and Hering, S.V., 1999, On-Road Measurement of Fine Particle and Nitrogen Oxide Emissions from Light- and Heavy-Duty Motor Vehicles, Atmospheric Environment, 33, 2955–2968.

Kim Oanh, N.T., Upadhyay, N., Zhuang, Y.H, Hao, Z.P., Murthy, D.V.S, Lestari, P., Villarine, J.T., Chengchua, K., Co, H.X., Dung, N.T., and Lindgren, E.S., 2006, Particulate air pollution in six Asian cities: Spatial and temporal distributions, and associated sources, Atmospheric Environment, 40 , 3367–3380.

Kim Oanh, N.T., Thiansathit, W., Bond, T.C., Subramanian, R.B., Winijkul, E., Paw-armart., I., 2009, Compositional characterization of PM2.5 emitted from in-use diesel vehicles, Atmospheric Environment, in press, 2009.

Kim Oanh, N. T., Thuy, L. B., Tipayarom, D., Manadhar, D. R., Pongkiatkul, P., Simpson, C. D., Liu, S. L-J., 2010, Characterization of particulate matter emission from open burning of rice straw, Atmospheric Environment, In press.

Kojima, M., C. Brandon, and J. Shah., 2000, Improving Urban Air Quality in South Asia by Reducing Emissions From Two-Stroke Engine Vehicles, World Bank, Washington, D. C.

Kupiainen, K., and Klimont, Z., 2007, Primary emissions of fine carbonaceous particles in Europe, Atmospheric Environment, 41, 2156–2170.

Lappi, M., Vesala, H., Virtanen, A., Keskinen, J., Ålander, T., Leskinen, A., Turrek, T., Willman, P., Raunemaa, T., Pajander, H., Mäkela, T., Hillamo, R., Honkanen, M. & Honkanen, T., 2001b, Nykyaikaisen ajoneuvomoottorin hiukkasmittaus, hiukkaskoko jahiilen laatu. Bensiinihenkilöautokokeet. (Results from Modern Gasoline Vehicles), VTT Energy, Energy Use in Transportation. Espoo, 53 p. In Finnish.

Le, H.A., and Kim Oanh, N.T., 2009, Integrated Assessment of Brick Kiln Emission Impacts on Air Quality, Environmental Monitoring and Assessment, in press.

Li, X., Wang, S., Duan, L., Hao, J., Li, C., Chen, Y., Yang, L., 2007, Particulate and trace gas emissions from open burning of wheat straw and corn stover in china, Environmental Science & Technology, 41, 17, 6052-6058.

Meng, Z., Dabdub, D. and Seinfeld, J.H, 1997, Chemical Coupling between Atmospheric Ozone and Particulate Matter, Science, 277, 116-119.

Miguel, A.H., Kirchstetter, T.W., Harley, R.A. & Hering, S.V. 1998, On-road Emissions of Particulate Polycyclic Aromatic Hydrocarbons and Black Carbon from Gasoline and Diesel Vehicles, Environmental Science & Technology, 32, 4, 450-455.

Muhlbaier, R., and Williams, R.L., 1982, Fireplaces, furnaces, and vehicles emission sourcesof particulate carbons, in Particulate Carbon: Atmospheric Life Cycle, edited by G.T. Wolff and R.L. Klimsch, Plenum Press, New York, pp. 185-205.

Muhlbaier, R., and Cadle, S.H., 1989, Atmospheric carbon particles in Detroit urban area: wintertime sources and sinks, Aerosol Sci. Technol., 10, 237-248.

Muhlbaier Dasch J. 1982, Particulate and Gaseous Emissions from Wood-Burning Fireplaces. Environmental Science & Technology, 16, 10, 639-645.

Mumford, J.L., Harris, D.B., Williams, K., Chuang, J.C. & Cooke, M., 1987, Indoor Air Sampling and Mutagenicity Studies of Emissions from Unvented Coal Combustion, Environmental Science & Technology, 21, 3, 308-311.

Norbeck, J.M., Durbin, T.D. & Truex, T.J., 1998a, Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles. Final Report CRC Project No. E-24- 2. Center for Environmental Research and Technology, University of California. Riverside, CA, December 1998.

Norbeck, J.M., Durbin, T.D., Truex, T.J. & Smith, M.R., 1998b, Characterizing Particulate Emissions from Medium- and Light Heavy Duty Diesel-Fueled Vehicles, Final Report for South Coast Air Quality Management District, Contract No. 97031, Center for Environmental Research and Technology, University of California. Riverside, CA, September 1998.

NSE, 2004, National Status of Environment of Indonesia 2004, Ministry of Environment (MOE) of Indonesia, Indonesia.

Oanh, N. T. K., L. B. Reutergardh, and N. T. Dung., 1999, Emission of Polycyclic Aromatic Hydrocarbons and Particulate Matter from Domestic Combustion of Selected Fuels, Environment Science Technology, 33, 2703–2709.

Oanh, N.T.K., Albina, D.O., Ping, Li., Wang, X., 2005, Emission of particulate matter and polycyclic aromatic hydrocarbons from select cookstove–fuel systems in Asia, Biomass and Bioenergy, 28, 579–590.

OECD/IEA, 1998. Energy Statistics & Balances of Non-OECD Countries 1995-1996, OECD/ International Energy Agency, Paris.

Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K., Yan, X., and Hayasaka, T., 2007, An Asian Emission Inventory of Anthropogenic Emission Sources for the Period 1980-2020, Atmospheric Chemistry and Physics, 7, 4419-4444.

Patschull, J. & Roth, P., 1995, Measurement and Reduction of Particles Emitted from a Two-stroke Engine. Journal of Aerosol Science Vol. 26(6), 979-987.

Penner, J.E., Chuang, C.C., Liousse, C., 1996, The contribution of carbonaceous aerosols to climate change. 14th International Conference on Nucleation and Atmospheric Aerosols, 26-30 August 1996, Helisinki, Finland.

Pham, T. B. T., Manomaiphiboon, K., Vongmahadlek, C., 2008, Development of an Inventory and Temporal Allocation Profiles of Emissions from Power Plants and Industrial Facilities in Thailand, Science of the Total Environment, Vol. 397, No. 1-3, pp. 103-118.

Prashad, V.K., Kant, Y., Gupta, K.P., Sharma, C., Mitra, A.P., and Badarinath, K.V.S., 2001, Biomass and Combustion Characteristics of Secondary Mixed Deciduous Forests in Eastern Ghats of India, Atmospheric Environment, 35, 3085–3095.

Paw-amart, I., 2004, Development of mobile source emission factors for Bangkok using modeling and emission testing tools, AIT Master Thesis, 2004.

Purvis, C.R., McCrillis, R.C. & Kariher, P.H. 2000, Fine Particulate Matter (PM) and Organic Speciation of Fireplace Emissions. Environmental Science & Technology, 34, 9, 1653 - 1658.

Ramanathan, V., et al., 2001, Indian Ocean Experiment: An Integrated Analysis of the Climate Forcing and Effects of the Great Indo-Asian Haze, Journal of Geophysical Research, 106, 28, 371– 28,398.

Ramanathan, V. Agrawal, M., Akimoto, H., Auffhammer, M., Autrup, H., Barregard, L., Bonasoni, P., Brauer, M., Brunekreef, B., Carmichael, G., Chang, W.C., Chopra, U.K., Chung, C.E., Devotta, S., Duffus, J., Emberson, L., Feng, Y., Fuzzi, S., Gordon, T., Gosain, A.K., Hasnain, S.I., Htun, N., Iyngararasan, M., Jayaraman, A., Jiang, D., Jin, Y., Kalra, N., , J. Kim, Lawrence, M., Mourato, S., Naeher, L., Nakajima, T., Navasumrit, P., Oki, T., Ostro, B., Panwar, T.S., Rahman, M.R., Ramana, M.V., Rodhe, H., Ruchirawat, M., Rupakheti, M., Settachan, D., Singh, A.K., St. Helen, G., Tan, P.V., Tan, S.K.,. Viet, P.H, Vincent, J., Wang, J.Y., Wang, X., Weidemann, S., Yang, D., Yoon, S.C., Zelikoff, J. , Zhang, Y.H., and A. Zhu, 2008, Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia. United Nations Environment Programme, Nairobi, Kenya.

Ramanathan, V. and Crutzen, P.J., 2003, New Directions: Atmospheric Brown "Clouds", Atmospheric Environment, 37, 4033-4035.

Ramanathan, V., and Xu, Y.,2010, The Copenhagen Accord for limiting global warming: Criteria, constraints, and available avenues., Proc. Nat. Acad. Sci., 107 (18) 8055-8062

Reddy, M.S., and Venkataraman, C., 2002a, Inventory of aerosol and sulfur dioxide emissions from India. Part I – Fossil Fuel Combustion, Atmospheric Environment, 36, 677–697.

Roy, B., Pouliot, G.A., Gilliland., A., Pierce, T., Howard, S., Bhave, P.V., Benjey, W., 2007, Refining Fire Emissions for Air Quality Modeling with Remotely Sensed Fire Counts: A Wildfire Case Study, Remote Sensing Environment, 41, 655-665.

Roy, D.P., Boschetti, L., Justice, C.O., and Jil, J., 2008, The collection of 5 MODIS burned area product-Global evaluation by comparison with the MODIS active fire products, Journal Remote Sensing of Environment, 112, 3690-3707.

Roden, C.A., Bond, T.C., Conway, S., Pinel, A.B.O., MacCarty, N., Still, D., 2009, Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves, Atmospheric Environment, 43, 1170–1181.

Sahai, S., Sharma, C., Singh, D.P., Dixit, C.K., Sharma, P., et al., 2007, A Study for Development of Emission Factors for Trace Gases and Carbonaceous Particulate Species from in Situ Burning of Wheat Straw in Agricultural Fields in India, Atmospheric Environment, 41, 9173-9186.

Sajjakulnukit, B., Yingyua, R., Maneekhao, V., Pongnarintasut, V., Bhattacharya, S.C., Salam, P.A., 2005, Assessment of sustainable energy potential of non-plantation biomass resources in Thailand. *Biomass and Bioenergy*, 29(3), 214–224.

Sakai, T., T. Nakajima, and H. Yamazaki., 1999, O-PM/emitted matters caused by two-stroke engine oil and its reduction, SAE Pap. 1999-91- 3260, Soc. of Automotive Eng., Warrendale, Pa.

Schauer, J., 2003, Evaluation of elemental carbon as a marker for diesel particulate matter, Journal of Exposure Analysis and Environmental Epidemiology, 2003, 13, 443–453.

Schauer, J.J., Kleeman, M.J., Cass, G.R. & Simoneit, B.R.T., 2002, Measurement of Emissions from Air Pollution Sources. 5. C1-C32 Organic Compounds from Gasoline - Powered Motor Vehicles. Environmental Science & Technology 36(6), 1169-1180.

Schauer, J.J., Kleeman, M.J., Cass, G.R. & Simoneit, B.R.T., 1999, Measurement of Emissions from Air Pollution Sources. 1. C1 through C29 Organic Compounds from Meat Charbroiling. Environmental Science & Technology 33(10), 1566-1577.

Seinfeld, J.H. and Pandis, S.N., 1998, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, John Wiley & Sons, Inc, Canada.

Shrestha, R.M. and Malla, S., 1996, Air pollution from energy use in a developing country city: the case of Kathmandu Valley, Nepal. Energy, 21, pp. 785–794.

Smith, Kirk R. et al, 2000, Greenhouse Gases from Small-Scale Combustion Devices in Developing Countries: Phase IIA Household Stoves in India, U.S. EPA EPA/600/R- 00/052.

Smith, K. R., D. M. Pennise, P. Khummongkol, V. Chaiwong, K. Ritgeen, J. Zhang, W. Panyathanya, R. A. Rasmussen, and K. A. Khalil., 1999. Greenhouse gases from small-scale combustion devices in developing countries: Charcoal-making kilns in Thailand, EPA-600/R-99-109, U.S.A Environ. Prot. Agency, Research Triangle Park, N. C.

Streets, D.G., Gupta, S., Waldhoff, S. T., Wang, M. Q., Bond, T. C. and Bo, Y., 2001, Black Carbon Emissions in China, Atmospheric Environment, 35, 4281-4296.

Streets, D.G., Bond, T.C., Carmichael, G.R., Fernandes, S.D., Fu, Q., He, D., Klimont, Z., Nelson, S.M., Tsai, N.Y., Wang, M.Q., Woo, J.-H. and Yarber, K.F., 2003, An Inventory of Gaseous and Primary Aerosol Emissions in Asia in the Year 2000, Journal of Geophysical Research, 108, NO. D21, 8809, doi: 10.1029/2002JD003039.

Stroppiana, D., Brivio, P. A., and Gr´egoire, J.-M., 2000, Modelling the impact of vegetation fires, detected from NOAA-AVHRR data, on tropospheric chemistry in tropical Africa, in: Biomass burning & its inter-relations with the climate system, Kluwer Academic Publishers, The Netherlands, 193–213.

STi (Sonoma Technology, Inc), 2003, Recommendation Improvements to the CMU Model Ammonia Emission Inventory Model for Use by LADCO, Prepared for Lake Michigan Air Directors Consortium.

Srinivasan, J. and Gadgil, S., 2002, Asian Brown Cloud-Fact and Fantasy, *Current Science,* Vol.83, No. 5.

Spiro, P.A., Jacob, D.J. and Logan, J.A., 1992, Global Inventory of Sulfur Emissions with 1° X 1° Resolution, Journal of Geophysical Research, 97, 6023-6036.

Stockton, M.B. and Stelling, J.H.E., 1987, Criteria Pollutant Emission Factors for the 1985 NAPAP Emissions Inventory, Washington, EPA-600/7-87-015 XV-211.

Streets, D.G., Gupta, S., Waldhoff, S. T., Wang, M. Q., Bond, T. C. and Bo, Y., 2001, Black Carbon Emissions in China, Atmospheric Environment, 35, 4281-4296.

Streets, D. G., Yarber, K. F., Woo, J.-H. and Carmichael, G. R., 2003, Biomass Burning in Asia: Annual and Seasonal Estimates and Atmospheric Emissions, Global Biogeochem. Cycles, 17(4), 1099.

Subramanian, R., Winijkul, E., Bond, T.C., Thiansathit, W., Kim Oanh, N.T., Paw-armart, I., and Duleep, K.G., 2009, Climate-Relevant Properties of Diesel Particulate Emissions: Results from a Piggyback Study in Bangkok, Thailand, in press, Environ. Sci. Technol., Article ASAP DOI: 10.1021/es8032296.

Sinha, P., Hobbs, P.N., Yokelson, R.J., Christian, T.J., Kirchstetter, T.W. and Bruintjes, R., 2003, Emissions of Trace Gases and Particles from Two Ships in the Southern Atlantic Ocean, Atmospheric Environment, 37, 2139–2148.

Tipayarom, D., & Kim Oanh, N.T. , 2007, Effects from open rice straw burning emission on air quality in the Bangkok Metropolitan Region. *Science Asia,* 33(3), 339-345.

UNEP and C[4], 2002, The Asian Brown Cloud: Climate and Other Environmental Impacts, UNEP, Nairobi.

UN statistics division, 2009, Energy Yearbook-Definitions, (downloaded from http://unstats. un.org/unsd/energy/yearbook/def_english_print.htm

USEPA, 1995, Emission Factors & AP-42, Technology Transfer Network Clearinghouse for Inventories & Emissions Factors 2005, http://www.epa.gov/ttn/chief/ap42/.

USEPA, 2003, 1999 National Emission Inventory Draft Version 3. U.S. Environmental Protection Agency, RTP, NC. http://www.epa.gov/ttn/chief/net/1999 inventory.html.

USEPA, 2005, Emission Factors & AP-42, Technology Transfer Network clearinghouse for Inventories & Emissions Factors, http://www.epa.gov/ttn/chief/ap42/

USEPA, 2006, Emission Factors & AP-42, Technology Transfer Network Clearinghouse for Inventories & Emissions Factors 2006, Miscellaneous Sources: Industrial Aggregate Handling, http://www.epa.gov/ttn/chief/ap42/

USEPA, 2007, Emission Inventory Improvement Program (EEIP) Volume 1-10. Documents can be downloaded at http://www.epa.gov/ttn/chief/eiip/index.html.

Vallack, H., 2007, The Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual, Version 1.3.

Van der Werf, G. R., Randerson, J. T., Collatz, G. J., Giglio, L., Kasibhatla, P. S., Arellano, A. F., Olsen, S. C. and Kasischke, E. S., 2004. Continental-scale Partitioning of Fire Emissions during the 1997 to 2001 El Nino/La Nina period, Science, 303 (5654), 73-76.

Van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Kasibhatla, P. S. and Arellano, A. F., 2006, Interannual Variability in Global Biomass Burning Emissions from 1997 to 2004, Atmospheric Chemistry and Physics, 6, 3423-3441.

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A. H. and Friedlanderm, S.K., 2005, Residential Biofuels in South Asia: Carbonaceous Aerosol Emissions and Climate Impacts, Science, 307:1454-1456.

Venkataraman, C., Chandramouli, B. and Patwardhan, A., 1999, Anthropogenic Sulphate Aerosol from India: Estimates of Burden and Direct Radiative Forcing, Atmospheric Environment, 33, 3225– 3235.

Venkataraman, C., and G. U. M. Rao, 2001, Emission factors of carbon monoxide and size-resolved aerosols from biofuel combustion, Environ. Sci. Technol., 35, 2100–2107.

Wang, X., Mauzerall, D.L., Hu, Y., Russell, G.A., Larson, E.D., Wood, J.H., Street, D.G. and Guenther, A., 2005, A High-Resolution Emission Inventory for Eastern China in 2000 and Three Scenarios for 2020, Atmospheric Environment, 39, 5917–5933.

Watson J.G., Fujita E.M., Chow J.C., Zielinska B., Richards L.W., Neff W.D., and Dietrich D., 1998, Northern Front Range Air Quality Study (NFRAQS) final report, Chapter 4. DRI, Reno, 1998.

Williams, D. J., Milne, J.W., and Roberts, D.B., 1989, Particulate emissions from 'in-use' motor vehicles: I. Spark ignition engines, Atmos. Environ., 23, 2639– 2645.

Williams D.J., Milne, J.W., Quigley, S.M., Roberts, D.B., Kimberlee, M.C., 1989b, Particulate Emissions from 'In-use' Motor Vehicles – II. Diesel Vehicles. Atmospheric Environment 23(12), 2647-2661.

Yang, S., He, H., Lu, S., Chen, D., and Zhu, J., 2005, Quantification of Crop Residue Burning in the Field and its Influence on Ambient Air Quality in Suqian, China, Atmospheric Environment, 42, 1961-1969.

Yamaji, K., Ohara, T. and Akimoto, H., 2004, Regional-Specific Emission Inventory for NH_3, N_2O and CH_4 Via Animal Farming in South, Southeast and East Asia, Atmospheric Environment, 38, 7111–7121.

Zhang, J., Smith, K.R., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.K., Rasmussen, R.A. and Thorneloe, S.A., 2000, Greenhouse Gases and Other Airborne Pollutants from Household Stoves in China: A Database for Emission Factors, Atmospheric Environment, 34, 4537-4549.

Zhang, Q., Huang, J. and Yu, G., 2008, Polychlorinated Dibenzo-P-Dioxins and Dibenzofurans Emissions from Open Burning of Crop Residues in China between 1997 and 2004, Environmental Pollution, 151, 39-46.

Zhang, H., Ye, X., Cheng, T., Chen, J., Yang, X., Wang, L. and Zhang, R., 2008, A Laboratory Study of Agricultural Crop Residue Combustion in China: Emission Factors and Emission Inventory, Atmospheric Environment, doi: 10.1016/j.atmosenv.2008.08.015 (in press).

Zhang, Q., Streets, D.G., Carmichael, G.R., He, K.B., Huo,H., Kannari, A., Klimont, Z., Park, S., Reddy, S., Fu, JS., D. Chen, L. Duan, Y. Lei, L. T. Wang, and Z. L. Yao., 2009, Asian emissions in 2006 for the NASA INTEX-B mission, Atmos. Chem. Phys., 9, 5131–5153.

GLOSSARY

Activity

Activity refers to the exercise of a practice or ensemble of practices taking place in a delineated area over a given period of time.

Activity Data

Activity data refers to data on the magnitude of human activity that results in emissions or removals during a given period of time. Examples of activity data.include those pertaining to energy use, metal production, land areas, management systems, lime and fertilizer use and waste arisings.

Aerosol

Aerosol is a collection of solid or liquid airborne particles, typically of a size between 0.01 and 10 µm,that resides in the atmosphere for at least several hours. Aerosols may be of natural or anthropogenic origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly by acting as condensation nuclei for cloud formation or modification of the optical properties and lifetime of clouds.

Anthropogenic Emissions

Anthropogenic emissions are emissions of greenhouse gases, greenhouse gas precursors and aerosols associated with human activity. These include burning of fossil fuels for energy, deforestation and land-use changes that result in net increases in emissions.

Atmosphere

Atmosphere refers to the gaseous envelope surrounding the earth. Dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases, such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains greenhouse gas water vapour in amounts that are highly variable but are typically around 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.

Aviation Gasoline

Aviation gasoline is motor spirit prepared especially for aviation piston engines, with an octane number suited to the engine, a freezing point of -60ºC, and a distillation range usually within the limits of 30ºC to 180ºC.

Biofuel

Biofuel refers to any liquid, gaseous, or solid fuel produced from plant or animal organic matter. Examples include soybean oil, alcohol from fermented sugar, black liquor from the paper manufacturing process, wood as fuel, and so on. Second-generation biofuel products include ethanol and biodiesel derived from ligno-cellulosic biomass using chemical or biological processes.

Biogas

Biogas is derived principally from the anaerobic fermentation of biomass and solid wastes and combusted to produce heat and/or power. Included in this category are landfill gas and sludge gas (sewage gas and gas from animal slurries).

Biomass

Biomass, a renewable energy source, is biological material derived from living or recently deceased organisms, such as wood, waste and alcohol fuels. Forest residues, such as dead trees, branches and tree stumps, yard clippings and wood chips may be used as biomass. Biomass also includes plant or animal matter used in the production of fibers or chemicals. Biomass may also include biodegradable wastes that can be burnt as fuel. However, organic material, such as fossil fuel, which has been transformed by geological processes into such substances as coal or petroleum is not considered as biomass.

Biomass Open Burning

Biomass open burning is the burning of living or dead vegetation. It includes human-initiated burning of vegetation for land clearing and land-use change as well as lightning-induced natural,fires.

Black Carbon (BC)

Black carbon consists of soot, charcoal, and/or possible light-absorbing refractory organic matter. These are operationally defined species of particulate matter based on measurement of light absorption and chemical reactivity and/or thermal stability.

Brown Coal Briquettes (BKB)

Brown coal briquettes are composition fuels manufactured from lignite/brown coal, produced by briquetting under high pressure.

Blast Furnace Gas

Blast furnace gas is produced during the combustion of coke in blast furnaces in the iron and steel industry. It is recovered and used as fuel partly within the plant and partly in other steel industry processes or in power stations equipped to burn it.

Bottom-up Approach

Bottom-up approach means that emissions from individual sources are estimated and summed up to obtain state or country level estimates. While this approach is typically used for inventory of point sources, it can also be used in the inventorization of area sources, when resources are available, to collect local activity data through rigorous survey. This approach requires the use of more resources in order to collect site-specific information on emission sources, activity levels and emission factors. Compared with a top-down approach, the results are more accurate estimates because data are collected directly from individual sources and are not derived from national or regional estimates.

Carbon Dioxide (CO_2)

Carbon dioxide is a naturally occurring gas. It is also a by-product resulting from the burning of fossil fuels from fossil carbon deposits, such as oil, gas and coal, burning of biomas, land use changes and various industrial processes. The principal anthropogenic greenhouse gas that affects the Earth's radiative balance, carbon dioxide is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.

Charcoal

Charcoal refers to solid residues resulting from the destructive distillation and pyrolysis of wood and various vegetable materials.

Climate Change

Climate change refers to changes in the mean and/or variability of the climate's properties. Such change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or to changes in land use. Climate change can be identified by using statistical tests, for example, and may persist for an extended period, typically decades or longer.

Coking Coal

Coking coal refers to coal with a quality that allows the production of coke suitable to support a blast furnace charge. Its gross calorific value is greater than 23,865 kJ/kg (5700 kcal/kg), on an ash-free but moist basis.

Coke Oven Coke and Lignite Coke

Coke oven coke is the solid product obtained from the carbonization of coal, principally coking coal, at high temperature. Also included are semi-coke, a solid product obtained from the carbonization of coal at a low temperature, lignite coke, semi-coke made from lignite/brown coal, coke breeze and foundry coke.

Coke Oven Gas

Coke oven gas is obtained as a by-product from the manufacture of coke-oven coke in the production of iron and steel.

Criteria Pollutants

Criteria pollutants refer to six chemicals, carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter and sulphur dioxide,.which occur frequently in ambient air and can be harmful to human health and the environment and can cause property damage.

Crude Oil

Crude oil is mineral oil that consists of a mixture of hydrocarbons of natural origin. Yellowish or black in color, it is of variable density and viscosity. It also includes lease condensates (separator liquids) which are recovered from gaseous hydrocarbons in lease separation facilities.

Emission Factor

An emission factor is the rate of emission per unit of activity, output or input. For example, a particular fossil fuel power plant may generate a CO_2 emission factor of 0.765 kg/kWh.

Emission

Emission refers to the release of greenhouse gases and/or their precursors into the atmosphere over a specific area and period of time.

Elemental Carbon

Elemental carbon, often called "soot", is black. Elemental carbon contains pure graphite carbon in addition to non-volatile organic materials, such as tar, biogenic and coke, which are dark colored and of high molecular weight. Carbonate carbon is another material of inorganic fraction that plays an important role in altering pH characteristics and synergistically affects secondary aerosol formation.

Emission Inventory

Emission inventory is a major tool for identifying sources of pollution and for providing quantitative expression of pollution load in a defined area. Such a study involves preparation of detailed emission inventory with estimation of emissions, from various vehicular, industrial, residential, commercial activities, that are obtained using primary as well as secondary data collection. The impact of pollution from these sources depends on many factors, suchh as the distance to emission sources, concentration of pollutants, temporal and spatial variations in emission patterns and receptor types, and so on.

Emission Standard

Emission standard is a level of emission that by law or by voluntary agreement may not be exceeded. Many standards use emission factors in their prescription and therefore do not impose absolute limits on the emissions.

Energy

Energy refers to the amount of work or heat delivered. Energy falls under different classifications and becomes useful to human activities, when it flows from one place to another or is converted from one type to another.

Flaring

Flaring refers to open air burning of waste gases and volatile liquids, through a chimney, at oil wells or rigs, in refineries or chemical plants and at landfills.

Forests

Forests are defined under the Kyoto Protocol as land areas (minimum 0.05 to 1.0 ha) with a tree-crown cover (or equivalent stocking level), of which more than 10 to 30 % are trees with a potential to reach a minimum height of 2 to 5 m at maturity *in situ.* A forest may be an open forest or may consist of closed forest formations where trees of various heights and undergrowth cover a high proportion of the ground. Young natural trees and all plantations that have yet to reach a crown density of 10 to30 % or a tree height of 2 to 5 m may normally form part of a forest area that is temporarily un-stocked as a result of human intervention, such as harvesting, or natural causes, but which is expected to revert to being a forest.

Fossil Fuels

Fossil fuels are carbon-based fuels from fossil hydrocarbon deposits, including coal, peat, oil and natural gas.

Fugitive Losses

Fugitive losses are emissions of hydrocarbon vapors from process equipment and evaporation of hydrocarbons from open areas rather than through a stack or vent. Fugitive losses include emissions from valves, connectors, flanges, seals, process drains, oil/water separators, storage, transfer operations, and so on. This term may also be applied to PM losses.

Gas Coke

Gas coke is a by-product of hard coal used in the production of town gas in gas works. Gas coke is used for heating purposes.

Gas/Diesel Oil

Gas/diesel oil includes heavy gas oils. Gas oils are obtained from the lowest fraction from atmospheric distillation of crude oil, while heavy gas oils are obtained by vacuum re-distillation of the residual from atmospheric distillation. Gas/diesel oil distils between 180ºC and 380ºC. Several grades are available depending on the intended use, as follows: diesel oil for diesel compression ignition (cars, trucks, marine, and so on), light heating oil for industrial and commercial use, and other gas oils, including heavy gas oils, which distil between 380ºC and 540ºC and re used as petrochemical feed stocks.

Gas Works Gas

Gas works gas covers all types of gas produced in public or private utility plants whose main purpose is the manufacture, transport and distribution of gas. It includes gas produced by carbonization (including gas produced by coke ovens and transferred to gas works), total gasification, cracking natural gas, and reforming and simple mixing of gases and/or air. Also included is substitute natural gas, which is a high calorific value gas manufactured by chemical conversion of a hydrocarbon fossil fuel.

Gasoline Type Jet Fuel

Gasoline type jet fuel includes all light hydrocarbon oils for use in aviation turbine power units. They distil between 100ºC and 250ºC and are obtained by blending kerosene and gasoline or naphthas in such a way that the aromatic content does not exceed 25% in volume. Additives can be included to improve fuel stability and combustibility.

Global Warming

Global warming refers to observed or projected gradual increase in global surface temperature as a consequence of radiative forcing caused by anthropogenic emissions.

Greenhouse Gases (GHGs)

Greenhouse gases are natural and anthropogenic gaseous constituents of the atmosphere, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine- and bromine-containing substances dealt with in the Montreal Protocol. Besides carbon dioxide, nitrous oxide and methane, other greenhouse gases dealt with in the Kyoto Protocol are sulphur hexafluoride, hydro fluorocarbons, and per fluorocarbons.

Hazardous Air Pollutants (HAPs)

Hazardous air pollutants refer to chemicals which can adversely affect human health and the environment. These are pollutants that can cause cancer and neurological, respiratory and reproductive ailments.

Heavy Fuel Oil (HFO)

Heavy fuel oil includes oils that make up distillation residues. It comprises all residual fuel oils, including those obtained by blending. The flash point is always above 50ºC while the density exceeds 0.90 kg/l.

IEA

The International Energy Agency, based in Paris, is an autonomous agency linked with the Organization for Economic Co-operation and Development (OECD). The IEA Secretariat collects and analyses energy data, assesses Member countries' domestic energy policies and programmes, makes projections based on differing scenarios and prepares studies and recommendations on specialized energy topics. For more information see: http://www.iea.org/

Industrial Wastes

Industrial wastes used as fuel consist of solid and liquid products (for example, tyres) that are combusted directly, usually in specialized plants, to produce heat and/or power. These industrial wastes are not reported under the categories of solid biomass and animal products.

IPCC

IPCC stands for the Intergovernmental Panel on Climate Change. IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess available scientific, technical and socio-economic information in the field of climate change.

Kerosene Type Jet Fuel

Kerosene type jet fuel is a medium distillate used for aviation turbine power units. It has the same distillation characteristics and flash point as kerosene (between 150ºC and 300ºC but not generally above 250ºC). In addition, it has particular specifications (such as freezing point) which have been established by the International Air Transport Association (IATA).

Kerosene

Kerosene comprises refined petroleum distillate that is intermediate in volatility between gasoline and gas/diesel oil. It is a medium oil that distills between 150ºC and 300ºC.

Landfill

A landfill is a solid waste disposal site where waste is deposited below, at or above ground level. It is limited to engineered sites with cover materials, controlled placement of waste and management of liquids and gases. It excludes uncontrolled waste disposal.

Land-use

Land-use is the sum total of arrangements, activities and inputs undertaken in a certain land-cover type (a set of human actions). Land-use also refers to land management for social and economic purposes (for example, grazing, timber extraction, and conservation). Land-use change occurs, for example, when forest is converted to agricultural land or to urban areas.

Liquid Biomass

Liquid biomass includes bio-additives such as ethanol.

Lignite/Brown Coal

Lignite/brown coal is non-agglomerating coal that has a gross calorific value less than 17435 kJ/kg (4165 kcal/kg) and over 31 per cent volatile matter, on a dry mineral matter-free basis (UN, 2009).

Liquefied Petroleum Gases (LPG)

Liquefied petroleum gases are light hydrocarbon fractions of the paraffin series, derived from refinery processes, crude oil stabilization plants and natural gas processing plants, comprising propane (C_3H_8) and butane (C_4H_{10}) or a combination of the two. They are normally liquefied under pressure and are used for transportation and storage.

Landing and Take-off (LTO) Cycle

The LTO cycle includes all aircraft activities that occur under 914 metres (3,000 feet), including idling aircraft engines, taxi-out, take-off, ascent to 914 metres, descent, approach and taxi-in. While some statistics consider a single takeoff or landing as one cycle, the LTO cycle. definition includes both one take-off and one landing.

Motor Gasoline

Motor gasoline is light hydrocarbon oil used in internal combustion engines, such as motor vehicles, excluding aircraft. Motor gasoline is distilled between 35ºC and 215ºC and is used as fuel for land-based spark ignition engines. Motor gasoline may include additives, oxygenates and octane enhancers, including lead compounds, such as TEL (tetraethyl lead) and TML (tetramethyl lead).

Municipal Wastes

Municipal waste products may be combusted directly to generate heat and/or power. These comprise wastes produced by the residential, commercial and public services sectors and collected by local authorities for disposal in a central location. Hospital waste is included in this category.

Natural Gas

Natural gas comprises gases occurring in underground deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing only hydrocarbons in gaseous form, and "associated" gas produced in association with crude oil, as well as methane recovered from coal mines (colliery gas). Production is measured after extraction of NGL and sulphur. It includes gas consumed by gas processing plants and gas transported by pipeline and excludes re-injected gas quantities, vented or flared.

Natural Gas Liquids (NGLs)

Natural gas liquids refer to liquids or liquefied hydrocarbons produced in the manufacture, purification and stabilization of natural gas. These are portions of natural gas that are recovered as liquids in separators, field facilities, and gas processing plants. NGLs include but are not limited to ethane, propane, butane, pentane, natural gasoline and condensate.

Organic Aerosol

Organic aerosols are aerosol particles consisting predominantly of organic compounds, mainly C, H, and O, and lesser amounts of other elements.

Organic Carbon

Organic carbon refers to gases and particles containing carbon and hydrogen atoms in various ratios. Organic compounds found in ambient air may also be associated with other elements and compounds, particularly oxygen, nitrogen, sulphur, halogens and metals.

Other Bituminous Coals and Anthracite

Other bituminous coals are used for steam raising and space heating purposes and includes all anthracite coals and bituminous coals not included under the category of coking coal. Its gross calorific value is greater than 23,865 kJ/kg (5700 kcal/kg), but usually lower than that of coking coal (UN, 2009).

Other Petroleum Products

Other petroleum products include petroleum products not classified above, for example: tar, sulphur and grease. This category also includes aromatics (for example, BTX or benzene, toluene and xylene) and olefins (for example, propylene) produced within refineries.

Ozone

Ozone, the tri-atomic form of oxygen, is a gaseous atmospheric constituent. In the troposphere, ozone is created by photochemical reactions involving both natural and anthropogenic gases. Tropospheric ozone acts as a greenhouse gas and is also a powerful oxidant which is harmful to humans, animals and plants. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays a dominant role in the stratospheric radiative balance and is important for absorbing most of the solar UV radiation (which is harmful to terrestrial life).

Patent Fuel

Patent fuel is a composition fuel manufactured from hard coal fines with the addition of a

binding agent.

Petroleum Coke

A black solid residue, obtained mainly by cracking and carbonizing petroleum-derived feed stocks, vacuum bottoms, tar and pitches in such processes as delayed coking or fluid coking. It is used as feedstock in coke ovens for the steel industry, as well as for heating purposes, electrode manufacture and production of chemicals. The two most important qualities are "green coke" and "calcinated coke". This category also includes "catalyst coke" that is deposited on the catalyst during refining processes. This coke is not recoverable and is usually burned as refinery fuel.

Primary Solid Biomass

Primary solid biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. Included are wood, vegetable waste (including wood waste and crops used for energy production), animal materials/wastes, sulphite lyes, also known as "black liquor" (an alkaline-spent liquor from digesters in the production of sulphate or soda pulp during the manufacture of paper, where energy content is derived from lignin removed from the wood pulp) and other solid biomass. This category covers only primary solid biomass. This includes inputs to charcoal production but not the actual production of charcoal (this would be double counting since charcoal is a secondary product).

Precursors

Precursors are compounds which participate in chemical reactions that produce other compounds.

Refinery Gas

Refinery gas is defined as non-condensable gas obtained during distillation of crude oil or treatment of oil products (for example, cracking) in refineries. It consists mainly of hydrogen, methane, ethane and olefins. It also includes gases which are returned from the petrochemical industry.

Renewable Energy

Renewable energy is obtained from continuing or repetitive currents of energy occurring in the natural environment and includes non-carbon technologies, such as solar energy, hydropower, wind, tide and waves and geothermal heat, as well as carbon-neutral technologies, such as biomass.

Sink

Sink refers to any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.

Solvent Content

Solvent content refers to the percentage of organic solvent in a product.

Soot

Soot refers to particles formed during the quenching of gases at the outer edge of flames of organic vapours, consisting predominantly of carbon, with lesser amounts of oxygen and hydrogen present as carboxyl and phenolic groups and exhibiting an imperfect graphitic structure.

Source

Source refers to any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol into the atmosphere.

Spatial Variation

Spatial variation occurs based on location.

Solvent Content

Solvent content refers to the percentage organic solvent content of a product.

Sub-Bituminous Coals

Sub-bituminous coals are non-agglomerating coals with a gross calorific value between 17,435 kJ/kg (4165 kcal/kg) and 23,865 kJ/kg (5700 kcal/kg), containing more than 31 per cent volatile matter, on a dry mineral matter-free basis (UN, 2009).

Temporal Variation

Temporal variation occurs within a defined period of time.

Top-down Approach

Top-down approach means that emission estimates are arrived at based on national or regional estimates. One scales the national estimates to one's inventory area using some measure of activity data, to be directly or indirectly related to the emissions in one's area of study.

GLOSSARY OF POLLUTANTS

CH_4 - Methane

CO - Carbon Monoxide

CO_2 - Carbon Dioxide

NH_3 - Ammonia

NMVOCs - Non-Methane Volatile Organic Compounds

NO_x - Oxides of Nitrogen

N_2O - Nitrous Oxide

NO - Nitric Oxide or Nitrogen Monoxide

NO_2 - Nitrogen Dioxide

$PM_{2.5}$ – Fine Particulates, size 2.5 µm or less

PM_{10} – Coarse Particulates, size 10 µm or less

SO_2 - Sulphur Dioxide

TOC - Total Organic Carbon

TOPs - Total Ozone Precursors, includes: NO_x, NMVOCs, CO and CH_4

TSP – Total Suspended Particulates

VOCs - Volatile Organic Compounds

ANNEX 1
DUST FUGITIVE EMISSION

Dust fugitive emission sector mostly covers those emissions induced by natural conditions such as meteorological fields. Those would be dust fugitive emission from construction, industrial aggregate handling and mining, natural wind-blown dust, and particulates from paved and unpaved road. These sectors are considered to emit particulate matter in the form of PM_{10} and $PM_{2.5}$.

A1.1. Dust Emission from Construction, Industrial Aggregate Handling and Mining and Particulates from Unpaved Road

A1.1.1. Construction Activity

A. Emission Estimation Method

This sector covers activities from land clearing, ground excavations, cut and fill operations (i.e., earth moving) and construction of a particular facility itself.

A general EI equation as given below is used to calculate the emission.

$$Em = \sum AR \times EF \qquad \text{(eq. A.1)}$$

where,
Em = Particulate emission (tonne/month)
AR = Activity rate, in this particular sector is construction area (ha)
EF = Emission factors (tonne/ha/month)

B. Data on Activity Levels and Emission Factors

For dust emission, the data needed are construction area (ha) and construction period (months). This can only be obtained from country/site specific data. The site specific data can be obtained from public work ministry or contractor that conducts the construction. The emission factor obtained from AP-42 USEPA (1995) is also presented in Table A1.1.

The monthly temporal variation can be constructed from the data of monthly material transferred/constructions waste generated from the construction site during construction period. Normally this particulate emission will be higher in the first phase of construction where some activities such as land clearing, ground excavation, and cut and fill operation are taking place. Therefore, higher emission is expected during this time. Statistic data on number of construction activities and urban population data can be used to surrogate the spatial emission in the case where specific locations of construction sites are difficult to obtain. Or, the data of provincial construction company obtained from National Statistic can be also used.

Table A1.1: Emission Factors from Construction, Industrial Aggregate Storage and Unpaved Road

Activity sources	Emission factor	
	PM$_{10}$	PM$_{2.5}$
Dust emission from construction activities (non-combustion)[a]	2.7	na
Dust emission from industrial aggregate handling and material storage facilities[b]	$0.35 \times 0.0016 \times (V/2.2)^{1.3}/(M/2)^{1.4}$	$0.053 \times 0.0016 \times (V/2.2)^{1.3}/(M/2)^{1.4}$
Dust emission from unpaved road (non-combustion)[c]	$(1.8 \times (F/12) \times (H/30)^{0.5}/(G/0.5)^{0.2}) - 0.00047) \times 282$	$(0.18 \times (F/12) \times (H/30)^{0.5}/(G/0.5)^{0.2}) - 0.00047) \times 282$

Source/Remarks:
[a] AP-42, USEPA, 1995. The unit is in tonne/ha/month. Because emission factor is referenced to TSP, use of this factor to estimate PM$_{10}$ will result in conservatively high estimate.
Also, because derivation of the factor assumes that construction activity occurs 30 days per month, the above estimate is somewhat conservatively high for TSP as well.
[b] AP-42, USEPA, 1995. The unit is in kg/tonne material transferred, V is mean wind speed (m/s) and M is material moisture content (%).
[c] AP-42, USEPA, 1995. The unit is in g/VKT. F is surface material silt content (%), G is mean vehicle weight (tonne), and H is mean vehicle speed in mile per hour (mph).
na: not applicable

A1.1.2. Dust Emission from Industrial Aggregate Handling and Mining

Dust emission is emitted from operations that use minerals in aggregate form in the maintenance of outdoor storage piles. Dust emissions occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong wind currents and loading out from the pile. The emission related to movement of trucks and loading equipment in the storage pile area is not covered in this section.

A. Emission Estimation Method

The quantity of dust emissions from aggregate storage operations vary with the volume of aggregate passing through the storage cycle. Emission factors are calculated by using equations in Table A1.1 for both PM$_{10}$ and PM$_{2.5}$. The factors are calculated based on mean wind speed, material moisture content and particle size multiplier (AP-42 USEPA, 2006). The emissions are then estimated by multiplying EFs with tonnage of material/aggregates transferred/storage.

B. Data on Activity Levels

Various values of material moisture values for industrial and mining aggregate minerals are presented in the following Table A.1.2. Mean wind speed (V) can be obtained from local meteorology bureau or stations.

Table A1.2: Moisture Content of Several Industrial Aggregates

Industry	Material	Material Moisture Content (M),(%)
1. Iron and steel production	Pellet ore	0.64 - 4
	Lump ore	1.6 - 8
	Coal	2.8 - 11
	Slag	0.25 - 2
	Flue dust	7
	Coke breeze	6.4 - 9.2
	Blended ore	6.6
	Sinter	-
	Limestone	0.2
2. Stone quarrying and processing	Crushed lime stone	0.3-1.1
	Various limestone products	0.46 - 5
3. Taconite mining and processing	Pellets	0.05 - 2
	Tailings	0.4
4. Coal mining	Coal	2.8-20
	Overburden	-
	Exposed ground	0.8-6.4
5. Coal-fired power plant	Coal	2.7-7.4
6. Municipal solid waste landfills	Sand	7.4
	Slag	2.3-4.9
	Cover	8.9-16
	Clay/dirt mix	14
	Clay/dirt mix	8.9-11
	Fly ash	26 - 29
	Misc. fill materials	11

Source/Remarks: AP-42, USEPA, 1995

A1.1.3. Particulates from Paved and Unpaved Road

This sector estimates particulate emissions from resuspended road surface materials from both paved and unpaved road. In general, resuspended particulate emissions from paved roads originate from the loose material present on the surface (i.e., the surface loading) and spillage of material. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material where the particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface.

A. Emission Estimation Method

General EI equation is used to calculate the emissions from paved and unpaved road:

$$Em = \sum AR \times EF \qquad \text{(eq. A.2)}$$

where,
Em = Emissions (g/year)
AR = Activity rate (annual VKT)
EF = Emission factors (g/VKT)

Emission factor of particulate emissions from paved and unpaved road activities are calculated based on the following equation (USEPA, 1995):

(a) Paved road:

$$E = k \times \left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{w}{3}\right)^{1.5} - C \qquad \text{(eq. A.3)}$$

where,
E = Particulate emission factor (g/VKT),
k = Particle size multiplier for particle size range and (g/VKT)
sL = Road surface silt loading (grams per square meter) (g/m^2),
W = Average weight (tonnes) of the vehicles traveling the road, and
C = Emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

(b) Un-paved road:

$$E = \left(\frac{k \times (s/12)^a \times (S/30)^b}{(M / 0.5)^c} \right) - C \qquad \text{(eq. A.4)}$$

where,
E = Size-specific emission factor (g/VKT)
s = Surface material silt content (%)
W = Mean vehicle weight (tonnes)
M = Surface material moisture content (%)
S = Mean vehicle speed (km/hr)
C = Emission factor for 1980's vehicle fleet exhaust, brake and tire wear.

B. Data on Activity Levels and Emission Factors

The main activity data to calculate the emission is VKT. This data can be calculated by multiplying number of vehicles by mileage per vehicle (km/veh.) driven on roads. The source of data can be referred to chapter 3 from on-road transportation sector.

For paved road, several compiled data (k, sL, and C) are provided in table A1.3 to calculate the EF.

Table A1.3: Particle Size Multiplier, Emission Factor for Exhaust, and Silt Loading for Paved Roads

Size Range	Particle Size Multiplier (k) in g/VKT	Emission Factor for Exhaust, C in g/VKT	Silt Loading (sL) in g/m²
$PM_{2.5}$	0.66	0.1	0.03-400
PM_{10}	4.6	0.13	-

Source/Remarks:
USEPA, 1995

For unpaved road, the data is presented in Table A1.4, where W means the "fleet" average weight of all vehicles traveling the road that can be estimated from number of vehicles.

Table A1.4: Particle Size Multiplier, Surface Silt Content, Surface Moisture Content, Mean Vehicle Speed and Mean Vehicle Weight for Un-paved Road

Road Type	Size Range	Particle Size Multiplier (k) in lb/VMT	Surface Silt Content (S) (%)	Surface Moisture Content (M) (%)	Mean Vehicle Speed (km/hr) (S)	Mean Vehicle Weight (tonnes) (W)
Industrial roads	$PM_{2.5}$	0.9	1.8-25.2	0.03-13	8-69	2-290
	PM_{10}	0.9				
Public roads	$PM_{2.5}$	0.18	1.8-35	0.03-13	16-88	1.5-3
	PM_{10}	0.18				

Source/Remarks:
USEPA, 1995 Note: 1 Lb/Vehicle Mile Travelled (VMT) = 281.9 g/VKT

Temporal and spatial distribution of emission can refer to on-road sector (chapter 3) which uses the data of traffic counting and population distribution.

A1.2. Natural Wind-Blown Dust

Dust sources, particularly fugitive dust sources can result from both human-made and natural conditions. Conceptually, dust emissions can be categorized as (1) purely anthropogenic, resulting from direct human activities, and directly subject to human management or control; (2) purely natural, generally spontaneous, and not subject to human management or control; or (3) natural sources that may be influenced by human actions. Significant natural sources of atmospheric particulate matter are soil dust (mineral aerosol) and rock debris (Seinfeld and Pandis, 1998). Those can be uplifted by winds and transported by large-scale atmospheric circulation.

This sector covers the natural wind-blown dust from dessert, vacant/non-vacant lands and disturbed area.

A1.2.1. Emission Estimation Method

Emission flux of wind-blown dust is estimated as a function of surface frictional velocity and soil texture (Environ, 2006). The relationships developed by Alfaro and Gomes (2001) for each of the soil textures were applied to estimate dust emission fluxes. These relationships are presented in Figure A1.1.

FFS
$F = 2.45 \times 10^{-6} (u_*)^{3.97}$

FS
$F = 9.33 \times 10^{-7} (u_*)^{2.44}$

MS
$F = 1.243 \times 10^{-7} (u_*)^{2.64}$

CS
$F = 1.24 \times 10^{-7} (u_*)^{3.44}$
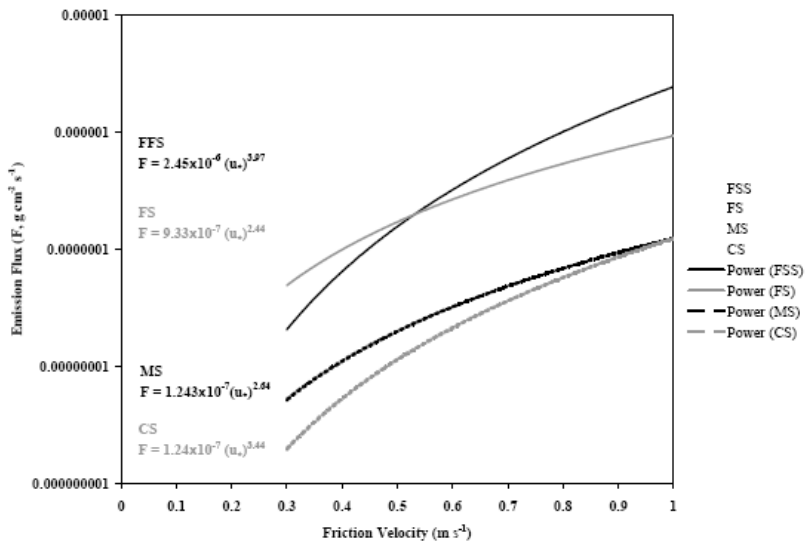
Figure A1.1: The Emission Flux as a Function of Friction Velocity

(Predicted by the Alfaro and Gomes (2001) model constrained by the four soil geometric mean diameter classes of [Soil texture categories; FSS: silt, FS: sandy silt, MS: silty sand, CS: sand]

The threshold friction velocity is estimated based on the relationship with typical surface aerodynamic roughness length as a function of land use cover. It is presented in Table A1.5.

Table A1.5: Typical Surface Aerodynamic Roughness Lengths Calculated from Available Data as Reported in Literature

Land cover Type	Surface Roughness z_0 (cm)	Threshold Frictional Velocity u^*_t (m/s)
Agricultural fields (bare)	0.031	0.38
Desert flat/pavement	0.133	0.79
Fan surface	0.088	0.57
Crusted	0.069	0.46
Playa	0.057	0.46
Prairie	0.049	0.43
Sand dune	0.007	0.32
Scrub dessert	0.045	0.42

Source/Remarks:
Gillette et al., 1980

A1.2.2. Data on Activity Levels and Emission Factors

The emission factors of wind-blown dust emission are expressed as emission flux (F) (presented in figure A1.1) which has unit of $g/cm^2/s$. It is obtained based on field and wind tunnel experiments which suggest that the emissions are proportional to wind friction speed.

Activity data needed are:

- Land use/land cover is needed to determine surface roughness (z_0). Global land use is provided by United State Geological Survey (USGS).
- Soil texture characteristics, soil characteristics, or type of soil is one of the parameters of primary importance for the application of the emission estimation relations derived from wind tunnel study results.
- Meteorology data and average wind speed data (10 m) are needed to calculate the frictional velocity. This data can be obtained from meteorological agency or output of meteorological models

The seasonal variation of emission can be constructed by using planting period (for agriculture) or climate condition (dry, higher wind speed). In addition, the emission can be spatially disaggregated by using land cover data.

ANNEX 2
QA/QC AND VERIFICATION IN ABC EIM

A2.1. Introduction

ABC EIM aims to provide guidance to develop the inventory that can be readily assessed in terms of quality. This is an important aspect of any database development, especially for that practical application like this. The emission inventory of precursors of ABCs will be used in assessment of the contributions of and interactions among ABC air pollutant sources in a region, as an input data for air quality models, climate models, and in the development, implementation, and tracking of control strategies. Therefore, it is necessary to implement quality assurance/ quality control (QA/QC) and verification procedures in the development of the inventory. QA/QC procedure in place will help to improve and know data quality.

This chapter describes major steps of inventory QA/QC and verification in-line with IPCC (2006), EMEP/CORINAIR (2006) and US EPA (1995). QA/QC and verification should be integral parts of the inventory process. The outcomes may reveal important particular variables within the inventory process for a certain category where the improvement efforts should be focused. QC procedures may be general as have been suggested in the previous inventory manuals while some practical considerations are needed in the particular characteristics of this ABC inventory. Suggested existing inventories for verification are also listed. Attempts to link QA/QC with uncertainty analysis will also be described in this chapter.

A2.2. Definitions

The terms of quality assurance, quality control, and verification are used widely in many applications in different ways. Their definitions quoted from IPCC (2006) are described below:

- **QA** is a planned system of review procedures conducted by personal not directly involved in the inventory compilation/development process. It is commonly done by independent third parties. Reviews are done to verify that the inventory represents the best possible estimates of emissions and removals, given the current state of scientific knowledge and data availability.
- **QC** is a system of routine technical activities to assess and maintain the quality of the inventory as it is being compiled. It is commonly performed by a personnel who conducts the inventory.
- **Verification** is collection of activities and procedures conducted during the planning and development or after completion of an inventory that can help to establish its reliability for the intended applications of the inventory. This may include comparisons with other inventories or through alternative methods such as comparison of bottom-up and top-down, and inverse modeling.

A2.3. Major Elements

The inventory compiler plays an important role for ensuring that the inventory results meet the standard quality so that it can be used for the planned purposes. Therefore, the compiler is also responsible for implementing QA/QC procedures to be integral part of inventory activities. QA/QC in this inventory is implemented by covering following major elements:

- Participation of inventory compilers/stake holders, who are responsible for coordinating this activity
- QA/QC plan
- Necessary general QC procedures to be applied to all categories
- Category-specific QC procedures
- Review process of inventory results (QA)
- Uncertainty analysis
- Verification
- Documentation

This chapter also describes how the supporting tools such as ABC EI EXCEL workbook are provided to be a part of the QA/QC activities. For QC general procedures, we follow the guidance of IPCC (2006) chapter 6: QA/QC and Verification. Category-specific QC procedures including factor rating for emission factors and activity data which are adopted from USEPA (1995) will also be defined here. The toughest part is linking the QA/QC with the uncertainty analysis, especially in its quantification effort. Several relevant methods which are reprinted from EMEP/CORINAIR 2004 are also presented. Several methods of verification are also introduced in this chapter including how to do the comparison with previous inventories and the accessible source of those work (internet web-page), and also the possibilities of inverse modeling. We provide information of available global emission inventories (web-site) to compare the results. The available ABC EI EXCEL workbook is one of the tools that can be used to record the inventory process and can also be recognized as 'documentation" of emission inventory. Description of QA/QC in this chapter will always be linked to the workbook as it is an important tool to support this good practice.

A2.4. QC General Procedures

QC general procedures aim to check generic quality related to calculations, data processing, completeness, and documentation that are applicable to all inventory sources. General checks may not be necessary for all aspects of inventory input data, but may be performed on selected sets of data and processes as presented in Table A2-1 which is adopted from IPCC (2006).

Table A2-1: ABC EI General QC Procedures

No	QC activity	Procedures
1	Documentation of every assumption and criteria taken in emission inventory	• Cross-check descriptions of activity data, emission factors and other estimation parameters with information on categories, and ensure that these are properly recorded and archived. • ABC EIM EXCEL workbook provide room to records as sumptions on emission factors selection and activity data involved, so users can always update the check records
2	Transcription errors identification in data input and references	• Confirm that bibliographical data references are properly cited in the internal documentation (ABC EIM EXCEL Workbook) • Cross-check a sample of input data from each category (in the EXCEL workbook) for transcription errors
3	Evaluation of emissions calculation and removals	• Reproduce a set of emissions and removals calculations (provided in the EXCEL Workbook) • Use a simple approximation method that gives similar results to the original and more complex calculation to ensure that there is no data input error or calculation error. Cross check the activity data magnitude with other data (i.e. provided in any international sources such as IEA, FAO statistics, etc). Users are requested to provide activity data following sector-wise division as provided in this manual and also in the ABC EIM EXCEL workbook to avoid double counting.
4	Double checking of every unit involved and conversion factors	• Check that units are properly labeled in ABC EIM EXCEL Workbook • Check that units are correctly carried through from beginning to the end of calculations • Check that conversion factors are correct (esp. data input in Unit Converter Menu in ABC EIM EXCEL Workbook) • Check that temporal and spatial adjustment factors are used correctly (name of surrogate factors and amounts should be recorded in ABC EXCEL Workbook)
5	Integrity of database files	Examine the included documentation to: • confirm that the appropriate data processing steps are correctly represented in the database • confirm that data relationships are correctly represented in the database • ensure that data fields are properly labeled and have the correct design specifications • ensure that adequate documentation of database, model structure and operation are archived

No	QC activity	Procedures
6	Consistency of input data between categories	• Identify parameters (e.g., activity data, constants) that are common to multiple categories and confirm that there is consistency in the values used for these parameters in the emission/removal calculations in ABC EIM EXCEL Workbook
7	Data exchange/movement in inventory data among processing	• Check that emissions and removals data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries as provided in ABC EIM EXCEL Workbook • Check that emissions and removals data are correctly transcribed between different intermediate products
8	Calculation/estimation of uncertainties in emissions	• Check that qualifications of individuals providing expert judgment for uncertainty estimates are appropriate as described in this chapter • Check that qualifications, assumptions and expert judgments are recorded • Check that calculated uncertainties are complete and calculated correctly
9	Evaluation of consistency of time series	• Check for temporal consistency in time series input data for each category as can be seen in the summary section in ABC EIM EXCEL Workbook • Check for consistency in the algorithm/method used for calculations throughout the time series • Check methodological and data changes resulting in recalculations • Check that the effects of mitigation activities have been appropriately reflected in time series calculations
10	Recheck of completeness	• Confirm that estimates are reported for all categories and for all years from the appropriate base year to the period of the current inventory and should be defined in ABC EIM EXCEL Workbook • For subcategories, confirm that entire category is being covered • Provide clear definition of 'Other' type categories, and refer this to the ABC EIM • Check that known data gaps that result in incomplete estimates are documented, including qualitative evaluation of the importance of the estimate in relation to total emissions

No	QC activity	Procedures
11	Trend checks	• For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any differences • Significant changes in emissions or removals from previous years may indicate possible input or calculation errors • Check value of implied emission factors (aggregate emissions divided by activity data) across time series whether any years show outliers • Check if there are any unusual and unexplained trends noticed for activity data or other parameters across the time series which should be recorded in ABC EIM EXCEL Workbook
12	Review of internal documentation and archiving	• Check that there is detailed internal documentation to support the estimates and enable reproduction of the emission, removal and uncertainty estimates in ABC EIM EXCEL Workbook • Check that inventory data, supporting data, and inventory records are archived and stored to facilitate detailed review

Source/Remarks:
Adapted from IPCC, 2006

Category-specific QC complements above mentioned general inventory QC procedures and is directed at specific types of data used in the methods for all sources and categories. This procedure is the addition to the Table A2-1 which requires knowledge of the specific category, the types of data available and the parameters associated with emission calculation and removal. The category-specific QC activities include emission factor, activity data and estimation methodology. Relevant QC procedures are developed based on the method used to estimate emission for a given category. Following table A2-2 summarizes the similar guidance taken from the IPCC (2006) and EMEP/CORINAIR (2004):

Table A2-2: ABC EIM Category-specific QC Procedures

No	QC activity	Procedures
1	Emission Factor	
	a) Using default emission factor from another inventory manuals (i.e., IPCC, EMEP/CORINAIR and GAPF manual)	• Assess the applicability of these factors to national circumstances • Evaluation of national conditions compared to conditions where the defaults EF were based
	b) Country-specific emission factor	• Check the background data used to develop EF • Check whether the EFs are compiled based on primary or secondary literature • Compare the magnitude with other sources
	c) Direct emission measurement	• Check the information measurement standard especially calibration of equipment, standard methods, etc. • Comparison with other site-specific measurements
2	Activity Data	
	a) National level activity data	• Check the reference source for national activity data • Compare the national data whenever possible with independently compiled activity data sources such as university research, international agency, etc. • Check the magnitude of national data with partial data sets at sub-national levels • Check the trends by comparing with previous year's data
	b) Site-specific activity data	• Check on the measurement protocol by requesting relevant information to individual sites • Compare the magnitude of site's data with national data • Use the production and consumption balance for further confirmation
3	Calculation-related	• Check the calculation algorithm (as provided in each summary section in ABC EIM) against duplication of inputs, unit conversion errors in the ABC EIM EXCEL Workbook • If the specific sector provides two tiers of method, examine both approaches and analyze the discrepancies • Discriminate between input data, calculation algorithm and the output in the proper documentation

Quality assurance comprises activities outside the actual inventory compilation. It is a good practice for QA procedures to include review and audit process to assess the quality of the inventory by third parties. According to IPCC (2006), the objective of QA implementation is to involve reviewers who can conduct unbiased review of the inventory and who may have a different technical perspective. Brief information of QA procedures are presented in Table A2-3 below:

Table A2-3: ABC EIM Category-specific QA Procedures

No	QA activity	Procedures
1	Expert peer review	• It is a good practice to conduct before completing the inventory to identify potential problems and revisions • Key categories should be given priority • The review consists of methods and assumptions review • Results of experts review should be considered as part of QA improvement process • All experts review should be well documented
2	Audits	• This aims to evaluate how effectively the inventory compiler complies the minimum QC procedures • The auditor should be independent of inventory compiler as much as possible • Audits may be conducted during the preparation of inventory • Audits should focus more on the analysis of respective procedures taken to develop the inventory rather than methods and inventory results

A2.5. Verification Procedures

For the purpose in this ABC EIM, verification activities include comparisons with emission or removal estimates prepared by other bodies and comparisons with estimates derived from fully independent assessment, e.g. atmospheric concentration measurements. The link between national inventory and independent estimates increases the confidence and reliability of the inventory estimates by confirming the results. As a new emerging air pollution issue, emission estimation of ABC's precursors provides challenge due to complex multiple species interaction in the atmosphere. Comparison with one emission inventory work will not be enough to conduct the comprehensive comparison. Therefore, more compiled EI's are needed. Discrepancies between inventory data and data compiled do not always imply that the inventory data are in error. It is important that there may be large uncertainties associated with the alternative calculations themselves. The summary of procedures taken from IPCC (2006) is presented in Table A2-4.

Table A2-4: ABC EIM Verification Procedures

No	Verification Activity	Procedures
1	**Comparison of National Estimates**	
	a) Applying lower tier method (based on top down approach)	• For users that use higher tier level (based on bottom up method), verification can be considered by comparing results to lower tier level • If large discrepancies are found, check the effect of control, assumptions involved, etc.
	b) Applying higher tier method (based on bottom up approach)	• For users that use low tier level which rely much on highly disaggregated data, results can be compared to alternative method of using higher tier level • If the data are lacking, the availability of even partial estimates for a subcategory of sources may provide a valuable verification tool for the inventory
	c) Comparison with independently compiled estimates	• Check the previous emission inventory at the same level and do main conducted by independent compiler if available • Confirm that underlying data for the independent estimate are not the same as that used for inventory • Determine if the relationships between the sectors and categories in the different inventories can be defined and matched appropriately • Example of independents emission inventory works: • The 0.5° x 0.5° anthropogenic emissions prepared by the Center for Global and Regional Environmental Research (CGRER), University of IOWA (http://www.cgrer.uiowa.edu/EMISSION_DATA/index_16.htm) • The 1° x 1° Emission Database for Global Atmospheric Research (EDGAR) for 1990 and 1995 (http://www.mnp.nl/edgar/) • The Atmospheric Composition Change by the European Network of Excellence (ACCENT) (http://www.aero.jussieu.fr/projet/ACCENT/database.php) • The Regional Emission inventory in Asia (REAS) for 1995 and 2000 (http://www.jamstec.go.jp/frcgc/research/d4/emission.htm) For biomass open burning, the data from Global Fire Emission Database (GFED) version 3 can be used for comparison. The data can be accessed at http://www.falw.vu/~gwerf/GFED/GFED3/emissions/.
	d) Comparison of intensity indicators between country	• Emission intensity (can be expressed in emissions per capita, transport emissions per cars, emission from power generation per kWh) can be compared with typical values from other countries • Differences between countries need to be expected and checks may flag potential anomalies at the country or sector level

No	Verification Activity	Procedures
2	Comparisons with Atmospheric Measurements	
	a) Inverse modeling	• Inverse model is able to calculate emission fluxes from concentration measurements and atmospheric transport models • Caution of involvement of natural sources in the emission fluxes before being compared with EI results
	b) Continental flumes	• Analyzing of transported air pollutants by using a continent and offshore routine measurements, coupled with trajectory analysis • Mostly used for subsequent quantification of the emission source strength by inverse modeling
	c) Global dynamic approaches	• Analyzing trends over time in the atmospheric concentration of particular compounds may also indicate a change in global balance • It also gives an estimate of the globally aggregated emissions • Can be applicable to cover a large proportion of global emissions

A2.6. Data Completeness

This section aims to indicate the completeness of data inside the manual or ABC EIM EXCEL Workbook. In any case, where it is not possible to fill a cell with numbers; for example, due to data availability, cells should be filled in using appropriate *notation keys* to provide transparency especially in documenting the inventory. The following notation keys are listed below:

Table A2- 5: Notation Key of Data Completeness

Notation	Abbreviation	Remarks
-	Not available	The data is not available during the arrangement of ABC EIM. Any related data found in the future are possible to be included.
NA	Not applicable	The source exists, but relevant emissions are considered to be not applicable for particular case.

A2.7. Uncertainty Analysis

This section will provide guidance in this respect, based on achievements with IPCC (2006) and EMEP/CORINAIR (2004). QA/QC process and uncertainty analysis provide valuable feedback to one another. The uncertainty can provide insights into weakness in the estimate, the sensitivity of the estimate to different variables, and the greatest contributor to uncertainty. An important aspect of an uncertainty is the ways on how to express the uncertainties associated with the emission inventory. In general, uncertainties are estimated by using measurements, literature, and expert judgment. It involves two important components in EI: activity data and emission factor. In this manual, the range of uncertainties is premilinary indicated based on low, high and best emission estimate considering the reported uncertainty of activity data and variation of available emission factors (EFs).

A2.7.1. Activity Data

Activity data are usually derived from economic statistics, including energy statistics and balances, population data, etc. which are obtained from national or international agencies. These agencies may have already assessed the uncertainties associated with their data or data collection procedures. We can use these uncertainties. However in some cases, uncertainty data for activity rates are not easily available. EMEP/CORINAIR (2004) provided the information of quantitative uncertainty ranges with some data source additions in Table A2-6:

Table A2-6: ABC EIM Quantitative Uncertainty Ranges of Activity Data

No	Data source	Error range	Remarks
1	The National / official statistics	-	It is assumed to be "fixed data" with no uncertainty.
2	Update of previous year's data using gross economic growth factors	2 – 5 %	The economic system of a country will probably not shift more than a few percent. Hence, if there is an update of last year's data, an uncertainty of a few percent seems reasonable.
3	FAOSTAT	2 - 5%	They have fully compliant with the principles of good practice governing international statistics.
4	IEA Energy statistics	OECD: 2 – 3 % Non-OECD: 5 – 10%	They publish national energy statistics for many countries. For OECD countries these statistics will ideally be equal to the official energy statistics. For other countries the uncertainties could be expected to be in order of 5 – 10%.
5	UN Data bases	5 – 10%	These data might have similar uncertainty as the ones provided by IEA.
6	Others	30 – 100%	

Source/Remarks:
Adapted from EMEP/CORINAIR, 2004

However, those values of course cannot be a true uncertainty range and may be suitable only for fossil fuel combustion activity. For some open burning sources; for example, forest fire which utilizes more technical data from satellite remote sensing, detail review on the data quality of the satellite products is needed. Attention should also be given on how valid the burning products data are that represent burning area. Therefore, detail review is needed on the particular literatures. The value here is given to facilitate for selection of a certain range. Users may need to rate the activity data by themselves. However, it is recommended to always use expert's opinion to make final selection.

A2.7.2. Emission Factor

The uncertainty in emission factor can be expressed in terms of emission factor ratings which provide indications of the robustness or the reliability of emission factors for estimating average emissions for a source activity. In this ABC EIM, the emission factors available are mainly compiled from published references or other literatures including direct measurements. Emission rating and its error ranges for ABC EIM follow US EPA (1995) and EMEP/CORINAIR (2004) which are rated from A to E and ranges of error from 10-300% as shown in the following Table A2-7.

Table A2-7: Comparative of US EPA and EMEP/CORINAIR Qualitative Emission Factor Rating

Ratings	Definition	
	US EPA	**EMEP/CORINAIR**
A	Excellent Emission factor is developed primarily from A and B rated source test data taken from many randomly chosen facilities in the industry population. The source category population is sufficiently specific to minimize variability.	Error range: 10-30% An estimate based on a large number of measurements made at a large number of facilities that fully represent the sector.
B	Above average Emission factor is developed primarily from A or B rated test data from a moderate number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.	Error range: 20-60% An estimate based on a large number of measurements made at a large number of facilities that represent a large part of the sector.
C	Average Emission factor is developed primarily from A, B and C rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.	Error range: 50-150% An estimate based on a number of measurements made at a small number of representative facilities, or an engineering judgment based on a number of relevant facts.
D	Below average Emission factor is developed primarily from A, B and C rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source population.	Error range: 100-300% An estimate based on single measurements, or an engineering calculation derived from a number of relevant facts.
E	Poor Factor is developed from C and D rated test data from a very few number of facilities, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.	Error range: order of magnitude An estimate based on an engineering calculation derived from assumptions only.

Source/Remarks:
US EPA, 1995, EMEP/CORINAIR, 2004 ;
A= tests are performed by a sound of methodology and reported in enough detail for adequate validation
B= tests are performed by a sound of methodology and lacking enough detail for adequate validation
C= tests are based on unproven/new methodology, or are lacking of significant amount of background information
D= tests are based on generally unacceptable methodology, but method may provide order of magnitude value for the source

US EPA emission factor rating is an overall assessment of how good a factor is, based on both the quality of the test(s) or information that is the source of the factor and on how well the factor represents the emission source. Test procedures for factor rating are described elsewhere (US EPA, 1995). Higher ratings are for factors based on many unbiased observations, or on widely accepted test procedures. For EMEP/CORINAIR, emission factor is obtained from European Union (EU) Guidance Report on Supplementary Assessment under European Comission (EC) Air Quality Directives. Factor rating is primarily based on the estimation approaches which rely on emission factor and activity indicators. The application of more direct approaches based on measurement would receive higher quality ranges (EMEP/CORINAIR, 2004).

In ABC EIM context, the encouragement to apply country- or region-specific emission factors is a major effort to those EI compilers and declared as "Excellent (A)" rate. A large number and single number of available data are considered to be an average and poor ratings respectively. ABC EIM consequently follows above guidance of emission factor rating since some of the emission factors are taken from those sources. For some other sources which may come from published journal, IPCC guidance and other sources, the rating will be following above rating criteria from US EPA and EMEP/CORINAIR. Therefore, checking the primary reference is necessary. With regards to aerosol emission factors; i.e., $PM_{2.5}$, PM_{10}, PM, OC and EC, the following notification must be applied: Thongchai and Kim Oanh (2010)

i) $PM_{2.5} < PM_{10} < PM$
ii) $EC+OC < PM_{2.5}$

A2.7.3. Calculation of Combined Uncertainties

In the inventory activities, uncertainties may come from emission factors or activity data and various source-sectors which are expressed in percentage (%). The error propagation equation is discussed more extensively in Annex 1 of EMEP/CORINAIR (2004), and in Annex I of the *IPCC Guidelines* (Reporting Instructions). Readers are suggested to refer those documents for detail information. However, this section just highlights briefly the available methods to estimate combined uncertainties.

Two rules for combining uncorrelated uncertainties are described below:

1)   Rule A: Where uncertain quantities are to be combined by addition, the standard deviation of the sum will be the square root of the sum of the squares of the standard deviations of the quantities that are added with the standard deviations all expressed in absolute terms (this rule is exact for uncorrelated variables). The relation is expressed by following equation:

$$U_{total} = \frac{\sqrt{(U_1 \bullet X_1)^2 + (U_2 \bullet X_2)^2 + ... + (U_n \bullet X_n)^2}}{(X_1 + X_2 + ... X_n)} \qquad \text{(eq. A2-1)}$$

where,

U_{total} is the percentage uncertainty in the sum of the quantities (half the 95-confidence interval divided by the total (i.e., mean) and expressed as a percentage);

X_n and U_n are the uncertain quantities and the percentage uncertainties (half the 95% confidence interval) associated with them respectively.

2)   *Rule B:* Where uncertain quantities are to be combined by multiplication, the same rule applies except that the standard deviations must all be expressed as fractions of the appropriate mean values (this rule is approximate for all random variables).

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$ (eq. A2-2)

where,

U_{total} is the percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage),

U_n is the percentage uncertainties (half the 95% confidence interval) associated with each of the quantities.

The inventory is principally the sum of products of emission factors and activity data. Therefore, Rules A and B can be used repeatedly to estimate the uncertainty of the total inventory. In simple way, in the EXCEL tool of ABC EIM the uncertainty can be examined preliminary from the ratio of low and high estimate, respectively, to the best estimate. Hence, a negative (-) uncertainty showed magnitude of difference (in %) between low estimate and best estimate while a positive (+) uncertainty showed the magnitude of difference between high and best estimate. Note that this range did not show the standard deviation of the best estimate but the range of emission estimates.

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