The Global Atmospheric Pollution Forum Air Pollutant Emission Inventory Manual

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SEI

GLOBAL ATMOSPHERIC POLLUTION FORUM

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Acknowledgments

This Manual and its associated Workbook were prepared by Harry Vallack[1] (Stockholm Environment Institute) and Kristin Rypdal (Centre for International Climate and Environmental Research - Oslo) in consultation with experts from Brazil (Gabriel Branco), China (Jiming Hao), India (Sumana Bhattacharya) and Malawi (Kenneth Gondwe). This work was co-sponsored by the BOC Foundation, the US EPA and the Swedish International Development Cooperation Agency (Sida) as part of its Regional Air Pollution in Developing Countries (RAPIDC) programme.

The Manual was based on, and grew out of, a manual initially prepared for UNDP/UN DESA by the Stockholm Environment Institute (principal authors: David von Hippel and Harry Vallack) entitled "Manual for Preparation of Emissions Inventories for use in Modelling of Transboundary Air Pollution" for use in Northeast Asia which has been subsequently modified for use by the Malé Declaration countries of South Asia and the Air Pollution Information Network for Africa (APINA). All these sources have been used in the preparation of this Forum Manual.

[1] For comments, suggested improvements, details of locally determined emission factors etc. please contact:

Harry Vallack
Stockholm Environment Institute
Environment Department
University of York
Heslington
YORK YO10 5DD,
UK

Tel +44 (0) 1904 322894
Fax +44 (0) 1904 322898
E-mail harry.vallack@york.ac.uk

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Executive summary

As air pollutant emissions management has increasingly to be conducted at wider geographical scales (including regional and hemispheric), the development and adoption of compatible approaches by different regional networks, is increasingly necessary. In particular, convergence of approaches for compiling emission inventories will enable the efficient transfer of information and expertise to assist the efforts of those regions with less experience.

This Manual has been produced under the auspices of the Global Atmospheric Pollution Forum (the Forum) which is coordinated by the Stockholm Environment Institute (SEI), based at the University of York, U.K. and The International Union of Air Pollution Prevention Associations (IUAPPA). The purpose of the Forum Manual is to provide a simplified and user-friendly framework for emissions inventory preparation that is suitable for use in different developing and rapidly industrialising countries and which is compatible with other major international emissions inventory initiatives. However, the methodologies suggested in the Manual and Workbook are indicative only and the actual level of detail used for different parts of the inventory will vary according to data availability and capacity of the country concerned. In some cases, the level of detail possible will surpass that provided for in the Forum Manual/Workbook and users are then free to use alternative methods or tools so long as these are properly documented.

Inventory methods are provided for estimating emissions from the following sources: fuel combustion and transformation; fugitive emissions from fuels; industrial process emissions (non-combustion); emissions from solvent and other product use; emissions from agriculture (including savanna fires); emissions from other vegetation fires and forestry; and emissions from the treatment and disposal of wastes. The air pollutants covered are sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4), ammonia (NH_3), particulate matter (PM_{10}, $PM_{2.5}$, black carbon (BC), organic carbon (OC)) and carbon dioxide (CO_2). An Excel workbook (FORUM Workbook Version 4.6.xlsm) has been prepared as a companion to this Manual for use as an aid and tool in preparing national emissions inventories and is available for download from http://www.sei-international.org/rapidc/gapforum/html/emissions-manual.php.

Use of the Forum Manual and its companion Workbook will, it is hoped, enable non-OECD countries to develop emissions inventories in an accurate, complete, comparable, consistent and transparent manner to support the process of regional cooperation on the modelling and mitigation of transboundary air pollution.

Acronyms and Abbreviations

ACCENT   Atmospheric Composition Change the European Network of Excellence

APINA   Air Pollution Information Network for Africa

AP-42   Common name for the US EPA's *Compilation of Air Pollutant Emission Factors*

BC   black carbon

BEIS   Biogenic Emissions Inventory System

BKB   brown coal briquettes

Btu   British thermal unit

CD-ROM   Compact Disc--Read Only Memory (A form of storage of digital information)

CEC   Commission of the European Communities

CFC   chloroflourocarbon

CLRTAP   Convention on Long Range Transboundary Air Pollution

CNG   compressed natural gas

CORINE   **CO**-o**R**dination d'**IN**formation **E**nvironmentale

COG   coke oven gas

CH_4 methane

CO   carbon monoxide

CO_2 carbon dioxide

EDGAR   Emission Database for Global Atmospheric Research

EF   emission factor

EFDB   Emission Factor Database

EMEP   Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe

EPA   (US) Environment Protection Agency

EEATF   European Environment Agency Task Force

ESP   Electrostatic Precipitator

EU   European Union

FAO   United Nations Food and Agriculture Organization

FGD   flue gas desulphurization

g   gram

GAPF   Global Atmospheric Pollution Forum

Gcal   gigacalorie (one billion calories)

GCV   Gross calorific value (= higher heating value, HHV)

GEIA	Global Emissions Inventory Activity
Gg	gigagram (10^9 grams, equal to one thousand "metric tonnes" (t))
GHG(s)	greenhouse gas(es)
GIS	Geographical Information System
GJ	gigajoule (one billion Joules)
GWG	gas works gas
GWh	gigawatt-hour (= 3.6 TJ)
HFO	heavy fuel oil (also called residual fuel oil (RFO))
HHV	higher heating value (= gross calorific value, GCV)
IAM	Integrated Assessment Model
IEA	International Energy Agency
IISI	International Iron and Steel Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
IVL	Swedish Environmental Research Institute
J	joule
JRC-IES	Joint Research Centre of the European Commission - Institute for Environment and Sustainability
kcal	kilocalorie (= 4.18 kJ)
K	Kelvin
kg	kilogram (1000 grams)
kt	kilotonne (1000 metric tonnes (t) = 1 Gg)
LNB	low NO_x burner
LPG	Liquefied Petroleum Gas
LPS	large point source
LRTAP	Long Range Transboundary Air Pollution
LTO	landing and take-off cycle (for aircraft)
LULUCF	Land Use, Land-Use Change and Forestry
Mg	megagram (10^6 grams, equal to one "metric tonne" (t))
MPIC-AC	Max-Planck-Institute for Chemistry, Department of Atmospheric Chemistry, Germany
MSW	municipal solid waste
Mt	megatonne (10^6 metric tonnes (t) = Tg)
Mtoe	megatonne (Tg) oil equivalent
MW	megawatt (1000000 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
NARSTO	A North American Consortium for Atmospheric Research in Support of Air-Quality Management
NCV	net calorific value (= lower heating value, LHV)
NGL	natural gas liquids
NH_3	ammonia
NIA	National Implementing Agency
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	nitrogen oxides ($NO + NO_2$)
O_3	ozone
OC	organic carbon
OECD	Organization for Economic Co-operation and Development
OFA	over-fire air (a form of NO_x emission control)
P	Pascal
PM	particulate matter
PM_{10}	particulate matter less than or equal to 10 micrometers in aerodynamic diameter
$PM_{2.5}$	particulate matter less than or equal to 2.5 micrometers in aerodynamic diameter
ppm	parts per million
POP	Persistent organic pollutant
RAINS-Asia	**R**egional **A**cidification **IN**formation and **S**imulation Model for Asia
RAPIDC	Regional Air Pollution in Developing Countries
RFO	residual fuel oil (also called 'Heavy Fuel Oil')
RIVM-MNP	National Institute for Public Health and the Environment - Netherlands Environmental Assessment Agency
S	sulphur
SAFARI	Southern African Regional Science Initiative
SADC	Southern Africa Development Community
SCC	Source classification code

SCR	Selective Catalytic Reduction
SEI	Stockholm Environment Institute
Sida	Swedish International Development Agency
Sm^3	Standard cubic metre (one standard cubic metre of gas is that amount of gas which occupies 1 m^3 at Standard Temperature and Pressure (0 °C and 1 atm (1.01325×10^5 Pa) pressure).
SNAP	selected nomenclature for air pollution
SO_2	sulphur dioxide
SO_x	sulphur oxides
t	tonne (metric tonne = 1000 kg = 10^6 g))
TNO-MEP	TNO Environment, Energy and Process Innovation
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)
TTN CHIEF	Technology Transfer Network Clearinghouse for Inventories & Emissions Factors
UNECE	United Nation Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compounds
QA/QC	Quality Assurance/Quality Control

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). Units of greater magnitude can be denoted by attaching the appropriate multiple prefix.

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}

Thus one kilogram (kg) equals one thousand (10^3) grams, one megagram (Mg) equals 10^6 grams and a petajoule (PJ) equals 10^{15} joules. A common SI alternative to the Mg is the "metric tonne" (t), also equal to 10^6 grams, and this is used throughout the Manual and Workbook. Total emissions are often reported in Gg (10^9 g) which equals 1000 t.

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	2240.0
Short ton (st)	907.2	0.9072	0.893	1	2000.0
Pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5.0×10^{-4}	1

Fuel categories[2] used in the Forum Workbook

Coking coal

Coking coal refers to coal with a quality that allows the production of a coke suitable to support a blast furnace charge. Its gross calorific value is greater than 23 865 kJ/kg (5 700 kcal/kg) on an ash-free but moist basis.

Other Bituminous Coal & Anthracite

Other bituminous coal is used for steam raising and space heating purposes and includes all anthracite coals and bituminous coals not included under coking coal. Its gross calorific value is greater than 23 865 kJ/kg (5 700 kcal/kg), but usually lower than that of coking coal.

Sub-Bituminous Coal

Non-agglomerating coals with a gross calorific value between 17 435 kJ/kg (4 165 kcal/kg) and 23 865 kJ/kg (5 700 kcal/kg) containing more than 31 per cent volatile matter on a dry mineral matter free basis.

Lignite/Brown Coal

Lignite/brown coal is a non-agglomerating coal with a gross calorific value less than 17435 kJ/kg (4 165 kcal/kg), and greater than 31 per cent volatile matter on a dry mineral matter free basis.

Patent Fuel

Patent fuel is a composition fuel manufactured from hard coal fines with the addition of a binding agent.

Coke Oven Coke and Lignite Coke

Coke oven coke is the solid product obtained from the carbonisation of coal, principally coking coal, at high temperature. Also included are semi-coke, a solid product obtained from the carbonisation of coal at a low temperature, lignite coke, semi-coke made from lignite/brown coal, coke breeze and foundry coke.

Gas coke

Gas coke is a by-product of hard coal used for the production of town gas in gas works. Gas coke is used for heating purposes.

Brown Coal Briquettes (BKB)

BKB are composition fuels manufactured from lignite/brown coal, produced by briquetting under high pressure.

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[2] As defined by the international Energy Agency (IEA) in their Statistics and Balances databases. Presented in the order in which they are listed in the energy worksheets of the Forum Manual.

Gas Works Gas

Gas works gas covers all types of gas produced in public utility or private plants, whose main purpose is the manufacture, transport and distribution of gas. It includes gas produced by carbonisation (including gas produced by coke ovens and transferred to gas works), by total gasification, by cracking of natural gas, and by reforming and simple mixing of gases and/or air. This heading also includes substitute natural gas, which is a high calorific value gas manufactured by chemical conversion of a hydrocarbon fossil fuel.

Coke Oven Gas

Coke oven gas is obtained as a by-product of the manufacture of coke oven coke for the production of iron and steel.

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 a fuel partly within the plant and partly in other steel industry processes or in power stations equipped to burn it.

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, and excludes re-injected gas, quantities vented or flared. It includes gas consumed by gas processing plants and gas transported by pipeline.

Crude Oil

Crude oil is a mineral oil consisting of a mixture of hydrocarbons of natural origin, being yellow to black in colour, of variable density and viscosity. It also includes lease condensate (separator liquids) which are recovered from gaseous hydrocarbons in lease separation facilities.

Natural Gas Liquids (NGL)

NGLs are the liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilisation of natural gas. These are those portions of natural gas which are recovered as liquids in separators, field facilities, or gas processing plants. NGLs include but are not limited to ethane, propane, butane, pentane, natural gasoline and condensate.

Refinery Gas

Refinery gas is defined as non-condensable gas obtained during distillation of crude oil or treatment of oil products (e.g. cracking) in refineries. It consists mainly of hydrogen, methane, ethane and olefins. It also includes gases which are returned from the petrochemical industry.

Liquefied Petroleum Gases (LPG)

These are the light hydrocarbons fraction of the paraffin series, derived from refinery processes, crude oil stabilisation plants and natural gas processing plants comprising propane (C_3H_8) and

butane (C4H10) or a combination of the two. They are normally liquefied under pressure for transportation and storage.

Motor Gasoline

This is light hydrocarbon oil for use in internal combustion engines such as motor vehicles, excluding aircraft. Motor gasoline is distilled between 35°C and 215°C and is used as a 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).

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 -60°C, and a distillation range usually within the limits of 30°C and 180°C.

Gasoline type Jet Fuel

This includes all light hydrocarbon oils for use in aviation turbine power units. They distil between 100°C and 250°C. It is obtained by blending kerosenes and gasoline or naphthas in such a way that the aromatic content does not exceed 25 percent in volume. Additives can be included to improve fuel stability and combustibility.

Kerosene type Jet Fuel

This is medium distillate used for aviation turbine power units. It has the same distillation characteristics and flash point as kerosene (between 150°C and 300°C but not generally above 250°C). In addition, it has particular specifications (such as freezing point) which are established by the International Air Transport Association (IATA).

Kerosene

Kerosene comprises refined petroleum distillate intermediate in volatility between gasoline and gas/diesel oil. It is a medium oil distilling between 150°C and 300°C.

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 redistillation of the residual from atmospheric distillation. Gas/diesel oil distils between 180°C and 380°C. Several grades are available depending on uses: diesel oil for diesel compression ignition (cars, trucks, marine, etc.), light heating oil for industrial and commercial uses, and other gas oil including heavy gas oils which distil between 380°C and 540°C and which are used as petrochemical feedstocks.

Heavy Fuel Oil (HFO)

This heading defines oils that make up the distillation residue. It comprises all residual fuel oils, including those obtained by blending. The flash point is always above 50°C and the density is always more than 0.90 kg/l.

Petroleum Coke

A black solid residue, obtained mainly by cracking and carbonising of petroleum derived feedstocks, vacuum bottoms, tar and pitches in processes such as delayed coking or fluid coking. It is used as a feedstock in coke ovens for the steel industry, for heating purposes, for electrode manufacture and for production of chemicals. The two most important qualities are "green coke" and "calcinated coke". This category also includes "catalyst coke" deposited on the catalyst during refining processes: this coke is not recoverable and is usually burned as refinery fuel.

Other Petroleum Products

Includes the petroleum products not classified above, for example: tar, sulphur, and grease. This category also includes aromatics (e.g. BTX or benzene, toluene and xylene) and olefins (e.g. propylene) produced within refineries.

Primary Solid Biomass

Biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. Included are wood, vegetal 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 the digesters in the production of sulphate or soda pulp during the manufacture of paper where the energy content derives from the lignin removed from the wood pulp) and other solid biomass. This category contains 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).

Biogas

Biomass gases are 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).

Liquid Biomass

Liquid biomass includes bio-additives such as ethanol.

Municipal Wastes

This consists of municipal waste products that are combusted directly to produce heat and/or power and comprises wastes produced by the residential, commercial and public services sectors that are collected by local authorities for disposal in a central location. Hospital waste is included in this category.

Industrial Wastes

Industrial waste consists of solid and liquid products (e.g. tyres) combusted directly, usually in specialised plants, to produce heat and/or power and that are not reported in the category solid biomass and animal products.

Charcoal

Charcoal covers the solid residue of the destructive distillation and pyrolysis of wood and other vegetal material.

THE GLOBAL ATMOSPHERIC POLLUTION FORUM AIR POLLUTANT EMISSIONS INVENTORY MANUAL

1.   Introduction

1.1 The need for regional cooperation on emissions inventories

The increased levels of pollutants in the atmosphere are of growing concern due to their detrimental effect on human health, agriculture and natural ecosystems. Some air pollutants can be transported across national boundaries and even spread across an entire hemisphere of the globe. Addressing problems associated with these 'transboundary' and 'hemispheric' air pollutants requires coordinated regional planning. In this version of the manual the climate forcers, black carbon (BC), organic carbon (OC), methane (CH_4) and carbon dioxide (CO_2) emissions are included in order to allow for the assessment of co-benefits for climate change arising from actions or scenarios that address the traditional air pollutants.

Air pollutant emission inventories are the basic building blocks of air quality modelling and of wider air quality management processes. In Europe and North America there is official national reporting of emission inventories for a number of pollutants to the Convention on Long-Range Transboundary Air Pollution. However, in Asia, Africa and Latin America, routine calculation of emission estimates of high quality is either absent or only available for a few countries. There is no official calculation or reporting by governments in most of the remaining countries and capacity to undertake the necessary calculations is generally lacking.

Without detailed and reliable emission inventories, there is little opportunity to develop strategic plans of how to deal internationally, nationally, or locally with air pollution problems and to monitor the effect of such plans. In many cases the sources of pollution are obvious and are already being tackled in parts of Asia (such as CNG buses and CNG three wheelers in Delhi) but the level of emission reduction achieved or achievable by these measures remains poorly understood due to the lack of high quality emission factors and inventory techniques and has led to a lot of debate there as to whether it is an effective measure. Good quality emission inventories are the foundation on which optimised emission prevention and control strategies can be developed at different scales. Regional issues such as acidic deposition, eutrophication of sensitive ecosystems, tropospheric ozone formation and increasing atmospheric loads of small particulate matter (especially those less than 2.5 μm in diameter) also require high quality emission inventories in order to develop regionally coordinated abatement strategies.

1.2 Regional air pollution initiatives

There are several regional air pollution initiatives emerging in these developing regions where cooperation between countries to tackle this problem is a goal. These include the Malé Declaration in South Asia, the East Asian Network for Acid Rain Monitoring (EANET) and in Asia as a whole, the ASEAN Haze Protocol. In Africa, the Air Pollution Information Network for Africa (APINA) is developing regional cooperation amongst SADC countries, and in Latin America the Inter-American Network for Atmospheric/Biospheric Studies (IANABIS) is developing scientific understanding of the air pollution issue. Developing emission inventories is one of the activities prioritised by these initiatives and some have sought help to develop the

manuals and frameworks required. In response to this, emissions inventory manuals have been produced for the Malé Declaration and APINA, from activities coordinated by SEI at the University of York, as part of a Sida-funded programme on Regional Air Pollution in Developing Countries. These manuals have formed the starting point for the development of this Forum Manual.

Issues related to emission inventory development need to be addressed internationally. As pollutant emissions management has increasingly to be conducted at wider geographical scales, now including both the regional and hemispheric, the development and adoption of harmonised approaches by different regional networks is increasingly necessary. Harmonised approaches will allow efficient transfer of information and expertise to help regions or countries with little experience in emission inventory preparation.

1.3   The Global Atmospheric Pollution Forum

The Global Atmospheric Pollution Forum (the Forum) was established in 2005, on the initiative of the International Union of Air Pollution Prevention Associations (IUAPPA) and the Stockholm Environment Institute (SEI), to support co-operation and development of common practice among scientific and policy networks concerned with the abatement of air pollution at the regional scale. The Forum emerged from a widespread recognition among regional air pollution networks of the timeliness and merit of closer consultation and co-operation. The Forum is already promoting a Global Atlas of Atmospheric Pollution and undertaking a collaborative review of Hemispheric Pollution. It is now developing a programme of collaborative development and demonstration problems on common technical issues. A project entitled 'Developing and Disseminating International Good Practice in Emissions Inventory Compilation' is among the first initiatives of this programme and this Manual and its associated Excel-based Workbook are its main products. The purpose of the manual is to present a framework for emission inventory preparation that is suitable for use in different developing and rapidly industrialising countries and which is compatible with other major emissions inventory preparation approaches such as those described in the EMEP/CORINAIR Guidebook[3] and the IPCC Guidelines[4].

2.   Principles of good practice in preparing inventories

2.1 Basic inventory principles

An emission inventory lists emissions of different pollutants from defined sources. An inventory can have different geographical scope ranging from global down to individual plant level. The focus of this manual is national inventories. An inventory can be compiled at the national level, or emissions at the national level can be the sum of emissions compiled at smaller geographical scales (e.g. county, municipality or even facility level). An inventory can be given for a single year only, but inventories for more years (time-series) are needed for most applications.

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[3] EMEP/CORINAIR *Atmospheric Emission Inventory Guidebook - 2007*, European Environment Agency, Copenhagen, Denmark. (Available via Internet: http://www.eea.europa.eu/publications/EMEPCORINAIR5.)

[4] Intergovernmental Panel on Climate Change (IPCC), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (Available via Internet: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html).

The generally accepted objectives of inventories are that they should be transparent, accurate, complete, consistent and comparable.

Transparency: There is sufficient and clear documentation such that individuals or groups other than the inventory compilers can understand how the inventory was compiled and can assure themselves that it meets the requirements set for the inventory.

Completeness: Estimates are reported for all relevant sources, gases and geographic areas within the scope of the inventory. Where elements are missing their absence should be clearly documented internally and highlighted in association with any published data.

Consistency: Estimates for different inventory years, gases and sources are made in such a way that differences in the results between years and sources reflect real differences in emissions. Inventory annual trends, as far as possible, should be calculated using the same method and data sources in all years and should aim to reflect the real annual fluctuations in emissions and not be subject to changes resulting from methodological differences.

Comparability: The inventory is reported in a way that allows it to be compared with inventories for other countries. This should be reflected in appropriate use of tables and use of a common classification and definition of sources of emissions.

Accuracy: That the inventory contain neither over- nor underestimates so far as can be judged, This means making all endeavours to remove bias from the inventory estimates.

It is important to implement appropriate quality assurance/quality control (QA/QC) checks to the inventory to ensure that these objectives are met. The principles for QA/QC developed by IPCC (2006 Guidelines, Volume 1[5]) are also generally applicable to other inventories.

Time-series consistency can be a particular challenge when inventories are updated with new years. Often new emission factors, methods and other information are available to improve the estimates. In this situation it is important to apply the new method and data also to previous years of the time-series. This principle is called 'recalculations'. If emissions are not appropriately recalculated real changes in emissions may be masked by changes that are due to changes in emission factors or methods. Sometimes data are not available for all years or the method is not possible or practical to implement annually. In this situation IPCC (2006 Guidelines, Volume 1) suggests using so-called splicing techniques. These techniques include extrapolations, interpolations, overlap considerations and use of surrogate data (data that are correlated with real emissions).

An inventory consists of a large number of sources and it can often be labour intensive to collect data, in particular when more detailed methods are used. In this situation priority should be given to the *key sources*. Key sources are those *that have a significant influence on a country's inventory in terms of the absolute level of emissions, the trend in emissions, or uncertainty*. Key sources should be the priority for countries during inventory resource allocation for data collection, compilation, QA/QC and reporting.

Key sources can be defined with respect to the total emissions or the trend. In IPCC Approach 1 only the size of a source of emissions is taken into account. Approach 2 also includes uncertainties. The IPCC method for level assessment has been developed for air quality pollutants

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[5] These were finalised and accepted by IPCC in 2006 and are available at the website of the IPCC National Greenhouse Gas Inventories Programme (http://www.ipcc-nggip.iges.or.jp/).

in the EMEP/CORINAIR Emission Inventory Guidebook (Good Practice Guidance for CLRTAP Emission Inventories). The method is simple to implement in a spreadsheet if an initial inventory is available. If an initial inventory is not available it is recommended to first compile an inventory using simple methods before setting priorities. The EDGAR inventory or inventories in countries with similar national circumstances may also be used to initially identify key sources.

2.2 Estimation methods

Most emissions can be estimated using the simple relation:

Emissions = Emission factor x Activity rate

An emission factor provides emissions per unit activity, for example kg NOx emitted per TJ fuel. Abatement of emissions can be taken into account by applying a different, technology-specific emission factor. In other situations, abatement is taken into account by subtraction:

Emissions = Emission factor x Activity rate – Abatement/Recovery

Some methods are more complex and include more than one emission factor or type of activity data. Examples are in the agriculture or road transportation sector.

Air pollution inventories often include data from large point sources (LPS). Such data can be based on direct emission measurements, calculations from emission factors or mass balance considerations. In combining data from LPS with data estimated from aggregated emission factors and activity data (for example at the country level), it is particularly important to check that emissions are not double counted and that the inventory is complete. In applying emission measurements to determine emissions it is important to adhere to accepted standards for making such measurements (e.g. ISO).

2.3 Data collection

The data that need to be collected are described in this Manual. Default emission factors given in this Manual can be used in an initial inventory and for non-key sources. However, to improve the inventory it is important to take into account national and regional information and data available, for example, from peer reviewed literature, national/regional research organisations or industry organisations. It can be time consuming to identify relevant data, assess its quality and establish cooperation with data providers. Therefore it is important to develop a realistic plan for these tasks.

Specific advice on activity data collection is given in this Manual. Most activity data needed to compile an inventory will be available from national statistical offices or ministries. However, data on biomass burning and small scale waste incineration for example can be more difficult to obtain without targeted surveys. Such surveys can be very resource demanding and should be made in collaboration with experts (e.g. from statistical offices). Implementation of the detailed methods usually requires collection of additional data, in particular on technologies and abatement. To set up a stable inventory system it is important to establish cooperation arrangements with data providers.

In compiling an inventory there is usually a need for information (data or assumptions) which is difficult or impossible to obtain. An example is the use of different technologies. In this situation it is recommended that *expert judgement* be applied. It is important that expert judgements are performed in a systematic manner, that several experts are independently involved in making such judgements and that these judgements are well documented.

2.4 Data structure

A major purpose of using a defined structure for an inventory of air pollutants is to increase transparency and ensure comparability. Using a defined, common structure helps users of the data to assess the scope and completeness of each inventory, as well as to use the inventory results as inputs to different regional models of transboundary air pollution. Using a consistent structure also allows inventories to be more readily updated, and allows new data sets to be generated more quickly from updated data. This Chapter provides an overview of the data format used in this Manual and its associated Workbook including the elements that the structure shares with other international inventory methodologies, the pollutants included and the sources of pollutants covered.

2.5 Shared elements with other emissions inventories

Both the IPCC and the EMEP/CORINAIR approaches are currently in use for drawing up and presenting national emission inventories. The IPCC approach meets UNFCCC needs for calculating national totals at a country level (without further spatial resolution) and identifying sectors within which emissions/removals occur, whereas the EMEP/CORINAIR approach is technology-based and includes spatial allocation of emissions (point and area sources). Both systems follow the same basic principles:

- complete coverage of anthropogenic[6] emissions;

- annual source category totals of national emissions;

- clear distinction between energy and non-energy related emissions; and

- transparency and documentation permitting detailed verification of activity data and emission factors.

Considerable progress has been made in harmonizing these two approaches, to the extent that a complete EMEP/CORINAIR inventory can be used to produce reports in both the UNFCCC/IPCC or EMEP/CORINAIR reporting formats. Through the introduction of the NFR, nomenclatures and definitions have been harmonised.

The approach used in this Manual borrows elements of both of these methodologies. The emission source categories used here (summarized in Table 2-1) are based on the sectoral structure given in the IPCC Guidelines[7]. Some of the activities included in the IPCC Guidelines are exclusively sources of greenhouse gas pollutants (such as methane (CH_4) and nitrous oxide (N_2O)) and are not included below.

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[6] Natural emissions are excluded from both inventories. Natural emissions are needed for modelling purposes, but are normally not included in national reporting.

[7] This structure has been changed in the 2006 Guidelines. 'Industrial processes' and 'Solvents and other product use' has been merged into one sector as have 'Agriculture' and 'LULUCF'.

In common with both IPCC and EMEP/CORINAIR methods, as far as possible, the SI system of units is used in this Manual (see the "Units and Conversions" section at the front of the Manual). Emissions are calculated as metric tonnes (t = Mg) (or kilotonnes (kt) = Gg in the final summary worksheet).

Table 2-1:
Summary of sectoral structure for emission source categories used in this Manual

SECTORS	DESCRIPTION OF ACTIVITIES INCLUDED
1 to 5 ENERGY	Emissions from stationary and mobile energy activities (fuel combustion as well as fugitive emissions from production and handling of fuels).
6 INDUSTRIAL PROCESSES	Emissions within this sector comprise by-product (process) or fugitive emissions from industrial processes. Emissions from fuel combustion in industry should be reported under Energy.
7 SOLVENT AND OTHER PRODUCT USE	Emissions resulting from the use of solvents and other products.
8 AGRICULTURE	Describes all anthropogenic emissions from this sector except for fuel combustion emissions which are covered in the Energy sector. Includes ammonia emissions from manure management and fertilizer application; methane emissions from manure management and livestock enteric fermentation; total emissions from savanna burning and from agricultural residue burning, and methane emissions from rice cultivation.
9 VEGETATION FIRES & FORESTRY	Total emissions from on-site burning of forests and other vegetation.
10 WASTE	Emissions from waste disposal, waste incineration and human excreta. Includes methane emissions from municipal solid waste in landfill and methane from domestic waste water treatment

The pollutants are defined as follows:

- NO_x includes NO and NO_2 reported in NO_2 mass equivalents.
- SO_2 includes all sulphur compounds expressed in SO_2 mass equivalents.

- NMVOC means any non-methane organic compound having at 293.15 K a vapour pressure of 0.01 kP or more, or having a corresponding volatility under the particular conditions of use.
- PM_{10} includes all particulate matter with an aerodynamic diameter less than or equal to 10 microns (μm)
- $PM_{2.5}$ includes all particulate matter with an aerodynamic diameter less than or equal to 2.5 microns (μm)
- BC and OC form part of the PM (and are assumed to be less than or equal to 1.0 microns in diameter).

The commonality between the IPCC and EMEP/CORINAIR methods described above underscores the overlap between the inventory information needed for, respectively, greenhouse gas modelling (and policy analysis), and modelling of transboundary air pollution. In this Manual, a focus has been to draw as much as possible on inventory methods that are likely to be already in use by the countries of the region in compiling GHG emissions inventories, so that the process of compiling emissions inventories for transboundary air pollution modelling can make full use of existing inventory databases. The correspondence between the emission source structure used in this manual and those of the EMEP/CORINAIR and IPCC approaches are shown in Table 2.2.

Table 2-2:
Correspondence between the emission source categories used in this Manual, the CORINAIR/SNAP classification and the categories used in the IPCC guidelines.

Forum Manual	CORINAIR/SNAP classification	IPCC Guidelines
1 Combustion in the Energy Industries 2 Combustion in Manufacturing Industries and Construction 3 Transport 4 Combustion in Other Sectors	01 Combustion in Energy and Transformation Industry 03 Combustion in Manufacturing Industry 07 Road Transport 08 Other Mobile Sources and Machinery 02 Non-industrial Combustion Plants	1 Energy (1A Fuel Combustion Activities)
5 Fugitive emission from fuels	05 Extraction and Distribution of Fossil Fuels and Geothermal Energy	1 Energy (1B Fugitive Emissions from Fuels)
6 Industrial Processes	04 Production Processes	2 Industrial Processes
7 Solvent and Other Product Use	06 Solvent and Other Product Use	3 Solvent and Other Product Use
8 Agriculture	10 Agriculture	4 Agriculture
9 Vegetation Fires & Forestry	11 03 Forest and other vegetation fires	5 Land-Use Change & Forestry
10 Waste	09 Waste Treatment and Disposal	6 Waste

2.6 Completeness

The aim is to include all known sources of emissions in the inventory. If 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 increase transparency. The following notation keys are recommended:

NE	Not estimated	Emissions may occur but have not been estimated or reported (e.g. due to lack of activity data)
IE	Included elsewhere	Emissions for this source are estimated and included in the inventory but not presented separately for this category. The source where these emissions are included should be indicated (for example in the documentation box in the correspondent table).
C	Confidential information	Emissions are aggregated and included elsewhere in the inventory because reporting at a disaggregated level could lead to the disclosure of confidential information
NA	Not applicable	The source exists but relevant emissions are considered never to occur
NO	Not occurring	An activity or process does not exist within a country

2.7 Pollutants covered in this manual

2.7.1 Sulphur dioxide

Although the primary product of the oxidation of the sulphur component of fuels during the combustion process is sulphur dioxide (SO_2), other oxidation states (such as sulphur trioxide (SO_3)) are also usually formed. These compounds are jointly referred to as 'sulphur oxides' (SO_x) although they may also be termed 'oxides of sulphur' or 'sulphuric oxides'. SO_x emissions are usually expressed on the basis of the molecular weight of SO_2, and for convenience often simply referred to as 'SO_2' - this convention is followed in this Manual.

Sulphur oxides are the major cause of the wet and dry acidic depositions commonly referred to as "acid rain". They are subject to long-range transport and can give rise to acidification problems at locations well away from sites of emission, sometimes in neighbouring countries. SO_2 is also an aerosol (particulate matter) precursor.

The main anthropogenic source of SO_2 is the combustion of fossil fuels containing sulphur; predominantly coal and heavy fuel oil. Some industrial processes including metal smelting, oil refining and sulphuric acid production also emit significant amounts of SO_2. Globally, the combustion of coal in power stations constitutes the largest single source of anthropogenic SO_2 emissions. Volcanoes are the most important source of natural SO_2 emissions.

2.7.2 Nitrogen oxides

The two most important nitrogen oxides with respect to air pollution are nitric oxide (NO) and nitrogen dioxide (NO_2), jointly referred to as 'NO_X'. Although nitrous oxide (N_2O) is also an oxide of nitrogen, it is usually treated separately as its role in atmospheric chemistry is distinct from that of NO and NO_2. NO_X emissions are usually expressed on the basis of the molecular weight of NO_2, and the same convention is followed in this Manual.

Nitrogen oxides, like SO_X, are acid rain precursors. NO_X compounds are also major contributors to the formation of photochemical oxidants. Since NO_X can be transported over considerable distances, these impacts of NO_X emissions are not localized problems. NO_x is also an aerosol precursor.

2.7.3 Ammonia

Estimates of ammonia (NH_3) emissions are important to include in atmospheric models as ammonia can have a significant effect on the oxidation rates, and hence on the deposition rates, of acidic species. Although much less research has been done on the effects of atmospheric NH_3 compared to sulphur dioxide and nitrogen oxides, it is well known that over large areas of Europe, acid precipitation is falling in which up to 70 percent of the original acid is neutralized by NH_3 (Battye et al., 1994[8]). This neutralization occurs close to the point of emission of ammonia and ammonium ions are formed which may be transferred over large distances. When the ammonium (NH_4^+) ion is deposited on ecosystems it can acidify after transformation in the nitrogen cycle to nitrate. Acidification is caused if the nitrate ion leaches from the soil. Therefore, ammonium deposition has the potential to acidify even if ammonia (NH_3) buffers acidity close to the point of its emission, and is a component of acidifying deposition together with nitrate and sulphate. NH_3 is also an aerosol precursor.

The majority of anthropogenic NH_3 emissions originate from agricultural practices such as livestock manure management and fertilizer application. Cars equipped with catalytic converters have been a source of increasing importance. There is also evidence that significant NH_3 emissions come from undisturbed soils and from biomass burning.

2.7.4 NMVOCs

Volatile organic compounds (VOCs) are an important class of organic chemical air pollutants that are volatile at ambient air conditions. VOCs are composed of many hundreds of compounds, the exact number depending on the choice of definition. Other terms used to represent VOCs are hydrocarbons (HCs), reactive organic gases (ROGs) and non-methane volatile organic compounds (NMVOCs).

NMVOCs are major contributors (together with NO_x and CO) to the formation of photochemical oxidants. The problem of photochemical oxidants is of international significance because it has been proven that relevant concentrations and fluxes of NMVOCs and their by-products can be transported over long distances. An important by-product of the degradation of NMVOCs in the troposphere is ozone (O_3), a toxic agent, which can adversely affect human and animal health, plant growth and materials (plastics, for example) even at sub-ppm (parts per million) concentrations. Some NMVOC species also act as aerosol precursors.

By definition, methane (CH_4) is not a NMVOC and because of its importance as a direct greenhouse gas, methane is inventoried separately in GHG inventories. Methane has a long residence time in the atmosphere and has therefore become mixed uniformly throughout the lower atmosphere (troposphere). Although methane slightly enhances ozone formation in photochemical smog, its effect is small compared with the more reactive organic gases. The contribution of methane to background ozone formation can be accounted for by ozone modellers without detailed knowledge of methane emissions. For these reasons, estimation of methane emissions is not included in this manual

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[8] Battye, R., Battye W., Overcash C. and Fudge S. (1994), *Development and Selection of Ammonia Emission Factors – Final Report.* Prepared for the U.S. Environmental Protection Agency - Office of Research and Development, Washington, D.C. 20460.

The major sources of anthropogenic NMVOC emissions are organic solvents (such as those used in the formulation and use of paints, inks and adhesives), the oil and chemical industries (especially petroleum product handling and gasoline distribution), motor vehicles, and other combustion sources (especially residential biomass burning). Natural, or biogenic, NMVOC emissions from vegetation are also important.

There are thousands of individual chemical species that can be classified as NMVOCs. For the purposes of modelling the atmospheric chemistry involved on ozone formation, it is often necessary to "speciate" VOC emissions into so-called "reactivity groups". Speciation of NMVOCs is described in more detail in Annex 3.

2.7.5 Carbon monoxide

Carbon monoxide (CO) is one of the most widely distributed and commonly occurring air pollutants. It is produced in large quantities by the incomplete combustion of fossil fuel (especially in the transport sector) and of other organic matter. It is also emitted as a by-product of some industrial processes such as in the aluminium and steel production industries. Natural sources of CO include volcanic eruptions, the photolysis of certain naturally-occurring VOCs (such as methane and terpenes), chlorophyll decomposition, forest fires, and microbial action in oceans.

The major concern regarding CO pollution relates to its adverse effects on human health. When inhaled, CO is absorbed in the lungs and combines irreversibly with hemoglobin (Hb) in the blood to form carboxyhemoglobin (COHb). The principal toxic properties of CO arise from the resulting lack of oxygen in tissues (hypoxia).

Carbon monoxide pollution is of particular concern in urban situations where air concentration can vary widely from a background level of a few parts per million (ppm) up to 50-60 ppm, depending on the weather and the traffic density. Although mainly of local importance, CO is also of interest to transboundary air pollution modellers because of its role in tropospheric (ground level) ozone formation.

2.7.6 Particulate matter

Particulate matter (PM) is a collective term used to describe small solid and/or liquid particles. Individual particles vary considerably in size, chemical composition and physical properties depending on their source. Particles may be produced by natural processes (pollen and particles from salt spray, soil erosion, and volcanic eruptions are examples) or by human activities that produce particulate emissions such as soot, fly ash and iron oxide.

"Primary particles" are produced by physical and chemical processes within (or shortly after being emitted from) a source whereas "secondary particles" are formed in the atmosphere as a result of chemical and physical reactions that involve gases (e.g. SO_2 and NH_3). The two major sources of primary PM are industrial processes and fuel combustion (in particular small-scale coal and biomass burning). Secondary particles may be produced from gases of anthropogenic or natural origin (e.g. sulphur and nitrogen compounds). This manual offers emissions estimation

procedures only for primary PM; estimates of secondary PM concentrations are made using models of atmospheric processes.

Particles larger than about 10 μm in diameter tend to settle on surfaces near the source of emission and so give rise to local nuisance. However, particulate matter less than 10 μm in diameter (that is, PM_{10}) can travel considerable distances because atmospheric residence times increase with a decrease in particle size. PM_{10} also pose a greater threat to human health because they can penetrate more deeply into the respiratory tract. For both these reasons, PM_{10} is the category chosen for the inventory process described in this Manual. $PM_{2.5}$ (particles less than 2.5 μm in diameter) have been found to be particularly relevant to human health impacts and so methods for the estimation of $PM_{2.5}$ emissions are also provided in this Manual and Workbook.

Total suspended particulate matter (TSP) is often monitored for air quality management purposes and TSP emissions are sometimes included in emissions inventories. However, this category of PM is not covered by the Forum Manual and Workbook. This is partly because it is not generally used for regional air pollution modelling and partly because many of the important anthropogenic sources of TSP, such as fugitive emissions from mining and quarrying, are not part of the emission source structure of this manual and emission inventory methodologies are often non-existing or little developed. If required, emissions of TSP can be estimated using the World Health Organisation's (WHO) rapid assessment manual[9] "Assessment of Sources of Air, Water, and Land Pollution" and developed by the World Bank into decision support software package called the Industrial Pollution Control (IPC) system.

In this version of the Manual, two other categories of PM are inventoried separately, namely black carbon (BC) and organic carbon (OC) both of which are assume to be submicron in size (i.e. less than or equal to 1.0 μm in diameter). BC is formed through the incomplete combustion of fossil fuels, biofuel and biomass and is emitted as part of anthropogenic and naturally occurring soot. It consists of pure carbon (C) in several linked forms. BC warms the Earth by absorbing sunlight and re-emitting heat to the atmosphere and by reducing albedo (the ability to reflect sunlight) when deposited on snow and ice. OC has a cooling effect on the atmosphere and can be defined as the carbon fraction of the submicron PM that is not black. There is a close relationship between emissions of BC and OC as they are always co-emitted, but in different proportions depending on the source. Black carbon and organic carbon are now included in this manual to enable the co-benefits for near-term climate to be assessed when scenarios of emission reduction for the tradition transboundary air pollutants are modelled.

2.7.7 Methane

Methane is a potent greenhouse gas and its increased concentration in the atmosphere has caused the largest radiative forcing by any greenhouse gas after carbon dioxide. Methane concentrations have grown as a result of human activities related to agriculture, including rice cultivation and the keeping of ruminant livestock, coal mining, oil and gas production and distribution, biomass burning and municipal waste landfills. Methane has a direct influence on climate, but also has a number of indirect effects including its role as an important precursor to the formation of tropospheric ozone which damages human health and reduces crop yields. Methane is now

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[9] Economopoulos, A.P. (1993) Assessment of Sources of Air, Water, and Land Pollution: A guide to rapid source inventory techniques and their use in formulating environmental control strategies. Part one: Rapid inventory techniques in environmental pollution. Environmental Technology Series. WHO/PEP/GETNET/93.1-A. World Health Organisation, Geneva.

included in this manual primarily to enable the co-benefits for near-term climate to be assessed when scenarios of emission reduction for the tradition transboundary air pollutants are modelled.

2.7.8 Carbon dioxide

Carbon dioxide (CO_2) is the most important of the anthropogenic greenhouse gases, its increase in atmospheric concentration having caused the largest radiative forcing (i.e. atmospheric warming). The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (IPCC, 2007). The global increases in CO_2 concentration are due primarily to fossil fuel use and land use change. Carbon dioxide is now included in this manual to enable co-benefits for long-term climate to be assessed when scenarios of emission reduction for the tradition transboundary air pollutants are modelled.

2.8 Sources-sectors included

Table 2-3 presents an overview of the emission source categories used in this Manual, as well as the pollutants to be inventoried within each category and/or subcategory. Brief descriptions of the processes included in each sector are reflected in Table 2-3 and in the text that follows.

2.8.1 Energy

This sector includes Fuel Combustion Activities (Sectors 1 to 4 in this Manual) as well as sources of Fugitive Emissions from Fuels (Sector 5). Sectors 1 to 4 include fuel combustion activities within the Energy Industries (Sector 1), Manufacturing Industries and Construction (Sector 2), Transport (Sector 3), and Other Sectors (Commercial/Institutional, Residential and Agriculture/Forestry/Fishing—Sector 4). Sector 5 includes non-combustion activities related to the extraction, processing, storage, distribution and use of fuels.

2.8.2 Industrial processes

This category (Sector 6 in this Manual) covers those industrial processes that generate by-product emissions (that is, process emissions) or fugitive emissions of the pollutants covered by this Manual. It specifically *excludes all combustion emissions* from industry as these are already covered in Sector 2[10]. However, it includes emissions from energy commodities used as a raw material in processes and coal and coke used as reducing agents for metal production (e.g. in iron manufacture). This sector includes the Mineral Products Industry, the Chemical Industry, Metals Production and the Pulp and Paper Industry.

2.8.3 Solvent and Other Product Use

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[10] However, when estimates are based on emission monitoring in industrial plants it can sometimes be difficult to distinguish between energy related and process emissions. In this situation all emissions can be included in one category and it is important not to double count emissions.

This category (Sector 7 in this Manual) covers the use of solvents and other products. In this version of the manual, all contain volatile compounds that are sources of NMVOC emissions. This category includes the application of paint, glue and adhesives; metal degreasing and dry cleaning of fabrics; the manufacture of certain chemical products; and the use of solvents in the printing industry.

2.8.4 Agriculture

This category (Sector 8 in this Manual) includes livestock manure management (ammonia and methane emissions), enteric fermentation in livestock (methane emissions) and the application of nitrogen-containing fertilizers (ammonia and NOx emissions). Savanna burning is included here (both prescribed fires and fires of opportunity) as well as the field burning of agricultural crop residues. This sector also includes methane emissions from rice cultivation. Fuel combustion emissions in agriculture are excluded as these are covered in Sector 4. Solvent use is also excluded and is covered in Sector 7.

2.8.5 Vegetation fires and forestry

This sector (Sector 9 in this Manual) includes the on-site burning of forests and natural grasslands (excluding savannas). These fires may be man-induced (due to prescribed burning for management purposes or conversion to other land uses, or by accident) or due to natural causes (e.g. lightning).

2.8.6 Waste

This emissions source category (Sector 10 in this Manual) covers all types of waste incineration except waste-to-energy facilities (which are dealt with under Energy facilities, Sector 1) and on-field burning of crop residues (dealt with under Agriculture, Sector 8). It includes the incineration of municipal solid waste (MSW), industrial waste and commercial waste as well as methane emissions from MSW in landfill sites and from waste water treatment and disposal. Also included are emissions of ammonia from human excreta stored in latrines ("dry" toilets located outside the house) or deposited directly outside in the fields or bush.

Table 2-3:
Details of emission source categories used in this Manual (with equivalent ISIC[11] classification where applicable) and the pollutants inventoried by category

	Sector	Comments	Pollutants
1 COMBUSTION IN THE ENERGY INDUSTRIES		Emissions from fuels combusted in the fuel extraction and energy transformation industries	
1 A	**Public electricity and heat production**	Includes public electricity generation, public combined heat and power generation and public heat plants. It does *not* include fuel combustion for the generation of electricity and heat (that is, autoproduction) within manufacturing industries which is included under sector 2 below. *Emissions from own on-site use of fuel (ISIC Divisions 10, 11, 12, 23 and 40) should, however, be included.*	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
1 B	**Petroleum refining**	Combustion activities supporting the refining of petroleum products. Does not include evaporative emissions, which are dealt with in Sector 5B.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
1 C	**Manufacture of solid fuels and other energy industries**	Combustion activities supporting the manufacture of coke, brown coal briquettes (BKB), patent fuel, charcoal, gas works gas (GWG), and other energy industries (that is, energy industries' own (on-site) energy use not already included above—mainly own use in coal mining and oil and gas extraction). Excluded are emissions from flaring, which are dealt with under 5B.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2 COMBUSTION IN MANUFACTURING INDUSTRIES AND CONSTRUCTION		Emissions from the combustion of fuels in industry. This also includes combustion for the generation of electricity and heat (that is, auto-production) for use within the industry. Emissions for off-road mobile activities in this sub-sector are included. However, emissions for on-road transport by industry should be included under 3B (Road transport).	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2 A	**Iron and Steel** (ISIC Group 271 and Class 2731)	Emissions from fuel combustion in coke ovens within the Iron and Steel industry are included under 1C above. Emissions from the consumption of coke as a reducing agent are not included as these are accounted for as process emissions under Metal Production (6C) below. However, emissions from combustion of blast furnace gas are included here.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC

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[11] International Standard Industrial Classification of all Economic Activities, ST/ESA/STAT/SER.M/4/Rev.3.1, E.03.XVII.4, 2002 http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=17

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Table 2-3 (Continued)

		Sector	Comments	Pollutants
2	B	**Non-ferrous metals** (ISIC Group 272 and Class 2732)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2	C	**Non-metallic minerals** (ISIC Division 26)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2	D	**Chemicals** (ISIC Division 24)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC and OC
2	E	**Pulp, Paper and print** (ISIC Divisions 21 and 22)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2	F	**Mining and quarrying** (ISIC Divisions 10 to 14)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$ BC, OC
2	G	**Construction** (ISIC Divisions 45)		SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
2	H	**Non-specified industry**	Fuel combustion emissions from all remaining manufacturing industries not already specifically accounted for above.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC,OC
3		TRANSPORT (ISIC DIVISIONS 60, 61 AND 62)	Emissions from the combustion of fuel and, for road transport, re-suspended road dust.	
3	A	**Civil aviation**	Emissions from all landing and take-off (LTO) cycles and cruise activities for domestic air transport and LTO cycles only for international air transport. Excludes use of fuel for ground transport (see 3E below).	
		1 **International aviation**	LTO emissions from all international flights (whether operated by domestic airlines or foreign airlines). Emissions from international aviation cruise activities are not included in national totals but fuel use should be reported as a memo item under "International Aviation Bunkers". (The IPCC method also includes international LTO cycle emissions in the bunker category but, if possible, one half of these emissions should be included in national totals for the purposes of this Manual)	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
		2 **Domestic aviation**	Emissions from all LTO cycles and cruise activities for civil domestic passenger and freight air traffic.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC,OC

Table 2-3 (Continued)

		Sector	Comments	Pollutants
3	B	**Road transport**	All exhaust and dust emissions for on-road passenger cars, light commercial vehicles, heavy-duty vehicles (trucks and buses), motorcycles (2-stroke and 4-stroke) and 3-wheelers. Also includes evaporative losses from the vehicle (except from loading of gasoline into the vehicle).	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
3	C	**Railways**	Both freight and passenger	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
3	D	**Navigation (domestic)**	Emissions from fuels burnt by all vessels not engaged in international transport. Excludes emissions for fishing vessels, which are covered in 4C (OTHER SECTORS: Agriculture/Forestry/Fishing) below.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
3	E	**Pipeline transport**	Emissions from fuels used to transport materials by pipeline.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
3	F	**Non-specified transport**	Includes fuel combustion emissions from ground activities in airports and harbours. Excluded are mobile off-road activities in Manufacturing Industries and Construction (reported under sector 2), and in Agriculture, Forestry and Fishing (covered under 4C (OTHER SECTORS: Agriculture/ Forestry/ Fishing) below).	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
4		**COMBUSTION IN OTHER SECTORS**		
4	A	**Commercial/ Institutional**	Emissions from fuel combustion in commercial and institutional buildings (ISIC categories 4103, 42, 6, 719, 72, 8 and 91-96.)	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC and OC
4	B	**Residential**	Emissions from domestic fuel combustion within households.	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC,OC
4	C	**Agriculture/ Forestry/Fishing**	Emissions from fuel combustion (including mobile off-road activities) in agriculture, forestry and domestic inland, coastal or deep-sea fishing. (ISIC categories 05, 11, 12 and 1302)	SO_2, NO_x, CO, CO_2, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC

Table 2-3 (Continued)

	Sector	Comments	Pollutants
5	**FUGITIVE EMISSIONS FROM FUELS**	Non-combustion activities related to the extraction, processing, storage, distribution and use of fuels. Includes emissions of NMVOCs from crude oil exploration, production and transport; oil refining; the distribution and handling of gasoline: the production and distribution of natural gas: emissions of NMVOC and PM from the production of coke: and release of methane from coal mining. Excluded are evaporative emissions from vehicles, which are dealt with under the Transport sector.	
	5A Solid fuels	(i) Fugitive emissions from the *manufacture of coke*.	NMVOC, NH_3, PM_{10}, $PM_{2.5}$ BC, OC, CH_4
		(ii) The release of methane during underground and surface *coal mining* and post-mining activities.	CH_4
	5B Oil and natural gas	Emissions from venting and flaring are included here as this does not include energy recovery.	
	1 Oil	Fugitive emissions from: (i) *oil exploration* (oil well drilling),	NMVOC, CH_4
		(ii) *crude oil production* (emissions from facilities/platforms),	NMVOC, CH_4
		(iii) *transport* (loading onto marine tankers, rail tank cars & tank trucks, transit in marine tankers and pipeline transport),	NMVOC, CH_4
		(iv) *oil refining*, and	SO_2, NO_x, CH_4, CO, NMVOC
		(v) *distribution and handling of gasoline* (including emissions from service stations).	NMVOC
	2 Natural gas	Fugitive emissions from the production and distribution of natural gas	NMVOC, CH_4

Table 2-3 (Continued)

	Sector		Comments	Pollutants
6	**INDUSTRIAL PROCESSES**		Process (by-product) or fugitive emissions from industrial processes. (Emissions from fuel combustion in industry should be reported under Energy.) Emissions from coal and coke used as reducing agents are reported under this category.	
	6A	**Mineral products** (ISIC Division 26)	Cement Production, Lime Production, Road Paving with Asphalt and Brick Manufacture.	SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$ (+CO_2 for cement)
	6B	**Chemical industry** (ISIC Division 24)	Production of Ammonia, Nitric acid, Adipic acid, Carbon black, Urea, Ammonium nitrate, Ammonium phosphate, Sulphuric acid and Titanium dioxide and other chemicals.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
	6C	**Metal production** (ISIC Division 27)	Pig iron production, Aluminium production, Copper smelting (primary), Lead smelting (primary) and Zinc smelting (primary). Emissions from coke and coal used primarily as reducing agents are included here (and not as combustion emissions under 2A above).	SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$
	6D	**Paper and pulp** (ISIC Division 15)	Kraft pulping, Alkaline soda pulping, Acid sulphite pulping, Neutral sulphite semi-chemical (NSSC).	SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$
	6E	**Food and Drink** (ISIC Division 29)	All processes in food production chains that occur after the slaughtering of animals or harvesting of crops. Includes production of Meat, fish and poultry; Sugar; Margarines and solid cooking fats; Cakes, biscuits and breakfast cereals; Bread; Animal feed; Coffee roasting and Alcoholic beverage manufacture. Excludes vegetable oil extraction and tobacco	NMVOC, PM_{10}, $PM_{2.5}$
7	**SOLVENT AND OTHER PRODUCT USE**		Emissions resulting from the use of solvents and other products containing volatile compounds.	
	7A	**Paint Application**	The application of paint in industry (including the manufacture of vehicles, ship building etc.), vehicles refinishing, construction and building, and domestic.	NMVOC
	7B	**Degreasing and Dry cleaning**	Metal degreasing and Dry-cleaning of fabrics	NMVOC
	7C	**Chemical Products, Manufacture and Processing**	Manufacture of Polyester resins, Polyvinylchloride, Polyurethane, Polystyrene foam, Paint and varnish, Ink, Glue, Adhesive tape and Rubber processing.	NMVOC
	7D	**Other Solvent Use**	For example, glass/mineral wool enduction, Printing industry, the extraction of edible fat and non-edible oil and the application of glues and adhesives.	NMVOC

Table 2-3 (Continued)

	Sector	Comments	Pollutants
8	**AGRICULTURE**		
8A	**Manure management**	Ammonia and methane emissions from managing manure from farm animals	NH_3, CH_4
8B	**Animal husbandry**	Particle emissions from animal housing systems.	PM_{10}, $PM_{2.5}$
8C	**Fertilizer application**	Emissions of ammonia and NO_x from application of N-containing fertilizers (fertilizer volatilization, foliar emissions and decomposing vegetation)	NH_3, NO_x
8D	**Savanna burning**	Emissions from the burning of savannas. (Savannas are tropical and subtropical formations with continuous grass cover, occasionally interrupted by trees and shrubs.)	SO_2, NO_x, CO, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
8E	**Field burning of agricultural residues**	Field combustion of residues from Rice, Wheat, Millet, Soya and other crops.	SO_2, NO_x, CO, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
8F	**Rice cultivation**	Methane emissions from anaerobic decomposition of organic material in flooded rice fields.	CH_4
9	**VEGETATION FIRES & FORESTRY**		
9A	**Forest and Grassland fires**	All on-site burning of forests and natural grasslands (excluding Savannas) during conversion to other land uses, for management purposes or as a result of fires started either accidentally by man or naturally by lightning.	SO_2, NO_x, CO, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
10	**WASTE**		
10A	**Waste Incineration**	Incineration of all municipal solid waste (MSW), industrial waste and commercial waste except waste-to-energy facilities (which are dealt with under Energy, Sector 1). Includes trench and open burning as well as furnace incineration.	SO_2, NO_x, CO, NMVOC, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC, OC
10B	**Solid waste disposal on land**	Methane emissions from anaerobic microbial decomposition of organic matter in solid waste disposal sites	CH_4
10C	**Domestic wastewater treatment and discharge**	Treatment and discharge of liquid wastes from housing and commercial sources through: wastewater sewage systems collection and treatment systems, open pits/latrines, anaerobic lagoons, anaerobic reactors and discharge into surface waters.	CH_4
10D	**Human excreta**	Emissions from human excreta in latrines ('dry' toilets outside the house) and from defecation/urination in open fields/bush.	NH_3

2.9 Large points sources (LPS)

Many air pollution models include separate accounting for emissions from Large Point Sources (LPS). Accurate information about the location and height of emission for LPS sources improves the accuracy of air chemistry/transport modelling activities. Therefore, in emissions inventories, emission estimates are often provided for large individual plants or emission outlets, usually in conjunction with data on location, capacity or throughput, operating conditions, height of exhaust stacks, and other data. Reported emissions from point-sources can be related to the source-categories above; in particular, energy and industrial processes and should always be allocated to the appropriate source-category.

Examples of LPS would include large power stations, waste incineration plants and major industrial plants such as metal smelters and oil refineries. The number of LPS included in an inventory depends on the availability of individual plant data and on definitions of "large". Definitions of "large" for the purposes of this Manual are suggested in Chapter 9. LPS criteria for modelling purposes may be more limited than those given in this manual depending on the specific application. As modellers may need to select a sub-set of the inventoried point sources according to their own criteria, it is important to include data on parameters such as stack height in the LPS worksheets.

It is important not to double-count emissions reported from large point sources with the rest of the inventory. Once emissions from LPS have been calculated, LPS estimates must therefore be subtracted from the relevant area emissions totals to avoid double counting. This is done automatically in the workbook when data are aggregated into the summary sheets.

2.10 Temporal allocation of emissions

Temporal allocation of emissions, or allocation of emissions quantities over time intervals in a year, can be accomplished on many different time scales, including seasonal, monthly, weekly, day-of-week, day/night (diurnal), and hourly. Though many pollutant transport and atmospheric chemistry models require emissions data on an hourly basis, in practice, data limitations rarely allow emissions from more than a few specific sources to be specified on an actual hour-by-hour basis. There is no explicit provision in this manual for the temporal allocation of area or line source emissions although, where temporal information is available for a particular source category (e.g. monthly savanna burning data), this should be recorded in the relevant worksheet (with references). Also, information on the temporal emissions profiles of Large Point Sources (e.g. % of annual total emitted each month) should be sought and recorded next to each LPS for future possible use by modellers using the inventory.

2.11 Spatial allocation of emissions

In addition to allocation of emissions over time, modellers must also allocate emissions over "space", that is, the location or area (e.g. 1° x 1° grid squares) within the country from which they are emitted. Spatial allocation can be carried out by the air pollution transport and deposition modellers or by the inventory compilers. General procedures are, however, provided in this manual to allow large point source (LPS) emissions to be associated with one degree by one degree (longitude and latitude) grid squares, as well as to specify the height of exhaust stacks (also required by modellers). Area sources are often gridded using data sets that are spatially distributed

and correlated with the inventory data. This could for example be population data, road networks and agriculture areas. It is important to ensure an adequate correlation between emissions and the gridding dataset. Often, however, spatial data are limited in availability.

3. Emissions from energy-related activities

3.1 Introduction

The sectors covered here include Fuel Combustion Activities within the Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (Commercial/ Institutional, Residential and Agriculture/Forestry/ Fishing) as well as sources of Fugitive Emissions from the extraction, processing, storage, distribution, and use of fuels. Unless measured directly, emissions are generally estimated using emission factors:

Emission = (emission factor) x (activity rate)

For fuel combustion activities, the "activity rate" is some measure of the annual rate of consumption of a fuel. For fugitive emissions from fuels, the relevant "activity rate" might be the annual rate of fuel production (e.g. for the manufacture of coke). Ideally, estimations of emissions from fuel combustion should be based on national emission factors for the activity concerned. However, where such detailed information is not available, emissions can still be estimated using default emission factors published in sources such as the USEPA's *AP-42*[12], the *EMEP/CORINAIR Guidebook*[13] and the *IPCC Guidelines*[14].

The approach used here is similar to the IPCC Tier 1 method except that a more detailed disaggregation of fuel types, based on the International Energy Agency (IEA) categories, is used (Table 3-1)[15]. Emissions are estimated in the Workbook with the relevant activity rates being the amount of each of the various fuel types combusted within each sector (entered into the Workbook as either TJ, ktoe or kt depending on the data source). This calculation could be carried out at the district/province scale if detailed fuel use data at this level of disaggregation are available. Otherwise, national energy balance data at the required level of detail could be used, for example, as reported by the IEA[16] or the United Nations.

In the Workbook, SO_2 emission factors for fuel combustion are calculated based on the sulphur content and Net Calorific Value (NCV) of each type of fuel, the proportion of sulphur retained in the ash after combustion, and the percentage reduction in emissions achieved by any emission controls technology employed (such as FGD (Flue Gas Desulphurization) on power stations). Default values for the S-content of fuels are taken from the *IPCC Guidelines*, *AP-42*, Spiro *et al.* (1992)[17] and Kato and Akimoto, (1992)[18]. The default NCVs, and the reference sources from which they were derived, are included in Table 3-1.

***Table 3-1: Fuel categories and default Net Calorific Values (NCVs) used in this manual**.*

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[12] USEPA (1995) *Compilation of Air Pollution Emission Factors. Vol. 1: Stationary Point and Area Sources, 5th Edition, AP-42*; US Environmental Protection Agency, Research Triangle Park, North Carolina, USA. (Available via Internet: http://www.epa.gov/ttn/chief/ap42/index.html)

[13] EMEP/CORINAIR *Atmospheric Emission Inventory Guidebook - 2006*, European Environment Agency, Copenhagen, Denmark. (Available via Internet: http://reports.eea.eu.int/EMEPCORINAIR4/en.)

[14] Intergovernmental Panel on Climate Change (IPCC), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual* (Available via Internet: http://www.ipcc-nggip.iges.or.jp/public/ gl/invs1.htm).

[15] For fuel definitions see Section on "Units and Conversions"

[16] *Energy balances of non-OECD countries,* IEA. http://www.iea.org/stats/index.asp

[17] Spiro, P.A., Jacob, D.J. and Logan, J.A., (1992) Global inventory of sulphur emissions with 1° x 1° resolution. *Journal of Geophysical Research* **97**:6023-6036.

[18] Kato, N. & Akimoto, H., (1992) Anthropogenic emissions of SO_2 and NO_x in Asia: Emission Inventories. *Atmospheric Environment* **26A**:2997-3017.

Fuel class	Fuel type	Default Net Calorific Value (NCV)	
		Terajoules per kilotonne (TJ/kt)	Tonnes of oil equivalent per tonne (toe/t)
Coal	Coking Coal	a	a
	Other Bituminous Coal & Anthracite	a	a
	Sub-Bituminous Coal	a	a
	Lignite	a	a
	Patent Fuel	a	a
	Coke Oven Coke	a	a
	Gas Coke	a	a
	BKB (Brown coal briquettes)	a	a
	Coke Oven Gas (COG)	28 [b]	0.6688
	Blast Furnace Gas (BFG)	2.2 [b]	0.0523
Gas	Gas Works Gas (GWG)	28	0.6688 (Assume =COG)
	Natural Gas	50.81	1.2137 [c]
Oil	Crude Oil	a	a
	Natural Gas Liquids (NGL)	a	a
	Refinery Gas	48.15	1.150 [d]
	Liquefied Petroleum Gases (LPG)	47.31	1.130 [d]
	Motor Gasoline	44.8	1.070 [d]
	Aviation Gasoline	44.8	1.070 [d]
	Gasoline type Jet Fuel	44.8	1.070 [d]
	Kerosene type Jet Fuel	44.59	1.065 [d]
	Kerosene	43.75	1.045 [d]
	Gas/Diesel Oil	43.34	1.035 [d]
	Heavy Fuel Oil (HFO)	40.19	0.960 [d]
	Petroleum coke	30.98	0.740 [d]
	Other Petroleum Products	40.19	0.960 [d]
Combustible renewables/ wastes	Solid Biomass and Animal Products:		
	Wood	15	0.3583 [e]
	Vegetal materials and wastes	12	0.2866 [e]
	Other (e.g. animal products/ wastes)	15	0.3583 [e]
	Gas/Liquids from Biomass + wastes	17.7 [f]	0.4229
	Municipal Waste	11	0.2627 [e]
	Industrial Waste	11	0.2627 [e]
	Charcoal	30	0.7360 [d]

[a] For coal, coal products, crude oil and natural gas liquids refer to OECD/IEA[19] or the *IPCC Guidelines*.

[b] Average values given in the *CORINAIR methodology (EEATF, 1992* [20]*)*.

[c] Assuming a default Gross Calorific Value (GCV) of 38 TJ/million m^3 and a GCV to NCV conversion factor of 0.9 (IEA, 1998); and density of 0.673 kg/m^3 (US EPA, 1995).

[d] Conversion factors used in OECD/IEA[15]

[e] Average values given in the *IPCC Guidelines*.

[f] Value for domestic biogas given by Smith, Kirk R. et al, (2000)[21]

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[19] OECD/IEA (2003) *Energy Statistics and Balances of non-OECD Countries 200-2001*, 2003 Edition, International Energy Agency, OECD, Paris, France.

[20] EEATF (European Environment Agency Task Force) (1992) *Default Emission Factors Handbook, Technical annexes Vol. 2.*, European Commission, Brussels, Belgium.

[21] 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

Default "retention-in-ash" values for coal combustion were derived from *AP-42* and are indicated in Table 3-2. Sulphur retention-in-ash is usually assumed to be negligible for solid biomass fuels and zero for liquid and gaseous fuels. Emission controls for all the inventoried pollutants, including SO_2, are described below separately for each sub-sector. For emissions from the Transport sector, a more detailed alternative to the IPCC Tier 1-based approach is also offered in this Manual and the accompanying workbook.

Tables of the default emission factors for fuel combustion and fugitive emissions for fuels offered in the Workbook for NO_X, CO, CO_2, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC, OC and CH_4 are given in Annex 4 of this Manual.

Table 3-2:
Sulphur retention-in-ash factors

Fuel	Sectors	Sulphur retention-in-ash (%)
Hard coal (i.e. coking coal, other bituminous coal and anthracite)	Power generation and Industry	5
	Transport and Other Sectors (Commercial/Institutional, Residential and Agriculture/ Forestry/Fishing)	22.5
Brown coal (i.e. sub-bituminous coal) / Lignite	All sectors	25
Solid Biomass	All sectors	Negligible
Liquid and gaseous fuels	All sectors	0

3.2 Sector 1: Fuel Combustion in the Energy Industries

3.2.1 Introduction

The energy industries are those industries involved either in energy production (that is, energy transformation) or in fossil fuel extraction. All of the energy industries are potential sources of SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, and $PM_{2.5}$ emissions. These sources comprise:

- *Public Electricity and Heat Production* – All emissions from the combustion of fuel for generation of electricity or the production of heat for sale to the public. The power stations or utilities may be in public or private ownership. Emissions from own on-site use of fuel are included. Emissions from autoproducers[22] of electricity or heat are not included under "Energy Industries" but are either assigned to the industrial sector where they were generated or are included under the "Remainder (non-specified)" category within the "Combustion in Manufacturing Industries and Construction" sector.

- *Petroleum Refining.* – All emissions from the combustion of fuel used to support the refining of petroleum products. Evaporative emissions of NMVOC are dealt with separately under "Fugitive Emissions from Fuels".

- *Manufacture of Solid Fuels and Other Energy Industries.* – All emissions from the combustion of fuels used during the manufacture of secondary or tertiary products from solid fuels. Included are emissions from the production of coke (from hard coal in coke ovens and gas works), brown coal briquettes (from brown coal or lignite), patent fuel (from hard coal) and charcoal (from wood). Also included are the combustion emissions from own (on-site) energy use in coal mining and in oil and gas extraction.

3.2.2 Procedures and default data used in this Manual

The approach adopted in this Manual is similar to the IPCC Tier 1 method except that a more detailed disaggregation of fuel types is used as detailed above in Table 3.1. SO_2 emissions are calculated as described in Section 3.1 above. No default values for emission controls are offered for the generalized emission factor calculations (in Worksheets 1.2.1 – 1.2.4 of the workbook that accompanies this Manual) because these will depend on the proportion of total capacity in a particular sector subject to controls. The default assumption is that SO_2 emission controls for fuel combustion are insignificant except in the "Public Electricity and Heat Production" sector. (Measures such as coal washing or use of low-sulphur diesel should be reflected in the values given for the S contents of fuel entered into Worksheet 1.2.1.) For the "Public Electricity and Heat Production" sector, "emission control calculators" are included at the bottom of Worksheet 1.2.1 in which the proportion of coal- and oil-fired generating capacity subject to the main types of SO_2 emission control can be entered. The calculator then returns the average percentage emission control achieved for that fuel type and automatically carries it forward into the "SO_2 emission control efficiency" column of the main worksheet. The most common types of FGD (flue gas desulphurization) employed are "wet scrubber" and "spray dry absorption" (with 90 and 80 percent reduction efficiencies respectively). A mean reduction efficiency of 85 percent can be assumed for FGD where the precise form of the pollution control equipment employed is unknown. Atmospheric Fluidized Bed Combustion (AFBC) with sorbent injection reduces SO_2 emissions by 70-90%; an 80% removal efficiency is therefore assumed by default in the

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[22] Autoproducers undertaking the generation of electricity and/or heat, wholly or partly for their own use, as a secondary activity (not as their main business). They may be privately or publicly owned.

Workbook. For heavy fuel oil (HFO) combustion with furnace injection an SO_2 emission control rate of 38 percent is assumed.

For NO_X, most of the (uncontrolled) default emission factors given in the workbook (see Table A4.1) are derived from Kato and Akimoto (1992) because these authors give values by sector for each individual fuel. The *IPCC Guidelines* and the *EMEP/CORINAIR Guidebook* were used to fill in certain gaps. Various types of control technology can be used to reduce NO_X emissions, and some of these may be employed in non-OECD countries. Table 3-3 lists the main NO_x control technologies applicable to power stations, along with representative values for percentage emissions reductions associated with each technology. For NO_x there is a separate worksheet (1.3.2) in the workbook for entering the NO_x emission control rates. Emission control calculators are also provided at the bottom of the worksheet for coal, oil and gas combustion and as before, the outputs of the emission control calculators are automatically carried forward into the main worksheet table.

Table 3-3:
Representative NO_x emission control reductions for power stations and industrial boilers.

Technology	Representative NO_x reduction (%)
Low Excess Air (LEA)	15
Overfire Air (OFA) - Coal	25
OFA - Gas	40
OFA - Oil	30
Low NOx Burner (LNB) - Coal	45
LNB - Tangentially Fired	35
LNB - Oil	35
LNB - Gas	50
LNB with OFA - coal	50
Cyclone Combustion Modification (in power stations)	40
Flue Gas Recirculation (in industrial boilers)	40
Ammonia Injection	60
Selective Catalytic Reduction (SCR) - Coal	80
SCR - Oil	80
SCR - Gas	80
Water Injection - Gas Turbine Simple Cycle	70
SCR - Gas Turbine	80

Source: Radian, 1990[23]

The particulate matter (PM_{10} and $PM_{2.5}$) emission factors (controlled and uncontrolled) for fuel combustion in power station boilers are given in *AP-42*. For coal and petroleum coke, the defaults are expressed as a function of the percentage ash content (A) of the fuel. Therefore, in order to inventory PM emissions for these fuels, the ash contents of the fuels must be known (or estimated). PM emissions from power stations can be controlled by a variety of technologies, including Multiple Cyclone, Scrubber, Electrostatic Precipitator (ESP) and Baghouse (fabric

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[23] Radian Corporation (1990) *Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO_x , N_2O, CH_4 , CO, and CO_2.* Prepared for the Office of Research and Development, US Environmental Protection Agency, Washington, D.C., USA

filtration in "baghouses") systems. As for NO_x, there are separate worksheets (1.4.2 and 1.4.5) in the Workbook for entering the PM emission control rates and emission control calculators are provided below the main table. As before, the outputs of the emission control calculators are then automatically carried forward into the main table and used to calculate the controlled emissions. Emission factors for BC and OC are derived from Bond et al. (2004)[24]. There are no significant emission controls for CO, NMVOC and NH_3 in this sector.

The relevant activity rates are annual fuel consumption per sector and national energy balance data at the required level of detail, as well as net calorific values, are reported by the IEA[25].

For Large Point Sources in this sector, SO_2, NO_x and PM emission control efficiencies (or controlled emission factors) for each utility will be required unless stack emissions are normally measured directly.

3.3 Sector 2: Fuel Combustion in Manufacturing and Construction

3.3.1 Introduction

For most countries, the major fuel-consuming activities in this sub-sector are iron and steel manufacture (excludes coal and coke consumed in the furnaces as these are primarily used as reducing agents), non-ferrous metal smelting, non-metallic minerals (including cement production but excluding brick manufacture), the manufacture of chemicals and petrochemicals, the pulp and paper industry, mining (excluding coal mining) and quarrying, , the construction industry and brick manufacture (not included under non-metallic minerals). The combined totals for all remaining unspecified industries should be included under the "Non-specified industry" category in the Workbook. A separate category is used for fuel consumed for autoproduction of electricity within manufacturing industry.

3.3.2 Procedures and default data used in this manual

Emissions of pollutant gases are calculated in the same way as described above for the energy industries using emission factors and the rates of fuel combustion. The (uncontrolled) default emission factors given in the workbook were derived from Kato and Akimoto[26] for NO_X, from the *IPCC guidelines* for CO and NMVOC, from *AP-42* for PM, from Bond et al. (2004) for BC and OC, from Battye et al.[27] for NH_3 and from IPCC (2006) for CO_2 and CH_4 (see Tables A4.1 – A4.10). Controls for NO_x and PM can be accounted for, as for the Energy Industries, in the emission control worksheets. In general it is expected that control technologies are less frequently applied than in the Energy Industries. The relevant activity rates are annual fuel consumption per

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[24] Bond TC, Streets DG, Yarber KF, Nelson SM, Woo JH & Klimont Z (2004) A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Research-Atmospheres 109, D14203.

[25] *Energy balances of non-OECD countries,* IEA, http://www.iea.org/stats/index.asp.

[26] Kato, N. & Akimoto, H., (1992) Anthropogenic emissions of SO_2 and NO_x in Asia: Emission Inventories. *Atmospheric Environment* **26A**:2997-3017.

[27] Battye, R., Battye W., Overcash C. and Fudge S. (1994) *Development and Selection of Ammonia Emission Factors – Final Report*. Prepared for the U.S. Environmental Protection Agency - Office of Research and Development, Washington, D.C. 20460

sector and national energy balance data at the required level of detail, as well as net calorific values, are reported by the IEA[28].

3.4 Sector 3: Transport

3.4.1 Introduction

Transport sector emissions include emissions from the combustion of fuel during transport activities, evaporative losses from vehicles (except from loading of gasoline into the vehicle) and, for road transport, tyre wear and road dust emissions. The activities included are road transport, civil aviation, railways, navigation and, within the category "Other Transportation", pipeline transportation and ground activities in airports and harbours. Specifically excluded are off-road mobile activities because these are included in their respective sectors, "Manufacturing Industry and Construction" and in "Agriculture/Forestry/Fishing". However, estimation methods and emission factors are different from those of stationary sources. Emissions from road transport generally account for the bulk of emissions in this sub-sector. Fuel combustion emissions from mobile sources include SO_2, NO_X, CO, CO_2, NMVOC, NH_3, PM_{10} , $PM_{2.5}$, BC, OC, and CH_4. There are also non-combustion-related emissions of NMVOC from vehicles as a result of fuel gasoline evaporation (excluding refueling emissions at service stations, which are covered under "Fugitive emissions" in sub-sector 1B). Diesel-powered vehicles produce minimal evaporative NMVOC emissions.

3.4.2 Procedures and default data used in this manual

Two possible methods for inventorying emissions from the transport sector are offered in this Manual: a "Simple method" and a "Detailed method".

3.4.2.1 Simple method

Emissions of all pollutants are estimated in a way similar to that described above for fuel combustion in the Energy Industries and in the Manufacturing Industries and Construction (based on fuel combusted). It is similar to the IPCC Tier 1 method except that a more detailed disaggregation of fuel types is used. An average emission factor for a particular fuel, taking into account average emission controls where relevant, is multiplied by the annual fuel combustion for the entire sub-sector (civil aviation, road transport, railways, navigation or pipeline transport). The simple method is recommended for estimating all SO_2 transport emissions which depend only on the sulphur content of fuel. For the other pollutants, the simple method just gives a very approximate estimate of emissions and should only be used by countries lacking the data required for the preferred "Detailed method" described below. The simple method is expected to overestimate emissions in a country with a modern car fleet since it does not take into account implementation of catalytic converters and other technologies to reduce emissions from vehicles. Default emission factors for the simple method are taken mainly from the 1996 *IPCC Guidelines* and the *EMEP/CORINAIR Guidebook*. The relevant activity rates are annual fuel consumption per sector and national energy balance data at the required level of detail are reported by the IEA[29].

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[28] *Energy balances of non-OECD countries,* IEA, http://www.iea.org/w/bookshop/add.aspx?id=564.
[29] *Energy balances of non-OECD countries,* IEA, http://www.iea.org/stats/index.asp

3.4.2.2 Detailed method (preferred)

Road-transport emission factors for NO_X, CO, NMVOCs and PM vary greatly depending on the vehicle type, age, operating characteristics, emission controls, and maintenance procedures as well on fuel type and its quality and the "Simple method" does not adequately deal with all of these variables. A "Detailed method" is also offered in the workbook which addresses the differences relating to vehicle class, and to some extent, control technology (e.g. for gasoline passenger cars). This method is recommended where some transport activity data (i.e. numbers of each vehicle type is use, average annual distance travelled) are available. The vehicle categories covered are: passenger cars, light duty vehicles, heavy duty vehicles, motorcycles <50cc (2-stroke), motorcycles >50cc (2-stroke), motorcycles <50cc (4-stroke) and 3-wheelers. These categories are further subdivided by fuel type and, for gasoline passenger cars, by control technology (uncontrolled, medium control (as for 2-way catalysts) and good control (as for 3-way catalysts)). The relevant activity rates are the number of vehicles in use and the average annual kilometres driven for each vehicle category. These activity data should be available from national statistical offices and, for some countries, from the International Road Federation's statistics[30].

Where known, average fuel economy (i.e. km travelled per litre fuel consumed) by vehicle type may also be entered into the workbook (Sheet 1.9.3) by the compiler which then enables the workbook to calculate total fuel consumed (in PJ) for road transport by fuel type. This therefore provides a way of checking the totals calculated for the 'detailed method' with the total fuel consumption for road transport entered for the 'simple method' (and reported as PJ in Sheet 1.1.1). Large differences between total fuel consumption for the two methods should be investigated (in case it is due to user error) and indicated in the inventory report.

If the compiler wants to enter non-default emission factor (EFs) whose original units are in g/kg fuel (rather than in g/km travelled as required by Sheet 1.9.3)) these can be converted into g/km if the fuel economy is known. User-entered fuel economy (in km/litre fuel) is automatically converted by the workbook into fuel economy expressed as km/kg fuel. The user can then divide the original EF by the fuel economy in km/kg to give the EF in the required units (g/km). For example, for heavy duty diesel vehicles having a fuel economy of 3.3 km/litre (which is converted into 4.02 km/kg fuel by the workbook) a NOx EF of 50 g/kg would become 12.4 g NO_X/km (50/4.02 = 12.4) and this value can then be entered into the worksheet instead of the default NO_X EF of 10.4 g/km.

The default emission factors are mainly derived from the Indian Central Pollution Control Board (CPCB, 2000) these being considered to be more appropriate for developing countries in general than emission factors taken from North American or European sources. Particulate matter emission factors for exhaust, tyre wear and paved road dust combined are from the Japan Environment Agency (1997).[31] Dust emissions from vehicles travelling on unpaved roads are an important source of PM emissions in many developing countries and so these are also covered by this detailed method. The dry weather PM emission factors given in the workbook are derived from Gillies et al. (2005)[32] and require an estimate of the percentage days during the year when

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[30] IRF World Road Statistics 2005, Geneva, Switzerland (http://www.irfnet.org/)

[31] JEA (1997) Manual for predicting atmospheric concentrations of suspended particulate matters, Japan Environment Agency, 1997, ISBN4-491-01392-6 (in Japanese)

[32] Gillies, J.A., Etyemezian, V., Kuhns, H., Nikolic, D., Gillette, D.A., 2005. Effect of vehicle characteristics on unpaved road dust emissions. Atmospheric Environment 39:2341-2347..

rainfall or other precipitation was less than 0.25 mm. The default road transport emissions factors offered in the workbook are shown in Table A4.13.

If sufficiently detailed activity data are available, existing road transport emissions estimation models such as COPERT 4[33] (used in Europe) or MOBILE6[34] (used in North America) should be used as an alternative to the detailed method offered in this Manual/ Workbook. These models require a detailed technology split of vehicles (by engine size and emission control technology) and data on driving patterns, temperature data etc. In using European default emission factors in developing countries it is important to bear in mind that actual emission levels are determined by fuel quality and vehicle maintenance. Therefore it is important to assess whether actual emissions can be higher than those generated using the default emission factors in a model. For example, the use of leaded gasoline or adulterated fuels (a common practice in some developing countries) will often prevent the catalytic converter from working properly. Vehicles imported into some developing countries may also have their catalytic converters removed to improve fuel economy. Cars converted from gasoline to LPG will usually have their catalytic converters cut out. Lastly, imported, reconditioned vehicles (especially trucks) which initially meet certain emission standards may deteriorate rapidly due to the poor state of the roads and/or poor fuel quality. In general, it may be best to assumed that reconditioned vehicles will have pre-control levels of emissions even if newly registered.

Inventory compilers may also refer to COPERT model for the calculation of off-road vehicle emissions although these should be reported under their relevant source sectors.

For civil aviation, the detailed method offered in this Manual is based on the EMEP/CORINAIR "Simple methodology" and is also similar to the *IPCC Guidelines* Tier 2 method. It includes landing and take-off (LTO) cycle[35] and cruise activity emissions for domestic aircraft and, for international aviation, half of the LTO cycle emissions (the other half occurring other countries) Cruise emissions for international aircraft are not included as these mainly occur outside the country being inventoried.

This detailed approach is recommended for all pollutants emitted by civil aviation (including SO_2) where annual domestic LTO data are available. The default emission factors by individual aircraft type given in the Workbook (and listed in Tables A4.11 and A4.12) are mainly from the EMEP/CORINAIR guidebook. If total LTO data are available but they not allocated to individual aircraft type, it is still possible to use this detailed method by entering data for 'Type unknown: old fleet' (represented by Boeing B737-100) or 'Type unknown: average fleet' (represented by Boeing B737-400) whichever is most appropriate Landing and take-off statistics will be available from individual airports, the official aviation authority or national reports.

For railways, navigation (shipping) and pipeline transport, the simple method (Section 3.4.2.1), utilizing bulk emission factors, is considered adequate for the purposes of this Manual. Emission methodologies for shipping are also given in the EMEP/CORINAIR emission inventory guidebook. The COPERT model can also be used to estimate emissions from off-road transport, including off-road machinery, although these would be reported under the relevant source sector rather than under transport.

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[33] European Environment Agency (2011) COPERT 4 Estimating emissions from road transport (http://www.eea.europa.eu/publications/copert-4-2014-estimating-emissions).

[34] MOBILE6 Vehicle Emission Modeling Software, USEPA (http://www.epa.gov/otaq/m6.htm)

[35] Landing/Take-off (LTO) cycle. Consists of one take-off and one landing and includes engines running idle, taxi- in and out, and climbing and descending under 914 metres (3000 feet).

National inventories normally exclude emissions from international shipping and aviation (from use of bunkers) from national totals. Emissions based on the bunker sales in the country are rather estimated and included as a memo item. Nevertheless these emissions are of course important for air quality modelling. Often it can be more useful to use global datasets (e.g. EDGAR) for the purpose rather than national inventories.

3.4.3 Application of parameters for control equipment

For road transport, the default assumption is that use of emission controls is negligible. However, the number of catalytic controlled vehicles is increasing in non-OECD countries and application of the pre-catalytic converter emission factors offered in the Workbook may produce an overestimate of emissions. On the other hand, even if cars are equipped with catalytic converters, it is important to determine their maintenance before choosing emission factors. Catalytic converters are destroyed if the fuel quality is not adequate (e.g. if it contains lead or is adulterated) causing catalytic converters to lose their efficiency over time if they are not replaced. Also, as is often the case in Africa for example, catalytic converters from imported vehicles may be removed to improve fuel consumption. Therefore, the assumption that use of emission controls is negligible may still be adequate even if cars with catalytic converters are being imported.

Emissions from aviation are reflected by the use of different aircraft and engine combinations representing different emission levels. The default emission factors given in the Workbook for civil aviation (detailed method) represent an average level of technology for each type of aircraft listed.

It can be assumed that for other non-road transport (railways, navigation and pipeline transport), the use of emission controls is negligible. However, sulphur content of fuel can be regulated in certain areas.

3.5 Sector 4: Combustion of fuel in "Other sectors" (Residential, Commercial/Institutional, Agriculture, Forestry and Fishing)

3.5.1 Introduction

This sector includes emissions of SO_2, NO_X, CO, NMVOC, NH_3, PM_{10}, and $PM_{2.5}$ from fuel combustion in "Commercial and Institutional" buildings, residential "Households" and in "Agriculture, Forestry and Fishing". The sector includes mobile emissions from off-road activities in agriculture and forestry and from water-borne vessels engaged in domestic inland, coastal or deep-sea fishing.

3.5.2 Procedures and default data used in this manual

A simple method is proposed in this Manual for the "Other sectors" using bulk emission factors for each type of fuel used in each sector (see Tables A4.1 – A4.6). The relevant activity rates are annual fuel consumption per sector (*Residential, Commercial/institutional, Agricultural* or

Forestry). National energy balance data are reported by the IEA[36] although data for 'primary solid biomass'[37] are not further sub-divided by type in this database. Thus, IEA data for 'Primary solid biomass' should be entered into the Forum Workbook under the category 'Unspecified primary solid biomass'. Other activity data sources for biomass fuel consumption are the United Nations Energy Statistics Yearbooks (for fuelwood, charcoal and bagasse) and FAOSTAT[38] (for wood fuel and wood charcoal). For both these reference sources, data are in cubic metres (m^3) which must be converted into mass units (for wood assume 1000 m^3 = 0.732 kilotonnes) before being entered into the Workbook (sheet 1.1.1c). Also, for the UN Energy Statistics Yearbook and FAOSTAT database, assume that consumption equals production plus imports minus exports. Official and international data sources for biomass combustion may be unreliable and underestimate the real consumption and therefore it is important to identify additional data sources (e.g. dedicated studies).

The (uncontrolled) default emission factors given in the Workbook were mostly derived from Kato and Akimoto[39] for NO_X, from the *IPCC Guidelines* for CO and NMVOC, from *AP-42* for PM and from Battye et al.[40] for NH_3. For SO_2, emission factors are calculated from the average sulphur content, sulphur retention-in-ash and Net Calorific Value (NCV) of each type of fuel. The inclusion of factors for emission controls is unlikely to be applicable in this sector.

Household stoves and fires, although individually small, are numerous and have the potential to contribute significantly to regional air pollution, particularly in developing countries. Unfortunately, few measurements have been made to determine emissions factors relevant to developing countries. Some recent studies calculating emission factors for various fuel/stove combinations have been carried out for India[41] and China[42] and Bertshi *et. al.* (2003)[43] have calculated emission factors for domestic open wood cooking fires and charcoal cooking fires in Zambia. As it is unlikely that regional or national fuel data will be stove specific, the EFs shown in Table 3.4 below are mean values of all stove types tested.

If considered more appropriate, the inventory compiler may chose alternatives to the defaults suggested in the workbook, either from Table 3.4 or from other relevant sources. (As not all fuel types were tested in all regions, it is better to use an emission factor from a different region to your own rather than leave the cell blank). If detailed activity data are available by stove type the user may refer to Zhang et. al. (2000) or Smith et. al. (2000) for stove-specific emission factors by fuel type.

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[36] *Energy balances of non-OECD countries,* IEA, http://www.iea.org/stats/index.asp.

[37] Included in the IEA category 'Primary solid biomass' are wood, vegetal waste (including wood waste and crops used for energy production), animal materials/wastes, "black liquor" (an alkaline spent liquor from the digesters in the production of sulphate or soda pulp during the manufacture of paper) and other solid biomass.

[38] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD

[39] Kato, N. & Akimoto, H. (1992), "Anthropogenic emissions of SO_2 and NO_x in Asia: Emission Inventories". *Atmospheric Environment* **26A**:2997-3017.

[40] Battye, R., Battye W., Overcash C. and Fudge S. (1994), *Development and Selection of Ammonia Emission Factors – Final Report*. Prepared for the U.S. Environmental Protection Agency - Office of Research and Development, Washington, D.C. 20460

[41] 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

[42] Zhang,J.; Smith,K.R.; Ma,Y.; Ye,S.; Jiang,F.; Qi,W.; Liu,P.; Khalil,M.A.K.; Rasmussen,R.A.; 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.

[43] Bertschi, I.T., Yokelson, R.J., Ward, D.E., Christian, T.J. and Hao, W.M. (2003) Trace gas emissions from the production and use of domestic biofuels in Zambia measured by open-path Fourier transform infrared spectroscopy. Journal of Geophysical Research-Atmosperes, 108(D13), Art. No. 8469.

Table 3.4

Emission factors for domestic fuel combustion, averaged across different stove types for China and India, and for open cooking fires in Zambia. (Those offered as defaults in the Workbook are shown in bold.)

Study/Fuel type	Emission factors as g/kg fuel dry wt *(and kg/TJ)*				
	SO$_2$	NO$_x$	CO	NH$_3$	TSP
China (Zhang et. al., 2000)					
Wood[44] (ultimate emission)	0.008 *(0.51)*	1.2 *(73)*	69.2 *(4260)*	-	**3.82** *(235)*
Crop residues[45]	0.216 *(14.3)*	0.70 *(47)*	86.3 *(5730)*	-	**8.05** *(535)*
Coal/coal briquettes	2.67 *(97.8)*	0.91 *(34)*	71.3 *(2610)*	-	**1.3** *(47.6)*
Kerosene	0.025 *(0.58)*	1.10 *(25)*	7.39 *(171)*	-	**0.13** *(3.1)*
Gases[46]	0.33 *(6.87)*	1.76 *(37)*	3.72 *(77.5)*	-	0.26 *(5.4)*
India (Smith et. al. 2000)					
Wood[47]	-	-	83.5 *(5490)*	-	2.36 *(156)*
Crop residues[48]	-	-	70 *(4650)*	-	4.52 *(317)*
Charcoal	-	-	275 *(10700)*	-	**2.38** *(92.3)*
LPG	-	-	14.9 *(326)*	-	**0.51** *(11.2)*
Biogas	-	-	1.95 *(110)*	-	**0.53** *(29.6)*
Kerosene[49]	-	-	39.9 *(925)*	-	0.61 *(14.2)*
Dung	-	-	43.2 *(3680)*	-	**1.6** *(137)*
Zambia (Bertschi et. al. 2003)					
Open wood cooking fires	-	3.13 *(209)*	96 *(6400)*	**1.29**	-
Charcoal cooking fires	-	2.16 *(72)*	134 *(4470)*	**0.97**	-

3.6 Sector 5: Fugitive emissions from fuels

3.6.1 Introduction

This sub-sector covers all non-combustion activities related to the extraction, processing, storage, distribution and use of fossil fuels. During all of the stages from the extraction of fossil fuels

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[44] Mean for fuel wood and brushwood.
[45] Mean for maize and wheat residues.
[46] Mean for LPG (Liquefied petroleum gas), coal gas and natural gas.
[47] Mean over all Indian stoves for Acacia and Eucalyptus fuel wood.
[48] Mean over all Indian stoves for mustard and rice crop residues
[49] Mean for kerosene delivered by wick and pressure

through to their final use, the escape or release of gaseous fuels or volatile components of liquid fuels may occur. Fugitive emissions from refining, transport and distribution of oil products are a major component of national CH_4 and NMVOC emissions in many countries. This sub-sector includes fugitive emissions of CH_4 and NMVOC from crude oil exploration, production and transport, oil refining, the distribution and handling of gasoline (including emissions from service stations) and the production and distribution of natural gas (including venting). Other pollutants of relevance to transboundary air pollution are also emitted from activities in this sub-sector. In addition to NMVOC, fugitive emissions of particulate matter (including BC and OC) arise from the production of coke, and SO_2, NO_x and CO are emitted during oil refining (from catalytic cracking, sulphur recovery plants (SO_2 only) and flaring[50]), as well as from flaring during oil and gas extraction. Lastly, this sector include CH_4 emissions from mining and post-mining activities at surface and underground coal mines.

Excluded from consideration under fugitive emissions are 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. These two emissions sources are dealt with under Sector 1 (Fuel Combustion Activities).

3.6.2 Procedures suggested in this Manual

The methods used in this Manual are based on the EMEP/CORINAIR simpler methodologies for fugitive emissions from the "Extraction and distribution of fossil fuels", "Gasoline distribution", "Gas distribution networks" and for flaring, whereas the EMEP/CORINAIR detailed methodology (using emission factors for each sub-process) was used as the basis for fugitive emissions from coke production. The IPCC Tier 1 methodology was used as the basis for estimating CH_4 emissions from coal mining. Table A4.14 presents a listing of the process and sub-process types to be inventoried, along with a listing of the activity data to be compiled for each category and the default emission factors included in the Workbook that accompanies this Manual. It should be noted that emission factors for fugitive emissions from fuels can be climate specific as well as depending on technologies and fuel qualities. **Thus, for tropical and sub-tropical countries with higher ambient temperatures than Europe, the actual NMVOC emission factors could be much higher.** For activity data, production rates for crude oil (tonnes), natural gas (TJ), gasoline (tonnes) and coke (tonnes coke oven coke and lignite coke) and consumption rates for gasoline (tonnes) are reported in the IEA statistics.[51] Other activity data will usually be obtained from the facilities themselves or from national statistical offices in each country.

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[50] Flaring is gas combusted without utilization of the energy released—essentially a method of disposal of gaseous fuels that cannot be used on-site or transported for fuels elsewhere.

[51] *Energy statistics of non-OECD countries,* IEA, http://www.iea.org/w/bookshop/add.aspx?id=564

4. Industrial Process (non-combustion) emissions (Sector 6)

4.1 Introduction

A number of air pollutants not associated with fuel combustion are emitted during a variety of industrial processes. An example is SO_2 emissions from copper smelting where the sulphur comes from the copper ore and not the fuel used to smelt it. **It is important not to include emissions due to fuel combustion here. This would be 'double counting' as fuel combustion emissions are already accounted for under** *'Combustion in Manufacturing Industries and Construction'* **above.**

The industrial process emission categories covered in this Manual are:

- Mineral Products,
- The Chemical Industry,
- Metals Production,
- Pulp and Paper Industries,
- Alcoholic Beverages Production,
- Food Production, and
- Fugitive emissions of PM from major construction activities

4.2 Procedures and default data used in this manual

Table 4-1 lists the process and sub-process types to be inventoried with the default emission factors included in the Workbook that accompanies this Manual. References for the source documents used to compile the default emission factors in Table 4-1 are provided in the Workbook. If activity data are not available from national statistical offices or other official sources, internationally compiled data can be obtained from the USGS Minerals Yearbooks[52], the Steel Statistical Yearbook[53] (for pig iron production), the United Nations Industrial Commodity Statistics Yearbooks[54] and, for pulp/paper industries, the FAOSTAT database[55]. Trade or branch organisations may also be able to provide data.

4.3 Application of parameters for control equipment

Some provision for reflecting the use of control equipment is provided in the workbook in the form of alternative emission factors for commonly used control technologies. Also, some of the footnotes to the Excel worksheets suggest alternative emission factors where emission controls are used. The default is to assume no emission control.

Table 4-1:

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[52] United States Geological Survey (USGS) Minerals Yearbooks up to 2010/11 (Volume III: Area reports: international) http://minerals.usgs.gov/minerals/pubs/country/

[53] International Iron and Steel Institute (IISI), Steel Statistical Yearbook 2006 http://www.worldsteel.org/?action=stats_search&keuze=iron

[54] United Nations (2003), *2000 Industrial Commodity Statistics Yearbook,* United Nations, New York

[55] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD

Default emission factors for industrial process emissions
(Mineral products)

Sub-sector/Process	Emission factors (kg per tonne product output)						
	SO_2	NO_x	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$
Mineral products (ISIC Division 26)							
Cement production:							
Wet process kiln (uncontrolled)	0.3 [a]	NA	NA	NA	NA	16 [b]	4.64 [b]
Wet process kiln with ESP	0.3 [a]	NA	NA	NA	NA	0.33 [b]	0.25 [b]
Dry process kiln with fabric filter	0.3 [a]	NA	NA	NA	NA	0.084 [b]	0.045 [b]
Lime production							
Coal-fired rotary kiln (uncontrolled)	NA	NA	NA	NA	NA	22 [b]	2.57 [b]
Coal-fired rotary kiln (with ESP)	NA	NA	NA	NA	NA	2.2 [b]	0.62 [b]
Asphalt roofing production	NA	NA	0.0095 [c]	0.046 [c]	NA	0.6 [c]	-
Asphalt blowing	NA	NA	0.014 [b]	0.66 [d]	NA	0.33 [e]	-
Road paving:							
Asphalt plant - Batch Mix Hot Mix, (uncontrolled)	NA	NA	NA	0.018 [b]	NA	2.25 [b]	0.14 [b]
Asphalt plant- Batch Mix Hot Mix, (fabric filter PM control)	NA	NA	NA	0.018 [b]	NA	0.0135 [b]	0.0042 [b]
Asphalt plant -Drum Mix Hot Mix, (uncontrolled)	NA	NA	NA	0.016 [b]	NA	3.25 [b]	0.75 [b]
Asphalt plant - Drum Mix Hot Mix, (fabric filter PM control)	NA	NA	NA	0.016 [b]	NA	0.0115 [b]	0.0015 [b]
Liquefied asphalt - rapid cure (RC)	NA	NA	NA	170 [f]	NA	NA	NA
Liquefied asphalt -medium cure (MC)	NA	NA	NA	140 [f]	NA	NA	NA
Liquefied asphalt - slow cure (SC)	NA	NA	NA	50 [f]	NA	NA	NA
Brick manufacturing							
Grinding and screening (dry material; uncontrolled)	NA	NA	NA	NA	NA	0.26 [b]	

[a] IPPC (1996) non-combustion default.

[b] Derived from US EPA (1995). The PM default EFs include combustion emissions (apart from the EF for grinding and screening within brick manufacture). Therefore, if using these defaults, set combustion PM EFs to **zero** in workbook Sheets 1.6.1 (PM_{10}) and 1.6.4 ($PM_{2.5}$)

[c] EMEP/Corinair Guidebook (2005) CO, total organic carbon (TOC) and PM default values are for 'dip saturator - uncontrolled'. For dip saturator with ESP use 0.049 for TOC and 0.016 for PM. For dip saturator with High Energy Air Filter (HEAP) use 0.047 for TOC and 0.035 for PM. For the 'spray/dip saturator - uncontrolled' process no value is given for CO but the TOC emission factor is 0.13 kg/t (uncontrolled) or 0.16 kg/t (HEAP) and particulate emission factors are 1.6 kg/t (uncontrolled) or 0.027 kg/t (HEAP).

[d] US EPA (1995). Total organic carbon (TOC) value for saturant asphalt with no control. With afterburners = 0.0022 kg/t asphalt blown. Values for coating asphalt = 1.7 (uncontrolled) and 0.085 (with afterburner) kg/t asphalt blown.

[e] US EPA (1995). Default = filterable PM value for saturant asphalt with no control. With afterburners = 0.14 kg/t asphalt blown. (Values for coating asphalt = 12 (uncontrolled) and 0.41 (with afterburner) kg/t asphalt blown.)

[f] EMEP/Corinair Guidebook (2005). Assumes 25% by volume diluent content. (For 35% diluent in cutback, assume emission factors of 240 (RC), 200 (MC) and 80 kg NMVOC/t (SC).)

NA   Not applicable

-     Not available

Table 4-1 (continued):

Activity categories and default emission factors for industrial process emissions (Chemical industry)

Sub-sector/Process	Emission factors (kg per tonne output)						
	SO_2	NO_x	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$
Chemical industry (ISIC Division 24)							
Ammonia	0.03[a]	NA	7.9[a]	4.7[b]	2.1[a]	NA	NA
Nitric acid	NA	12[c]	NA	NA	0.01[d]	NA	NA
Adipic acid	NA	8.1[a]	34.4[a]	9[a]	NA	0.5[a j]	-
Carbon black	3.1[e]	0.4[e]	10[e]	40[e]	NA	6.56[a j]	-
Urea (uncontrolled)	NA	NA	NA	NA	11.8[f]	125.6[f]	-
Urea (wet scrubbber)	NA	NA	NA	NA	11.8[f]	0.71[f]	-
Ammonium nitrate	NA	NA	NA	NA	29 – 63[g]	4.7-9.0[g j]	-
Ammonium phosphate	0.04[h]	NA	NA	NA	0.07[h]	0.34[h j]	-
Sulfuric acid	0 – 48[i]	NA	NA	NA	NA	NA	-
Titanium dioxide	14.6[e]	NA	NA	NA	NA	-	-
Other (user specified)							

[a] US EPA (1995) uncontrolled default.

[b] US EPA (1995) default = 4.7 kg Total Organic Carbon/tonne ammonia.

[c] Factors range from 0.1 - 1.0 kg NOx/t nitric acid for the direct strong acid process to 10 - 20 kg NOx/t for the low pressure process. IPCC (1996) suggest a default of 12.0 kg NOx/tonne nitric acid where process details are not known.

[d] EMEP/Corinair (1996) default.

[e] IPPC (1996) default.

[f] US EPA (1995) uncontrolled default assuming fluidized bed prilling for agricultural grade material.

[g] US EPA (1995) range for uncontrolled emission factors assuming use of high density prill towers (high density prill is used for fertilizer).

[h] US EPA (1995) average controlled emission factor.

[i] Emission factors range from 0 - 48 kg SO2/t sulphuric acid depending on the SO_2 to SO_3 conversion efficiency, and can be calculated as 682 - (6.82 x (% conversion)) (EPA, 1995). Assume 17 kg/tonne for single contact process; 3.4 kg/tonne for double contact process.

[j] Total particulate matter.

NA Not applicable

- Not available

Activity categories and default emission factors for industrial process emissions
(Metal production and Pulp and Paper Industries)

Sub-sector/Process	Emission factors (kg per tonne output)						
	SO_2	NO_x	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$
Metal production **(ISIC Division 27)**							
Pig iron production	3 [a]	0.076 [d]	1.34 [c]	0.12 [c]	NA	0.05 [i]	-
Aluminum production	15.1 [e]	2.15 [e]	135 [d]	0.02 [d]	NA	47 [b]	-
Copper smelting (primary)	2120 [f]	NA	NA	0.03 [d]	NA	230 [f]	193 [f]
Lead smelting (primary)	320 [g]	NA	NA	NA	NA	0.43 [k]	-
Lead smelting (secondary)	40 [h]	NA	NA	NA	NA	162 [h]	-
Zinc smelting (primary)	1000 [g]	NA	NA	NA	NA	293 [j]	-
Pulp and Paper Industries **(ISIC Division 15)**							
Kraft or Alkaline soda pulping	3.8 [l]	1.5 [m]	5.6 [m]	3.7 [m]	NA	92 [p]	81 [p]
Acid sulfite pulping	30 [m]	NA	NA	NA	NA	1.5 [o]	1.3 [o]
Neutral sulfite semi-chemical (NSSC)	-	0.5 [n]	NA	0.15 [n]	NA	-	-

[a] Emission factors range from 1 - 3 kg SO_2/t iron (IPCC, 1996). Use 3 kg/t as default.

[b] US EPA (1995) uncontrolled default for total particulate for prebake cell process.

[c] IPCC (1996) default for blast furnace charging and pig iron tapping combined.

[d] IPCC (1996) default.

[e] IPCC (1996) default for electrolysis and anode baking combined.

[f] US EPA (1995) uncontrolled default for multiple hearth roaster followed by reverberatory furnace and copper converter. Adjust SO_2 emission factor according to S recovery rate e.g. if S recovery is 50%, factor should be 1060. For PM_{10} and $PM_{2.5}$ emission controls, assume 20 - 80% efficiency for hot ESP and up to 99% efficiency for cold ESP.

[g] Kato & Akimoto (1992) uncontrolled default.

[h] US EPA (1995) uncontrolled default for reverberatory smelting; If PM_{10} and $PM_{2.5}$ emissions are controlled, assume 99% efficiency (i.e. EF becomes 1.62).

[i] EMEP/Corinair (2000) 'Dust' emission factor of 0.02 kg/t for blast furnace charging and 0.03 kg/t (uncontrolled) for pig iron tapping (use 0.0128 kg/t for pig iron tapping if fabric filters used).

[j] US EPA (1995) PM uncontrolled default for multiple hearth roaster and sinter plant (assume zinc = 60% of zinc ore concentrate).

[k] US EPA (1995) uncontrolled default for primary lead blast furnace.

[l] US EPA (1995) uncontrolled default for Kraft pulp. Assume alkaline soda has same emission factor.

[m] IPCC (1996) uncontrolled default.

[n] Stockton and Stelling (1987) uncontrolled default.

[o] US EPA (1995) uncontrolled default for sodium carbonate scrubber recovery system assuming PM_{10} is 0.75 of TSP and $PM_{2.5}$ is 0.67of TSP emissions. EMEP/Corinair (2000) controlled defaults = 0.75 kg/t (PM_{10}) and 0.67 kg/t (PM2.5).

[p] US EPA (1995) uncontrolled default for Kraft pulp (PM emissions from recovery boiler with direct contact evaporator + lime kiln + smelt dissolving tank). If PM emission controls, use EF = 1 for PM_{10} and 0.8 for $PM_{2.5}$. Assume alkaline soda pulping has same emission factors.

NA Not applicable

- Not available

Table 4-1 (continued):
Activity categories and default emission factors for industrial process emissions
(Food and Drink Industries)

Sub-sector/Process	Emission factors (kg per tonne or hectolitre output)						
Food and Drink (ISIC Division 29)	SO$_2$	NO$_x$	CO	NMVOC [a]	NH$_3$	PM$_{10}$	PM$_{2.5}$
Alcoholic Beverages							
Beer	NA	NA	NA	0.035	NA	-	-
Red wine	NA	NA	NA	0.08	NA	-	-
White wine	NA	NA	NA	0.035	NA	-	-
Wine (unspecified)	NA	NA	NA	0.08	NA	-	-
Malt whiskey	NA	NA	NA	15	NA	-	-
Grain whiskey	NA	NA	NA	7.5	NA	-	-
Brandy	NA	NA	NA	3.5	NA	-	-
Other Spirits (unspecified)	NA	NA	NA	15	NA	-	-
Food Production							
Meat, fish and poultry	NA	NA	NA	0.3	NA	-	-
Sugar	NA	NA	NA	10	NA	-	-
Margarines and solid cooking fats	NA	NA	NA	10	NA	-	-
Cakes, biscuits and breakfast cereals	NA	NA	NA	1	NA	-	-
Bread	NA	NA	NA	4.5	NA	-	-
Animal feed	NA	NA	NA	1	NA	-	-
Coffee roasting	NA	NA	NA	0.55	NA	-	-

[a] Default emission factors (uncontrolled) suggested by EMEP/Corinair (2004). For food production, where process is controlled, assume a control rate of 90%.

NA Not applicable

-    Not available

4.4 Sources of emission factor data

Default emission factors for industrial non-combustion processes are available from a variety of sources, including the IPCC workbook and background manuals, the EMEP/CORINAIR reference sources, and factors from the US EPA in AP-42. In some cases, local emission factors can be derived from emissions and production data that have been measured for particular plants in the country for which emissions estimates are prepared, or from national or provincial emissions factor reference sources.

5.   Emissions from solvent and other product use (Sector 7)

5.1 Introduction

In some countries, the use of solvents and other products containing light hydrocarbon compounds can be a major source of emissions to the atmosphere of non-methane volatile organic compounds (NMVOCs). The general approach to estimating emissions is to find out the extent of the relevant activity - for example, the tonnage of solvent-based paint used in a particular application - and multiply this by an emission factor (for example, kg of NMVOCs per tonne of paint used). Emissions from solvent use may alternatively be estimated using mass balances. This is more accurate, but also more data intensive as it requires information about detailed consumption of pure solvents, solvent containing products and their solvent content.

The major solvent and other product use categories covered in this manual are:

- Paint application (solvent based),
- Paint application (water based),
- Metal degreasing,
- Dry cleaning of fabrics,
- Chemical products manufacture, and
- Other use of solvents.

5.2 Procedure and default data suggested in this manual

Table 5-1 lists the categories and sub-categories of solvent and other product use to be inventoried together with the default emission factors included in the Workbook that accompanies this Manual. References for the source documents of the default emission factors are provided in the Workbook, generally the uncertainty is high. The annual output or use is estimated (in tonnes of commodity, being sure to use consistent commodity specifications) for each of the categories and sub-categories. Activity data may be obtained from national statistical office (or other official sources), industrial sources or, for commodity production data, the UN Industrial Commodity Statistics. The estimates of annual output are multiplied by the user-selected (or default) emission factors to yield estimates of total annual NMVOC emissions by process/sub-process.

5.3 Application of parameters for control equipment

As with industrial process emissions, no explicit provision for reflecting the use of control equipment is provided in the procedure suggested here, but the use of control equipment can be implicitly included in the calculation by using (lower) non-default emission factors that are consistent with the use of emission controls. For example, use of solvents in dry cleaning installations where controls are used may, based on USEPA data, result in an 80 percent reduction in emissions (from 1000 to 200 kg/tonne of solvent use). It should also be taken into account that there can be large regional and country differences in solvent content and solvent composition due to regulations, so use of standard emission factors can be misleading.

Table 5-1: Activity Categories, Units, and Default Emission Factors for NMVOC Emissions from Solvent and Other Product Use

Category/Sub-category	Activity Units	NMVOC Emissions (kg/Unit)
Paint application (solvent based)		
Industrial	tonnes paint sold	750 [a]
Decorative	""	300 [d]
Unknown	""	750 [a]
Paint application (water based)	""	33 [d]
Metal degreasing	tonnes solvent consumed	1000 [c d]
Dry cleaning of fabrics	tonnes solvent consumed	1000 [c d]
Chemical products manufacture		
Polyester resins—manual lay-up	tonnes resin	40 [b]
Polyester resins—closed system	tonnes resin	10 [b]
Polyvinylchloride	tonnes product	40 [b]
Polyurethane—rigid foam	tonnes product	15 [b]
Polyurethane—soft foam	tonnes product	25 [b]
Polystyrene foam	tonnes product	15 [b]
Rubber processing	tonnes product	15 [b]
Paint and varnish	tonnes product	15 [b]
Ink	tonnes product	30 [b]
Glue	tonnes product	20 [b]
Adhesive tape	m^2 product	60 [b]
Other use of solvents:		
Glass/mineral wool enduction	tonnes product	0.8 [b]
Printing industry—Lithography (offset)	tonnes ink consumed	350 [b]
Printing industry—Rotogravure (heliography)	tonnes ink consumed	100 [b]
Printing industry—Packaging (helio-flexo)	tonnes ink consumed	1200 [b]
Fat, edible and non-edible oil (solvent extraction)	tonnes oil processed	18 [b]
Application of glue and adhesives	tonnes product used	600 [b]

[a] Uncontrolled default emission factors for paint application in 'other industry' given in EMEP/Corinair (2004).

[b] Uncontrolled default emission factors given in Corinair (1992).

[c] Assume all solvent consumed is emitted unless process is well-controlled in which case a control rate of 80% (derived from US EPA, 1995) can be applied, giving an emission factor of 200 kg NMVOC/t.

[d] Uncontrolled default emission factors given in EMEP/Corinair (2004).

6. Emissions from Agriculture (Sector 8)

6.1 Introduction

Several types of agricultural activity emit air pollutants including treatment of livestock manures (a source of ammonia (NH_3) and methane (CH_4) emissions), application of fertilizers (a source of both NO_x and NH_3), Savanna burning and burning of agricultural crop residues both of which emits a range of air pollutants (NO_x, SO_x, NH_3, CO, CH_4, NMVOC and particulate matter), and rice cultivation (CH_4 emissions).

In general, agricultural emissions are calculated by multiplying an activity rate by an emission factor. Activity data such as the numbers of livestock present, the amount of fertilizer applied and annual crop production (for crop residue burning) are available on the internet from the FAOSTAT database[56].

6.2 Procedures suggested for use in this Manual

6.2.1 Sources of emissions covered

- **Manure management**: This source covers emissions of ammonia (NH_3) and methane (CH_4) from the storage and disposal of livestock manures from 10 categories of livestock. Emissions are a function of the number of livestock and, for NH_3 emissions, the way in which manures are handled.

- **Enteric fermentation:** Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. Ruminant livestock (e.g., cattle, sheep, goats, buffalo, camels) are major sources of CH_4 with moderate amounts produced from non-ruminant livestock (e.g., pigs, horses).

- **Particle emissions from animal husbandry**: This source covers emissions of primary PM_{10} and $PM_{2.5}$ from ventilated animal housing systems. It does not cover PM emissions from free-range animals because of the lack of published emission factors. There are several PM emission sources within livestock buildings; the feed itself and the feeding process, bedding materials), animal skin, fleece or plumage of housed animals and their dung and droppings, and re-suspension of dust already settled (re-entrainment) by animal activities.

- **Emissions from fertilizer application**: Some of the nitrogen contained in various types of fertilizer is typically released to the atmosphere as both NH_3 and NO. Ammonia emissions from this source depend, among other factors, on the type and amount of fertilizer applied the method and timing of application, the types of soils to which each fertilizer is applied, and climatic factors. The method described below for ammonia includes individual consideration of eight different types of fertilizer, with default emission factors for three different soil/climate combinations. Nitric oxide (NO) emissions are calculated more simply as a fraction of the total fertilizer-N applied.

- **Emissions from savanna burning**: Savannas are intentionally burned during the dry season, primarily for agricultural purposes such as ridding the grassland of weeds and pests, promoting nutrient cycling, and encouraging the growth of new grasses for animal grazing. Burning of savannas takes place every one to four years on average and is a potential source of combustion-related emissions of CO, NO_x, NMVOCs, particulate matter, SO_2, and NH_3.

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[56] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD

Estimation of these emissions involves consideration of the area burned, the biomass fuel load, the fraction of biomass burned, and emission factors for each pollutant.

- **Emissions from burning of agricultural residues**: Disposal of agricultural residues by on-field burning can result in releases of CO, NO_x, CH_4, NMVOCs, particulate matter, SO_2, and NH_3. Estimation of these emissions requires estimation of crop production, the amount of residue produced per unit crop production, the amount of residue burned, and emission factors.

- **Methane emissions from rice cultivation**: Anaerobic decomposition of organic material in flooded rice fields (paddy fields) produces methane (CH_4), which escapes to the atmosphere primarily by transport through the rice plants. Paddy fields are a major source of atmospheric methane. Estimations of the annual amount of CH_4 emitted from a given area of rice is a function of the number and duration of crops grown, water regimes before and during the cultivation period, and incorporation of organic soil amendments.

6.2.2 Procedure for estimating emissions of ammonia and methane from livestock manure management and methane emissions from enteric fermentation

Emissions of NH_3 and CH_4 from livestock manure management and CH_4 from enteric fermentation depend on the average number of each type of livestock in the inventory year (given by FAOSTAT[57]) and a set of emission factors. For manure management, NH_3 emissions also depend on the way in which manures are handled for that type of animal. Table 6-1 presents the types of livestock included and the suggested default emission factors.

For NH_3, the emission factors (Bouwman *et al*., 1997[58]) are for developing country regions (Latin America, Oceania [excluding Australia and New Zealand], Africa and Asia [excluding the former USSR]. These emission factors take into account the generally lower N excretion rate of animals in developing countries as well as higher assumed ammonia loss rates (due to greater rates of volatilization at higher temperatures) during grazing. However, there is still a high degree of uncertainty associated with these emission factors and locally determined factors should be applied where possible.

For CH_4 emissions from manure management, the default emission factors (IPPC, 2006[59]) offered in the Workbook are for the Indian subcontinent assuming 26 ^{o}C annual average temperature. For other temperatures, other Asian countries or other regions, the user should consult the tables (taken from IPCC (2006), Vol 4, Tables 10.14 and 10.15) provided at the bottom of the relevant worksheet (Sheet 4.1) in the Workbook accompanying this manual.

The method used for estimating CH_4 emissions from enteric fermentation is based on the Tier 1 IPCC (2006) method. Default emission factors offered in the Workbook for cattle are for the Indian subcontinent, emission factors appropriate for cattle in other regions are given in a table (taken from IPCC, 2006) shown at the bottom of Sheet 4.1 in the Workbook. The default emission factors for sheep and pigs are for developing countries, those appropriate for developed countries are given in a footnote.

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[57] http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD
[58] Bouwman, A.F., Lee, D.S., Asman, W.A.H., Dentener, F.J., Van Der Hoek, K.W. and Olivier, J.G.J. (1997) A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles, 11:561-587.
[59] IPCC (2006) http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

Table 6-1: Livestock types and default emission factors for estimation of ammonia and methane emissions from livestock manure management and methane emissions from enteric fermentation

Livestock type	Assumed annual nitrogen excretion rate per animal (kg N/yr)	Default annually-averaged ammonia emission factors (kg NH$_3$ per animal-yr)		Manure management methane emission factors [a] (kg CH$_4$/head)	Enteric fermentation CH$_4$ emission factor (kg/head)
		Housing management (in barns/stalls/ stables etc.)	Grazing		
Dairy cattle	60	17.5	3.6	5	58 [c]
Other cattle	40	4.4	5.5	2	27 [c]
Buffalo	45	5.1	5.5	5	55 [d]
Pigs	14	4.8	b	5	1 [e]
Sheep	10	0.34	0.87	0.2	5 [e]
Goats	9	0.34	0.78	0.22	5 [d]
Horses, mules and asses	45	5.1	5.5	2.19	18 [d]
Poultry	0.5	0.22	b	1.2	10 [d]
Fur animals	4.1	1.69	NA	0.02	
Camels	55	6.1	6.7	0.68	46 [d]

[a] IPPC (2006)[60] CH$_4$ defaults for Indian subcontinent assuming 26°C annual average temp. For other Asian countries and other regions, see IPCC 2006 (Vol 4, Tables 10.14 and 10.15)

[b] Emission factors for pigs and poultry assume they only live in housing units. If entirely free-range, assume 2.4 kg/animal for pigs and 0.11 for poultry.

[c] IPPC enteric fermentation CH$_4$ default for cattle in the Indian subcontinent. For other Asia use 68 (dairy) and 47 (other cattle); For Africa and Middle East use 46 (dairy) and 31 (other cattle) and for L. America use 72 (dairy) and 56 (other cattle). For enteric fermentation EFs for cattle in other regions (Europe, N. America, Oceana) see IPCC 2006[60] (Vol 4, Chapter 10, Table 10.11).

[d] IPCC (2006) Tier 1 default values.

[e] IPCC (2006) Tier 1 default values for developing countries only. For developed countries use value of 8 for sheep and 1.5 for pigs (swine).

NA - Not applicable

6.2.3 Procedure for estimating emissions of particulate matter from indoor animal husbandry

Emissions of particulate matter from livestock housing are calculated from an estimate of the number of each type of animal reared, the type of animal housing system, the time spent within the housing system and a set of emission factors. The emissions factors shown in Table 6-2 are 'first estimate' factors taken from EMEP/CORINAIR (2006)[61]. Classification of the housing type depends on the prevailing manure system, solid (litter bedding) or liquid (slurry). For laying hens, the emission factors depend on whether they are kept in cage system (a closed building with forced ventilation, in which the birds are kept in tiered cages) or a perchery (a house for laying

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[60] IPCC (2006) *Guidelines for National Greenhouse Gas Inventories* (http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

[61] Pdf file B1101 at http://www.eea.europa.eu/publications/EMEPCORINAIR4/page019.html

hens with forced ventilation, where birds have freedom of movement over the entire house and a scratching area).

For grazing periods, particle emissions from cattle, pigs, sheep and horses are considered to be negligible. Therefore, the proportion of the time animals actually spend in the housing must be taken into account and this is provided for in the Workbook. The average total populations of live animals (cattle, pigs, chickens etc.) are given by FAOSTAT, but information on sub-categories (e.g. for cattle: dairy, beef or calves) and housing type (solid or slurry) will have to be found out from government ministries, agricultural research institutes etc.

Table 6.2 Emission factors for particle emissions
from animal husbandry (housing)

Animal category	Housing type	Emission factor for PM$_{10}$ kg animal^{-1} yr^{-1}	Emission factor for PM$_{2.5}$ kg animal^{-1} yr^{-1}
Dairy cattle	Tied or litter	0.36	0.23
	Cubicles (slurry)	0.70	0.45
Beef cattle	Solid	0.24	0.16
	Slurry	0.32	0.21
Calves	Solid	0.16	0.10
	Slurry	0.15	0.10
Sows	Solid	0.58	0.094
	Slurry	0.45	0.073
Weaners	Solid	n.a.	n.a.
	Slurry	0.18	0.029
Fattening pigs	Solid	0.50	0.081
	Slurry	0.42	0.069
Horses	Solid[1]	0.18	0.12
Laying hens	Cages	0.017	0.0021
	Perchery	0.27	0.052
Broilers	Solid	0.35	0.045

n.a.: not available
[1] wood shavings

6.2.4 Procedure for estimating emissions of ammonia from fertilizer use

Emissions of ammonia from fertilizer use are a function of the tonnes of nitrogen fertilizer use by type of fertilizer (activity data in FAOSTAT[62]) - and a set of emission factors describing the average percent volatilization of nitrogen as NH$_3$ per unit nitrogen in the fertilizer. A 'calcareous soil multiplier' is also given to account for the increased rates of volatilization that occur when certain fertilizers are used on calcareous soils. Information on the extent and distribution of calcareous soils can be obtained from agricultural institutes in the relevant country.

Total NH$_3$ emissions from fertilizer use are estimated by summing over the types of fertilizer considered. Table 6-3 presents the types of fertilizer included in the suggested method and the default emission factors included in the workbook that accompanies this manual. Because NH$_3$ loss through evaporation increases with higher temperatures, the default emission factors, derived from EMEP/CORINAIR data, are presented for three climate types: 'Region A'- mean spring air temperature > 13 ºC, 'Region B' - mean spring air temperature > 6 ºC but < 13 ºC and

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[62] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD

'Region C' - mean spring air temperature < 6 ℃. Emissions may differ in regions with higher temperatures and different agriculture practices so the data should be considered uncertain.

Table 6-3: Fertilizer types and default emission factors for estimation of ammonia emissions from fertilizer use

Fertilizer type	Default emission factors (% NH_3-N volatilized per unit fertilizer-N applied)		
	Region A	Region B	Region C
Ammonium sulphate*	2.5	2	1.5
Ammonium nitrate	2	1.5	1
Calcium ammonium nitrate	2	1.5	1
Anhydrous ammonia	4	3	2
Urea*	20	17	15
Combined ammonium phosphates	2.5	2	1.5
Other complex NK, NPK fertilizers	2	1.5	1
Nitrogen solutions (mixed urea and ammonium nitrate)	11	9	7

* 30% is suggested for NH_3-N volatilization from application of Ammonium sulphate or Urea to flooded rice fields.

6.2.5 Procedure for estimating emissions of NO_x from fertilizer use

Emissions of nitric oxide (NO) are estimated using the simple methodology recommended in the EMEP/CORINAIR guidebook (2005). Emissions of NO-N are calculated as 0.7% of the total weight of mineral fertilizer-N applied and then converted to the equivalent weight of NO_x (as NO_2). Emissions are probably very dependent on climate and agricultural practices so the default emission factor should considered uncertain.

6.2.6 Procedure for estimating emissions from burning of savannas

The IPCC Guidelines documents[63] describe emissions from prescribed burning of savannas as follows:

> "Savannas are tropical and subtropical formations with continuous grass coverage. The growth of savannas is controlled by alternating wet and dry seasons: most of the growth occurs during the wet season. Man-made and/or natural fires frequently occur during the dry season, resulting in nutrient recycling and regrowth. Large scale burning takes place primarily in the humid savannas because the arid savannas lack sufficient grass cover to sustain fire. Savannas are burned every one to four years on average, with the highest frequency in the humid savannas of Africa. "

Estimation of emissions from savanna burning in this manual includes the following steps:

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[63]Intergovernmental Panel on Climate Change (IPCC), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook* (Available via Internet: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm).

- Estimation of the amount of biomass burned (dry weight) based on the area of savanna burned during the inventory year, the fuel load biomass (not the same as total above ground biomass), and the fraction of this biomass that is actually burnt.
- Estimation of emissions of CO, NOx, SO_2, NMVOCs, particulate matter (PM_{10} and $PM_{2.5}$) and NH_3 by multiplying the amount of biomass burned by emission factors for each pollutant.

Default factors included in the Workbook for use in these calculations are as follows:
  - Fuel load biomass before burning (as dry tonnes/hectare): 4.9
  - Fraction of biomass actually burnt: 0.80 to 0.85
  - CO emission factor (kg/tonne biomass burned): 68
  - NO_x emission factor (kg (as NO_2)/tonne biomass burned): 5.1
  - SO_2 emission factor (kg/tonne biomass burned): 0.43
  - NMVOC emission factor (kg/tonne biomass burned): 3.4
  - PM_{10} emission factor (kg/tonne biomass burned): 10
  - NH_3 emission factor (kg/tonne biomass burned): 0.26

All the above pollutant emission factors are taken from research carried out as part of the Southern African Regional Science Initiative (SAFARI 2000) project[64]. Data on the extent of savanna burning may be available from national departments of agriculture statistics, or research publications. In southern hemisphere Africa, the burning season lasts from May to October or November, i.e. the dry winter season. The areas of savanna burned over these months during the year 2000 have been estimated for each southern African country (Table 6-4). Accurately estimating the fuel load biomass is more of a problem as it varies with percent tree cover and varies widely from year to year depending on the rainfall during the previous growing season. Determining fuel load biomass is thus a modelling exercise in its own right (e.g. Hely *et al.* (2003)[65]).

Table 6-4: Monthly burned area (km²) of savanna by country during the 2000 dry season.

	May	Jun	Jul	Aug	Sept	Oct	Nov	Total
D.R.Congo	59430	100830	105420	24890	2920	150	20	293660
Angola	8340	81110	120520	52950	6010	1150	1120	271200
Mozambique	520	3450	27020	34160	33310	13080	20	111560
Zambia	2780	16320	45020	17470	15470	6930	70	104060
Tanzania	8250	33070	24560	13220	4070	6260	370	89800
South Africa	2050	7240	8800	9840	15370	3540	320	47160
Zimbabwe	210	660	3090	2590	4410	4750	560	16270
Botswana	110	2090	160	1260	2360	3670	470	10120
Namibia	170	330	930	1430	3370	1990	1330	9550
Malawi	100	330	3030	510	1240	190	0	5400
Swaziland	10	40	320	70	200	20	0	660
Lesotho	30	60	40	60	30	0	0	220

From Silva *et al.* (2003) [66]

6.2.7 Procedure for estimating emissions from burning of agricultural wastes

[64] Sinha, P. et al. (2003) Emissions of trace gases and particles from savanna fires in southern Africa. *Journal of Geophysical Research* 108(D13), 8487, doi:10.1029/2002JD002325, 2003.

[65] Hely, C. *et al.* (2003) Regional fuel load for two climatically contrasting years in southern Africa. *Journal of Geophysical Research* 108(D13), 8475, doi 10.1029/2002JD002341.

[66] Silva, J.M.N. *et al.* (2003) An estimate of the area burned in southern Africa during the 2000 dry season using SPOT-VEGETATION satellite data. *Journal of Geophysical Research* 108(D13), 8498, doi:10.1029/2002JD002320.

The procedure is adapted from the IPCC methodology and includes the following steps:

- Estimation of the amount of crop residue biomass burned based on the amount of each crop produced (rice, wheat, millet, soya, maize, potatoes jute, cotton, groundnut, sugarcane, rapeseed and mustard), the residue to crop ratio for each crop, the dry matter in each type of residue, the fraction of each crop burned in the field, and the fraction of burned material that is oxidized during combustion.

- Estimation of the carbon released during combustion based on the amount of crop residues burned and the carbon fractions of the residues.

- Estimation of CO emissions based on the amount of carbon released, the fraction of carbon emitted as CO, and the ratio of the molecular weight of CO to the atomic weight of carbon (2.333).

- Estimation of NO_x emissions based on the amount of carbon released, the ratio of nitrogen to carbon in the crop residues, a NO_x emission ratio describing the amount of nitrogen released as NO_x relative to the total amount of nitrogen released due to burning, and a conversion factor incorporating the molecular weight of NO_x to the atomic weight of nitrogen (3.286).

- Estimation of emissions of SO_2, NMVOCs, NH_3, PM_{10} and $PM_{2.5}$ by multiplying the amount of residue burned by the emission factors for each pollutant.

Additional details regarding these calculations are provided in the Workbook that accompanies this Manual. Default factors included in the Workbook for use in the calculations described above are presented in Table 6-5. Activity data (annual production by crop type) are given by FAOSTAT[67].

Table 6-5: Default parameters for estimating emissions from crop residue burning

Parameter	Rice	Wheat	Millet	Soya	Maize	Potatoes	Jute	Cotton	Groundnut	Sugarcane	Rapeseed/ mustard
Residue to crop ratio [a]	1.4	1.5 [p]	1.2 [p]	2.1	0.33 [p]	0.4	2.15 [p]	3.0 [p]	2.0 [p]	0.1 [q]	1.8 [q]
Dry matter fraction [a]	0.83	0.80 [o]	0.80 [o]	0.80 [o]	0.4	0.45	0.80 [o]	0.80 [o]	0.80 [o]	0.80 [o]	0.80 [o]
Fraction burned in fields [b] [a]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Fraction oxidized during combustion [a]	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Carbon fraction of residue [a]	0.4144	0.4853	0.45	0.45	0.4709	0.4226	0.45	0.45	0.45	0.45	0.45
CO emission ratio [c] [a]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
CO conversion ratio [d]	2.333	2.333	2.333	2.333	2.333	2.333	2.333	2.333	2.333	2.333	2.333
Nitrogen to carbon ratio [a]	0.014	0.012	0.016	0.05	0.02	0.04	0.015	0.015	0.015	0.015	0.015
NO_x emission ratio [e] [a]	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
NO_x conversion ratio [d]	3.286	3.286	3.286	3.286	3.286	3.286	3.286	3.286	3.286	3.286	3.286
NMVOC emission factor (kg/tonnes burned) [f]	4 [g]	5.5 [h]	9	9	9	9	9	9	9	9	9
SO_2 emission factor (kg/tonnes burned) [m]	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
NH_3 emission factor	1.3 [n]	2.4 [l]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]	1.3 [n]

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[67] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD

50

(kg/tonnes burned) PM$_{10}$/PM$_{2.5}$ emission factor (kg/tonnes burned) [j]										
4 [g]	8.5 [k]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]	4.9 [i]
BC emission factor [n] (kg/tonnes burned)										
0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
OC emission factor [n] (kg/tonnes burned)										
3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
CH$_4$ emission factor [n] (kg/tonnes burned)										
2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7

[a] IPCC (1996) default values. Use locally determined factors where available.

[b] The average proportion, between 0 (none) and 1 (all), of the residue burned in the fields.

[c] The amount of carbon released as CO relative to the total amount of carbon released due to burning.

[d] Factor to convert to full molecular weight

[e] The amount of nitrogen released as NOx relative to the total amount of nitrogen released due to burning.

[f] US EPA (1995) default for unspecified crops unless otherwise indicated

[g] US EPA (1995) default factor for dry (15% moisture) rice straw

[h] Mean of US EPA (1995) defaults for headfire burning (6.5 kg NMVOC/Tonnes) and backfire burning (4.5 kg NMVOC/Tonnes).

[i] Default for unspecified crops (average PM factor reported by Reddy and Venkattaraman (2002b))

[j] Assume = TSP factors as PM from most agricultural refuse burning has been found to be in sub-micrometre size range (US EPA, 1995).

[k] Mean of US EPA (1995) defaults for headfire burning (11 kg PM/t) and backfire burning (6 kg PM/t).

[l] EMEP/Corinair (2004)

[m] Reddy and Venkataraman (2002b)

[n] Value given by Andreae and Merlet (2001) for agricultural residues

[o] Bhattacharya and Mitra (1998)

[p] TIFAC (1991)

[q] Tyagi (1989)

6.2.8 *Procedure for estimating emissions of methane from rice cultivation*

The procedure is adapted from the IPCC (2006) methodology and includes the following steps:

- Estimate the annual area of rice fields harvested (ha/yr) subdivided according to 3 types of rice ecosystem: *Irrigated* (fields are flooded for a significant period of time and water regime is fully controlled), *Rainfed and deep water* (fields are flooded for a significant period of time and water regime depends solely on precipitation) or *Upland*[68] (fields are never flooded for a significant period of time).

- Further subdivide the *Irrigated* area of rice production into two types of water regime during cultivation: either *Continuously flooded* (fields have standing water throughout the rice growing season and may only dry out for harvest (end-season drainage) or *Intermittently aerated* (fields have at least one aeration period of more than 3 days during the cropping season.)

- For each of the above categories, estimate the number of days within the inventory year that rice is cultivated for.

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[68] Note that for *Upland* rice cultivation, CH$_4$ emissions are zero even with organic amendments. This category is only included to enable the user to check that the total area under rice cultivation has been estimated correctly.

- As a starting point, a *baseline default emission factor* of 1.30 kg CH_4 ha^{-1} day^{-1} (from IPCC, 2006) for continuously flooded fields during the rice cultivation without organic amendments is used.

- Scaling factors are then used to adjust this baseline emission factor to account for:

  (a) differences in *water regime during the cultivation period* for irrigated fields (i.e. continuously flooded versus intermittently aerated)

  (b) differences in *water regime before the cultivation period* (an aggregated default value is given in case this information is lacking), and

  (c) the type (e.g. straw, compost, farmyard manure, green manure) and amount of any *organic amendments* incorporated into the soil. Default factors are 1.0 for straw incorporated within 30 days of cultivation or 0.29 for Straw incorporated more than 30 days before cultivation. (Or use 0.05 for compost; 0.14 for farmyard manure and 0.5 for green manure).

- Methane emissions are then calculated as: annual area harvested (hectares) x cultivation period (days) x baseline emission factor (kg CH_4 ha^{-1} day^{-1}) x scaling factors (for water regimes and organic amendments) summed across rice ecosystem types.

6.3 Sources of emission factors in literature and their limitations

The default emission factors offered in the Workbook for agricultural sources are mostly from European sources and the IPCC and their uncertainty, especially for non-OECD countries, should be considered to be very high. In some developing countries however, it may be possible to derive suitable factors from agricultural research stations and/or rural colleges and universities.

7. Emissions from Vegetation Fires and Forestry (Sector 9)

7.1 Introduction

This Chapter covers emissions of SO_2, NO_X, CO, CH_4, NMVOCs, NH_3 and PM (including BC and OC) released during on-site vegetation fires resulting from changes in land use, forestry management practices or by accident. This category includes burning that takes place during conversion of forests, woodlands, or grasslands to agricultural or other uses, prescribed burns for fire management or forest stand maintenance, and other vegetation fires (apart from savanna burning) started either accidentally by man or naturally by lightning. Although 'natural' forest fires may be started by lightning, on a global scale, almost all are human initiated. However, savanna burning is not included here as this is regarded as an agricultural activity and so covered under the Agriculture sector described in Chapter 5 above.

Many tree species, particularly conifers, are important sources of specific types of NMVOC and living trees in managed forests often produce significant emissions. However, because these NMVOC emissions are usually estimated by modellers, in the same way as for natural forests, they are not usually included in the inventory process, but treated as natural emissions (see ANNEX 1).

7.2 Procedures for estimating emissions from vegetation fires

The procedure for estimating annual emissions from the burning of forests and grasslands includes the following steps:

- Estimate the amount of biomass burned in each applicable vegetation type based on the annual land area burnt (in thousands of hectares)[69] and on locally-estimated or default values[70] for the biomass consumption rate (tonnes biomass burnt per hectare) for each vegetation type.
- Estimations of SO_2, NOx, CO, CH_4, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC and NH_3 emissions are based on the use of default emission factors expressed as kg pollutant per tonne biomass burnt.

7.3 Sources of emission factor data

Most of the emission factors for vegetation fires offered in the workbook (and shown in Table 7.1) are taken from Andreae and Merlet (2001)[71]. The default PM_{10} and $PM_{2.5}$ emission factors for temperate forest burning are the US EPA (1995) values given for prescribed burning (broadcast logging slash).

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[69] See FAO State of the World's Forests 2009   Annex 2: Table 2. Assume total forest area burnt = Mean annual forest cover change (if negative in sign). (http://www.fao.org/docrep/011/i0350e/i0350e00.htm)

[70] IPCC (2006) http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

[71] Andreae, M.O. and Merlet, P. (2001) Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles*, **15**:955-966.

Table 7-1:
Default biomass consumption and emission factors for use in estimation of emissions from burning of forests and grasslands

Vegetation type	Biomass consumption (tonnes/ha)[a]	SO_2 emission factor (kg/tonne biomass burned)	NOx emission factor (kg as NO_2/tonne biomass burned)	CO emission factor (kg CO/tonne biomass burned)	NMVOC emission factor (kg/tonne biomass burned)	PM_{10} emission factor (kg/tonne biomass burned)	$PM_{2.5}$ emission factor (kg/tonne biomass burned)	NH_3 emission factor (kg/tonne biomass burned)	BC emission factor (kg/tonne biomass burned)	OC emission factor (kg/tonne biomass burned)	CH_4 emission factor (kg/tonne biomass burned)
Tropical/subtropical forest (primary)	120	0.57	2.45	104	8.1	10.5	9.1	1.3	0.66	5.2	6.8
Tropical/subtropical forest (secondary)	42	0.57	2.45	104	8.1	10.5	9.1	1.3	0.66	5.2	6.8
Tropical/subtropical grassland (exluding savanna burning)	5.2	0.35	6	65	3.4	8.3	5.4	0.26[j]	0.48[j]	3.4[j]	2.3[j]
Tropical pasture	24	0.35	6	65	3.4	8.3	5.4	0.26[j]	0.48[j]	3.4[j]	2.3[j]
Eucalypt forests	69	1	4.6	107	5.7	17.6	13	1.4	0.56	8	4.7
Other temperate forest	50	1	4.6	107	5.7	17.6	13	1.4	0.56	8	4.7
Shrubland (general)	27[c]	0.35[h]	6[h]	65[h]	3.4[h]	8.3[h]	5.4[h]	0.26[j]	0.48[j]	3.4[j]	2.3[j]
Temperate grasslands	4.1	0.35	6	65	3.4	8.3	5.4	0.26[j]	0.48[j]	3.4[j]	2.3[j]
Boreal forest	41	1	4.6	107	5.7	17.6	13	1.4	0.56	8	4.7
Peatland	41	1	4.6	107	5.7	17.6	13	1.4	0.56	8	4.7
Boreal grasslands/Tundra	10	0.35	6	65	3.4	8.3	5.4	0.26[j]	0.48[j]	3.4[j]	2.3[j]

a All biomass is expressed on a dry weight basis.

b IPCC (2006) default values. Use locally relevant factors if possible e.g. from FAO State of the World's Forests 2009. http://www.fao.org/docrep/011/i0350e/i0350e00.htm

c For *Calluna* heath, use 11.5; for sagebrush use 5.7 and for Fynbos use 12.9 t/ha

d The amount of carbon released as CO relative to the total amount of carbon released due to burning.

e Factor to convert to full molecular weight

f The amount of nitrogen released as NOx relative to the total amount of nitrogen released due to burning.

g Assume = TSP value from Andreae and Merlet (2001)

h Assume equal to default for grassland

i From Andreae and Merlet (2001) unless otherwise stated

j Assume = factor for savanna burning

8. Emissions from the treatment and disposal of Waste (Sector 10)

8.1 Introduction

Methods for treating and disposing of wastes include incineration/burning, disposal of wastes in landfills, and aerobic and/or anaerobic treatment of municipal sewage. The incineration and other burning of municipal solid wastes (MSW) and other industrial and commercial wastes constitutes a source of combustion-related emissions of SO_2, NO_X, CO, CH_4, NMVOC, NH_3 and particulate matter. Disposal of wastes in landfills and waste water handling both generate methane (CH_4) emissions. Also, the storage of human excreta in latrines (simple dry toilets built outside the house) is often a significant source of NH_3 emissions.

8.2 Procedure selected for use in this Manual

8.2.1 Procedure for estimating emissions from combustion of solid wastes

The suggested procedure for estimation of annual emissions from the combustion of wastes includes the following steps:

- Estimate total amount of Municipal Solid Waste (MSW) generated by multiplying the population whose waste is collected (i.e. the urban population) by a per capita MSW generation rate (country specific values are given in Annex 2A.1 of the draft 2006 IPCC guidelines[72]).

- Estimate the fraction of total MSW which is incinerated. (Some country-specific data are also included in Annex 2A.1 of the draft 2006 IPCC guidelines and a default of 5% would seem appropriate for most developing countries unless country specific data are given.)

- Unless better information is available, assume this waste in burned in the open.

- Estimate the amount of commercial/industrial solid waste incinerated in kilotonnes (kt) by type of combustion method employed.

- A list of waste incinerator types, and default emission factors for each, are presented in Table 8-1. In this version of the manual, emission factors for incineration of medical waste and animal carcasses are not included.

- Estimation of emissions of SO_2, NO_X, CO, CH_4, NMVOCs, PM_{10}, $PM_{2.5}$, BC, OC and NH_3 by multiplying the amount of waste burned for each waste incinerator type by emission factors (locally-derived or default values) for each pollutant.

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[72] Draft IPCC Guidelines Annex 2A.1
http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

Table 8-1:
Default emission factors (uncontrolled) for estimating emissions from waste combustion

Waste/Incinerator Type	Emission factors[a] (kg per tonne waste incinerated)									
	SO_2	NO_X	CO	NMVOC	NH_3[d]	PM_{10}[c]	$PM_{2.5}$[f]	BC	OC	CH_4
Municipal Wastes:										
--Mass burn refractory wall	1.73	1.23	0.685	0.02[e]	0	5.7	3.9	-	-	
--Modular excess air	1.73	1.24	-	-	0	10.1	8.1	-	-	
--Modular starved air	1.61	1.58	0.15	-	0	1.72	1.38	-	-	
--Refuse-derived fuel-fired	1.95	2.51	0.96	-	0	34.8	27.8	-	-	
--Trench	1.25	-	-	-	0	18.5	14.8	-	-	
--Open burning	0.5	3	42	3.34	0	8	6.4	1.48[g]	1.48[g]	6.5[h]
Industrial/commercial:										
--Multiple chamber	1.25	1.5	5	1.5[b]	0	3.5	2.8	-	-	
--Single chamber	1.25	1	10	75[b]	0	7.5	6	-	-	

[a] US EPA (1995) uncontrolled defaults unless otherwise indicated
[b] Includes methane
[c] Factors for PM_{10} not given by US EPA (1995); For default assume = TSP factor
[d] EMEP/Corinair (2004) - assume negligible
[e] EMEP/Corinair (2004) uncontrolled default
[f] Assume same $PM_{2.5}/PM_{10}$ ratio as for Modular excess air
[g] Derived from Bond et al. (2004) assuming $PM_{1.0}$ factor of 0.5 of which BC and OC represent 0.37 each.
[h] IPCC (2006)
- No factor available

8.2.2 Procedure for estimating methane emissions from municipal solid waste (MSW) in landfill

The approach used in this manual is based on the IPCC Tier 1 method. The following steps are required:

- Estimate the population whose waste is collected (i.e. the urban population in developing countries).

- Estimate the per capita Municipal Solid Waste (MSW) generation rate (country specific values are given in Annex 2A.1 of the 2006 IPCC guidelines[73]).

- Total amount of MSW generated is then calculated as the (urban) population multiplied by the chosen per capita MSW generation rate.

- Enter a value for the fraction of total MSW disposed of within solid waste disposal sites (SWDS) i.e. to landfill (country-specific values also given in Annex 2A.1 of the 2006 IPCC guidelines).

- Enter default or country-specific values for MCF (methane correction factor) - which accounts for the effect of SWDS management practice; **DOC** (degradable organic carbon) – the fraction

of organic carbon that is degradable; DOC_F – the fraction of DOC that decomposes under anaerobic conditions; F (fraction of methane in generated landfill gas); R (recovered CH_4) - the proportion of methane generated in the SWDS that is recovered and combusted in a flare or energy device; and OX (oxidation factor) – which reflects the amount of CH_4 from the SWDS that is oxidised in the soil or other material covering the waste.

8.2.3 Procedure for estimating methane emissions from domestic wastewater treatment and disposal

The approach used in this manual is based on the IPCC Tier 1 method. The following steps are required:

- Enter the total population of the geographic area being inventoried.
- Enter regional- or country-specific default value for BOD (Biochemical Oxygen Demand) which is a measure of the degradable organic component of the wastewater (expressed as kg BOD/capita/yr)
- Income group allocation - estimate the fractions (between 0-1) of the total population that can be classified as either 'Rural', 'Urban high income' or 'Urban low income' (total for all 3 must = 1.0).
- For each of the three income groups, estimate the fraction of population that uses each type of treatment system (*Latrine*, *Septic tank*, *Anaerobic reactor or deep lagoon*, *Aerobic treatment plant* or *Untreated* (discharge to sea, river or lake).
- Enter default values (or country-specific values if known) for the maximum methane producing capacity (B_0) and the methane correction factor (**MCF**) for each type of treatment system.
- Subtract the amount of methane (**R**) that is either recovered for energy use or flared.

8.2.4 Procedure for estimating ammonia emissions from latrines

The suggested procedure for the estimation of annual emissions of ammonia from latrines is based on the EMEP/CORINAIR methodology. The number of people using latrines is estimated and multiplied by an emission factor for ammonia. The default emission factor value of 1.6 kg NH_3 per year per person using latrines is based on a European diet and an assumption that during storage of excreta in latrines for one year, about 30 percent of the nitrogen is emitted as ammonia. In many developing countries, a significant proportion of the rural populations may simply defecate and urinate outside in the open fields or bush. Bouwman et. al. (1997) present typical 'meadow' ammonia-N annual losses of 15 percent for cattle, buffalo, camels and horses in developing country regions (compared with 28- 36 percent for animal housing). In the absence of a specific emission factor, it may be assumed that the ammonia-N loss rate for human 'free-range' defecation/urination is also reduced by approximately half and that the appropriate default emission factor is therefore 0.8 kg NH_3 per year per person.

8.3 Application of parameters for control equipment

For waste incinerators, no explicit provision has been made for the application of parameters for control equipment, but the penetration of emissions control equipment can be reflected by reducing emission factors by a suitable amount. Switching from dry latrines to other kinds of toilet (e.g. water closets) will reduce ammonia emissions and this will be reflected in a lower estimate of the population using latrines. For methane emissions from MSWD (landfill) and from wastewater treatment, the amount of methane recovered for energy use or flared is explicitly accounted for.

8.4 Sources of emission factor data in literature

Most of the factors available at present are from North American or European sources such as the US EPA and EMEP/CORINAIR or from the IPCC. These factors should be treated as very uncertain, especially for non-OECD countries. Locally-derived emission factors should be used if available. No factor is offered for slow smouldering of open waste dumps which is a common occurrence in developing country regions.

9.   Emissions from Large Point Sources

9.1   Introduction

In modelling of air pollutant transport, so-called "large point sources" (LPS) of emissions have special significance. Typical examples of LPS include power plants, large metal smelters, district heating plants, and large industrial boilers. The significance of LPS derives both from their "size" (the mass and volume of emissions they produce over time relative to other individual emissions sources) and from the conditions under which they emit pollutants. For example, large point sources typically release stack gases through a tall smoke or exhaust stack. Because their emissions enter the atmosphere at a greater altitude than emissions from (for example) area sources, the characteristics of LPS emissions with regard to atmospheric transport and atmospheric chemistry can be different than those of emissions from other sources. In addition, the exhaust temperatures and other physical conditions of emissions from LPS are usually considerably different than for area sources. Finally, emissions control solutions are often available (and cost-effective) for large point sources that are not as applicable to other emissions sources. As a consequence, most transboundary air pollution models include separate accounting for emissions from large point sources.

In general, a LPS is any emission source, at a fixed location, for which individual data are collected. In practice, the definition is usually narrower and more specific in order to limit the number of LPS. For example, in the RAINS-ASIA model, 355 LPS were identified at 332 unique locations. In the RAINS-ASIA program a LPS was defined as an emitting complex with:

- total electric output capacity $\geq$ 300 MW$_e$ [electric power plants], or

- total thermal input capacity $\geq$ 900 MW$_{th}$ [industrial plants], or

- annual SO_2 emissions greater than 20,000 metric tons.

This LPS definition was chosen only to limit the number of existing LPS modelled to about 355. The data collected for the LPS database are detailed and comprehensive, and a complete description is given in Bertok, *et al.* [74].

In the CORINAIR90 methodology (used in the *EMEP/CORINAIR Guidebook*), the sources to be provided as point sources are:

- Power plants with thermal input capacity >=300 MW

- Refineries

- Sulphuric acid plants

- Nitric acid plants

- Integrated iron/steel works with production capacity >3 Mt/yr

- Paper pulp plants with production capacity > 100 kt/yr

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[74] Bertok, I., J. Cofala, Z. Klimont, W. Schöpp, M. Amann, (1993) *Structure of the RAINS 7.0 Energy and Emissions Database,* IIASA Working Paper, WP-93-67.

- Airports with >100000 LTO cycles/yr

- Other plants emitting >=1000 t/yr SO_2, NO_x

It is suggested, as a starting point for inventory preparation, that the above CORINAIR90 criteria be adopted for this Manual with the exception that all power plants rated over 25 MW should be included where sufficiently detailed data are available. *It is recognized, however, that the most useful and workable definition of "large" may vary substantially from country to country. Therefore it is recommended that each team preparing a country inventory should review the above criteria, and modify them as is most appropriate to their country's situation. As long as the criteria for large point sources in a given country are clearly specified, consistently applied, and presented clearly to users of the emissions inventory, the use of different definitions of LPS for different countries should not pose a major problem.*

9.2 Location and emissions data to be compiled for large point sources (LPS)

In the Workbook, LPS are inventoried in two main groups, "Fuel Combustion" emission sources and "Process (non-combustion) and Fugitive" emission sources. For LPS "Fuel Combustion" emissions the following plant-specific data are required:

- *Sectoral information* (sector, sub-sector, sub-sub sector etc.)

- *Locational information* (province, and latitude, longitude and/or 1° x 1° grid code)

- *Stack details* (stack height and emitted stack gas volume)

- *Fuel details* (type, annual consumption, Net Calorific Value (NCV), sulphur content and sulphur retention in ash [SO_2] and ash content [for particulate matter])

- *Emission controls* (type and efficiency for each pollutant)

- *Measured pollutant emissions* (where available)

For "Process (non-combustion) and Fugitive" emissions, data requirements are similar except that the relevant process activity rates are required instead of fuel details. Where either the measured emissions or plant-specific emission factors are unavailable, default emission factors are used. Emission factors should be nationally-determined if possible; otherwise factors given in the Workbook accompanying this Manual for area emissions can be used.

Data on exhaust stack height are important as high-elevation pollutant emissions result in different transport processes compared with pollutants emitted at or near ground level. Transboundary atmospheric pollution modellers may, therefore, choose to treat pollutants emitted above a given height (> 100 metres, for example) differently in their models, and the LPS emissions that fall into this category must be identifiable.

In order to avoid double-counting of LPS emissions, emissions from large point sources are subtracted from the total emissions calculated for the relevant sector as area emissions to give revised (non-LPS) area emissions estimates. This is done automatically in the summary worksheet (8) of the Workbook that accompanies this manual.

9.3   Temporal aspects of modelling large point sources

There may be considerable temporal variation in power station emissions as a result of diurnal, weekday/weekend and seasonal fluctuations in demand. It would be helpful if monthly temporal profiles can be recorded in the workbook for each LPS as these will provide important information for future transport and atmospheric chemistry modelling activities. These temporal profiles will reflect, for example, increases in demand for electricity in cold months (for heating) and/or in hot months (for air-conditioning and other cooling equipment). For each LPS power station, the temporal disaggregation of annual emissions can be determined from the temporal change in production of electrical power or the temporal change in fuel consumption. Ideally, plant-specific temporal profiles should be obtained, but an alternative method is to use a default temporal profile appropriate for power generation in the particular country or province concerned.

Oil refineries, metal smelters, and many manufacturing industries often operate more or less continuously throughout the year. They may, however, be subject to periodic shut-downs (for example, due to breakdown or planned maintenance). Information on such outages can be obtained directly from the individual plant.

10. Guide to use of Excel Workbook for emissions compilation

10.1 Introduction

In order to provide a standardized structure for use in compiling inventories of air pollutants, an Excel workbook template is provided. This workbook, entitled **FORUM Workbook Version 5.0**, is intended to provide a structure for input activity data and emission factors, areas for calculation of intermediate and final emissions, areas for tabular reporting of results, and areas for annotations of data sets, as well as tools for moving from place to place within the workbook and for accomplishing inventory preparation functions.   The workbook is designed to be flexible enough to accommodate the range of emissions situations and modelling requirements that exist across the countries of the region.   Also, because it is a workbook template rather than a dedicated piece of software, the workbook can be modified (albeit carefully) by users in order to conform to data availability and modelling needs (for example) in each individual country. However, to edit areas other than data input cells (e.g. if the user needs to add another row) the worksheet will have to be 'unprotected' using a password ("RAPIDC") After inserting a row, any green calculation areas will then have to be filled with the appropriate calculation formulae, usually by dragging down the fill handle of the cell immediately above. The sheet should then be protected again after the editing session. ***Only experienced Excel spreadsheet users should attempt to unprotect and modify worksheets.*** Backup copies should be made of the Workbook, both initially and regularly during inventory construction, in case any major and irretrievable errors occur during such editing sessions. The remainder of this Chapter provides an overview of the structure and main elements of the workbook.

10.2 General structure of the workbook

10.2.1 Division into worksheets

The workbook consists of worksheets grouped by emission source sectors, sub-sectors or categories. The user can move from one part of the workbook to another with the aid of a series of menus. The first worksheet, the "Main Menu", allows the user to select and go to one of the other nine menus (Box 10-1) by clicking on the relevant "GO" button. Having selected the desired second level menu, the user can then click on the "GO" button for the worksheet of interest. This menu also includes the "GO" button to move to the emissions summary sheet (Sheet 9) that calculates and displays total annual emissions of all pollutants by major source sector. Also on this sheet, just above the main menu, are yellow cells for entering "Inventory year", "Region", "Country" and, if required, "Province". Menus 1 to 10, shown in Boxes 10-2 to 10-11, reveal the structure of the workbook in addition to allowing the user to navigate the different areas of the workbook. Each individual worksheet also has a "BACK TO MENU" button or, in the case of Menus 1 to 10, a "BACK TO MAIN MENU" button. It is also possible to move between sheets using the sheet tabs at the bottom of the workbook window by use of the tab scrolling buttons to the left of the tabs and clicking on the desired sheet tab.

Box 10-1: Main menu worksheet

User must enter inventory details here:

Inventory year:	2000
Region:	Some continent
Country:	Someland
Province:	Somestate (optional)

MENU OVERVIEW

GO	**Menu1**	**Sectors 1. to 4. Fuel combustion activities**
GO	**Menu2**	**Sector 5. Fugitive emissions (non-combustion) for fuels**
GO	**Menu3**	**Sector 3. Fuel combustion activities. Sector: Transport (Detailed method)**
GO	**Menu4**	**Sector 6. Industrial processes (non-combustion) emissions**
GO	**Menu5**	**Sector 7. Solvent and other product use**
GO	**Menu6**	**Sector 8. Agriculture**
GO	**Menu7**	**Sector 9. Vegetation fires and Forestry.**
GO	**Menu8**	**Sector 10. Waste**
GO	**Menu9**	**Large Point sources**
GO	**Sheet 9**	**Summary sheet - Annual emissions of each pollutant by source sector**
GO	**References**	

Box 10-2: Menu 1 - Energy (Fuel combustion activities).

Sectors 1 to 4 Fuel combustion activities: **Energy Industries,**
Manufacturing Industries and Construction,
Transport, and
Other Sectors

`Back to Main Menu`

1.1 General fuel combustion worksheets

`GO` Sheet: 1.1.1a Fuel consumption in terajoules per year (TJ/year)
or
`GO` Sheet: 1.1.1b Fuel consumption in thousands of tonnes oil equivalent per year (ktoe/year)
or
`GO` Sheet: 1.1.1c Fuel consumption in kilotonnes (1000s of tonnes) per year (kt/year)

`GO` Sheet: 1.1.2 Default net calorific values for fuel (toe/t)

`GO` Sheet: 1.1.3 Error check sheet for net calorific values for fuel (toe/t)

1.2. Sulphur dioxide (SO_2) - Calculation of emission factors and emissions for fuel combustion activities.

`GO` Sheet 1.2.1 Sulphur dioxide (SO_2) - Calculation of emission factors and emissions for Energy Industries

`GO` Sheet 1.2.2 Sulphur dioxide (SO_2) - Calculation of emission factors and emissions, Manufacturing Industries and Construction

`GO` Sheet 1.2.3 Sulphur dioxide (SO_2) - Calculation of emission factors and emissions, Transport

`GO` Sheet 1.2.4 Sulphur dioxide (SO_2) - Calculation of emission factors and emissions for Other Sectors

1.3. Nitrogen oxides (NO_x) - Calculation of emissions for fuel combustion activities.

`GO` Sheet: 1.3.1 Nitrogen oxides (NO_x) - emission factors (kg/TJ)

`GO` Sheet: 1.3.2 Nitrogen oxide (NOx) - combustion emission controls (%)

`GO` Sheet: 1.3.3 Nitrogen oxides (NO_x) - emissions by fuel (tonnes)

1.4. Carbon monoxide (CO) - Calculation of emissions for fuel combustion activities.

`GO` Sheet: 1.4.1 Carbon monoxide (CO) - emission factors (kg/TJ)

`G0` Sheet: 1.4.2 Carbon monoxide (CO) - emissions by fuel (tonnes)

1.5. NMVOC - Calculation of emissions for fuel combustion activities.

`GO` Sheet: 1.5.1 NMVOC emission factors (kg/TJ)

`GO` Sheet: 1.5.2 NMVOC combustion emissions by fuel (tonnes)

1.6. Particulate matter (PM_{10}, $PM_{2.5}$, BC and OC) - Calculation of emission factors and emissions for fuel combustion activities.

`GO` Sheet: 1.6.1 Particulate matter (PM_{10}) - combustion emission factors (kg/tonne)

`GO` Sheet: 1.6.2 Particulate matter (PM_{10}) - combustion emission controls (%)

`GO` Sheet: 1.6.3 Particulate matter (PM_{10}) - combustion emissions (tonnes)

`GO` Sheet: 1.6.4 Particulate matter ($PM_{2.5}$) combustion emission factors (kg/tonne fuel).

`GO` Sheet: 1.6.5 Particulate matter ($PM_{2.5}$) combustion emission controls (%)

`GO` Sheet: 1.6.6 Particulate matter ($PM_{2.5}$) combustion emissions (tonnes)

`GO` Sheet: 1.6.7 Black carbon (BC) combustion emission factor (kg/tonne fuel)

`GO` Sheet: 1.6.8 Black carbon (BC) combustion emissions (tonnes)

`GO` Sheet: 1.6.9 Organic carbon (OC) combustion emission factor (kg/tonne fuel)

`GO` Sheet: 1.6.10 Organic carbon (OC) combustion emissions (tonnes)

1.7 Ammonia (NH_3) - Calculation of emission factors and emissions for fuel combustion activities.

`GO` Sheet: 1.7.1 Ammonia (NH_3) combustion emission factors (kg/tonne except for Natural gas, kg/TJ)

`GO` Sheet: 1.7.2 Ammonia (NH_3) combustion emissions (tonnes)

1.7.3 and 1.7.4 Carbon dioxide (CO2) - Calculation of emission factors and emissions for fuel combustion activities.

`GO` Sheet: 1.7.3 Carbon dioxide (CO_2) - emission factors (kg/TJ)

`GO` Sheet: 1.7.4 Carbon dioxide (CO2) - emissions by fuel (tonnes) from combustion activities

1.7.5 and 1.7.6 Methane (CH4) - Calculation of emission factors and emissions for fuel combustion activities.

`GO` Sheet: 1.7.5 CH_4 emission factors (kg/TJ)

`GO` Sheet: 1.7.6 CH_4 combustion emissions by fuel (Tonnes)

Box 10-3: Menu 2 – Fugitive emissions for fuels.

Sector 5. Fugitive emissions (non-combustion) for fuels

Back to Main Menu

GO   Sheet: 1.8.1   Fugitive (non-combustion) emissions from production of coke.

GO   Sheet: 1.8.2   Fugitive (non-combustion) emissions of NMVOC and CH_4 from oil exploration and crude oil production and transport

GO   Sheet: 1.8.3   Fugitive and process (non-combustion) emissions from oil refining

GO   Sheet: 1.8.4   Fugitive (non-combustion) emissions of NMVOC from distribution and handling of gasoline.

GO   Sheet: 1.8.5   Fugitive (non-combustion) emissions NMVOC and CH_4 from production and distribution of natural gas.

GO   Sheet: 1.8.6   Fugitive (non-combustion) emissions of CH_4 from coal mining

Box 10-4: Menu 3 - Fuel combustion activities: Transport (Detailed method).

Sector 3.   Fuel combustion activities. Sector: Transport (Detailed method)

Back to Main Menu

GO   Sheet 1.9.1   Emissions for LTO and cruise activities of domestic aircraft.

GO   Sheet 1.9.2 Emissions for LTO activities of international aviation.

GO   Sheet 1.9.3   Mobile emissions for on-road vehicles.

Box 10-5: Menu 4 - Industrial processes (non-combustion) emissions.

Sector 6. Industrial processes (non-combustion) emissions

Back to Back to Main

GO   Sheet: 2.1   Process (non-combustion) emissions from the production of mineral products.

GO   Sheet: 2.2   Process (non-combustion) emissions from the production of chemicals.

GO   Sheet: 2.3   Process (non-combustion) emissions from metal production.

GO   Sheet: 2.4   Process (non-combustion) emissions of SO_2, NOx and NMVOCs from pulp and paper production.

GO   Sheet: 2.5   Process (non-combustion) emissions of NMVOC from alcoholic beverage manufacture.

GO   Sheet: 2.6   Process (non-combustion) emissions of NMVOC, PM_{10}, and $PM_{2.5}$ from food production

GO   Sheet: 2.7   Fugitive emissions of particulate matter from major building construction activities.

Box 10-6: Menu 5 – Solvent and Other Product Use

Sector 7. Solvent and Other Product Use
Back to Main Menu

GO **Sheet: 3 Emissions of NMVOC from solvent and other product use.**

Box 10-7: Menu 6 - Agriculture

Sector 8. Agriculture
Back to Main Menu

GO **Sheet: 4.1 Livestock emissions of NH3 and CH4 from manure management and CH4 from enteric fermentation.**

GO **Sheet: 4.2 Particle emissions from animal housing**

GO **Sheet: 4.3 Emissions of NH_3 and NO_x from application of N-containing fertilizers (fertilizer volatilization, foliar emissions and decomposing vegetation).**

GO **Sheet: 4.4 Savanna burning.**

GO **Sheet 4.4.1 Temporal distribution of savanna burning emissions**

GO **Sheet: 4.5 Emissions from agricultural residue burning.**

GO **Sheet: 4.6 Methane emissions from rice cultivation.**

Box 10-8: Menu 7 – Vegetation fires and forestry

Sector 9. Vegetation fires and Forestry.
Back to Main Menu

GO **Sheet: 5.1   Emissions from on-site burning of forests and grasslands.**

Box 10-9: Menu 8 – Waste

Sector 10. Waste
Back to Main Menu

GO **Sheet: 6.1 Emissions from waste incineration**

GO **Sheet: 6.2 Ammonia emissions from human excreta**

GO **Sheet: 6.3 Methane emissions from municipal solid waste (MSW) in landfill.**

GO **Sheet: 6.4 Methane emissions from domestic wastewater treatment and discharge.**

Box 10-11: Menu 9 – Large Point Sources

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┌─────────────────────────────────────────────────────────────────────────────────┐
│ Large Point Sources                                               ┌──────────┐    │
│                                                                   │ Back to  │    │
│                                                                   │ Main Menu│    │
│                                                                   └──────────┘    │
│   ┌──┐                                                                            │
│   │GO│  Sheet 8.1  Large point source combustion emissions, general plant-       │
│   └──┘              specific details                                             │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.1  Large point source combustion emissions  -       │
│              └──┘               sulphur dioxide (SO2)                             │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.2 Large point source combustion emissions  -        │
│              └──┘              nitrogen oxides (NOx)                              │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.3 Large point source combustion emissions  -        │
│              └──┘              carbon monoxide (CO)                               │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.4 Large point source combustion emissions  - NMVOCs │
│              └──┘                                                                 │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.5 Large point source combustion emissions  - PM₁₀   │
│              └──┘                                                                 │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.6 Large point source combustion emissions  - PM₂.₅  │
│              └──┘                                                                 │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.1.7 Large point source combustion emissions  -        │
│              └──┘              ammonia (NH3)                                      │
│   ┌──┐                                                                            │
│   │GO│  Sheet 8.2  Large point source process (non-combustion) and fugitive      │
│   └──┘              emissions, general plant-specific details                    │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.1  Large point source process (non-combustion)      │
│              └──┘               emissions, sulphur dioxide (SO2).                 │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.2  Large point source process (non-combustion)      │
│              └──┘               emissions, nitrogen oxides (NOx).                 │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.3  Large point source process (non-combustion)      │
│              └──┘               emissions, carbon monoxide (CO).                  │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.4  Large point source process (non-combustion) and  │
│              └──┘               fugitive emissions, NMVOCs.                       │
│                                                                                   │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.5  Large point source process (non-combustion) and  │
│              └──┘               fugitive emissions, particulate matter, (PM₁₀    │
│                                 and PM₂.₅).                                       │
│              ┌──┐                                                                 │
│              │GO│  Sheet 8.2.6  Large point source process (non-combustion)      │
│              └──┘               emissions, ammonia (NH3).                         │
└─────────────────────────────────────────────────────────────────────────────────┘
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10.2.2 General data input areas

Each sheet contains white cells for users to input data. Country-specific annual activity rate data are always required: for example, fuel consumption (by fuel type), production rates (of manufactured products), product consumption rates, number of farm animals, crop production for crop residue burning, and so on. **CAUTION**: If you enter data into the wrong cell(s), **do not use 'cut and paste' within the worksheets** to shift data into correct cells as you will destroy the cell references for the linked green calculation cells. So if you enter data into the wrong cell(s), you may 'copy and paste' into the correct cell(s) and then go back and delete the wrong data entries, or simply type data into the correct cells and then delete the wrong data entries.

For fuel consumption, activity data can be entered in a choice of three units; terajoules per year (TJ/yr) in Sheet 1.1.1a, kilotonnes oil equivalent per year (ktoe/yr) in Sheet 1.1.1b or kilotonnes per year (kt/yr) in Sheet 1.1.1c depending on the form in which source data are presented. If data for a particular type of fuel and source sector are erroneously entered into more than one of these three sheets, the workbook will only recognise one entry, the hierarchy for multiple entries being TJ>ktoe>kt. For example, if someone mistakenly entered fuel consumption as both ktoe and kt then only the entry for ktoe would be carried forward to Sheet 1.1.1 for use in subsequent calculations. *The user must check that they are entering fuel consumption data in the correct sheet for the units in which the data are expressed*.

Reference sources for the activity data should be entered into the table at the bottom of the worksheet. For other types of data (such as sulphur content and Net Calorific Values (NCVs) of

fuels, emission factors), default values or ranges are generally offered in the worksheets. The default values are mostly from U.S. or European sources although some are more specific to non-OECD regions (e.g. South African emission factors for savanna burning, domestic biomass fuel combustion). Default data and factors are included so that users lacking country- or regionally-specific data or factors can still produce an emissions inventory without having to wait for the data/factors to become available. Internationally available sources of activity data are also suggested, where possible, in case more reliable nationally sourced data are not readily available.

The emission factor columns in the worksheets are split into two parts so that users can enter (into the left-hand cells) either their own value or the default value (offered in the right-hand cell). *The user must enter the default values into the left-hand cells if more appropriate local factors are not available. If the user does not enter an emission factor into the left-hand column, subsequent calculations for that source cannot proceed*. Where an emission factor other than the default is entered, the reference source and any other relevant details should be entered into the table at the bottom of the worksheet.

10.2.3 General data output/report areas

Calculations are carried out automatically by the workbook with results appearing in the green coloured columns/cells. Users are not required to (and indeed should not attempt to) enter data into green areas. These areas are protected and will require a password ("RAPIDC") to unprotect them. *Only experienced Excel spreadsheet users should attempt to unprotect and modify the worksheets*. Areas or individual cells within worksheet columns that are not required for specific sources, either as input or output areas, are coloured light grey.

10.2.4 Summary worksheet

The emissions summary sheet (Sheet 9) draws together (automatically) total annual emissions of all pollutants (in kilotonnes pollutant per year) by major source sector from the previous worksheets. It consists of three sections: total emissions, large point source (LPS) emissions and area emissions (calculated as total minus LPS emissions). The box below (Box 10-10) shows only the total emissions section of the summary worksheet

Box 10-10: Summary worksheet (Sheet 9)

Sheet 9 Summary sheet - Annual emissions of each pollutant by source sector

Sector	Sub-sector	Total emissions (kilotonnes pollutant per year (kt/yr))										
		SO₂	NOₓ	CO	NMVOC	NH₃	PM₁₀	PM₂.₅	BC	OC	CH4	CO2
1. Combustion in the Energy Industries	Public Electricity and Heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Petroleum Refining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Manufacture of Solid Fuels and Other Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Combustion in Manufacturing Industries and construction	Iron and Steel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Non-ferrous metals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Non-metallic minerals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chemicals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pulp, Paper and print	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mining and Quarrying	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Brick kilns (Not included under Non-metallic minerals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Autoproduction of electricity/heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Non-specified industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3. Transport	Civil Domestic Aviation (Simple--not used if Detailed used)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Civil Aviation (Detailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
	Road transport (Simple--not used if Detailed used)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Road transport (Detailed - exhaust)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
	Road transport (Detailed - unpaved road dust only)						0.00	0.00				
	Railways	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Navigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pipeline transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Non-specified transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Combustion in Other Sectors	Commercial/Institutional	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Residential	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture/Forestry/Fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Non-specified "Other sectors"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5. Fugitive emissions from fuels	Production of coke				0.00		0.00	0.00	0.00	0.00	0.00	0.00
	Oil exploration and crude oil production and transport				0.00						0.00	0.00
	Oil refining	0.00	0.00	0.00	0.00						0.00	
	Distribution and handling of gasoline				0.00							
	Production and distribution of natural gas.				0.00						0.00	0.00
	Coal mining										0.00	
6. Industrial processes	Mineral products	0.00		0.00	0.00		0.00	0.00				0.00
	Chemicals	0.00	0.00	0.00	0.00	0.00	0.00	0.00				0.00
	Metals	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00		0.00
	Pulp and paper	0.00	0.00	0.00	0.00		0.00	0.00				
	Food and drink				0.00							
	Major construction site activities (Fugitive PM only)						0.00	0.00				
7. Solvent and other product use					0.00							
8. Agriculture	Manure management					0.00					0.00	
	Animal husbandry						0.00	0.00				
	Methane form enteric fermentation										0.00	
	Application of N-containing fertilizers		0.00			0.00						
	Savanna burning	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Burning of agricultural crop residues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Methane emissions from rice cultivation.										0.00	
9. Vegetation fires and Forestry	On-site burning of forests and grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
10. Waste	Waste incineration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Waste landfill (methane)										0.00	
	Domestic wastewater (methane)										0.00	
	Human excreta					0.00						
Total anthropogenic		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Annex 1: Emissions from Natural Sources

A1.1 Introduction

Although natural emissions should be taken into account by air pollutant atmospheric transport modellers, they are not generally included in national emissions inventories. This is partly because policy interventions can only realistically reduce anthropogenic (mad-made) emissions and partly because natural emissions are often more accurately estimated on a regional basis by modellers rather than on a national or provincial basis by inventory compilers. However, this appendix is provided in order to inform users of this Manual about the different sources of natural emissions and, for some of these, how an inventory compiler might go about estimating emissions from them.

Natural sources include:

- **Emissions of sulphur oxides from subaerial volcanoes**. Volcanic activities release gases from the minerals being heated to form magma. The most important emissions are of SO_2 and PM.

- **Emissions of NMVOCs from natural vegetation**.   This sub-category of emissions is similar to that for emissions from managed forests, but is intended to cover emissions from land and vegetation types that are not managed by humans.

- **Biogenic emissions of NH_3 from natural vegetation**. In addition to NMVOCs, natural vegetation releases significant amounts of ammonia from its leaves.

- **Emissions of NO_x from soils.** Biogenic emissions of NO_x from all non-agricultural soils including soils under both managed and non-managed forests and natural grasslands.

- **Emissions of NH_3 from human breath and perspiration**. Human breath and perspiration is also a source of ammonia.

- **Entrainment in the atmosphere of dust particles from disturbed soils and natural areas**. Dust, and in particular, alkaline dust, lifted into the atmosphere by prevailing winds, is important to atmospheric chemistry.

With the exception of emissions from soils and volcanoes, preparing estimates of emissions from the above sources follows the typical pattern of estimating the extent of the emission-producing source, then applying emission factors. Estimation of emissions from many of these sources is, however, made more difficult by either a lack of reliable data, by a lack of reliable and/or local emission factors or both. These uncertainties can only be addressed by targeted research, but the estimation procedures outlined below should help to indicate whether specific sources of emissions are likely to be significant in a given country.

A1.2 Natural emissions of SO_2 from subaerial volcanoes

For emissions of SO_2 from volcanoes the name, longitude, latitude, altitude of gas release (in meters), and type (continuous or sporadic erupting) of each emitting volcano can be specified, along with estimates, based on geological research, of the average annual flux of SO_2 and PM emissions per volcano specified (in tonnes per year).

A1.3 Biogenic emissions of NMVOCs from vegetation

Trees and other vegetation, whether completely natural or in managed forests or other managed land types, emit specific classes of NMVOCs. In some inventories, trees in managed forests are treated separately from trees and other plants on natural lands because they are under human care and so considered anthropogenic. However, in line with the EMEP/CORINAIR approach, biogenic NMVOC emissions from living trees in managed forests are considered to be 'natural' for the purposes of the Forum Manual and are therefore, not to be formally inventoried

Estimates of NMVOC emissions from vegetation can be calculated as the land area (in km^2) covered by each type of forest/vegetation multiplied by an emission factor that provides an estimate of the average NMVOC emissions (in tonnes per square kilometre per year)

A1.4 Biogenic emissions of NH_3 from natural vegetation

Natural vegetation is a source of ammonia emissions although the magnitude of these emissions is poorly understood. The (very approximate) default emission factors shown in Table A1-1 are estimates of soil NH_3 flux minus canopy absorption and are derived from Bouwman et al. (1997)[75]. Emissions of NH_3 from natural vegetation are calculated as the land area (in km^2) covered by the relevant vegetation type multiplied by the emission factors.

Table A1-1: Vegetation-type categories and default emission factors for use in estimation of ammonia emissions from natural vegetation

Vegetation type category	NH_3 emission factor (tonnes/km^2/yr)
Closed tropical forest	0.036
Open tropical forest	0.049
Tropical savanna	0.061
Temperate forest	0.012
Grasslands	0.036
Shrub lands	0.049
Deserts	0.012

A1.5 Emissions of NO_x from non-agricultural soils

Although this source is not covered in the IPCC Guidelines, two methods are offered in the EMEP/CORINAIR Guidebook. In the simple method, a background emission rate of 0.1 ng NO-N m^{-2} s^{-1} is assumed in addition to 0.3% of applied N (returned to the atmosphere as NO) from animal manure and atmospheric deposition. This method is only appropriate where N-deposition estimates are available. The detailed methodology is based on the Biogenic Emissions Inventory

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[75] Bouwman, A.F., Lee, D.S., Asman, W.A.H., Dentener, F.J., Van Der Hoek, K.W. and Olivier, J.G.J. (1997) A global high-resolution emission inventory for ammonia. *Global Biogeochemical Cycles*, **11**:561-587

System[76] (BEIS) and employs soil temperature data and experimentally-derived constants for each land use category. Both methods require land use coverage data. There is a high degree of uncertainty in the magnitude of emission factors and other parameters required to calculate NO emissions from soils.

A1.6 Emissions of ammonia from human breath and perspiration

Emission of NH_3 from human breath and perspiration is also a source that is poorly understood at present. Estimation of these emissions involves multiplying the number of people present in a given area (for example, a state or province, or the country as a whole) by an estimated emission factor expressed in kg of NH_3 per person-yr. Human population data can be obtained form national statistical offices and are also given by FAOSTAT[77]. An emission factor of 0.05 kg NH_3 per person-yr has been suggested as a default[78] although much larger value of 0.25 kg NH_3 per person-yr also appears in the literature[79].

A1.7 Wind-blown dust from desert and disturbed areas

A1.7.1 Mechanism of action of wind-blown dust in buffering

Soil dust is often an important component of the atmosphere and, because of the presence of carbonates and other alkaline minerals, can contribute significantly to the buffering of acidic deposition, either through chemical reaction in the atmosphere or due to neutralization within the ecosystems where soil dust is deposited. Soils of different size fractions are uplifted by wind and transported by large-scale atmospheric circulation. The processes involved in deposition of wind-blown dust are gravitational sedimentation, turbulent mixing and wet deposition by rain. Removal efficiencies for each process are dependent on the particle size.

Acidic emissions are buffered, either in the atmosphere or at the point of deposition, by alkaline materials collectively described as "Base Cation Deposition". For example, Larssen and Carmichael[80] have shown that high concentrations of alkaline dust are an important feature of the atmosphere in large parts of China, and that base cation deposition must be taken into account when discussing the possible effects of acidic deposition on soils and vegetation. There are two main sources of base cation deposition: the uplift and transportation of soil dust in the atmosphere and particulates emitted from anthropogenic sources. The relative importance of industrial sources will depend on the extent of dust control technology used.

Base cation emission and deposition related to wind-blown dust are not currently accounted for by international inventory-building methodologies such as those described by

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[76] Information on the current version of BEIS (version 3.12) is available on the USEPA website http://www.epa.gov/asmdnerl/biogen.html. The BEIS model is configured to provide emissions estimates for counties in the United States.

[77] FAOSTAT http://faostat3.fao.org/home/index.html#DOWNLOAD

[78] Simpson, D. and W. Winiwarter (1998), *Emissions from Natural Sources.* Report R-147. Contribution to the Nature Expert Panel to the EMEP/CORINAIR Atmospheric Inventory Emission Inventory Guidebook (SNAP code 11), Umweltbundesamt, Wien

[79] Battye, R., Battye W., Overcash C. and Fudge S. (1994) *Development and Selection of Ammonia Emission Factors – Final Report.* Prepared for the U.S. Environmental Protection Agency - Office of Research and Development, Washington, D.C. 20460.

[80] Larssen, T and G.R. Carmichael (2000) Acid rain and acidification in China: The importance of base cation deposition. *Environmental Pollution*, **110**:89-102.

EMEP/CORINAIR or IPCC. However, regional emission models often incorporate modelled base cation deposition estimates for the region when calculating the net acidifying effects of the acidic deposition rates it calculates from the input data (i.e. the emissions of SO_2, NO_X and NH_3 inventoried in the Workbook accompanying this Manual).

A1.7.2 Models of soil dust uplift

To calculate the source strength of the mineral aerosol produced by soil dust in the atmosphere, the proportion of the mass fraction that is available for dust uplift must be determined for each size class. Clay particles of less than 0.5 μm are not uplifted due to cohesive forces whereas clay particles of between 0.5 –1.0 μm are uplifted. Other particle sizes are divided into silt (small and large) and sand. The upper estimate of sand available for uplift has been estimated to be 50 μm. Table A1-2 (source: Tegen and Fung[81]) shows the particle sizes available for uplift and the mass available for uplift. Assumptions need also to be made as to the size distributions within the different particle sizes.

Table A1-2 Assumptions for modelling for different dust particle size classes

Type	Size range (μm)	α	Density (g cm^{-3})
Clay	0.5-1	1/50 -1/6	2.5
Silt, small	1-10	1	2.65
Silt, large	10-25	1	2.65
Sand	25-50	1/50-1/6	2.65

α = ratio of the mass available for uplift and the total mass of the respective size class.

In lightly managed areas, the crucial factors for the determination of the source strength of mineral aerosols are surface wind speed, soil water content and vegetation cover. In managed areas, disturbance of the soil by land-use practices alter the source strength. Wind erosion occurs only in dry soils. Tegen and Fung assumed that uplift occurs only when the matric potential is higher than 10^4 J kg^{-1}. The soil matric potential is determined by soil texture and soil moisture. Various methods are available to estimate soil moisture contents, and there are typical curves relating the soil matric potential to soil water potential for clay, silt, and sand. Uplift of dust only occurs when the vegetation cover is sparse and therefore a vegetation map is needed to identify source regions. Tegen and Fung assumed that uplift occurs in grassland, shrubland and desert regions. Emission factors have been estimated by Gillette[82] and others. Gillette estimated the uplift of dust to be:

$$Qa = C(u-u_{tr})u^2$$

Where:

Qa is the dust flux from the surface

C is a dimensional constant to be determined *a posteriori* in this model

u is the wind speed, and

u$_{tr}$ is the threshold wind velocity (Tegen and Fung used 6.5 m s^{-1} at 10 m height)

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[81] Tegen, I. and I. Fung (1994) "Modelling of mineral dust in the atmosphere: Sources, transport, and optical thickness". *Journal of Geophysical Research*, **99:**22 897 – 22 914.

[82] Gillette, D. (1978) "A wind tunnel simulation of the erosion of soil: Effect of soil texture, sandblasting, wind speed, and soil consolidation on dust production", *Atmospheric Environment,* **12:**1735 – 1743.

As the dust uplift is highly dependent on the surface wind speed, it is essential to use wind data with high resolution in time and space. For example, the European Centre for Medium Range Weather Forecasting (ECMWF) data could be used. Once uplifted the transport of the dust in the atmosphere would be determined by the use of an appropriate atmospheric transfer model.

Areas where soils are disturbed by management practices also need to be included so that all relevant source regions are covered in calculations of dust uplift. Dust flux from disturbed sources may be stronger than dust flux from natural sources, as freshly exposed earth can contain more fine material for uplift than "old surfaces" where the fine material has already blown away. Also, in cultivated areas the soil is often disrupted by agricultural practices, in which case a lower threshold wind velocity is sufficient to start dust uplift into the atmosphere. Only those disturbed soils in dry areas (mainly in north and north-eastern China and in Mongolia) were considered by Tegen and Fung to contribute to the dust emission (that is, no significant dust emission was estimated in southern China, Korea or in Japan).

Some work concerning the modelling of emissions, transfer and deposition has been carried out at global scale by Tegen and Fung[83,84] and in Asia by Chang et al[85]. Ideally the chemical composition of the soil dust would be determined at the source regions and the neutralizing capacity of the soil dust could then be estimated. Gomes and Gillette[86] estimated the percent calcium (associated with carbonate) to be 5 to 10 percent.

[83] Tegen, I. and I. Fung (1994) "Modeling of mineral dust in the atmosphere: Sources, transport, and optical thickness". *Journal of Geophysical Research*, **99:** 22 897 – 22 914.
[84] Tegen, I. and I. Fung (1995) "Contribution to the atmospheric mineral aerosol load from land surface modification". *Journal of Geophysical Research*, **100**:18 707 – 18 726.
[85] Chang, Y.–S., Arndt, R.L. and Carmichael, G.R. (1996) "Mineral base-cation deposition in Asia". *Atmospheric Environment,* **30**:2417 – 2427.
[86] Gomes, L. and Gillette, D.A. (1993) A comparison of characteristics of aerosol from dust storms in central Asia with soil-derived dust from other regions. *Atmospheric Environment,* **27A**:2539 – 2544.

Annex 2: Summary of inventory approaches used by other groups and in other regions

A2.1 Past and present inventory approach in Europe

There have been several international initiatives over the past two decades that have built on each other in developing the atmospheric emission inventory methodology currently used in Europe. These include:

- The OECD Control of Major Air Pollutants (MAP) Project;

- The DGXI Inventory;

- The CORINE (CO-oRdination d'Information Environmentale) Programme and subsequent work by the European Environment Agency;

- The Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP); and

- The European Pollutant Emission Register (EPER) and the European Pollutant Release and Transfer Register (E-PRTR)

A2.1.1 OECD/MAP Project

The MAP Project, started in 1983, was designed to assess pollution caused by large-scale photochemical oxidant episodes in Western Europe, as well as to evaluate the impact of various emission control strategies designed to minimize such episodes. The MAP emission inventory covered sulphur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOCs). The MAP project quantified point and area source emissions in nine main source sectors from 17 European OECD (Organization for Economic Co-operation and Development) countries.

A2.1.2 The DGXI Inventory

In 1985, the CEC (Commission of the European Communities) Environment Directorate (DGXI) funded the compilation of an emission inventory for the EU (European Union). The aim of the DGXI Inventory was to collect data on emissions from all relevant sources in order to produce a database for use in the study of air pollution problems and to form a basis for policy measures in the field of air pollution control. The inventory covered four pollutants (SO_2, NO_x, VOCs and particulates (PM)), and recognized 10 main source sectors.

A2.1.3 CORINE

The CORINE (CO-oRdination d'Information Environmentale) work programme was established as an experimental project for gathering, coordinating and ensuring the consistency of information on the state of the environment and natural resources in the European Community. It included a project to gather and organize information on air pollutant emissions that were relevant to acidic deposition – CORINAIR. This project started in 1986 with the objective of compiling a

coordinated inventory of atmospheric emissions from the 12 Member States of the Community for 1985.

The CORINAIR 1985 Inventory was developed in collaboration with the Member States, Eurostat, OECD and UNECE/EMEP and was completed in 1990. It covered three pollutants – SO_2, NO_x, and VOC (total volatile organic compounds) and recognized eight main source sectors. During the project, a source sector nomenclature—NAPSEA (Nomenclature for Air Pollution Socio-Economic Activity) and SNAP (Selected Nomenclature for Air Pollution)—was developed for emission source sectors, sub-sectors and activities. A Default Emission Factor Handbook (EEATF, 1992[87]) and computer software package for data input and the calculation of sectoral, regional and national emission estimates were also produced.

Subsequently, a 1990 update of CORINAIR was carried out in co-operation with EMEP and IPCC-OECD to assist in the preparation of inventories required under the Long Range Transboundary Air Pollution (LRTAP) Convention and the United Nations Framework Convention on Climate Change (UNFCCC). This collaboration produced a more developed nomenclature (source sector split)—SNAP90—involving over 260 activities grouped into a three level hierarchy of sub-sectors and 11 main sectors. It also extended the list of pollutants to be covered to eight (SO_2, NO_x, NMVOC, ammonia (NH_3), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)). Data were provided for large point sources (LPS) on an individual basis and on other smaller or more diffuse sources on an area basis.

The goal of CORINAIR90 was to provide a complete, consistent and transparent air pollutant emission inventory for Europe in 1990 and to enable widespread use of the inventory for policy, research and other purposes. Consistency in providing emission estimates was achieved by the systematic application of the CORINAIR methodology, including the CORINAIR software and the SNAP90 nomenclature. Transparency was achieved through the provision, within the inventory, of activity statistics/data and emission factors (or details of emission measurements where available) used to calculate emissions and through the supply of full references to the sources of these data. The CORINAIR90 project was completed in 1994 and a series of reports prepared during 1995 and early 1996.

A2.1.4 EMEP

The Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP) was formed by a Protocol under the Convention on Long – Range Transboundary Air Pollution (CLRTAP). In 1991, a task force (The Task Force on Emission Inventories and Projections) was set up under the EMEP to provide a sound technical basis for exchange of information, to evaluate methodologies, and to achieve harmonization through co-operation with other international organizations working on emission inventories.

Parties to CLRTAP report annual emission inventories of SO_2, NO_x, NMVOC, NH_3, CO, $PM_{2.5}$ and PM_{10}. In addition there are requirements for reporting a range of heavy metals and persistent organic pollutants (POPs). They are asked to report projections, emissions by grid and emissions from large point sources every fifth year. Data are made available in the EMEP

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[87] EEATF (European Environment Agency Task Force), (1992) *Default Emission Factors Handbook, Technical annexes Vol. 2.* European Commission, Brussels, Belgium.

database (http://www.emep.int/). Data are reported using the Nomenclature for Reporting (NFR) which can be mapped to the IPCC nomenclature.

An important product of the Task Force on Emission Inventories and Projections is the joint EMEP/EEA Air Pollutant Emission Inventory Guidebook - 2009 (formerly called the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook) hosted by the European Environment Agency[88]. The Guidebook provides comprehensive guidance on estimation methodologies (including default emission factors). Usually a simple and a detailed methodology are given. Parts of the guidebook are updated annually and new chapters are added regularly. It also addresses generic issues, for example general principles for uncertainty calculations and quality assurance/quality control (QA/QC).

A2.1.5 EPER/E-PRTR

EPER is the European Pollutant Emission Register, the first European-wide register of industrial emissions into air and water. According to the EPER Decision, Member States have to produce a triennial report, which covers the emissions of 50 pollutants to be included if predefined threshold values are exceeded.

The first reporting year was 2001, reported in 2003 and published on the internet (www.eper.cec.eu.int) in February 2004. The website, which is hosted by the European Environment Agency (EEA) gives access to information on the annual emissions of approx. 9 200 industrial facilities in the 15 old Member States of the EU as well as of Hungary and Norway. The second reporting year will be 2004 (published in 2006) and will include data from the new Member States. Data are available by pollutant, activity (sector), air and water (direct or via a sewerage system) or by EU/country. It is also possible to see detailed data on individual facilities and rank them by the size of their pollutant emissions.

E-PRTR is the European Pollutant Release and Transfer Register, which will succeed the EPER and is intended to fully implement the obligations of the UN-ECE PRTR Protocol. The obligations under the E-PRTR Regulation extend beyond the scope of EPER mainly in terms of more facilities included, more substances to report, additional coverage of releases to land, off-site transfers of waste and releases from diffuse sources, public participation and annual instead of triennial reporting. The first reporting year under the E-PRTR will be 2007.

A2.2 Past and present inventory approach in North America

In 1980 the US government created the National Acid Precipitation Assessment Program (NAPAP), and gave it a ten-year mandate to investigate acidic precipitation issues and report the results of its investigations to Congress. The 1985 NAPAP emission inventory effort supported joint acid precipitation deposition research with Canada, including atmospheric modelling, through comprehensive, detailed source emission estimates provided by local and state agencies.

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[88] EMEP/EEA Air Pollutant Emission Inventory Guidebook - 2009, Technical report No 9/2009, European Environment Agency, Copenhagen, Denmark (http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009).

An inventory of emissions and facility data representing point and area source classification code (SCC)-level operating characteristics for 1985 was developed to provide information for assessing acid deposition problems. The 1985 NAPAP effort produced a "bottom-up" inventory that should be considered a snapshot of the 1985 emissions. The NAPAP inventory is widely regarded as the most comprehensive and accurate national inventory compiled to date.

The United States *Clean Air Act Amendments of 1990* (*CAAA*) require that state and local agencies prepare and submit a periodic emission inventory to the (US) Environmental Protection Agency (EPA). The USEPA is mainly concerned with emissions which are, or could be, harmful to people calling this set of principal air pollutants "criteria pollutants". (The criteria pollutants are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulphur dioxide (SO_2).) Each year, the US EPA prepares national estimates for assessing trends in criteria pollutant emissions. Within the USEPA, The Technology Transfer Network Clearinghouse for Inventories & Emissions Factors (TTN CHIEF) provides access to information and software tools relating to inventories, emission factors and emissions modelling (http://www.epa.gov/ttn/chief/).

The USEPA's *Compilation of Air Pollutant Emission Factors (Fifth Edition)*, commonly referred to as *AP-42* (USEPA, 1995) is the principal means by its emission factors are documented. Volume I of *AP-42* deals with Stationary Point and Area Sources and contains information on over 200 source categories (http://www.epa.gov/ttn/chief/ap42/ index.html). This information includes brief descriptions of processes, potential sources of air emissions from the processes and in many cases common methods used to control these air emissions. Methodologies for estimating the quantity of air pollutant emissions are presented in the form of Emission Factors in *AP-42*. Volume II of the Compilation deals with mobile sources (http://www.epa.gov/otaq/ap42.htm).

Further guidance on constructing and improving emissions inventories is provided by the Emission Inventory Improvement Program (EIIP), a co-operative effort between EPA, state/local agencies and industry (see http://www.epa.gov/ttn/chief/eiip/index.html).

The NARSTO project (http://www.narsto.com/) is a public/private partnership, whose membership spans government, the utilities, industry, and academe throughout Mexico, the United States, and Canada. Its primary mission is to coordinate and enhance policy-relevant scientific research and assessment of tropospheric pollution behaviour; its activities provide input for science-based decision-making and determination of workable, efficient, and effective strategies for local and regional air-pollution management. A component of the NARSTO project addresses emission inventories and has provided recommendations on improvements in the inventory system, including better uncertainty management, quality control/assurance systems and improved timeliness and accessibility. An action plan has been developed.

A2.3 The IPCC (Intergovernmental Panel on Climate Change)

Signature of the United Nations Framework Convention on Climate Change (UNFCCC) by approximately 150 countries in Rio de Janeiro in June 1992 indicated widespread recognition that climate change is potentially a major threat to the world's environment and economic development. The Kyoto Protocol under UNFCCC was adopted in 1997 (and ratified in 2005), setting specific targets for emissions in developed countries.

Amongst other resolutions, the Convention calls for all Parties to develop, update periodically, publish and make available to the Conference of the Parties (COP) their national inventories of anthropogenic emissions by sources and removals by sinks, of all GHG (Greenhouse gases) not controlled under the Montreal Protocol. It also calls for all Parties to use comparable methodologies for inventories of GHG emissions and removals. The Kyoto Protocol will have additional requirements for reporting emission data from the Parties. The Kyoto Protocol has requirements for establishing a national system for estimating and reporting emissions. The guidance for national systems also *inter alia* includes requirements for documentation, implementing adequate QA/QC procedures and estimating uncertainties in emissions.

To assist all Parties in providing high quality inventories, a three-volume publication, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1996*),* was produced under the IPCC (Intergovernmental Panel on Climate Change)/OECD/IEA (International Energy Agency) *Programme on National Greenhouse Gas Inventories*. The three volumes together provide the range of information needed to plan, carry out and report results of a national inventory using the IPCC system (All three can be accessed or downloaded from the internet at http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm). The 1996 Guidelines include emission factors for SO_2 and the ozone precursors CO, NMVOC and NO_x in addition to the direct greenhouse gases.

The IPCC Guidelines have been supplemented by the Good Practice Guidance and Uncertainty Management in National Greenhouse Inventories and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (http://www.ipcc-nggip.iges.or.jp/ public/public.htm). These can be used together with the Revised 1996 Guidelines, but include some emission factor updates and methodologies for some additional sources/sinks. The good practice reports also include extended guidance on methodological choice, time-series consistency, QA/QC and verification and uncertainties. Methodological choice is guided by decision trees. The so-called key categories (sources) with respect to level and trend should be prioritised. The good practice guidance provides methods to identify key categories.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories was adopted by IPCC in 2006. It includes five volumes. Volume 1 provides general guidance on data collection, uncertainties, QA/QC, estimation of key categories, time-series consistency and reporting. Volume 2-5 are sectoral volumes on Energy, Industrial processes and product use, Agriculture, forestry and other land use and Waste. It is building on both the 2006 Guidelines and the good practice guidance. Emission factors have been updated, new sources/sinks have been added and the number of gases has been expanded. For estimating emissions of ozone precursors and SO_2 the 2006 guidelines make reference to the EMEP/EEA Atmospheric Emission Inventory Guidebook.

IPCC has also developed an emission factor database (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php), the EFDB. The EFDB is meant to be a recognised library, where users can find emission factors and other parameters with background documentation or technical references that can be used for estimating greenhouse gas emissions and removals. Users are encouraged to provide the EFDB with any relevant proposals on emission factors or other related parameters. This information is assessed by an editorial board before inclusion in the database.

A2.4 Point source inventories

Some inventory approaches focuses on data reported from emission generating facilities, for example industrial plants. These approaches often also address water and soil pollution.

A PRTR (Pollution Release and Transfer Register) is an environmental database or inventory of potentially harmful releases to air, water and soil. Also included in the database are wastes transferred for treatment and disposal from the site of their production. In addition to collecting data for PRTRs from stationary (or point) sources such as factories and waste facilities, some PRTRs are designed to include estimates of releases from diffuse sources; these include agricultural and transport activities based on other data elements (e.g. number of automobiles). Data concerning releases and transfers are provided by the facility, and the type, quantity and affected environmental media must be reported. Data are then made available to the public.

Building on a Council Decision from 1996, OECD calls on Member countries to implement a PRTR. To support this, OECD has established a programme to help countries design, develop and implement effective PRTR programmes. This includes the development of practical tools and guidance to help Member countries implement a PRTR; outreach activities to non-member countries (including the provision of information and technical support); and co-ordination of international PRTR activities.

The aim of this project is to help countries develop and implement PRTR systems by making the data about chemical releases and transfers easier to find and use. It does this through a two-pronged approach: 1) creating a general, over-arching view of available release estimation techniques; and 2) identifying individual industrial processes that do not have a reliable or acceptable estimation technique. A Task Force on Release Estimation Techniques was created in 2000 with these aims in mind.

A2.5 The World Bank Industrial Pollution Control (IPC) system

Another inventory approach, used in Latin American countries in particular, is that described in the World Health Organisation's (WHO) rapid assessment manual[89] "Assessment of Sources of Air, Water, and Land Pollution" and developed by the World Bank into decision support software package called the Industrial Pollution Control (IPC) system. As its name suggests, this approach considers emissions of liquid and solid wastes (to water and land) as well as direct emissions to the atmosphere. This methodology is used, often at the city scale, as a means of making an initial appraisal of the sources and levels of emissions from an area that has little or no previous pollution load data. Because its emission source structure follows that given in the International Standard Industrial Classification of all Economic Activities (ISIC), there is not always a clear distinction between combustion and non-combustion emissions. Also, savanna burning and on-site burning of forests and grassland are not included. The technology splits are often very detailed, especially for sources of PM (TSP emission factors only are presented).

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[89] Economopoulos, A.P. (1993) Assessment of Sources of Air, Water, and Land Pollution: A guide to rapid source inventory techniques and their use in formulating environmental control strategies. Part one: Rapid inventory techniques in environmental pollution. Environmental Technology Series. WHO/PEP/GETNET/93.1-A. World Health Organisation, Geneva

A2.6 Global research inventories

A2.6.1 The GEIA (Global Emissions Inventory Activity)

The Global Emissions Inventory Activity (GEIA) was created in 1990 to develop and allocate to source countries and regions global emissions inventories of gases and aerosols emitted into the atmosphere from natural and anthropogenic (human-caused) sources. (GEIA's internet home page is located at http://geiacenter.org/) The long-term goal of the Activity is to develop inventories of all trace species that are involved in global atmospheric chemistry. GEIA is a component of the International Global Atmospheric Chemistry (IGAC) Project, a core project of the International Geosphere-Biosphere Program. The emphasis in GEIA is on changes affecting the oxidizing capacity of the atmosphere, impacts on climate, and atmospheric chemical interactions with biota. This scope encompasses a number of urgent policy-related environmental issues such as acid precipitation, stratospheric ozone depletion, greenhouse warming and biological damage from increased oxidant levels.

GEIA together with ACCENT (Atmospheric Composition Change the European Network of Excellence) provide an 'emissions data portal' through which it is possible to access various emissions datasets.

A2.6.2 The EDGAR inventory

The EDGAR (Emission Database for Global Atmospheric Research) (http://themasites.pbl.nl/tridion/en/themasites/edgar/) inventory provides emissions datasets of 1 x 1 degree gridded data and country data for 1990, 1995 and 2000 for greenhouse gases, indirect greenhouse gases and aerosols. The EDGAR information system is a joint project of RIVM-MNP (NL), TNO-MEP, (NL), JRC-IES (IT) and MPIC-AC (D). EDGAR consists of: (a) fossil-fuel related sources and (b) bio fuel combustion, both on a per country basis; (c) industrial production and consumption processes (including solvent use) also on a per country basis; (d) land use-related sources, including waste treatment, partially on a grid basis and partially on a per country basis; and (e) selected natural sources on a grid basis. The EDGAR database uses the International Energy Agency (IEA) energy statistics and established inventory methodologies (e.g. IPCC).

Annex 3: Speciation of pollutant emissions

A3.1 Introduction

Several of the pollutants that play a role in transboundary air pollution are not, in fact, single chemical species, but are categories of emissions that include two or more individual chemical compounds. "SO_x", for example, includes the oxides of sulphur SO_2 and SO_3, and oxides of nitrogen (NO_x) include NO and NO_2. The category of pollutants where distinctions between individual species have the most impact on transboundary air pollution modelling however, is that of volatile organic compounds (VOCs, also sometimes referred to as "hydrocarbons" and by other names). There are thousands of individual chemical species that can be classified as VOCs. For the purposes of transboundary air pollution modelling, it is often necessary to "speciate" emissions—particularly VOC emissions—into so-called "reactivity groups" for use in the modelling of atmospheric chemistry processes. The speciation of VOCs is, however, typically highly model dependent, as different atmospheric chemistry models require different reactivity groupings. As a consequence, no specific method of speciation is formally recommended in this manual, but a description of possible procedures and data resources for accomplishing the "speciation" of VOC emissions estimates are presented in this Annex.

A3.2 The need for speciation of VOC

Ground level ozone is a secondary pollutant that results primarily from photochemical interactions between volatile organic compounds (VOCs) and nitrogen oxides (NO_x). In addition to the total mass of precursor pollutants, the formation of ground level ozone is affected by the reactivities of the organic pollutants. Because different VOC species have different reactivities with respect to ozone-forming processes, ground level ozone models require assumptions about the mixture of reactive organic gases emitted and initially present.

A3.3 Approaches used for NMVOC speciation

Some modellers prefer to classify NMVOCs according to chemical groups such as alkanes, alkenes, aromatics, alcohols and so on. For anthropogenic NMVOC emissions, other modellers prefer a classification system based their reactivity with the hydroxyl radical using, for example, the concept of photochemical ozone creating potential (POCP). The POCP value for a given hydrocarbon is a measure of its ability to form ozone relative to ethylene for an identical atmospheric emission. In order to cope with the vast number of emitted hydrocarbons and the wide spectrum of POCP values, species with similar reactivities can be grouped for comparing emission distributions (Leggett, 1996)[90]. The EMEP ozone model uses a simplified mixture with seven "representative compounds" chosen to represent the normal range of ozone creating potential for most organic pollutants. The EMEP representative compounds are: ethane, ethanol, *n*-butane, *o*-xylene, propene, ethene and "unreactive".

Natural NMVOC emissions mainly consist of compounds in the isoprene and terpene groups, and emissions from natural sources are thus generally reported as "isoprenes", "terpenes" and "other reactive NMVOC".

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[90] Leggett, S. (1996), "Forecast Distribution of Species and their Atmospheric Reactivities for the U.K. VOC Emission Inventory". <u>Atmospheric Environment</u> Vol. 30. No.2. pp 215-226.

A3.4 Sources of speciation factors in the literature

Speciation profiles (percentage composition) for NMVOC emissions are available in the *EMEP/EEA Guidebook*. Depending on the original reference source, these profiles may comprise individual NMVOC compounds or groups of compounds.

A3.5 Speciation models

A convenient model for the speciation of VOC/NMVOC emissions is "SPECIATE", a software system for speciating organic compounds that was developed for use in ozone formation models such as the USEPA's UAM (Urban Airshed Model) and ROM (Rural Ozone Model). SPECIATE is available from the USEPA[91].

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[91] http://www.epa.gov/ttn/chief/software/speciate/index.html

Annex 4: Default emission factors for the Energy sectors (fuel combustion emissions and fugitive emissions from fuels)

Table A4.1 Nitrogen oxides (NOx) - default emission factors (kg/TJ)

Sector groupings: **Combustion in the Energy industries** (Public Electricity and Heat Production; Petroleum refining; *Manufacture of Solid Fuels and Other Energy* [a]: Coke ovens, Patent fuel BKB, Gas works, Charcoal production, Other own use) · **Combustion in Manufacturing Industries and Construction** (Iron and Steel … Remainder Non-specified) · **Transport** (Civil Aviation … Pipeline transport) · **Combustion in Other sectors** (Commercial/Institutional … Non-specified "Other sectors")

Fuel type	Sub-sector	Public Electricity and Heat Production [a]	Petroleum refining [a]	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoproduction of electricity/heat	Remainder (Non-specified)	Civil Aviation [e]	Road transport	Railways	Navigation [e]	Pipeline transport	Commercial/Institutional	Residential	Agriculture/Forestry/Fishing	Non-specified "Other sectors"
Coal	Coking Coal																									
	Other Bituminous Coal & Anthracite	300[c]		300[c]		300[c]		300[c]		300[c]	300[c]	300[c]	300[c]	300[c]	300[c]	300[c]	300[c]			300[c]			100[c]	34[k]	100[c]	100[c]
	Sub-Bituminous Coal	300[c]																								
	Lignite	300[c]																								
	Patent Fuel																							100[c]		100[c]
	Coke Oven Coke			300[c]	300[c]	300[c]		300[c]		300[c]	300[c]	300[c]	300[c]	300[c]	300[c]	300[c]	300[c]						100[c]	100[c]	100[c]	100[c]
	Gas Coke																									
	BKB																							100[c]		100[c]
	Coke Oven Gas	77.8[b]		55[b]		55[b]		55[b]	176[b]		55[b]	55[b]	55[b]	55[b]	55[b]	55[b]	55[b]						38[b]	38[b]		38[b]
	Blast Furnace Gas	10.5[b]	7.4[b]						76[b]																	
Gas	Gas Works Gas	10.5[b]	7.4[b]			7.4[b]			76[b]	7.4[b]	7.4[b]	7.4[b]	7.4[b]	7.4[b]	7.4[b]	7.4[b]	7.4[b]						5.25[b]	5.25[b]		5.25[b]
	Natural Gas	105[b]	53[b]			53[b]		53[b]	53[b]	53[b]	53[b]	53[b]	53[b]	53[b]	53[b]	53[b]	53[b]			53[b]		53[b]	37[b]	37[b]	37[b]	37[b]
Oil	Crude Oil	200[c]	200[c]					200[c]	200[c]	200[c]	200[c]	200[c]	200[c]	200[c]	200[c]	200[c]	200[c]						100[c]		100[c]	100[c]
	Natural Gas Liquids	200[c]														200[c]										
	Refinery Gas	16[b]	11[b]					11[b]				11[b]				11[b]	11[b]									
	Liquefied Petroleum Gases	79[b]	56[b]					56[b]	56[b]	56[b]	56[b]	56[b]	56[b]	56[b]	56[b]	56[b]	56[b]		383[b]				33[b]	18.7[b]	33[b]	33[b]
	Motor Gasoline	373[b]							373[b]	373[b]	373[b]	373[b]	373[b]	373[b]	373[b]	373[b]	373[b]		708[b]		220[f]		373[b]	373[b]	373[b]	373[b]
	Aviation Gasoline																	234[b]								
	Gasoline type Jet Fuel																	235[b]								
	Kerosene type Jet Fuel																	234[b]								
	Kerosene	485[b]	167[b]					167[b]	167[b]	167[b]	167[b]	167[b]	167[b]	167[b]	167[b]	167[b]	167[b]		167[b]				100[b]	25[k]	100[b]	100[b]
	Gas/Diesel Oil	632[b]	222[b]					222[b]	222[b]	222[b]	222[b]	222[b]	222[b]	222[b]	222[b]	222[b]	222[b]		632[b]	900[c]	1000[g]		133[b]	74[b]	133[b]	133[b]
	Heavy Fuel Oil	249[b]	145[b]					145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]		682[b]	1249[b]	1800[h]		87[b]	49[b]	87[b]	87[b]
	Petroleum coke	300[i]	300[i]					300[i]	300[i]	300[i]	300[i]	300[i]	300[i]	300[i]	300[i]	300[i]	300[i]									
	Other Petroleum Products	200[c]	145[b]					145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]	145[b]			1200[c]	1500[c]					
Combustible renewables and waste	Primary Solid Biomass:																									
	Wood	100[c]					12.3[j]			100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]							100[c]	73[k]	100[c]	100[c]
	Vegetal materials and wastes	100[c]								100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]							100[c]	47[k]	100[c]	100[c]
	Other (e.g. animal products/wastes)	100[c]								100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]							100[c]	100[c]	100[c]	100[c]
	Unspecified primary solid biomass	100[c]								100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]							100[c]	100[c]	100[c]	100[c]
	Gas/Liquids from biomass + wastes																									
	Municipal Waste	100[c]																								
	Industrial Waste	100[c]								100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]										
	Charcoal								100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]	100[c]							100[c]	72[l]	100[c]	72[l]

[a] Includes own use

[b] Derived 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] IPCC, 1996

[d] Range given by EMEP/Corinair, 1996

[e] excluding international bunkers

[f] IPCC Guidelines (IPCC,1996) default for 4-stroke gasoline used on inland waterways (2-stroke = 60).

[g] IPCC Guidelines (IPCC,1996) default for gas/diesel used on inland waterways.

[h] IPCC Guidelines (IPCC,1996) default for RFO used in ocean-going ships.

[i] Assumed = emision factor for 'Other Bituminous Coal & Anthracite'

[j] EF derived from Bertschi *et al.* (2003) for earthen charcoal-making kilns (in Zambia).

[k] Zhang et al. (2000) Average EF for household stoves in China. (For 'vegetal materials and waste', EF = average for wheat and maize residues)

[l] EF derived from Bertschi *et al.* (2003) for charcoal cooking fires.

Table A4.2 Carbon monoxide (CO) - default emission factors (kg/TJ)

Column groups: **Combustion in the Energy industries[a]** (Public Electricity and Heat Production; Petroleum refining; Manufacture of Solid Fuels and Other Energy: Coke ovens, Patent fuel BKB, Gas works, Charcoal production, Other own use) · **Combustion in Manufacturing Industries and Construction[a]** (Iron and Steel; Non-ferrous metals; Non-metallic minerals; Chemicals; Pulp, Paper and print; Mining and Quarrying; Construction; Autoproduction of electricity/heat; Remainder (Non-specified)) · **Transport[a]** (Civil Aviation[c]; Road transport; Railways; Navigation[c]; Pipeline transport) · **Combustion in Other sectors[a]** (Commercial/Institutional; Residential; Agriculture/Forestry/Fishing; Non-specified "Other sectors")

Fuel type	Sub-sector	Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoproduction of electricity/heat	Remainder (Non-specified)	Civil Aviation[c]	Road transport	Railways	Navigation[c]	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry/Fishing	Non-specified "Other sectors"
Coal	Coking Coal										150															
	Other Bituminous Coal & Anthracite	20		20		20		20		150	150	150	150	150	150	150	150			150			2000	2610[f]	2000	2000
	Sub-Bituminous Coal	20																						2000		2000
	Lignite	20																								
	Patent Fuel																							2000		2000
	Coke Oven Coke			20	20	20		20		150	150	150	150	150	150	150	150						2000	2000	2000	2000
	Gas Coke																									
	BKB																							2000		2000
	Coke Oven Gas	20		20		20		20	150		150	150	150	150	150	150	150									
	Blast Furnace Gas	20		20					150																	
Gas	Gas Works Gas	20	20	20		20			150	150	150	150	150	150	150	150	150							150		150
	Natural Gas	20	20			20		20	30	30	30	30	30	30	30	30	30		400			400	50	50		50
Oil	Crude Oil	15	15					15	10	10	10	10	10	10	10	10	10						20		20	20
	Natural Gas Liquids	15	15													15										
	Refinery Gas	15	15					15				10				15	15									
	Liquefied Petroleum Gases	15	15					15	10	10	10	10	10	10	10	10	10		2650[b]				20	326[m]		20
	Motor Gasoline	15	15						10	10	10	10	10	10	10	10	10		8000		22000[d]		20	20	1000[i]	20
	Aviation Gasoline																	15000								
	Gasoline type Jet Fuel																	15000								
	Kerosene type Jet Fuel																	100								
	Kerosene	15	15					15	15	15	15	15	15	15	15	15	15		1000				20	171[f]	20	20
	Gas/Diesel Oil	15	15					15	15	15	15	15	15	15	15	15	15		1000	250[b]	250[b]		20	20	1000[i]	20
	Heavy Fuel Oil	15	15					15	15	15	15	15	15	15	15	15	15			1000	180[e]		20	20	20	20
	Petroleum coke	20	20					20	20	20	20	20	20	20	20	20	20									
	Other Petroleum Products	15	15					15	15	15	15	15	15	15	15	15	15	1000	1000	1000			20	20	20	20
Combustible renewables and waste	Primary Solid Biomass:																									
	Wood	1000					6453[h]				2000	2000	2000	2000	2000	2000	2000						5000	4260[f]	5000	5000
	Vegetal materials and wastes	1000									4000	4000	4000	4000	4000	4000	4000						5000	5730[f]	5000	5000
	Other (e.g. animal products/wastes)	1000									4000	4000	4000	4000	4000	4000	4000						5000	3676[k]	5000	5000
	Unspecified primary solid biomass	1000									4000	4000	4000	4000	4000	4000	4000						5000	4260[l]	5000	5000
	Gas/Liquids from biomass + wastes																						110[j]	110[j]		110[j]
	Municipal Waste	1000																								
	Industrial Waste	1000									4000	4000	4000	4000	4000	4000	4000									
	Charcoal								4000	4000	4000	4000	4000	4000	4000	4000	4000						7000	4467[g]	7000	7000

[a] Unless otherwise indicated - from IPCC Guidelines (1996), Tier 1, uncontrolled defaults

[b] Derived from EMEP/Corinair, 1996

[c] Excluding international bunkers

[d] Derived from EMEP/Corinair (1996). Default for 4-stroke gasoline used on inland waterways (2-stroke = 20000).

[e] IPCC Guidelines (IPCC, 1996), Reference Manual, Default marine emission factor for RFO.

[f] Zhang et al. (2000) Average EF for household stoves in China.

[g] EF derived from Bertschi *et al.* (2003) for charcoal cooking fires (in Zambia).

[h] EF derived from Bertschi *et al.* (2003) for earthen charcoal-making kilns (in Zambia).

[i] Assume agriculture/forestry/fishing use of gasoline and gas/diesel oil is for mobile sources (e.g. tractors, fishing boats)

[j] Value for domestic biogas use given by Smith, Kirk R. et al, (2000)

[k] Mean EF for dung burnt in a range of household stoves in India. Smith, Kirk R. et al, (2000)

[l] Assume = wood

[m] Smith, Kirk R. et al, (2000)

Table A4.3 Default NMVOC emission factors (kg/TJ)

Fuel type	Sub-sector	Public Electricity and Heat Production[a]	Petroleum refining[a]	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoproduction of electricity/heat	Remainder (Non-specified)	Civil Aviation[c]	Road transport	Railways	Navigation[c]	Pipeline transport	Commercial/Institutional	Residential	Agriculture/Forestry/Fishing	Non-specified "Other sectors"
		Combustion in the Energy industries[a] (Manufacture of Solid Fuels and Other Energy)							**Combustion in Manufacturing Industries and Construction[a]**									**Transport[a]**					**Combustion in Other sectors[a]**			
Coal	Coking Coal										20															
	Other Bituminous Coal & Anthracite	5		5		5		5		20	20	20	20	20	20	20	20			20			200	200	200	200
	Sub-Bituminous Coal	5																								
	Lignite	5																								
	Patent Fuel																							200		
	Coke Oven Coke			5	5	5		5		20	20	20	20	20	20	20	20						200	200	200	200
	Gas Coke										20															
	BKB																							200		
	Coke Oven Gas	5		5		5		5	20		20	20	20	20	20	20	20						200	200		
	Blast Furnace Gas	5		5					20		20															
Gas	Gas Works Gas	5		5		5			5	5	5	5	5	5	5	5	5						5	5		
	Natural Gas	5	5			5		5	5	5	5	5	5	5	5	5	5		5			5	5	5		
Oil	Crude Oil	5	5					5	5	5	5	5	5	5	5	5	5						5		5	5
	Natural Gas Liquids	5															5									
	Refinery Gas	5	5					5				5				5	5									
	Liquefied Petroleum Gases	5	5					5	5	5	5	5	5	5	5	5	5		600				5	5	5	5
	Motor Gasoline	5							5	5	5	5	5	5	5	5	5		1500		760[d]		5	5	5	5
	Aviation Gasoline																	300								
	Gasoline type Jet Fuel																									
	Kerosene type Jet Fuel																	50								
	Kerosene	5	5					5	5	5	5	5	5	5	5	5	5						5	5	5	5
	Gas/Diesel Oil	5	5					5	5	5	5	5	5	5	5	5	5		200	110[e]	110[e]		5	5	200	5
	Heavy Fuel Oil	5	5					5	5	5	5	5	5	5	5	5	5		200	200	52[e]		5	5	5	5
	Petroleum coke	5	5					5	5	5	5	5	5	5	5	5	5									
	Other Petroleum Products	5	5					5	5	5	5	5	5	5	5	5	5		200	200	200		5	5	5	5
Combustible renewables and waste	Primary Solid Biomass:																									
	Wood	1000					2190[h]				50	50	50	50	50	50	50						600	600	600	600
	Vegetal materials and wastes	1000									50	50	50	50	50	50	50						600	600	600	600
	Other (e.g. animal products/wastes)	1000									50	50	50	50	50	50	50						600	600	600	600
	Unspecified primary solid biomass	1000									50	50	50	50	50	50	50						600	600	600	600
	Gas/Liquids from biomass + wastes																							32[i]		
	Municipal Waste	1000																								
	Industrial Waste	1000									50	50	50	50	50	50	50									
	Charcoal								100	100	100	100	100	100	100	100	100						100	100	100	100

[a] IPCC Guidelines (1996), Tier 1 uncontrolled defaults (unless otherwise indicated)

[b] Derived from EMEP/Corinair, 1996

[c] Excluding international bunkers

[d] Derived from EMEP/Corinair (1996). Default for 4-stroke gasoline used on inland waterways (2-stroke = 11000).

[e] IPCC (1996), Tier 2 method (uncontrolled defaults).

[h] EF from Bertschi et al. (2003) for earthen charcoal-making kilns (in Zambia).

[i] Value for biogas burning given by Smith, Kirk R. et al, (2000)

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Table A4.4 Particulate matter (PM$_{10}$) combustion emission factors (kg/tonne fuel)

		Percentage ash content of fuel (A)	Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
					Manufacture of Solid Fuels and Other Energy																						
Sub-sector: / Sub-sub-sector:			Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoproduction of electricity/ heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified 'Other sectors'
Coal	Coking Coal																										
	Other Bituminous Coal & Anthracite		1.23 x A[b]								4.23[c]	4.23[c] or 0	4.23[c]	4.23[c]	4.23[c]	4.23[c]	4.23[c]	4.23[c]						4.23[c]	1.3[d]	4.23[c]	4.23[c]
	Sub-Bituminous Coal		1.23 x A[b]																								
	Lignite		1.03 x A[e]																								
	Patent Fuel																										
	Coke Oven Coke																										
	Gas Coke																										
	BKB																										
	Coke Oven Gas																										
	Blast Furnace Gas																										
Gas	Gas Works Gas																										
	Natural Gas		0.122[k]	0.104					0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104						0.104	0.104		
Oil	Crude Oil																										
	Natural Gas Liquids																										
	Refinery Gas																										
	Liquefied Petroleum Gases																									0.51[p]		
	Motor Gasoline																				7.5[r]							
	Aviation Gasoline																											
	Gasoline type Jet Fuel																											
	Kerosene type Jet Fuel																											
	Kerosene									0.148[m]	0.148[m]	0.148[m] or 0	0.148[m]	0.148[m]	0.148[m]	0.148[m]	0.148[m]	0.148[m]						0.16[n]	0.13[d]		
	Gas/Diesel Oil		0.333[h]							0.142[m]	0.142[m]	0.142[m] or 0	0.142[m]	0.142[m]	0.142[m]	0.142[m]	0.142[m]	0.142[m]		5.2[s]	5.14[t]	4.12[t]		0.15[n]			
	Heavy Fuel Oil		0.9[f]							1.09[l]	1.09[l]	1.09[l] or 0	1.09[l]	1.09[l]	1.09[l]	1.09[l]	1.09[l]	1.09[l]						0.792			
	Petroleum coke		1.23 x A[j]							4.23[j]	4.23[j]	4.23[j] or 0	4.23[j]	4.23[j]	4.23[j]	4.23[j]	4.23[j]	4.23[j]							4.23[j]		
	Other Petroleum Products																											
Combustible renewables and waste	Primary Solid Biomass:																										
	Wood							2.6[o]																	3.82[d]		
	Vegetal materials and wastes																								8.05[d]		
	Other (e.g. animal products/wastes)																								1.6[p]		
	Unspecified primary solid biomass																								3.82[i]		
	Gas/Liquids from biomass + wastes																								0.53[p]		
	Municipal Waste																										
	Industrial Waste																										
	Charcoal																								2.38[p]		

[a] Unless otherwise indicated, uncontrolled EFs derived from AP-42 (EPA, 1995); A=ash content

[b] Mean AP-42 value for pulverised coal-fired boilers.

[c] Mean AP-42 value for stoker boilers

[d] Zhang et al. (2000) Average EF for household stoves in China. (For 'vegetal materials and waste', EF = average for wheat and maize residues)

[e] AP-42 mean value for tangentially- and wall-fired pulverized lignite boilers

[f] AP-42 uncontrolled EF for utility boilers firing No 5 grade residual fuel oil

[h] AP-42 uncontrolled EF for filterable plus condensable PM10 for utility boilers firing No 2 grade distillate oil (diesel)

[i] Assume = woodfuel factor

[j] Assume = emission factor for Other Bituminous Coal & Anthracite

[k] AP42

[l] AP-42 value for No. 5 oil

[m] AP-42 uncontrolled EF for industrial boilers firing distillate oil

[n] AP-42 uncontrolled EF for comercial boilers firing distillate oil

[o] Bond et al., 2004.

[p] Assume = TSP value given by Smith, Kirk R. et al, (2000). For 'Primary Solid Biomass - Other' the EF is for dung combustion. For 'Gas/liquids from biomass + wastes' the EF is for biogas.

[q] These 'non-metallic minerals' default factors should be set to zero if the default factors given for mineral processes (Sheet 2.1) are used which include combustion emissions already (as well as process PM emissions).

[r] From Bond et al, 2004. In Asia, Africa and Latin America the value of 7.5 assumes that 52% of gasoline vehicles are 'unimproved', 35% are 2-stroke (high emissions) and 13% are 'super-emitters'. If there is little 2-stroke fuel use and there are no super-emitters then use 0.5 kg/t for 'unimproved' and 0.15 for 'standards in place'.

[s] From Bond et al, 2004. In Asia, Africa and Latin America the value of 5.2 assumes that 20% of diesel vehicles are 'super-emitters'. Otherwise use 3.5 kg/t for 'standards just beginning' and 1.5 for 'standards in place'.

[t] EMEP/CORNAIR (2006)

Table A4.5 Particulate matter (PM$_{2.5}$) combustion emission factors (kg/tonne fuel)

	Sub-sub-sector:	Percentage ash content of fuel (A)	Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity/ heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified "Other sectors"
Coal	Coking Coal																										
	Other Bituminous Coal & Anthracite	0.52 x A [b]									1.8[c]	1.8[c] or 0	1.8[c]	1.8[c]	1.8[c]	1.8[c]	1.8[c]	1.8[c]						1.8[c]	1.17[d]	1.8[c]	1.8[c]
	Sub-Bituminous Coal	0.52 x A [b]																									
	Lignite	0.33 x A [e]																									
	Patent Fuel																										
	Coke Oven Coke																										
	Gas Coke																										
	BKB																										
	Coke Oven Gas																										
	Blast Furnace Gas																										
Gas	Gas Works Gas																										
	Natural Gas		0.122																								
Oil	Crude Oil																										
	Natural Gas Liquids																										
	Refinery Gas																										
	Liquefied Petroleum Gases																								0.49[d]		
	Motor Gasoline																			7.5[r]							
	Aviation Gasoline																										
	Gasoline type Jet Fuel																										
	Kerosene type Jet Fuel																										
	Kerosene									0.037[l]	0.037[l]	0.037[l] or 0	0.037[l]	0.037[l]	0.037[l]	0.037[l]	0.037[l]	0.037[l]						0.123[m]	0.125[d]		
	Gas/Diesel Oil		0.244[j]							0.036[l]	0.036[l]	0.036[l] or 0	0.036[l]	0.036[l]	0.036[l]	0.036[l]	0.036[l]	0.036[l]		5.2[r]	4.83[s]	3.87[s]		0.118[m]			
	Heavy Fuel Oil		0.66[f]							0.71[k]	0.71[k]	0.71[k] or 0	0.71[k]	0.71[k]	0.71[k]	0.71[k]	0.71[k]	0.71[k]							0.29[k]		
	Petroleum coke		0.52 x A [h]							1.8[h]	1.8[h]	1.8[h] or 0	1.8[h]	1.8[h]	1.8[h]	1.8[h]	1.8[h]	1.8[h]									
	Other Petroleum Products																										
Combustible renewables and waste	Primary Solid Biomass:																										
	Wood							2.6[n]																	3.1[g]		
	Vegetal materials and wastes																								6.44[g]		
	Other (e.g. animal products/wastes)																								1.28[g]		
	Unspecified primary solid biomass																								3.1[o]		
	Gas/Liquids from biomass + wastes																								0.51[p]		
	Municipal Waste																										
	Industrial Waste																										
	Charcoal																								1.9[g]		

[a] Unless otherwise indicated, uncontrolled EFs derived from AP-42 (EPA, 1995); A=ash content

[b] Mean AP-42 value for pulverized coal-fired boilers.

[c] Mean AP-42 value for stoker boilers

[d] Assume a PM2.5/PM ratio of 0.9 for coal and 0.964 for kerosene and LPG. Reddy and Venkataraman (2002a)

[e] AP-42 mean value for tangentially- and wall-fired pulverized lignite boilers

[f] AP-42 uncontrolled EF for utility boilers firing No 5 grade residual fuel oil

[g] Assuming PM$_{2.5}$/PM ratio of 0.8 as reported for wood and crop waste (Reddy and Venkataraman, 2002b)

[h] Assume = emission factor for Other Bituminous Coal & Anthracite

[i] TERI,1987

[j] AP-42 uncontrolled EF for filterable plus condensable PM10 for utility boilers firing No 2 grade distillate oil (diesel)

[k] AP-42 value for No. 5 oil

[l] AP-42 uncontrolled EF for industrial boilers firing distillate oil

[m] AP-42 uncontrolled EF for comercial boilers firing distillate oil

[n] Assume = PM$_{10}$ factor (From Bond et al., 2004).

[o] Assume = woodfuel factor

[p] Assume PM2.5/PM ratio of 0.964 as for kerosene.

[q] These 'non-metallic minerals' default factors should be set to zero if the default factors given for mineral processes (Sheet 2.1) are used which include combustion emissions already (as well as process PM emissions).

[r] Assume = PM10 factor

[s] EMEP/CORNAIR (2006)

Table A4.6 Black carbon combustion emission factors (kg/tonne fuel)

Sub-sector:		Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
Sub-sub-sector:				Manufacture of Solid Fuels and Other Energy																						
		Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity/ heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified "Other sectors"
Coal	Coking Coal																1.2									
	Other Bituminous Coal & Anthracite	0.009								1.2	1.2	1.2	1.2	1.2		0.009	1.2			3.0			5.4[b]	5.4	5.4[b]	5.4[b]
	Sub-Bituminous Coal	0.009								1.2	1.2	1.2	1.2	1.2		0.009	1.2									
	Lignite	0.002								0.15	0.15	0.15	0.15	0.15		0.002	0.15									
	Patent Fuel	0.009[j]														0.009[j]									5.4[j]		
	Coke Oven Coke	0.011								0.005	0.005	0.005	0.005	0.005		0.011	0.005							0.15		
	Gas Coke																									
	BKB																							0.18		
	Coke Oven Gas																									
	Blast Furnace Gas																									
Gas	Gas Works Gas																									
	Natural Gas	0.002							0.002	0.002	0.002	0.002	0.002	0.002		0.002	0.002	0								
Oil	Crude Oil																						0	0	0	0
	Natural Gas Liquids																									
	Refinery Gas																									
	Liquefied Petroleum Gases																						0.2[b]	0.2	0.2[b]	0.2[b]
	Motor Gasoline																		0.43				0.9[b]	0.9	0.9[b]	0.9[b]
	Aviation Gasoline																	0.1								
	Gasoline type Jet Fuel																	0.1								
	Kerosene type Jet Fuel																	0.1								
	Kerosene								0.14	0.14	0.14	0.14	0.14	0.14			0.14						0.117[b]	0.117	0.117[b]	0.117[b]
	Gas/Diesel Oil	0.25							4.4	4.4	4.4	4.4	4.4	4.4		0.25	4.4		3.6	0.51	0.34		3.4[n]	4	3.7[c]	4[b]
	Heavy Fuel Oil	0.04							0.04	0.04	0.04	0.04	0.04	0.04		0.04	0.04				0.34		0.07[b]	0.07	0.07[b]	0.07[b]
	Petroleum coke																									
	Other Petroleum Products																									
Combustible renewables and waste	Primary Solid Biomass:																									
	Wood	0.04					0.2		0.55	0.55	0.55	0.55	0.55	0.55		0.04	0.55						0.62[b]	0.62	0.62[b]	0.62[b]
	Vegetal materials and wastes								0.55	0.55	0.55	0.55	0.55	0.55			0.55						1.0[b]	1.0	1.0[b]	1.0[b]
	Other (e.g. animal products/wastes)								0.55	0.55	0.55	0.55	0.55	0.55			0.55						0.53[b]	0.53	0.53[b]	0.53[b]
	Unspecified primary solid biomass								0.55	0.55	0.55	0.55	0.55	0.55			0.55						0.62[j]	0.62[j]	0.62[j]	0.62[j]
	Gas/Liquids from biomass + wastes																									
	Municipal Waste	0.013														0.013										
	Industrial Waste	0.013							0.013	0.013	0.013	0.013	0.013	0.013		0.013	0.013									
	Charcoal																						0.95[b]	0.95	0.95[b]	0.95[b]

[a] Unless otherwise indicated, EFs are from Bond et al. (2004, Table 9) and are central values for the technology/emission control mix for India in the mid 1990s (i.e. if a range is given by Bond et al., then upper value taken)

[b] Assume = residential EF

[c] Value for tractors.

[h] value for traditional brick kiln (highly uncertain)

[i] Assume = woodfuel factor

[j] Assume = emission factor for Other Bituminous Coal & Anthracite

[m] Bond et al (2004) value for Middle/light distillate oil - external combustion

[n] Value for diesel generator use

[r] Value for 4-stroke only

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Table A4.7 Organic carbon (OC) default[a] combustion emission factors (kg/tonne fuel)

		Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
Sub-sector:	Sub-sub-sector:	Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity/ heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified "Other sectors"
				Manufacture of Solid Fuels and Other Energy																						
Coal	Coking Coal																0.9									
	Other Bituminous Coal & Anthracite	0.001		0.9		0.9		0.9		0.9	0.9	0.9	0.9	0.9	0.9	0.001	0.9			0.1			4.3[b]	4.3	4.3[b]	4.3[b]
	Sub-Bituminous Coal	0.001														0.001										
	Lignite	0.04														0.04										
	Patent Fuel																									
	Coke Oven Coke	0.004		0.008	0.008	0.008		0.008		0.008	0.008	0.008	0.008	0.008	0.008	0.004	0.008									
	Gas Coke	0.004														0.004										
	BKB																									
	Coke Oven Gas																									
	Blast Furnace Gas																									
Gas	Gas Works Gas																									
	Natural Gas	0.001	0.001	0.001				0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		0.001			0.001	0.001[b]	0.001	0.001[b]	0.001[b]
Oil	Crude Oil																									
	Natural Gas Liquids																									
	Refinery Gas																									
	Liquefied Petroleum Gases																						0.05[b]	0.05	0.05[b]	0.05[b]
	Motor Gasoline								0.04	0.04	0.04	0.04	0.04	0.04	0.04		0.04		5.4				0.09[b]	0.09	0.09[b]	0.09[b]
	Aviation Gasoline																	0.03								
	Gasoline type Jet Fuel																	0.03								
	Kerosene type Jet Fuel																	0.03								
	Kerosene								0.04	0.04	0.04	0.04	0.04	0.04	0.04		0.04		5.4				0.09[b]	0.09	0.09[b]	0.09[b]
	Gas/Diesel Oil	0.001	1.4	1.4				1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.001	1.4		1.1	1.6	1.1		1.1[b]	1.1	1.2[c]	1.1[b]
	Heavy Fuel Oil	0.015	0.015	0.015	0.015				0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015				1.1		0.015[b]	0.015	0.015[b]	0.015[b]
	Petroleum coke																									
	Other Petroleum Products																									
Combustible renewables and waste[c]	Primary Solid Biomass:																									
	Wood	0.18					1.3					3.2	3.2	3.2	3.2	0.18	3.2						1.77[b]	1.77	1.77[b]	1.77[b]
	Vegetal materials and wastes																						3.3[b]	3.3	3.3[b]	3.3[b]
	Other (e.g. animal products/wastes)																						1.8[b]	1.8	1.8[b]	1.8[b]
	Unspecified primary solid biomass																						1.77[j]	1.77[j]	1.77[j]	1.77[j]
	Gas/Liquids from biomass + wastes																									
	Municipal Waste	0.002														0.002										
	Industrial Waste	0.002										0.002	0.002	0.002	0.002	0.002	0.002									
	Charcoal																						0.95[b]	0.95	0.95[b]	0.95[b]

[a] Unless otherwise indicated, uncontrolled factors are from Bond et al. (2004, Table 9) and are central values for the technology/emission control mix for India in the mid 1990s (i.e. if a range is given by Bond et al., then upper value taken)

[b] Assume = residential EF

[c] Value for tractors

[h] value for traditional brick kiln (highly uncertain)

[i] Assume = woodfuel factor

[j] Assume = emission factor for Other Bituminous Coal & Anthracite

[m] Bond et al (2004) value for Middle/light distillate oil - external combustion

[n] Value for diesel generator use

[r] Value for 4-stroke only

Table A4.8 Ammonia (NH₃) default[a] combustion emission factors (kg/tonne fuel)

Sub-sector:		Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
				Manufacture of Solid Fuels and Other Energy																						
Sub-sub-sector:		Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity / heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified "Other sectors"
Coal	Coking Coal																									
	Other Bituminous Coal & Anthracite	0.00028		0.0003		3E-04		0.00028		0.00028	0.00028	0.0003	0.00028	0.00028	0.00028	0.00028	0.00028			0.00028			0.00028	0.0003	0.00028	0.00028
	Sub-Bituminous Coal	0.00028																								
	Lignite	0.00028			0.0003																					
	Patent Fuel																									
	Coke Oven Coke																									
	Gas Coke																									
	BKB																									
	Coke Oven Gas																									
	Blast Furnace Gas																									
Gas	Gas Works Gas																									
	Natural Gas	1.31	1.31			1.31		1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31						0.2	0.2		0.2
Oil	Crude Oil																									
	Natural Gas Liquids																									
	Refinery Gas																									
	Liquefied Petroleum Gases																									
	Motor Gasoline								0.005[c]	0.005[c]	0.005[c]	0.005[c]	0.005[c]	0.005[c]	0.005[c]	0.005[c]	0.005[c]		0.101	0.101						
	Aviation Gasoline																									
	Gasoline type Jet Fuel																									
	Kerosene type Jet Fuel																									
	Kerosene																									
	Gas/Diesel Oil								0.007[c]	0.007[c]	0.007[c]	0.007[c]	0.007[c]	0.007[c]	0.007[c]	0.007[c]	0.007[c]		0.126	0.126	0.126					
	Heavy Fuel Oil	0.101		0.101	0.101			0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101		0.101	0.101	0.101		0.101	0.101	0.101	0.101
	Petroleum coke	0.00028						0.00028	0.0003	0.00028	0.00028	0.0003	0.00028	0.00028	0.00028	0.00028	0.00028									
	Other Petroleum Products																									
Combustible renewables and waste[c]	Primary Solid Biomass:																									
	Wood						0.37[e]																	1.29[d]		
	Vegetal materials and wastes																									
	Other (e.g. animal products/wastes)																									
	Unspecified primary solid biomass																							1.29[f]		
	Gas/Liquids from biomass + wastes																									
	Municipal Waste																									
	Industrial Waste																									
	Charcoal																							0.97[d]		

[a] Unless otherwise indicated - EFs are taken from Battye et al. (1994) defaults (no NOx controls). The gasoline default is for unleaded. For leaded gasoline use 0.068.

[b] excluding international bunkers

[c] EMEP/Corinair (1996)

[d] Bertschi et al. (2003) [Zambian open fires]

[e] Bertschi et al. (2003) [Zambian earthen charcoal-making fires]

[f] Assume = woodfuel factor

Table A4.9 Carbon dioxide (CO$_2$) combustion emission factors (kg/tonne fuel)

	Sub-sub-sector:	Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
		Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity/heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/Institutional	Residential	Agriculture/Forestry/Fishing	Non-specified "Other sectors"
Coal	Coking Coal		94600																							
	Other Bituminous Coal & Anthracite	94600	94600	94600		94600		94600		94600	94600	94600	94600	94600	94600	94600	94600			94600			94600	94600	94600	94600
	Sub-Bituminous Coal	96100	96100																							
	Lignite	101000	101000																							
	Patent Fuel		97500																					97500		97500
	Coke Oven Coke		107000	107000	107000	1E+05		107000		107000	107000	107000	107000	107000	107000	107000	107000						107000	107000	107000	107000
	Gas Coke		107000																							
	BKB		97500																					97500		97500
	Coke Oven Gas	44400	44400	44400		44400		44400	44400		44400	44400	44400	44400	44400	44400	44400						44400	44400		44400
	Blast Furnace Gas	260000	260000	260000	260000				260000																	
Gas	Gas Works Gas	44400	44400	44400		44400		44400	44400	44400	44400	44400	44400	44400	44400	44400	44400						44400	44400		44400
	Natural Gas	56100	56100		56100	56100		56100	56100	56100	56100	56100	56100	56100	56100	56100	56100		56100			56100	56100	56100	56100	56100
Oil	Crude Oil	73300	73300		73300	73300		73300	73300	73300	73300	73300	73300	73300	73300	73300	73300						73300		73300	73300
	Natural Gas Liquids	64200			64200	64200										64200										
	Refinery Gas	57600	57600		57600	57600		57600								57600	57600									
	Liquefied Petroleum Gases	63100	63100		63100	63100		63100	63100	63100	63100	63100	63100	63100	63100	63100	63100		63100				63100	63100	63100	63100
	Motor Gasoline	69300			69300	69300		69300	69300	69300	69300	69300	69300	69300	69300	69300	69300		69300		69300		69300	69300	69300	69300
	Aviation Gasoline			70000	70000													70000								
	Gasoline type Jet Fuel			70000	70000													70000								
	Kerosene type Jet Fuel			71500	71500													71500								
	Kerosene	71900	71900		71900	71900		71900	71900	71900	71900	71900	71900	71900	71900	71900	71900	71900					71900	71900	71900	71900
	Gas/Diesel Oil	74100	74100	74100	74100	74100		74100	74100	74100	74100	74100	74100	74100	74100	74100	74100		74100	74100	74100		74100	74100	74100	74100
	Heavy Fuel Oil	77400	77400	77400	77400	77400		77400	77400	77400	77400	77400	77400	77400	77400	77400	77400		77400	77400	77400		77400	77400	77400	77400
	Petroleum coke	97500	97500	97500	97500	97500		97500	97500	97500	97500	97500	97500	97500	97500	97500	97500									
	Other Petroleum Products	73300	73300	73300	73300	73300		73300	73300	73300	73300	73300	73300	73300	73300	73300	73300		73300	73300	73300		73300	73300	73300	73300
Combustible renewables and waste [c]	Primary Solid Biomass:																									
	Wood																									
	Vegetal materials and wastes																									
	Other (e.g. animal products/wastes)																									
	Unspecified primary solid biomass																									
	Gas/Liquids from biomass + wastes																	0.000								
	Municipal Waste																									
	Industrial Waste	143000									143000	143000	143000	143000	143000	143000	143000									
	Charcoal							0	0	0			0													

[a] Includes own use

[b] IPPC 2006 Guidelines - Tier 1 default EFs

[c] Assume carbon neutral thus EFs = 0

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Table A4.10 Methane (CH_4) default[a] combustion emission factors (kg/TJ)

Sub-sector:		Energy industries							Manufacturing Industries and Construction									Transport					Combustion in Other sectors			
Sub-sub-sector:				Manufacture of Solid Fuels and Other Energy																						
		Public Electricity and Heat Production	Petroleum refining	Coke ovens	Patent fuel, BKB	Gas works	Charcoal production	Other own use	Iron and Steel	Non-ferrous metals	Non-metallic minerals	Chemicals	Pulp, Paper and print	Mining and Quarrying	Construction	Autoprod-uction of electricity/ heat	Non-specified industry	Civil Aviation	Road transport	Railways	Navigation	Pipeline transport	Commercial/ Institutional	Residential	Agriculture/Forestry / Fishing	Non-specified "Other sectors"
Coal	Coking Coal										10															
	Other Bituminous Coal & Anthracite	1		1		1		1		10	10	10	10	10	10	1	10			2			10	300	300	300
	Sub-Bituminous Coal	1																					10	300	300	300
	Lignite	1			1																		10	300	300	300
	Patent Fuel																						10	300	300	300
	Coke Oven Coke			1	1	1		1		10	10	10	10	10	10		10						10	300	300	300
	Gas Coke										10												10	300	300	300
	BKB				1																		10	300	300	300
	Coke Oven Gas	1		1		1		1	1	1	1	1	1	1	1	1	1						5	5	5	5
	Blast Furnace Gas	1		1					1	1	1	1	1	1	1	1	1									
Gas	Gas Works Gas	1	1	1		1			1	1	1	1	1	1	1	1	1						5	5	5	5
	Natural Gas	1	1			1		1	1	1	1	1	1	1	1	1	1		92				5	5	5	5
Oil	Crude Oil	3	3					3	3	3	3	3	3	3	3	3	3						10	10	10	10
	Natural Gas Liquids	3							3	3	3	3	3	3	3	3	3									
	Refinery Gas	1	1					1	1	1	1	1	1	1	1	1	1									
	Liquefied Petroleum Gases	1	1					1	1	1	1	1	1	1	1	1	1		62				5	5	5	5
	Motor Gasoline	3							3	3	3	3	3	3	3		3		33				10	10	10	10
	Aviation Gasoline								3	3	3	3	3	3	3		3	0.5								
	Gasoline type Jet Fuel								3	3	3	3	3	3	3		3	0.5								
	Kerosene type Jet Fuel								3	3	3	3	3	3	3			0.5								
	Kerosene	3	3					3	3	3	3	3	3	3	3	3	3						10	10	10	10
	Gas/Diesel Oil	3	3	3				3	3	3	3	3	3	3	3	3	3		3.9	4.15			10	10	10	10
	Heavy Fuel Oil	3	3	3	3			3	3	3	3	3	3	3	3	3	3				7		10	10	10	10
	Petroleum coke	3	3					3	3	3	3	3	3	3	3	3	3						10			
	Other Petroleum Products	3	3					3	3	3	3	3	3	3	3	3	3						10	10	10	10
Combustible renewables and waste[c]	Primary Solid Biomass:																									
	Wood	30					893[h]				30	30	30	30	30	30	30						300	300	300	300
	Vegetal materials and wastes	30									30	30	30	30	30	30	30						300	300	300	300
	Other (e.g. animal products/wastes)	30									30	30	30	30	30	30	30						300	300	300	300
	Unspecified primary solid biomass	30									30	30	30	30	30	30	30						300	300	300	300
	Gas/Liquids from biomass + wastes																		18[j]				5(gas),10 (liquid)	5(gas),1 0(liquid)	5(gas),1 0 (liquid)	5(gas),1 0 (liquid)
	Municipal Waste	30																								
	Industrial Waste	30									30	30	30	30	30	30	30									
	Charcoal								200	200	200	200	200	200	200		200						200	200	200	200

[a] IPCC Guidelines (IPCC, 1996), Reference Manual, Tier 1 (Reference Approach) uncontrolled defaults (unless otherwise indicated)

[b] Derived from EMEP/Corinair, 1996

[c] Excluding international bunkers

[d] Derived from EMEP/Corinair (1996). Default for 4-stroke gasoline used on inland waterways (2-stroke = 11000).

[e] IPCC Guidelines (IPCC, 1996), Reference Manual, Tier 2 method (uncontrolled defaults).

[h] NMOC emission factor from Bertschi *et al.* (2003) for earthen charcoal-making kilns (in Zambia).

[i] Value for biogas burning given by Smith, Kirk R. et al, (2000) for TNMOC (total non-methane organic compounds) Greenhouse Gases from Small-Scale Combustion Devices in Developing Countries: Phase IIA Household Stoves in India. U.S. EPA EPA/600/R-00/052

[j] IPCC 2006 default for Ethanol cars in Brazil

Table A4.11 Emissions for LTO[a] and cruise activities of domestic aircraft.

Domestic flights: aircraft type (* =old fleet)	Fuel consumption per LTO (kg/LTO) Default[b]	SO_2 emission factor per LTO (kg/LTO) Default[c]	SO_2 emission factor for cruise activities (kg/t) Default[c]	NOx emission factor per LTO (kg/LTO) Default[b]	NOx emission factor for cruise activities (kg/t) Default[b]	CO emission factor per LTO (kg/LTO) Default[b]	CO emission factor for cruise activities (kg/t) Default[b]	NMVOC emission factor per LTO (kg/LTO) Default[b]	NMVOC emission factor for cruise activities (kg/t) Default[b]	PM_{10} emission factor per LTO (kg/LTO) Default[d]	PM_{10} emission factor for cruise activities (kg/t) Default[j]	$PM_{2.5}$ emission factor for LTO (kg/LTO) Default[e]	$PM_{2.5}$ emission factor for cruise activities (kg/t) Default[i]	CO_2 emission factor per LTO (kg/LTO) Default[e]	CO_2 emission factor for cruise activities (kg/t) Default[e]
Airbus A310	1540.5	1.5	1	23.2	10.3	25.8	2.0	5	0.1	0.14	0.2	0.14	0.2	4853	3150
Airbus A320	802.3	0.8	1	10.8	10.3	17.6	2.0	1.7	0.1	0.09	0.2	0.09	0.2	2527	3150
Airbus A330	2231.5	2.2	1	36.1	10.3	21.5	2.0	1.9	0.1	0.19	0.2	0.19	0.2	7029	3150
Airbus A340	2019.9	2	1	35.4	10.3	50.6	2.0	16.9	0.1	0.21	0.2	0.21	0.2	6363	3150
BAe 111	681.6	0.7	1	4.9	10.3	37.7	2.0	19.3	0.1	0.17	0.2	0.17	0.2	2147	3150
BAe 146	569.5	0.6	1	4.2	10.3	9.7	2.0	0.9	0.1	0.08	0.2	0.08	0.2	1794	3150
Boeing 727*	1412.8	1.4	1	12.6	9.4	26.4	2.0	6.5	0.8	0.22	0.2	0.22	0.2	4450	3150
Boeing 737-100	919.7	0.9	1	8	10.3	4.8	2.0	0.5	0.1	0.1	0.2	0.1	0.2	2897	3150
Boeing 737-400	825.4	0.8	1	8.3	10.3	11.8	2.0	0.6	0.1	0.07	0.2	0.07	0.2	2600	3150
Boeing 747 100-300	3413.9	3.4	1	55.9	10.3	78.2	2.0	33.6	0.1	0.47	0.2	0.47	0.2	10754	3150
Boeing 747-400	3402.2	3.4	1	56.6	10.3	19.5	2.0	1.6	0.1	0.32	0.2	0.32	0.2	10717	3150
Boeing 757	1253	1.3	1	19.7	10.3	12.5	2.0	1.1	0.1	0.13	0.2	0.13	0.2	3947	3150
Boeing 767 300 ER	1617.1	1.6	1	26	10.3	6.1	2.0	0.8	0.1	0.15	0.2	0.15	0.2	5094	3150
Boeing 777	2562.8	2.6	1	53.6	10.3	61.4	2.0	20.5	0.1	0.2	0.2	0.2	0.2	8073	3150
McDonnel Douglas DC-8*	1839.4	1.8	1	14.8	9.4	65.2	2.0	52.2	0.8	0.16	0.2	0.16	0.2	5794	3150
McDonnel Douglas DC-9*	876.1	0.9	1	7.3	9.4	5.4	2.0	0.7	0.8	0.16	0.2	0.16	0.2	2760	3150
McDonnel Douglas DC-10	2381.2	2.4	1	41.7	10.3	61.6	2.0	20.5	0.1	0.32	0.2	0.32	0.2	7501	3150
McDonnel Douglas M81-88	1003.1	1	1	12.3	10.3	6.5	2.0	1.4	0.1	0.12	0.2	0.12	0.2	3160	3150
Fokker 28	666.1	0.7	1	5.2	10.3	32.7	2.0	29.6	0.1	0.15	0.2	0.15	0.2	2098	3150
Fokker 100	744.4	0.7	1	5.8	10.3	13.7	2.0	1.3	0.1	0.14	0.2	0.14	0.2	2345	3150
Type unknown (old fleet[h])	920	1	1	8	10.3	4.8	2.0	0.5	0.8	0.1	0.2	0.1	0.2	2898	3150
Type unknown (average fleet[g])	825	0.85	1	8.3	10.3	11.8	2.0	0.5	0.1	0.07	0.2	0.07	0.2	2599	3150
Other (Please specify)			1		10.3		2.0				0.2		0.2	0	3150

[a] Landing/Take-off (LTO) cycle. Consists of one take-off and one landing and includes engines running idle, taxi-in and out, and climbing and descending under 914 metres (3000 feet).

[b] Factors given by EMEP/Corinair (2001)

[c] Assuming 0.05% S content of the jet kerosene. Adjust the emission factor if actual S content differs e.g., if S content is 0.01 %, the SO_2 emission factor should be divided by 5.

[d] Assume PM10 = PM2.5

[e] Factors given by EMEP/Corinair

[f] From sheet 1.1.2

[g] Default given by EMEP/Corinair (2001) for 'average fleet' represented by Boeing B737-400.

[h] Default given by EMEP/Corinair (2001) for 'old fleet' represented by Boeing B737-100.

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Table A4.12 Emissions for LTO[a] activities of international aviation.

International flights: aircraft type (* =old fleet)	Fuel consumption per LTO (needed for BC and OC emissions)	SO_2 emission factor per LTO (kg/LTO)	NOx emission factor per LTO (kg/LTO)	CO emission factor per LTO (kg/LTO)	NMVOC emission factor per LTO (kg/LTO)	PM_{10} emission factor per LTO (kg/LTO)	$PM_{2.5}$ emission factor for LTO (kg/LTO)	BC emission factor for LTO activities (kg/tonne fuel)	OC emission factor for LTO activities (kg/tonne fuel)	CO_2 emission factor per LTO (kg/LTO)
	Default[b]	Default[bc]	Default[b]	Default[b]	Default[b]	Default[d]	Default[e]	Default[i]	Default[i]	Default[b]
Airbus A310	1540.5	1.5	23.2	25.8	5	0.14	0.14	0.098	0.028	4853
Airbus A320	802.3	0.8	10.8	17.6	1.7	0.09	0.09	0.098	0.028	2527
Airbus A330	2231.5	2.2	36.1	21.5	1.9	0.19	0.19	0.098	0.028	7029
Airbus A340	2019.9	2	35.4	50.6	16.9	0.21	0.21	0.098	0.028	6363
BAe 111	681.6	0.7	4.9	37.7	19.3	0.17	0.17	0.098	0.028	2147
BAe 146	569.5	0.6	4.2	9.7	0.9	0.08	0.08	0.098	0.028	1794
Boeing 727*	1412.8	1.4	12.6	26.4	6.5	0.22	0.22	0.098	0.028	4450
Boeing 737-100	919.7	0.9	8	4.8	0.5	0.1	0.1	0.098	0.028	2897
Boeing 737-400	825.4	0.8	8.3	11.8	0.6	0.07	0.07	0.098	0.028	2600
Boeing 747 100-300	3413.9	3.4	55.9	78.2	33.6	0.47	0.47	0.098	0.028	10754
Boeing 747-400	3402.2	3.4	56.6	19.5	1.6	0.32	0.32	0.098	0.028	10717
Boeing 757	1253	1.3	19.7	12.5	1.1	0.13	0.13	0.098	0.028	3947
Boeing 767 300 ER	1617.1	1.6	26	6.1	0.8	0.15	0.15	0.098	0.028	5094
Boeing 777	2562.8	2.6	53.6	61.4	20.5	0.2	0.2	0.098	0.028	8073
McDonnel Douglas DC-8*	1839.4	1.8	14.8	65.2	52.2	0.16	0.16	0.098	0.028	5794
McDonnel Douglas DC-9*	876.1	0.9	7.3	5.4	0.7	0.16	0.16	0.098	0.028	2760
McDonnel Douglas DC-10	2381.2	2.4	41.7	61.6	20.5	0.32	0.32	0.098	0.028	7501
McDonnel Douglas M81-88	1003.1	1	12.3	6.5	1.4	0.12	0.12	0.098	0.028	3160
Fokker 28	666.1	0.7	5.2	32.7	29.6	0.15	0.15	0.098	0.028	2098
Fokker 100	744.4	0.7	5.8	13.7	1.3	0.14	0.14	0.098	0.028	2345
Type unknown (old fleet[h])	920	1	8	4.8	0.5	0.1	0.1	0.098	0.028	7500
Type unknown (average fleet[g])	825	0.85	8.3	11.8	0.5	0.07	0.07	0.098	0.028	5094

[a] Landing/Take-off (LTO) cycle. Consists of one take-off and one landing and includes engines running idle, taxi-in and out, and climbing and descending under 914 metres (3000 feet)

[b] Factors given by EMEP/Corinair (2001)

[c] Assuming 0.05% S content of the jet kerosene. Adjust the emission factor if actual S content differs e.g., if S content is 0.01 %, the SO_2 emission factor should be divided by 5.

[d] Assume PM10 = PM2.5

[e] Factors given by EMEP/Corina

[g] Default given by EMEP/Corinair (2001) for 'average fleet' represented by Boeing B737-400.

[h] Default given by EMEP/Corinair (2001) for 'old fleet' represented by Boeing B737-100.

[i] Default values from Bond et al 2004

Table A4.13 Mobile emissions for on-road vehicles (Detailed method).

Fuel	Vehicle class	NOx emission factor (g/km) Default	CO emission factor (g/km) Default	NMVOC emission factor (g/km) Default [a]	NH3 emission factor (g/km) Default [r]	Exhaust PM10 emission factor (g/km) (Assume = TSP emission factors) Default [m]	Exhaust PM2.5 emission factor (g/km) (Assume = PM10 emission factors) Default [y]	Unpaved road dust (PM10) emission factor in dry weather (g/km) Default [s]	Unpaved road (PM2.5) emissions factor (g/km) Default [t]	CO2 emission factor (g/kg fuel) Default [G]	BC emission factor (g/kg fuel) Default [c]	OC emission factor (g/kg fuel) Default [c]
Gasoline	Passenger cars (Uncontrolled)	1.8[A]	9.8[A]	1.7[A]	0.002	0.06[A]	0.06[A]	126	19	3180	0.58	0.61
	Passenger cars (Moderate control) [w]	1.1[B]	3.9[B]	0.8[B]	0.002	0.05[B]	0.05[B]	126	19	3180	0.14	0.15
	Passenger cars (Good control - Euro I) [x]	0.2[C]	2.0[C]	0.25[C]	0.1	0.03[C]	0.03[C]	126	19	3180	0.043	0.046
	Motorcycles (2-stroke) (Uncontrolled)	0.03[A]	6.5[A]	3.9[A]	0.002	0.23[A]	0.23[A]	36	5	3180	1.43	22.5
	Motorcycles (2-stroke) (Medium control)	0.06[B]	4[B]	3.3[B]	0.002	0.1[A]	0.1[A]	36	5	3180	0.71	11.3
	Motorcycles (2-stroke) (Good control)	0.07[C]	2.2[C]	2.13[C]	0.002	0.05[A]	0.05[A]	36	5	3180	0.71	11.3
	Motorcycles (4-stroke) (Uncontrolled)	0.31[A]	3[A]	0.8[A]	0.002	0.07[A]	0.07[A]	36	5	3180	0.58	0.61
	Motorcycles (4-stroke) (Medium control)	0.3[B]	2.6[B]	0.7[B]	0.002	0.06[B]	0.06[B]	36	5	3180	0.14	0.15
	Motorcycles (4-stroke) (Good control)	0.3[C]	2.2[C]	0.7[C]	0.002	0.05[C]	0.05[C]	36	5	3180	0.043	0.046
	3-Wheelers (2-stroke) (uncontrolled)	0.05[A]	14[A]	8.3[A]	0.002	0.35[A]	0.35[A]	90	14	3180	1.43	22.5
	3-Wheelers (2-stroke) (Medium control)	0.09[B]	8.6[B]	7.0[B]	0.002	0.15[B]	0.15[B]	90	14	3180	0.71	11.3
	3-Wheelers (2-stroke) (Good control)	0.11[C]	4.3[C]	2.05[C]	0.002	0.08[C]	0.08[C]	90	14	3180	0.71	11.3
Diesel	3-Wheelers (Uncontrolled)	13[v]	2.25[v]		0.001	1.54[v]	1.54[v]	90	14	3140	6.8	2.2
	Passenger cars (Uncontrolled)	2.77[A]	7.3[A]	0.37[A]	0.001	0.84[A]	0.84[A]	126	19	3140	6.8	2.2
	Passenger cars (Moderate control)	0.69[B]	1.2[B]	0.37[B]	0.001	0.42[B]	0.42[B]	126	19	3140	2	0.63
	Passenger cars (Good control)	0.5[C]	0.9[C]	0.13[C]	0.001	0.07[C]	0.07[C]	126	19	3140	0.85	0.27
	Light-duty vehicles (Uncontrolled)	3.15[A]	8.7[A]	0.34[A]	0.001	0.8[A]	0.8[A]	225	34	3140	6.8	2.2
	Light-duty vehicles (Moderate control)	2.49[B]	6.9[B]	0.28[B]	0.001	0.5[B]	0.5[B]	225	34	3140	2	0.63
	Light-duty vehicles (Good control)	1.28[C]	5.1[C]	0.14[C]	0.001	0.2[C]	0.2[C]	225	34	3140	0.85	0.27
	Heavy-duty vehicles (Uncontrolled)	14.3[D]	5.5[A]	1.78[A]	0.003	2.25[D]	2.25[D]	450	68	3140	6.8	2.2
	Heavy-duty vehicles (Moderate control)	12.6[E]	4.5[B]	1.21[B]	0.003	1.2[E]	1.2[E]	450	68	3140	2	0.63
	Heavy-duty vehicles (Good control)	9.15[F]	3.6[C]	0.87[C]	0.003	0.42[F]	0.42[F]	450	68	3140	0.85	0.27
CNG	3-wheeler 2-stroke (Good control - Euro-I)	0.11[d]	3.4[d]	0.25[d]		0.08[d]	0.08[d]	90	14	2750		
	3-wheeler 4-stroke (Good control - Euro-I)	0.61[d]	3.4[d]	0.06[d]		0.08[d]	0.08[d]	90	14	2750		
	Passenger car (uncontrolled)	2.1[H]	4.0[H]	0.5[H]		0.06[K]	0.06[K]	126	19	2750		
	Passenger car (Good control - Euro-I)	0.5[H]	0.3[H]	0.05[H]		0.03[K]	0.03[K]	126	19	2750		
	Bus/trucks	5.7[J]	12.0[J]	1.4[J]				450	68	2750		
LPG	Passenger cars (Uncontrolled)	2.1[L]	8.0[L]	3.5[L]		0.06[K]	0.06[K]	126	19	3030		
	Passenger cars (Good control - Euro-I)	0.05[L]	0.3[L]	0.25[L]		0.03[K]	0.03[K]	126	19	3030		
	Light-duty vehicles (Uncontrolled)	2.1[L]	8.0[L]	3.5[L]		0.06[K]	0.06[K]	225	34	3030		
	Light-duty vehicles (Good control - Euro-I)	0.05[L]	0.3[L]	0.25[L]		0.03[K]	0.03[K]	225	34	3030		
	Heavy-duty vehicles (Uncontrolled)	5.7[M]	24[M]	8[M]				450	68	3030		
	Heavy-duty vehicles (Good contro)	2.6[M]	1.0[M]	0.7[M]				450	68	3030		

[a] Assumed = EFs for Hydrocarbons (HC) given by CPCB (2000)

[c] Defaults from Bond et al 2004 where 'Uncontrolled' = 'Superemitters', 'Moderate control = 'Standards beginning' and 'Good control' = 'Standards in place'.

[d] Iyer (2004)

[m] CPCB (2000) PM value for Indian car fleet unless otherwise indicated

[r] Bulk NH_3 emission factors (EMEP/Corinair, 2004)

[s] Derived from Gillies et.al. (2005) for unpaved rural roads in dry weather (roadbed moisture content <0.5%; assume = to days when precipitation is < 0.25 mm; silt content range 4% - 7%). Emission factor = 3 x W x S g/km where S is the average speed in km/hr and W is the average vehicle wieght in tonnes. Factors suggested assume 30 km average speed for all vehicles and average weights of 0.4 t for 2-wheelers, 1 t for 3-wheelers, 1.4 t for passenger cars, 2.5 t for light commercial vehicles and 5 t for heavy duty vehicles (trucks and buses). If the average weight or average speed for a vehicle class differ from these assumptions then the formula should be used to calculate revised factors.

[t] Assume PM2.5 factor is 15% of PM10 factor (USEPA, 1995)

[v] Shrestha & Malla, 1996

[w] Moderate control as for 2-way (oxidation) catalysts.

[x] Good control as for 3-way catalysts (= Euro-I)

[y] Assume PM2.5 EF = PM10 EF

[z] Assume 2-stroke 3-wheelers have same EF for NMVOC as 2-stroke motorcycles >50cc

[A] CPCB (2000) value for Indian car fleet pre-1995

[B] CPCB (2000) value for Indian car fleet 1996-2000

[C] CPCB (2000) value for Indian car fleet 2001-2005

[D] CPCB (2000) value for Indian car fleet pre-1995, mean of EFs given for trucks and buses

[E] CPCB (2000) value for Indian car fleet 1996-2000, mean of EFs given for trucks and buses

[F] CPCB (2000) value for Indian car fleet 2001-2005, mean of EFs given for trucks and buses

[G] IPCC default CO2 EF for European vehicles

[H] IPCC (1996) default EF for US natural gas passenger cars

[J] IPCC (1996) default EF for US natural gas uncontrolled heavy duty vehicles with stoichiometric engine

[K] Assume = gasoline car factor

[L] IPCC (1996) default EF for US LPG passenger cars

[M] IPCC (1996) default EF for US LPG uncontrolled heavy duty vehicles with stoichiometric engine

Table A4.14 Activity categories, units and default emission factors for fugitive emissions from fuels

Sub-sector/Process	Activity type /Units	Default emission factor (kg pollutant per activity unit)										
		SO$_2$	NOx	CO	NMVOC	NH$_3$	PM$_{10}$	PM$_{2.5}$	BC	OC	CH$_4$	CO$_2$
Oil exploration, crude oil production and transport												
Oil well drilling	No. of wells drilled/year	NA	NA	NA	700 [a]	NA	NA	NA	NA	NA	325 [a]	NA
Fugitive emissions from facilities/platforms (includes venting and flaring)	Crude oil production (kt/yr)	NA	NA	NA	613 [f]	NA	NA	NA	NA	NA	1013 [f]	55621 [f]
Loading onto tankers: Marine vessels	Crude loaded (kt/yr)	NA	NA	NA	71 [b]	NA	NA	NA	NA	NA	7.1 [g]	0.65 [h]
Rail tank cars & tank trucks	Crude loaded (kt/yr)	NA	NA	NA	286 [f]	NA	NA	NA	NA	NA	28.6 [f]	2.63 [f]
Pipeline transport	Mass oil transported (kt/yr)	NA	NA	NA	62 [f]	NA	NA	NA	NA	NA	6.2 [f]	0.56 [f]
Transit in marine tankers	Mass transported (kt-weeks/yr)	NA	NA	NA	146 [b]	NA	NA	NA	NA	NA	14.6 [g]	0.74 [h]
Gasoline distribution/handling												
Refinery dispatch station	kt gasoline handled/year	NA	NA	NA	310 [d]	NA	NA	NA	NA	NA	NA	NA
Transport and depots	kt gasoline handled/year	NA	NA	NA	740 [d]	NA	NA	NA	NA	NA	NA	NA
Service station	kt gasoline handled/year	NA	NA	NA	2880 [d]	NA	NA	NA	NA	NA	NA	NA
Production and distribution of natural gas												
Production	TJ gas/year	NA	NA	NA	8.45 [f]	NA	NA	NA	NA	NA	77.2 [f]	36.7 [f]
Distribution	TJ gas/year	NA	NA	NA	0.61 [f]	NA	NA	NA	NA	NA	42.4 [f]	2.16 [f]
Oil refining	Throughput of crude oil tonnes/year	0.92 [e]	0.06 [e]	0.09 [e]	1.49 [e]	NA	NA	NA	NA	NA	0.12 [h]	1.49 [h]
Production of coke	Tonnes coke produced/yr	NA	NA	NA	0.017 [i]	0.99 [i]	28 [j]	25 [j]	1.7 [j]	1.2 [j]	0.0001 [k]	560 [k]
Methane from coal mining												
Underground mines: mining activities	kt coal mined / yr	NA	NA	NA	NA	NA	NA	NA	NA	NA	12.06 [l]	NA
Underground mines: post-mining activities	kt coal mined / yr	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.68 [l]	NA
Surface mines: mining activities	kt coal mined / yr	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.8 [l]	NA
Surface mines: post-mining activities	kt coal mined / yr	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.07 [l]	NA

[a] Value quoted in EMEP/Corinair (1996) for Norway.
[b] AP-42 (USEPA, 1995)
[c] Typical emission factor for splash loading (USEPA, 1995).
[d] Default value from EMEP/Corinair (1996)
[e] Default values (simple methodology) suggested by IPPC (1996).
[f] IPCC (2006) average of Tier 1 default ranges for developing countries.
[g] Assume = 1/10 of NMVOC default
[h] IPCC 2006 default for fugitive emissions (including venting and flaring).
 EMEP/EEA air pollutant emission inventory guidebook (2009) Tier 2 defaults for coke oven (door leakage and extinction)

[i] EMEP/EEA air pollutant emission inventory guidebook (2009) Tier 2 defaults for coke oven (door leakage and extinction)
[j] EFs are from Bond et al. (2004) and are central values for the technology/emission control mix (5% controlled/95% uncontrolled) for India in the mid 1990s (i.e. if a range is given by Bond et al., then upper value taken) - then adjusted assuming 1 tonne coal makes 0.7 tonnes coke.
[k] IPCC 2006 Tier 1 default for coke production
[l] IPCC 2006 Tier 1 default for coal mining
NA = Not applicable