Malé Declaration on Control and Prevention of Air Pollution
and Its Likely Transboundary Effects for South Asia

The Malé Declaration Air Pollutant Emissions Inventory Manual

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Preface

This Manual was prepared under the Phase II Implementation of Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia by the Stockholm Environment Institute[1] (SEI) and the National Implementing Agencies of the Malé Declaration. The Manual and its associated Workbook were based on, and grew out of, a manual prepared for UNDP/UN DESA by SEI (principal authors: David von Hippel and Harry Vallack) entitled "Manual for Preparation of Emissions Inventories for use in Modeling of Transboundary Air Pollution" for use in Northeast Asia. This work was sponsored by the Swedish International Development Cooperation Agency (Sida) as part of its Regional Air Pollution in Developing Countries (RAPIDC) programme.

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Executive summary

Air pollution is of significant concern to the countries of South Asia. Carried by prevailing winds in the region, some air pollutants can be transported across national boundaries. Addressing problems associated with these "transboundary" air pollutants, such as acidic depositions, is likely to require coordinated regional planning. In order to provide a quantitative basis for regional planning, regional coordination in modelling of the impacts of transboundary air pollution will be necessary. The compilation of national inventories of air pollutant emissions in a consistent format by each of the 8 countries of the Malé Declaration is a first step toward such coordinated modelling in the region.

This Manual provides suggested methods for estimating anthropogenic air pollutant emissions from a variety of emissions source categories. The methodologies presented 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 Malé 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; 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), ammonia (NH_3) and particulate matter (PM_{10} and $PM_{2.5}$). Brief descriptions are provided of the status of air pollutant emissions in the Malé Declaration countries, and of regional and international inventory efforts underway around the world in Annexes at the end of this Manual.

An Excel workbook has been prepared as a companion to this Manual for use as an aid and tool in preparing national emissions inventories. The final chapter of this Manual presents the main elements of this companion Workbook. Information on estimating natural emissions, international inventory approaches used elsewhere and on speciation of emissions is provided in an Annex at the end of the manual.

Use of this Manual and its companion Workbook will, it is hoped, enable the Malé Declaration countries of South Asia to develop emissions inventories in a consistent, transparent manner, simplifying the process of regional cooperation on modelling of transboundary air pollution and mitigating regional air pollution.

Acronyms and Abbreviations

ACCENT	Atmospheric Composition Change the European Network of Excellence
AP-42	Common name for the US EPA's *Compilation of Air Pollutant Emission Factors*
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
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
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
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
K	Kelvin
kg	kilogram (1000 grams)
kt	kilotonne (1000 tonnes)
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	
MSW	municipal solid waste
Mt	megatonne (1000 tonnes)
Mtoe	megatonne oil equivalent
MW	megawatt (1000 watts)
MW_e	megawatt (electricity)
MW_{th}	megawatt (thermal)
m^3	cubic meter

µm	micrometer (10^{-6} meter)
N	nitrogen
NAPAP	National Acid Precipitation Assessment Program
NAPSEA	nomenclature for air pollution socio-economic activity
NCV	net calorific value (= lower heating value, LHV)
NGL	natural gas liquids
NH_3	ammonia
NIA	National Implementing Agency
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	nitrogen oxides ($NO + NO_2$)
O_3	ozone
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 of less than 10 micrometers in aerodynamic diameter
$PM_{2.5}$	particulate matter of less than 10 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 Excel 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 Malé 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 (C3H8) 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^{o}C and 215^{o}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^{o}C, and a distillation range usually within the limits of 30^{o}C and 180^{o}C.

Gasoline type Jet Fuel

This includes all light hydrocarbon oils for use in aviation turbine power units. They distil between 100^{o}C and 250^{o}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^{o}C and 300^{o}C but not generally above 250^{o}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^{o}C and 300^{o}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^{o}C and 380^{o}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^{o}C and 540^{o}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^{o}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 MALÉ DECLARATION AIR POLLUTANT EMISSIONS INVENTORY MANUAL

1. Introduction

1.1 Regional context

Many South Asian countries have experienced rapid economic growth over the last 30 years and this trend is expected to continue. The combination of expanding economies with high population growth in the region has brought about a vast expansion in the need for energy, industrial and agricultural goods and services, and an expansion in the demand for the fuels and materials that help to supply these services. Energy consumption in Asia is projected to grow to 30% of the world's total by 2015, and much of this will be provided by fossil fuels. This is likely to lead to a dramatic increase in emissions of air pollutants such as sulphur and nitrogen oxides and particulate matter. Asia's increased emissions are already having wide-ranging impacts including acidic depositions (sometimes called "acid rain"). Thus the further increases in emissions projected for the future are likely to have major consequences for both local and regional air pollution. As a consequence, there is a great need for the countries of the region to cooperate to curb emissions of these pollutants. Such regional cooperation requires the nations to develop mutually agreeable models of air pollutant emissions and transport in the region so that the links between emissions and adverse impacts can be evaluated and the results fed into the policy process. This emissions inventory manual represents a first step toward formulating regional models of transboundary air pollution. This manual sets out a recommended common methodology for the countries of the South Asia region to use in compiling their own inventories of the transboundary air pollutants.

1.2 The Malé Declaration

The "Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia" is an inter-governmental agreement to tackle regional air pollution problems, established in 1998 by the South Asian countries at a meeting of the South Asia Cooperative Environment Programme (SACEP) Governing Council. It is the only environmental agreement covering all the countries of South Asia. Participating countries are Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan and Sri Lanka. This manual has been prepared as part of the 2001-2004 phase of the Sida-funded Programme on Regional Air Pollution in Developing Countries (RAPIDC) which is co-ordinated by the Stockholm Environment Institute (SEI). Implementation is co-ordinated by the UNEP Regional Resource Centre for Asia and the Pacific (RRC-AP) and SACEP in collaboration with the national governments from the eight participating countries. The countries are also providing national resources for the implementation of the Declaration and SEI provides technical support. A network of monitoring stations is being developed to provide the Malé Declaration with information about the level of regional-scale air pollution. The monitoring sites are located in rural areas remote from point sources of pollution and are able to provide information about long-distance transport of air pollutants. The activities are being technically supported by the Monitoring Committee (MoC) who are responsible for advising national monitoring institutions, creating manuals and ensuring the quality and sustained development of the monitoring network. At each station, rainwater, particulate matter and the gaseous pollutants SO_2 and NO_2 are being sampled. A number of parallel studies are being carried out to prepare information and tools required by the policy process in South Asia. One of these activities is the development of an integrated assessment tool which combines emissions, atmospheric transfer of pollutants, regional impacts (such as acidification) and mitigation options. The emissions inventory manual is part of this process and will help the Malé Declaration countries to compile national emission inventories which will provide more accurate emission input data for the Malé Declaration Integrated Assessment Model (IAM). This Manual has been developed in close consultation and collaboration with the National Implementing Agencies (NIAs) of the Malé Declaration countries and with regional experts.

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.

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) 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 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[3] 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[4]. 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.

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) in the final summary worksheet).

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

[4] This structure will be changed in the 2006 Guidelines. ‘Industrial processes’ and ‘Solvents and other product use’ will be merged into one sector and so will ‘Agriculture’ and ‘LULUCF’.

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	NMVOC emissions resulting from the use of solvents and other products containing volatile organic compounds.
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, and total emissions from agricultural residue burning.
9 VEGETATION FIRES & FORESTRY	Total emissions from on-site burning of forests and other vegetation.
10 WASTE	Emissions from waste incineration and human excreta.

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.
- NH_3 is reported in NH_3 mass units.

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.

Malé 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. The long range transport of atmospheric sulphur dioxide and nitrogen oxide, and the products of their reactions, have long been studied in relation to acidic deposition. Although much less research has been done on the effects of atmospheric NH_3, 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[5]). 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.

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[5] 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.

By definition, methane (CH_4) is not a NMVOC but 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

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.

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 Malé 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. If required, emissions of TSP can be estimated using the World Health Organisation's (WHO) rapid assessment manual[6] "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.

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.

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[6] 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

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. 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

This category (Sector 7 in this Manual) covers the use of solvents and other products containing volatile compounds that are sources of NMVOC emissions. It 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 and the application of nitrogen-containing fertilizers, both of which are responsible for ammonia emissions. It also covers field burning of agricultural crop residues. Fuel combustion emissions in agriculture are excluded as these are covered in Sector 4.

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 natural wildfires.

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. Also included are emissions of ammonia from human excreta stored in latrines ("dry" toilets located outside the house) or from defecation/urination outdoors (e.g. in the fields or bush).

Table 2-3:
Details of emission source categories used in this Manual (with equivalent ISIC[7] 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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$

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[7] 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

Table 2-3 (Continued)

		Sector	Comments	Pollutants
2	**B**	**Non-ferrous metals** (ISIC Group 272 and Class 2732)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**C**	**Non-metallic minerals** (ISIC Division 26)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**D**	**Chemicals** (ISIC Division 24)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**E**	**Pulp, Paper and print** (ISIC Divisions 21 and 22)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**F**	**Mining and quarrying** (ISIC Divisions 10 to 14)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**G**	**Construction** (ISIC Divisions 45)		SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
2	**H**	**Other**	Specify according to ISIC categories where possible. Combustion emissions from Textiles and Leather (ISIC Divisions 17, 18, and 19) and Food Processing, Beverages and Tobacco (ISIC Divisions 15 and 16) are included here.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
		2 **Domestic aviation**	Emissions from all LTO cycles and cruise activities for civil domestic passenger and freight air traffic.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$

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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
3	C	**Railways**	Both freight and passenger	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
3	D	**Navigation**	Emissions from fuel used by all water-borne vessels except fishing boats/ships.	
		1 **International marine**	Sea-going ships engaged in international transport. Emissions from these are not included in national totals but fuel use should be reported as a memo item under ”International Marine Bunkers”.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
		2 **Domestic navigation**	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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
3	E	**Pipeline transport**	Emissions from fuels used to transport materials by pipeline.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
4	B	**Residential**	Emissions from domestic fuel combustion within households.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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, NMVOC, NH_3, PM_{10}, $PM_{2.5}$

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: and emissions of NMVOC and PM from the production of coke. Excluded are evaporative emissions from vehicles, which are dealt with under the Transport sector.	
5A	**Solid fuels**	Fugitive emissions from the manufacture of coke. Includes emissions from coal handling, the cooking process and COG (coke oven gas) purification.	NMVOC, PM_{10}, $PM_{2.5}$
5B	**Oil and natural gas**	Emissions from flaring are included here as this does not include energy recovery.	
1	**Oil**	Fugitive emissions from:	
		(i) *oil exploration* (oil well drilling),	NMVOC
		(ii) *crude oil production* (emissions from facilities/platforms),	NMVOC
		(iii) *transport* (loading onto marine tankers, rail tank cars & tank trucks, transit in marine tankers and pipeline transport),	NMVOC
		(iv) *oil refining,* and	SO_2, NO_x, 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
3	**Flaring**	Emissions from gas flaring during oil and natural gas extraction.	NO_x, CO NMVOC

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}, $PM_{2.5}$
	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 emissions from farm animals	NH_3
	8B	**Fertilizer application**	Emissions of NH_3 and NO_x from application of N-containing fertilizers (fertilizer volatilization, foliar emissions and decomposing vegetation)	NH_3, NO_x
	8C	**Field burning of agricultural residues**	Field combustion of residues from Rice, Wheat, Millet, Soya and other crops.	SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$
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.	NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$
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, NH_3, PM_{10}, $PM_{2.5}$
	10B	**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 crop residue 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^o x 1^o 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*[8], the *EMEP/CORINAIR Guidebook*[9] and the *IPCC Guidelines*[10].

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). 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[11] 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)[12] and Kato and Akimoto, (1992)[13]. The default NCVs, and the reference sources from which they were derived, are included in Table 3-1.

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[8] 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)

[9] EMEP/CORINAIR *Atmospheric Emission Inventory Guidebook - 2005*, European Environment Agency, Copenhagen, Denmark. (Available via Internet: http://reports.eea.eu.int/EMEPCORINAIR4/en.)

[10] 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).

[11] *Energy balances of non-OECD countries*, IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics

[12] 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.

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

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

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	8.95	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[14] or the *IPCC Guidelines.*

[b] Average values given in the *CORINAIR methodology (EEATF, 1992* [15]*).*

[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)[16]

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

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

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.

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

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[16] 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

utilities may be in public or private ownership. Emissions from own on-site use of fuel are included. Emissions from autoproducers[17] 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 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 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

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[17] 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.

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[18]

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 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. 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[19].

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[18] 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

[19] *Energy balances of non-OECD countries*, IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics.

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 (excluding fuel combustion in coke ovens), non-ferrous metal smelting, non-metallic minerals (including cement and brick manufacture), the manufacture of chemicals and petrochemicals, the pulp and paper industry, mining and quarrying, the processing of foods, beverages and tobacco, and the textiles and leather industries. If another manufacturing industry is a significant fuel consuming activity for a particular country, it can be included under the "Other specified" category in the Workbook accompanying this Manual. The combined totals for all remaining unspecified industries should be included under the "Non-specified" category in the Workbook. A separate category is used for fuel consumed for non-specified 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[20] for NO_X, from the *IPCC guidelines* for CO and NMVOC, from *AP-42* for PM and from Battye et al.[21] for NH_3. 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 sector and national energy balance data at the required level of detail, as well as net calorific values, are reported by the IEA[22].

3.4 Sector 3: Transport

3.4.1 Introduction

Transport sector emissions include emissions from the combustion of fuel during mobile 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

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

[21] 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

[22] *Energy balances of non-OECD countries,* IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics.

Transportation", pipeline transportation and ground activities in airports and harbours. Specifically excluded are off-road mobile activities in "Manufacturing Industry and Construction" and in "Agriculture/Forestry/Fishing". 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, NMVOC, NH_3, PM_{10} and $PM_{2.5}$. 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, and for emissions of NMVOC and NH_3. 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 *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[23].

3.4.2.2 Detailed method (preferred)

Road-transport emission factors for NO_X, CO and PM vary greatly depending on the vehicle type, age, operating characteristics, emission controls, and maintenance procedures as well on fuel type. As the "Simple method" does not adequately deal with all of these variables, a "Detailed method" is recommended for inventorying these pollutants where the relevant data are available. The default emission factors are mainly derived from the Indian Central Pollution Control Board (CPCB)[24] although factors for re-suspended dust from paved and unpaved roads are from the Japan Environment Agency (1997)[25] and Economopoulos (1993)[26] respectively. It

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[23] *Energy balances of non-OECD countries*, IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics.

[24] CPCB (2000) *Transport Fuel Quality for Year 2005*. Central Pollution Control Board, Delhi, India.

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

was decided to use the Indian emission factors as the default values because Indian manufactured vehicles are common in many south Asian countries. The vehicle categories covered are: 2-wheelers, 3-wheelers, passenger cars, light commercial vehicles, trucks, buses and tractors and these are further subdivided by fuel type and (where possible) year of manufacture. As the vehicle emission factors are based on emission 'norms' for new vehicles, the calculated emissions have to be corrected for vehicle age using so-called 'deterioration factors' (which are also derived from the Indian CPCB). The workbook calculates this automatically depending on the inventory year entered by the user on the Workbook's main menu worksheet. If non-Indian (e.g. Japanese) vehicles predominate in the transport fleet, emission factors based on appropriate emission 'norms' for these vehicles should be inserted into the worksheet instead of the Indian default values (and details of the new factors noted in the table provided at the bottom of the worksheet).

The relevant activity data are the number of vehicles in use by type and year of manufacture 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[27].

If sufficiently detailed activity data are available, existing road transport emissions estimation models such as COPERT III[28] [29] (used in Europe) or MOBILE6[30] (used in North America) should be used as an alternative to the detailed method offered in this Manual/ Workbook. These 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 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[31] 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 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

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[26] Economopoulos, A. P. (1993) *Assessment of Sources of Air, Water, and Land Pollution. Part one: Rapid inventory techniques in environmental pollution*. Environmental Technology Series. WHO/PEP/GETNET/93.1-A. World Health Organisation, Geneva.

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

[28] COPERT III Computer programme to calculate emission from road transport (http://lat.eng.auth.gr/copert/).

[29] A version IV of COPERT is under development.

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

[31] 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).

B737-400) which ever 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.

National inventories normally exclude emissions from international shipping and aviation (from use of bunkers). 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, 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. 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[32] although data for 'primary solid biomass'[33] are not further sub-divided by type in this database. Thus, IEA data for 'Primary solid biomass' should be entered into the Malé 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[34] (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.

The (uncontrolled) default emission factors given in the Workbook were mostly derived from Kato and Akimoto[35] for NO_X, from the *IPCC Guidelines* for CO and NMVOC, from *AP-42* for PM and from Battye et al.[36] for NH_3. For SO_2, emission factors are calculated from the average sulphur content 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[37] and China[38] and Bertshi *et. al.* (2003)[39] have calculated emission factors for domestic open wood cooking fires and charcoal cooking fires in

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[32] *Energy balances of non-OECD countries*, IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics.

[33] Included in the IEA category 'Primary solid biomass' 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) and other solid biomass.

[34] FAOSTAT Forestry data, http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=forestry

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

[36] 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

[37] 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

[38] 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.

[39] 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-Atmospheres, 108(D13), Art. No. 8469.

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. 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.

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.)

	Emission factors as g/kg fuel dry wt *(and kg/TJ)*				
Study/Fuel type	**SO_2**	**NO_x**	**CO**	**NH_3**	**TSP**
China (Zhang et. al., 2000)					
Wood[40] (ultimate emission)	0.008 *(0.51)*	1.2 ***(73)***	69.2 *(4260)*	-	3.82 (235)
Crop residues[41]	0.216 *(14.3)*	0.70 ***(47)***	86.3 *(5730)*	-	8.05 *(535)*
Coal	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[42]	0.33 *(6.87)*	1.76 *(37)*	3.72 *(77.5)*	-	0.26 *(5.4)*
India (Smith et. al. 2000)					
Wood[43]	-	-	83.5 ***(5490)***	-	**2.36** *(156)*
Crop residues[44]	-	-	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[45]	-	-	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**	-

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

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 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 NMVOC emissions in many countries. This sub-sector includes fugitive emissions of 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 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[46]), as well as from flaring during oil and gas extraction. 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. Table 3.5 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. References to the source documents used to compile the default emission factors in Table 3.5 are provided in the inventory Workbook. 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.[47] Other activity data will usually be obtained from the facilities themselves or from national statistical offices in each country.

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[46] 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.

[47] *Energy statistics of non-OECD countries*, IEA, http://www.iea.org/bookshop/b.aspx?subject=statistics

Table 3-5:
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	PM_{10}
Oil exploration, crude oil production and transport						
Oil well drilling	No. of wells drilled/year	NA	NA	NA	0.7	NA
Fugitive emissions from facilities/platforms	Crude oil production (kt/yr)	NA	NA	NA	600	NA
Loading onto tankers:						
Marine vessels	Crude loaded (kt/yr)	NA	NA	NA	71	NA
Rail tank cars & tank trucks	Crude loaded (kt/yr)	NA	NA	NA	564	NA
Pipeline transport	Mass oil transported (kt/yr)	NA	NA	NA	72	NA
Transit in marine tankers	Mass transported (kt-weeks/yr)	NA	NA	NA	146	NA
Gasoline Distrib./Handling						
Refinery dispatch station	(kt gasoline handled/year)	NA	NA	NA	310	NA
Transport and depots	(kt gasoline handled/year)	NA	NA	NA	740	NA
Service station	(kt gasoline handled/year)	NA	NA	NA	2880	NA
Production and distribution of natural gas						
Production	kg/TJ gas/year	NA	NA	NA	9	NA
Distribution	kg/TJ gas/year	NA	NA	NA	109	NA
Oil refining	Throughput of crude oil tonnes/year	0.8	0.05	0.08	0.53	NA
Production of coke						
Coal crushing	tonnes coke/year	NA	NA	NA	NA	0.055
Coal preheating	tonnes coke/year	NA	NA	NA	NA	1.7
Oven charging	tonnes coke/year	NA	NA	NA	NA	0.24
Oven door leaks	tonnes coke/year	NA	NA	NA	NA	0.27
Oven pushing	tonnes coke/year	NA	NA	NA	NA	0.25
Quenching	tonnes coke/year	NA	NA	NA	NA	0.6
Flaring during oil and gas extraction	Volume of gas flared (thousands of standard cubic metres (1000s Sm^3)/year)	NA	0.12	1.0	0.1	NA

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.

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. In Table 4-1, "NA" denotes "Not Applicable". If activity data are not available from national statistical offices, internationally compiled data can be obtained from the USGS Minerals Yearbooks[48], the Steel Statistical Yearbook[49] (for pig iron production), the United Nations Industrial Commodity Statistics Yearbooks[50] and, for pulp/paper industries, the FAOSTAT database[51]. 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.

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[48] United States Geological Survey (USGS) Minerals Yearbook 2005 (Volume III: Area reports: international) http://minerals.usgs.gov/minerals/pubs/country/asia.html

[49] International Iron and Steel Institute (IISI), Steel Statistical Yearbook 2005 http://www.worldsteel.org/pictures/publicationfiles/SSY%202005.pdf

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

[51] FAOSTAT http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=forestry

Table 4-1:
Default emission factors for industrial process emissions
(Mineral products)

	Emission factors (kg per tonne product output)						
Sub-sector/Process	**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]	-
Kiln (uncontrolled)	NA	NA	NA	NA	NA	0.68 [b g]	0.44 [b g]

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

[b] From US EPA (1995) - these 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 Sheets 1.6.1 (PM_{10}) and 1.6.4 ($PM_{2.5}$)

[c] EMEP/Corinair Guidebook (1996) 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 (1996). 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).)

[g] The PM EFs offered for brick kilns are for coal-fired kilns; US EPA (1995). Use local factors if possible.

NA	Not applicable
-	Not available

Table 4-1 (continued):
Default emission factors for industrial process emissions
(Chemical industry)

	Emission factors (kg per tonne output)						
Sub-sector/Process	**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]	-
Sulphuric acid	0 – 48 [i]	NA	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

Table 4-1 (continued):
Default emission factors for industrial process emissions
(Metal production and Pulp and Paper Industries)

	Emission factors (kg per tonne output)						
Sub-sector/Process	**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 sulphite pulping	30 [m]	NA	NA	NA	NA	1.5 [o]	1.3 [o]
Neutral sulphite 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 pulping 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):
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 (cooked only)	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 (uncertainty high) included in the Workbook that accompanies this Manual. References for the source documents of the default emission factors are provided in the Workbook. 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, 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' 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).

5.4 Speciation of NMVOC emissions

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.

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) emissions), application of fertilizers (a source of both NO_x and NH_3), and burning of agricultural residues both of which emits a range of air pollutants (NO_x, SO_x, NH_3, CO, NMVOC and particulate matter).

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[52]. ***Note of warning**: data presented in the FAOSTAT database as 'Mt' are actually in 'metric tonnes' and not megatonnes (1,000,000 tonnes) as one would normally assume was meant by 'Mt'!*

6.2 Procedures suggested for use in this Manual

6.2.1 Sources of emissions covered

- **Manure management**: This source covers emissions of ammonia from the storage and disposal of livestock manures from 10 categories of livestock. Ammonia emissions are a function of the number of livestock, and the way in which manures are handled.
- **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 burning of agricultural residues**: Disposal of agricultural residues by on-field burning can result in releases of CO, NO_x, 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.

6.2.2 Procedure for estimating emissions of ammonia from livestock manure management

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[52] FAOSTAT http://faostat.fao.org/site/566/default.aspx

Emissions of ammonia from livestock manure management are a function of the average number of each type of livestock in the inventory year (given by FAOSTAT[53]) and a set of emission factors for the different ways in which manures are handled for that type of animal.

Table 6-1 presents the types of livestock included in the suggested method and the default emission factors given by Bouwman *et al*. (1997)[54] for developing countries (including Asia), and by EMEP/CORINAIR for fur animals, which are included in the Workbook accompanying this Manual. 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.

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

		Default annually-averaged emission factors (kg NH_3 per animal-yr)	
Livestock type	**Assumed annual nitrogen excretion rate per animal (kg N/yr)[a]**	**Housing management (in barns/stalls/ stables etc.)**	**Grazing**
Dairy cattle	60	17.5	3.6
Other cattle	40	4.4	5.5
Buffalo	45	5.1	5.5
Pigs	14	4.8	NA
Sheep	10	0.34	0.87
Goats	9	0.34	0.78
Horses, mules and asses	45	5.1	5.5
Poultry (chickens, ducks, geese etc.)	0.5	0.22	NA
Fur animals	4.1	1.69	NA
Camels	55	6.1	6.7

[a] If these values are considered too high, the emission factors should be revised downwards pro rata.

6.2.3 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[55]) - and a set of emission factors describing the average percent volatilization of nitrogen as NH_3 per unit nitrogen in the fertilizer. A ‘calcareous

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[53] FAOSTAT http://faostat.fao.org/site/568/default.aspx

[54] 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.

[55] FAOSTAT site still under development, fertilizer use available ‘soon’.

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 6-2 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 evaportion 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 'Region C' - mean spring air temperature < 6 ºC. Emissions may differ in regions with higher temperatures and different agriculture practices.

Table 6-2:
Fertilizer types and default emission factors for estimation of ammonia emissions from fertilizer use

	Default emission factors (% NH_3-N volatilized per unit fertilizer-N applied)		
Fertilizer type	**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.

6.2.4 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).

6.2.5 Procedure for estimating emissions from burning of agricultural wastes

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 6-3. Activity data (annual production by crop type) are given by FAOSTAT[56].

6.3 Sources of emission factors in literature and their limitations

Reference sources for the default emission factors and other parameters used in the workbook are given in Table 6-3. Location specific emission factors for many of these agricultural processes are not widely available. In some non-OECD countries however, it may be possible to derive suitable factors from agricultural research stations and/or rural colleges and universities.

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[56] FAOSTAT http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567

Table 6-3:
Default parameters for estimating emissions from crop residue burning

Parameter	Crop type										
	Rice	**Wheat**	**Millet**	**Soya**	**Maize**	**Potatoes**	**Jute**	**Cotton**	**Groundnut**	**Sugarcane**	**Rapeseed and 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]	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
SO_2 emission factor (kg/tonnes burned) [m]	4 [g]	5.5 [h]	9	9	9	9	9	9	9	9	9
NH_3 emission factor (kg/tonnes burned)	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]
$PM_{10}/PM_{2.5}$ 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]

[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 field crops (average PM emission factor for crop wastes reported by Reddy and Venkattaraman (2002b))

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

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

[l] EMEP/Corinair (2004)

[m] Reddy and Venkataraman (2002b)

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

[o] Bhattacharya and Mitra (1998)

[p] TIFAC (1991)

[q] Tyagi (1989)

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

7.1 Introduction

This Chapter covers emissions of SO_2, NO_X, CO, NMVOCs, NH_3 and particulate matter 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.

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 of SO_2, NO_X, CO, NMVOC, NH_3, PM_{10} and $PM_{2.5}$ 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)[57] and on locally-estimated or default values[58] for the amount of biomass burnt on-site for each vegetation type.
- Estimations of SO_2, NO_x, CO, NMVOC and PM_{10}, $PM_{2.5}$ 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)[59]. 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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[57] See FAO State of the worlds forests 2003 Annex 2: Table 2. Assume total forest area burnt = Mean annual forest cover change (if negative in sign). (http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/005/y7581e/y7581e00.htm)

[58] IPCC (2006) http://www.ipcc-nggip.iges.or.jp/public/2006gl/ppd/4_Vol_4/V4_Ch2_Generic_sb24.pdf

[59] 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 b]	SO_2 emission factor (kg/tonne biomass burned) [i]	NOx emission factor (kg as NO_2/tonne biomass burned) [i]	CO emission factor (kg CO/tonne biomass burned) [i]	NMVOC emission factor (kg/tonne biomass burned) [i]	PM_{10} emission factor (kg/tonne biomass burned) [g]	$PM_{2.5}$ emission factor (kg/tonne biomass burned) [i]	NH_3 emission factor (kg/tonne biomass burned) [i]
Tropical/subtropical forest (primary)	120	0.57	2.45	104	8.1	10.5	9.1	1.3
Tropical/subtropical forest (secondary)	42	0.57	2.45	104	8.1	10.5	9.1	1.3
Tropical/subtropical grassland (exluding savanna burning)	5.2	0.35	6	65	3.4	8.3	5.4	0.26[j]
Tropical pasture	24	0.35	6	65	3.4	8.3	5.4	0.26[j]
Eucalypt forests	69	1	4.6	107	5.7	17.6	13	1.4
Other temperate forest	50	1	4.6	107	5.7	17.6	13	1.4
Shrubland (general)	27[c]	0.35[h]	6[h]	65[h]	3.4[h]	8.3[h]	5.4[h]	0.26[j]
Temperate grasslands	4.1	0.35	6	65	3.4	8.3	5.4	0.26[j]
Boreal forest	41	1	4.6	107	5.7	17.6	13	1.4
Peatland	41	1	4.6	107	5.7	17.6	13	1.4
Boreal grasslands/Tundra	10	0.35	6	65	3.4	8.3	5.4	0.26[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 2003.

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, burial 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, NMVOC, NH_3 and particulate matter. Disposal of wastes in landfills and waste water handling both generate methane emissions but are not significant sources of the pollutants included in this manual. However, 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

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[60]).
- 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.

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[60] 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

	Emission factors[a] (kg per tonne waste incinerated)						
Waste/Incinerator Type	**SO_2**	**NO_X**	**CO**	**NMVOC**	**NH_3 [d]**	**PM_{10}[c]**	**$PM_{2.5}$**
Municipal Wastes:							
--Mass burn refractory wall	1.73	1.23	0.685	0.02 [e]	0	12.6	-
--Modular excess air	1.73	1.24	-	-	0	12.6	-
--Modular starved air	1.61	1.58	0.15	-	0	1.72	-
--Refuse-derived fuel-fired	1.95	2.51	0.96	-	0	34.8	-
--Trench	1.25	-	-	-	0	18.5	-
--Open burning	0.5	3	42	15	0	8	-
Industrial/commercial:							
--Multiple chamber	1.25	1.5	5	1.5 [b]	0	3.5	-
--Single chamber	1.25	1	10	75 [b]	0	7.5	-

[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

- No factor available

- Estimation of emissions of SO_2, NO_X, CO, NMVOCs, PM_{10}, $PM_{2.5}$ 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.

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. 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

No explicit provision has been made for the application of parameters for control equipment, but the penetration of emissions control equipment for waste incinerators can be reflected by reducing emission factors by a suitable amount. Control equipment is also often installed to reduce emissions of HM and POPs, which also can influence PM emissions. 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.

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. These factors should be treated as very uncertain as they are unlikely to reflect the true situation in 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.* [61].

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

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[61] 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.

- Paper pulp plants with production capacity > 100 kt/yr
- 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^o x 1^o 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

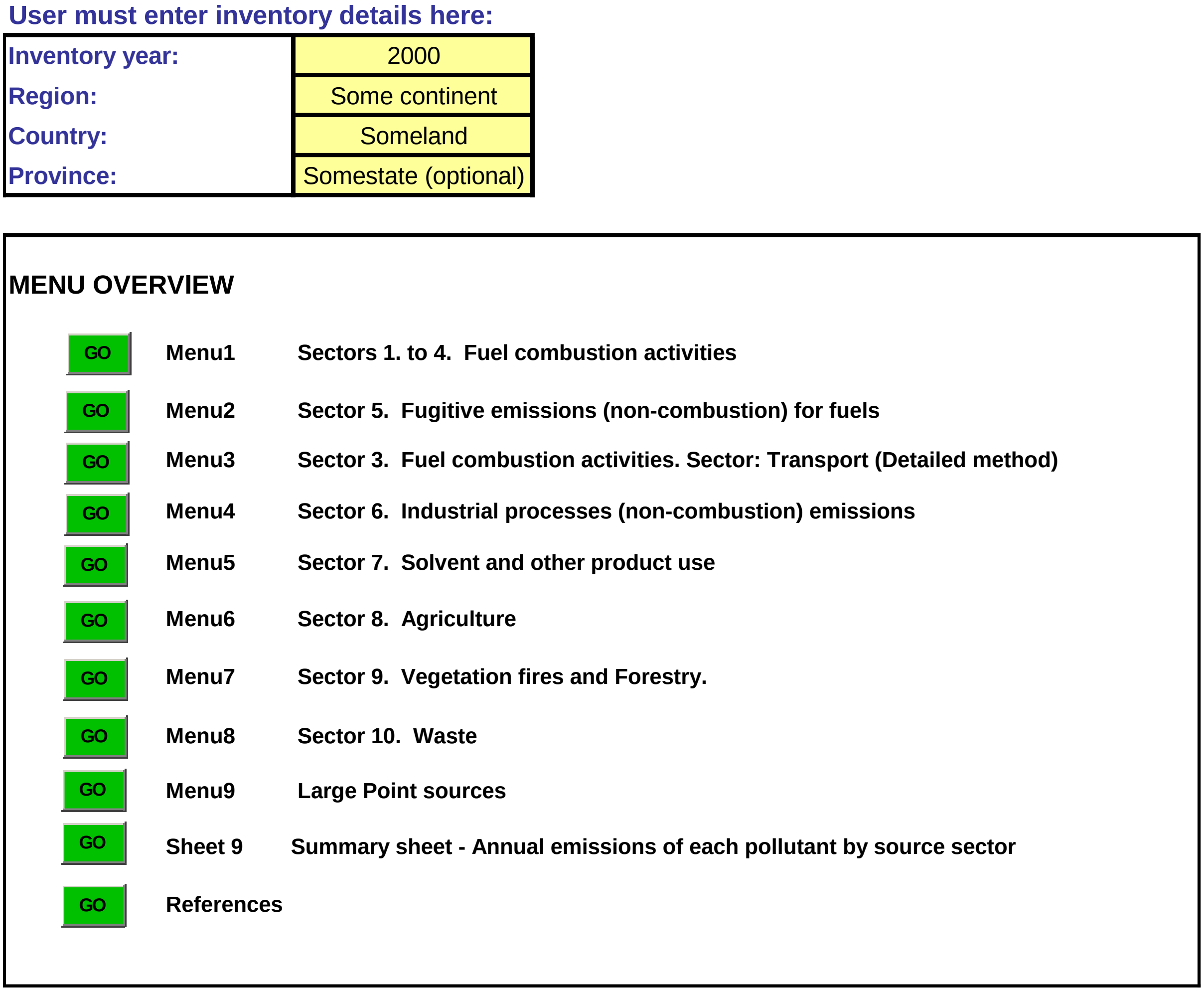
In order to provide a standardized structure for use in compiling inventories of air pollutants, an Excel workbook template is provided. This workbook, entitled **Male Inv workbook.xls**, is intended to provide a structure for input activity data and emission factors, areas for calculation of intermediate 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, **Male Inv workbook.xls** 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

1.1 General fuel combustion worksheets

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

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

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.

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

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

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

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.

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

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

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

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

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

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

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

Sheet: 1.5.1 NMVOC emission factors (kg/TJ)

Sheet: 1.5.2 NMVOC combustion emissions by fuel (tonnes)

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

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

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

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

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

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

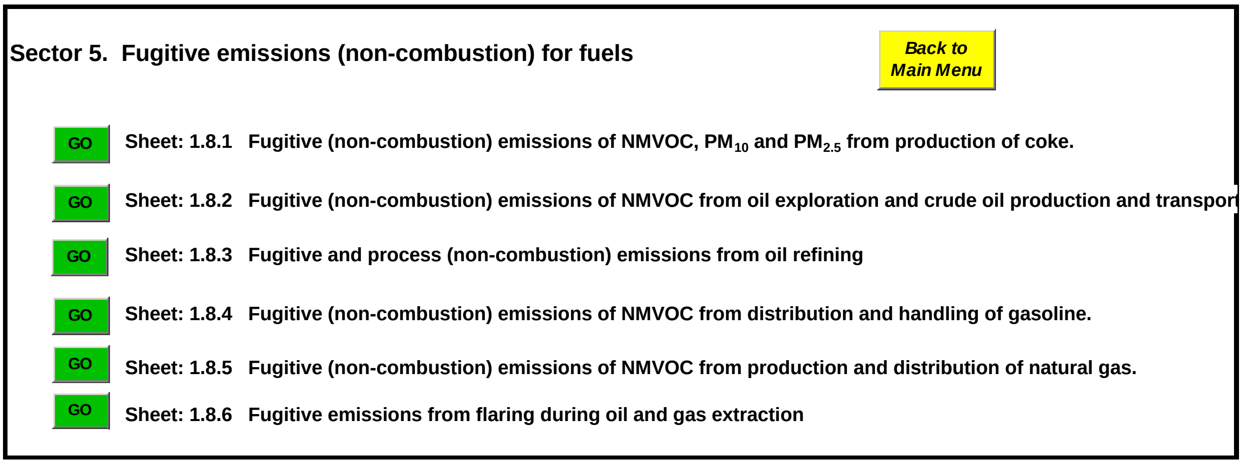
Sheet: 1.6.6 Particulate matter ($PM_{2.5}$) combustion emissions (tonnes)

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

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

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

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



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

Sheet: 1.8.1 Fugitive (non-combustion) emissions of NMVOC, PM_{10} and $PM_{2.5}$ from production of coke.

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

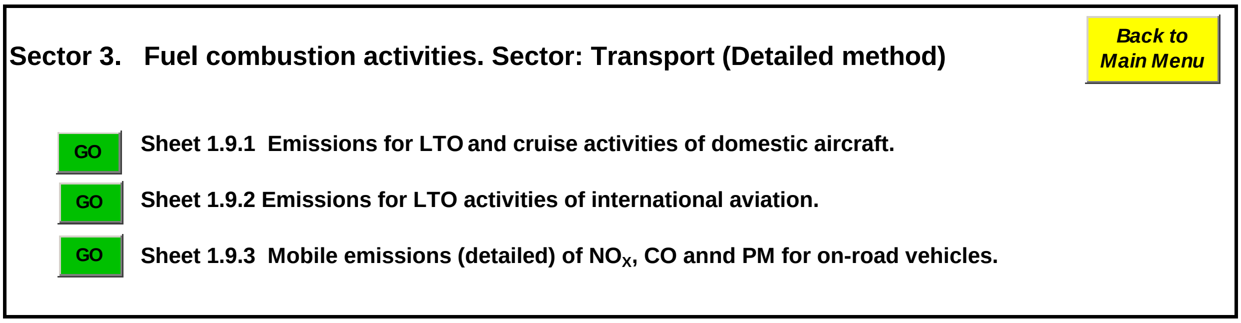
Sheet: 1.8.3 Fugitive and process (non-combustion) emissions from oil refining

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

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

Sheet: 1.8.6 Fugitive emissions from flaring during oil and gas extraction

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



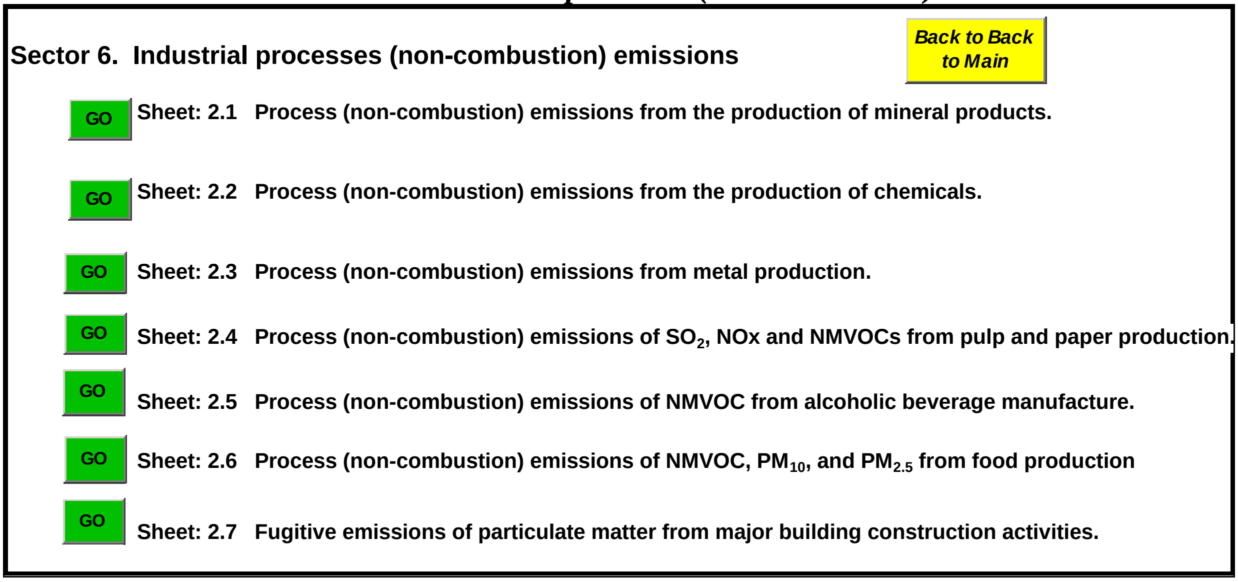
Sector 3. Fuel combustion activities. Sector: Transport (Detailed method)

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

Sheet 1.9.2 Emissions for LTO activities of international aviation.

Sheet 1.9.3 Mobile emissions (detailed) of NO_X, CO annd PM for on-road vehicles.

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



Sector 6. Industrial processes (non-combustion) emissions

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

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

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

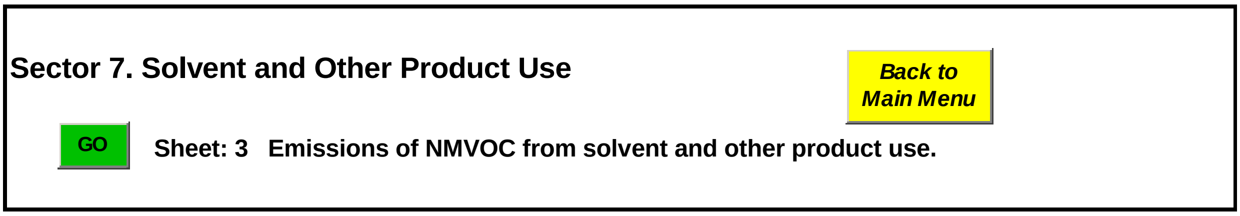
Sheet: 2.4 Process (non-combustion) emissions of SO_2, NOx and NMVOCs from pulp and paper production.

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

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

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

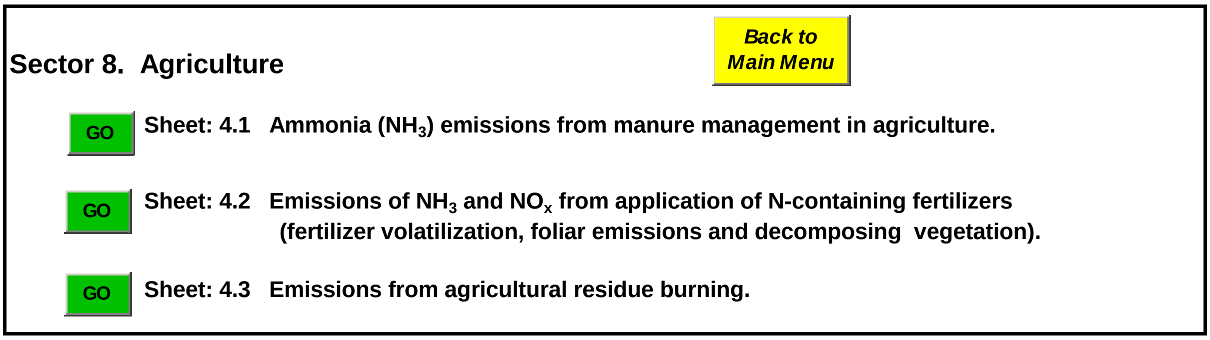
Box 10-6: Menu 5 – Solvent and Other Product Use



Sector 7. Solvent and Other Product Use

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

Box 10-7: Menu 6 - Agriculture



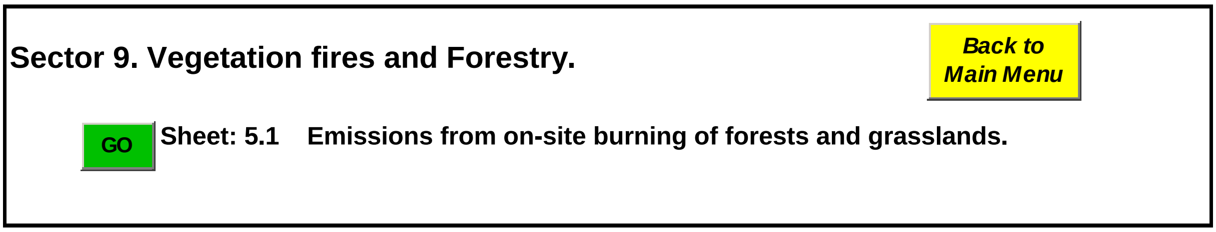
Sector 8. Agriculture

Sheet: 4.1   Ammonia (NH_3) emissions from manure management in agriculture.

Sheet: 4.2   Emissions of NH_3 and NO_x from application of N-containing fertilizers (fertilizer volatilization, foliar emissions and decomposing vegetation).

Sheet: 4.3   Emissions from agricultural residue burning.

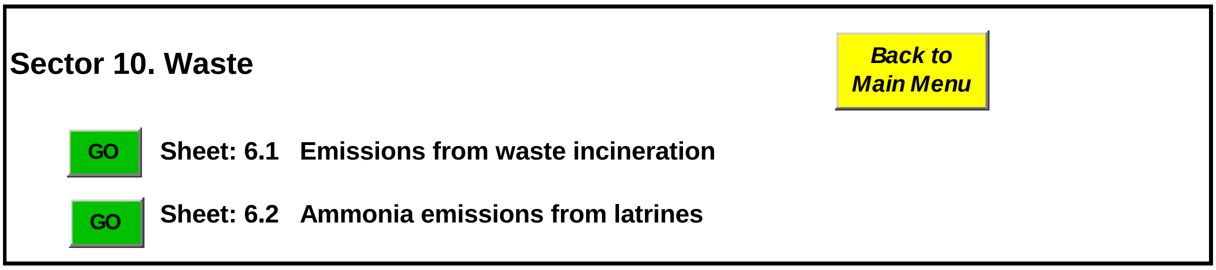
Box 10-8: Menu 7 – Vegetation fires and forestry



Sector 9. Vegetation fires and Forestry.

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

Box 10-9: Menu 8 – Waste

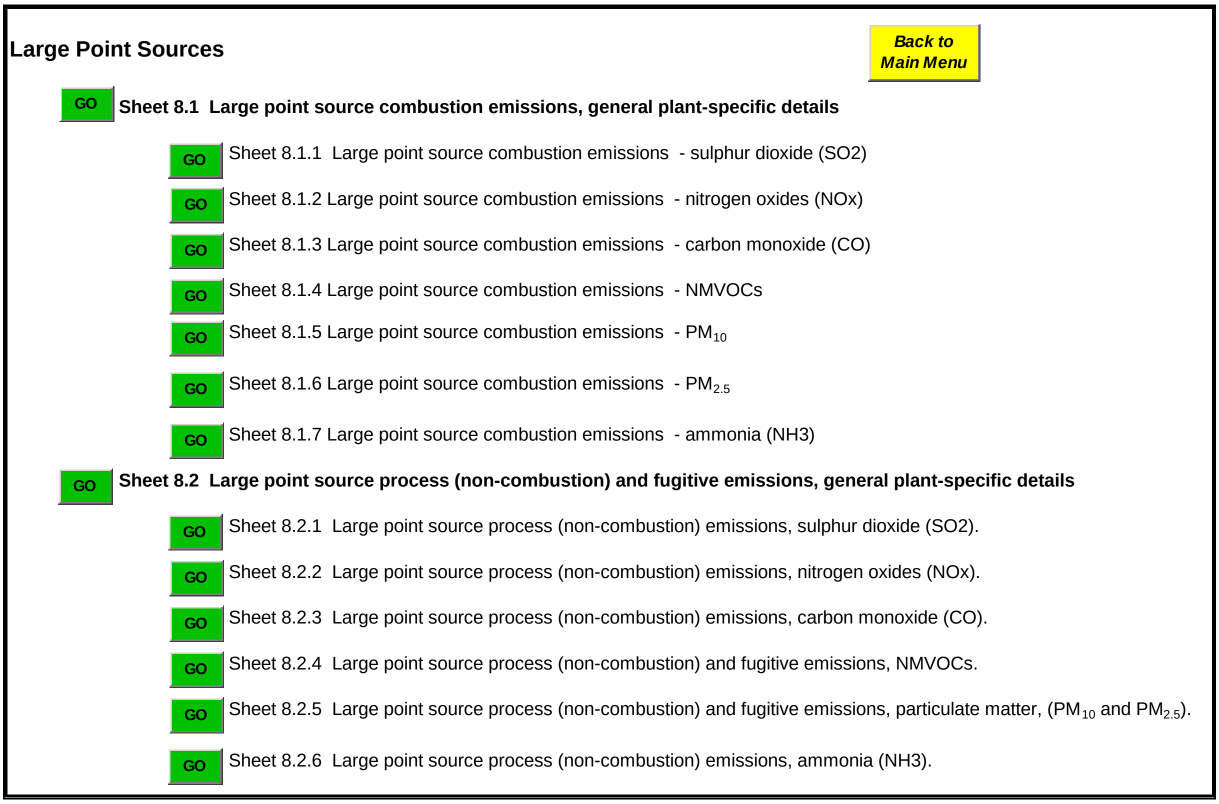


Sector 10. Waste

Sheet: 6.1   Emissions from waste incineration

Sheet: 6.2   Ammonia emissions from latrines

Box 10-11: Menu 9 – Large Point Sources



Large Point Sources

Sheet 8.1 Large point source combustion emissions, general plant-specific details

- Sheet 8.1.1 Large point source combustion emissions - sulphur dioxide (SO2)
- Sheet 8.1.2 Large point source combustion emissions - nitrogen oxides (NOx)
- Sheet 8.1.3 Large point source combustion emissions - carbon monoxide (CO)
- Sheet 8.1.4 Large point source combustion emissions - NMVOCs
- Sheet 8.1.5 Large point source combustion emissions - PM_{10}
- Sheet 8.1.6 Large point source combustion emissions - $PM_{2.5}$
- Sheet 8.1.7 Large point source combustion emissions - ammonia (NH3)

Sheet 8.2 Large point source process (non-combustion) and fugitive emissions, general plant-specific details

- Sheet 8.2.1 Large point source process (non-combustion) emissions, sulphur dioxide (SO2).
- Sheet 8.2.2 Large point source process (non-combustion) emissions, nitrogen oxides (NOx).
- Sheet 8.2.3 Large point source process (non-combustion) emissions, carbon monoxide (CO).
- Sheet 8.2.4 Large point source process (non-combustion) and fugitive emissions, NMVOCs.
- Sheet 8.2.5 Large point source process (non-combustion) and fugitive emissions, particulate matter, (PM_{10} and $PM_{2.5}$).
- Sheet 8.2.6 Large point source process (non-combustion) emissions, ammonia (NH3).

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.

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. 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)

		Total emissions (kilotonnes pollutant per year (kt/yr))						
Sector	**Sub-sector**	**SO_2**	**NO_x**	**CO**	**NMVOC**	**NH_3**	**PM_{10}**	**$PM_{2.5}$**
1. Combustion in the Energy Industries	Public Electricity and Heat	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
	Manufacture of Solid Fuels and Other Energy	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
	Non-ferrous metals	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
	Chemicals	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
	Mining and Quarrying	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
	Other (Please specify in sheet 1.1.1a, 1.1.1b or 1.1.1c)	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
	Remainder (Non-specified)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3. Transport	Civil Aviation (Simple--not used if Detailed used)	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
	Road transport (Simple--not used if Detailed used)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Road transport (Detailed)		0.00	0.00			0.00	0.00
	Railways	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
	Pipeline transport	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
4. Combustion in Other Sectors	Commercial/Institutional	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
	Agriculture/Forestry/Fishing	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
5. Fugitive emissions from fuels	Production of coke				0.00		0.00	0.00
	Oil exploration and crude oil production and transport				0.00			
	Oil refining	0.00	0.00	0.00	0.00			
	Distribution and handling of gasoline				0.00			
	Production and distribution of natural gas.				0.00			
	Flaring during oil and gas extraction		0.00	0.00	0.00			
6. Industrial processes	Mineral products	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
	Metals	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		0.00	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		
	Application of N-containing fertilizers		0.00			0.00		
	Burning of agricultural crop residues	0.00	0.00	0.00	0.00	0.00	0.00	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
10. Waste	Waste incineration	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Latrines					0.00		
Total anthropogenic		0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Wong, C.T. (1999) Vehicle emission project (Phase II) Final Report, Engineering Research Institute, University of Cape Town, February 1999.

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 Malé 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)[62]. 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

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[62] 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

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 System[63] (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[64]. An emission factor of 0.05 kg NH_3 per person-yr has been suggested as a default[65] although much larger value of 0.25 kg NH_3 per person-yr also appears in the literature[66].

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[67] 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

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[63] 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.

[64] FAOSTAT population database (http://faostat.fao.org/faostat/form?collection=Population.LTS&Domain=Population&servlet=1&hasbulk=0&version=ext&language=EN)

[65] 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

[66] 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.

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

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 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[68]) 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[69] and others. Gillette estimated the uplift of dust to be:

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

Where:

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[68] 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.

[69] 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.

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

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

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[70,71] and in Asia by Chang et al[72]. 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[73] estimated the percent calcium (associated with carbonate) to be 5 to 10 percent.

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[70] 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.

[71] 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.

[72] Chang, Y.–S., Arndt, R.L. and Carmichael, G.R. (1996) "Mineral base-cation deposition in Asia". *Atmospheric Environment,* **30**:2417 – 2427.

[73] 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[74]) 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

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

emissions from large point sources every fifth year. Data are made available in the EMEP 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/CORINAIR Atmospheric Emission Inventory Guidebook (3rd Edition, 2004) hosted by the European Environment Agency[75]. The Emission Inventory 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. 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

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[75] EMEP/CORINAIR Atmospheric Emission Inventory Guidebook - 2005, Technical report No 30, European Environment Agency, Copenhagen, Denmark (http://reports.eea.eu.int/EMEPCORINAIR4/en).

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 CORINAIR/EMEP 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[76] “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, 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).

A2.6 Global research inventories

A2.6.1 The GEIA (Global Emissions Inventory Activity)

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[76] 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

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://www.mnp.nl/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)[77]. 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”.

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

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”.

A3.4 Sources of speciation factors in the literature

Speciation profiles (percentage composition) for NMVOC emissions are available in the *EMEP/CORINAIR 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[78].

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

Annex 4: The status of air pollutant emissions in the participating countries of the Malé Declaration

A4.1 Air pollutant emissions in Bangladesh

A4.1.1 Introduction

Air pollution in Bangladesh is caused mostly by industrial and vehicular emissions. The larger cities such as Dhaka are badly affected by deteriorating ambient air quality. The Government has initiated various measures to control air pollution in order to protect public health and environment. Improved infrastructure, better traffic management system, proper monitoring and control of the industrial emission, and better implementation of existing rules and regulations would certainly help in improving the ambient air quality in the major cities of Bangladesh.

A4.1.2 Policy response

Government has addressed the problem of air pollution through promulgating various rules and acts, setting standards for ambient air quality and industrial emissions, and taking many other actions. Some of the initiatives taken by government included:

- Bangladesh Environmental Conservation Act, 1995 (ECA 1995): This Act includes regulation of vehicles emitting smoke harmful for the environment; regulation of industries and other development activities (e.g. discharge permits); and promulgation of standards for air quality.
- The Brick Burning (Control) Act, 1989: This Act restricts brick burning with fuel wood.
- Environment Court Law-1999: All the cases of Environment Conservation, Environmental Development, Control and Reduction of Environment Pollution will be settled in this Court. Environment Court can enforce all the Clauses and Sub Clauses of Environment Conservation Act, 1995.
- Other initiatives include: introduction of lead free gasoline; banning and phasing out 2-stroke engine (e.g. in Dhaka all 2-stroke 3-wheelers were replaced by CNG-powered 3-wheelers in 2002); air pollution monitoring and public involvement.

A4.1.3 National standards

National Ambient Air Quality Standards are prescribed under the Environmental Conservation Rules, 1997, for four categories of areas namely industrial, commercial, residential and sensitive. Parameters included in the standards are SPM, SO_2, CO and NO_X. Industry-specific emission standards are prescribed for industrial boilers and fertilizer, cement, nitric acid and sugar industries. Gaseous discharge quality standards are also prescribed for industrial units. Motor vehicle exhaust quality standards are also formulated for parameters such as black smoke, carbon monoxide, hydrocarbon and nitrogen oxides.

A4.1.4 Emission load

No proper emission inventory of SO_X, NO_X and PM emissions has been compiled for Bangladesh other than a few comparative studies on mobile source and area source emissions. These studies have found that the sulphur deposited in Bangladesh may originate from coal burning in the brick kilns and from burning petroleum products.

A4.2 Air pollutant emissions in Bhutan

A4.2.1 Introduction

Air pollution is an emerging issue in Bhutan. Although present levels of air pollution are not of much concern, growing urbanization and industrialization might lead to problems in the future unless specific policies and action plans are put in place. Sources of air pollution can be attributed to forest fires, fuel wood burning in the households, industrial operations and vehicular emission. In the urban area, air pollution is due to wood burning in heating appliances and vehicular emission. Existing impacts of air pollution are not known because of lack of data. However, government has recognized air pollution as one of the priority environmental issues. Government is also taking various measures to abate air pollution.

A4.2.2 Policy response

In Bhutan, over recent years, the combination of growing industrialization and urbanization together with a growth in the number of vehicles has led to increasing air pollution in the urban areas. This has resulted in many measures being taken to curb pollution from transport, industrial and domestic sources. The Government has addressed the problems of air pollution as an interim measure through specific acts, rules and regulations such as the Road and Safety Act 2000, the EA Act 2000 and other rules and regulations. This has led to a ban on the importation of two-stroke engines, improving infrastructure, environmentally sound industrial development through EIA practices and the promotion of electrical appliance to replace bukharis (domestic coal stoves).

A4.2.3 National standards

In 2002, Bhutan established a vehicular emission standard. At present there are no standards prescribed for ambient air quality and industrial discharge although the Government is in the process of developing these.

A4.2.4 Emission load

Bhutan is a signatory of the UNFCCC. As part of the communication to the UNFCCC, the National Environmental Commission Secretariat (NECS) has prepared a greenhouse gas inventory based on the guidelines developed by the IPCC. Other than this, there is no coordinated activity on air pollutant emission inventories. However, emissions of SO_2 and NO_x have been estimated in Bhutan based on emission factors applied to source-specific fuel consumption statistics given by the Central Statistics Office (CSO) Yearbook for 1998.

A4.3 Air pollutant emissions in India

A4.3.1 Introduction

In India, the problems of air pollution can be attributed to natural as well as anthropogenic sources. The meteorological conditions (temperature, wind currents, rainfall etc.) and soil borne dust are, to a great extent, responsible for pollution caused by natural sources. Among the anthropogenic factors, rapid industrialization, energy production, urbanization, commercialization and an increase in the number of motorized vehicles are the predominant cause of air pollution. Responses to the problem of air pollution have included: promulgating rules and acts; prescribing policy guidelines; developing national standards; creating institutional mechanisms and developing monitoring and reporting system.

A4.3.2 Policy response

To provide legislative support for prevention and control of air pollution, the Govt. of India enacted central legislation included: Air (Prevention and Control of Pollution) Act, 1981; Environment (Protection) Act, 1986; National Policy Statement on Abatement of Pollution (1992); The Environmental Action Programme (1993); The Motor Vehicle Act, 1988; and The Central Motor Vehicle Rules, 1989. The Air Act, 1981 aims at prevention, control and abatement of pollution, and Pollution Control Boards at the state level can be established under this act. The Environment (Protection) Act, 1986 is an umbrella Act which empowers the Central Government to take necessary measures for: a) protecting and improving the environment; and b) prevention, control and abatement of pollution. Under this Act, the government is empowered to set standards for environmental quality and limits for emissions/discharges of pollutants from various specified sources. In addition to the above laws, government has taken many initiatives to control air pollution included: setting up of ambient air quality standards; emission standards for industries; guidelines for siting of industries; environmental impact assessment; zoning atlas for siting of industries; environmental audit; development of pollution prevention technologies; pollution control strategy in problem areas; and epidemiological studies.

A4.3.3 National standards

The National Ambient Air Quality Standards legislation was prescribed by the Central Pollution Control Board (CPCB) to protect public health, vegetation and property. The standards included the following parameters: SPM, RPM (PM_{10}), SO_2, CO, NOx, lead (Pb) and ammonia (NH_3). Emission standards have been prescribed for 35 categories of air polluting industries. The industries covered included: thermal power plants; iron and steel plant; cement plant; coke oven plant; briquette industry; aluminium plant; oil refinery; large pulp and paper plant; copper, lead and zinc smelting; stone crushing unit; cupola; fertilizer; nitric acid; glass industry; and calcium carbide plant. Mass-based emission standards have been developed for eight categories of industries included: fertilizer, copper, lead and zinc smelter, nitric acid, sulphuric acid, coke oven, oil refinery, aluminium plants and glass industry. Emission standards for diesel and petrol driven vehicles are also prescribed for light and heavy categories of vehicles.

A4.3.4 Emission load

Various emission inventories have been compiled for India. Major sources of SO_2 emission are power plants, petroleum refineries, textiles, pulp & paper and industrial chemicals. Major sources of NOx are vehicular emission, power plants, nitric acid production, nitrogen fertilizer plants, and cement production. The major sources of SPM emission are combustion of fuels in domestic, industrial and transport sectors. In India, besides these sources, natural dust is also one of the major sources of SPM.

A4.4 Air pollutant emissions in Iran

A4.4.1 Introduction

All the major cities in Iran are facing problem due to air pollution which is of concern to both public health and environment. The problems of air pollution in Mashad, Esfahan, Shiraz, Tabriz and Arak are particularly severe although there are also problems in Tehran. Like many other cities in Asia, sources of air pollution in Iran can be attributed to urbanization, industrialization, commercialization and vehicular growth. Vehicular emissions are the major reason for rapidly deteriorating air quality in large cities. The main industrial activities contributing to air pollution include cement, brick, metal smelting, chemical industries, refineries, petrochemical and power stations. The health effects of air pollution are mostly in the form of nausea, headache, severe heart- pulmonary diseases, irritation of eyes, allergy, metabolism disorders, breath shortage and asthma. In order to protect the public health and environment from air pollution, the Islamic Republic of Iran has taken many measures in the form of introducing laws, setting ambient air quality standards and emission standards, prescribing siting guidelines for the location of industries and promoting cleaner technologies.

A4.4.2 Policy response

Regulations and legislation are prescribed in Iran to address air pollution issues. An Act specific to the control of air pollution was approved in 1995 and it includes the following provisions:

- For industries: the transferral of industries out of large cities; fuel switching to gas; establishment and enforcement of industrial standards (subject of article 14,15 – Air pollution Law); and improvement and development of ISO 14000 standards; and
- For transport: the establishment and enforcement of standards; to change the fuel of vehicles to gas; vehicle inspection and maintenance programs (IM-programs); improvement of transport system; and establishment of traffic plans for the centre of large cities.

A4.4.3 National standards

National Air Quality Standards have been prescribed in Iran as follows: the regulation of industry settlement and service; Clean Air Standards; the permissible limit of emissions from the exhaust of petrol vehicles; and the standard of emissions from different industrial factories and workshops. Clean Air Standards include CO, SO_2, NO_2 and SPM. Emission standards are also prescribed for vehicular exhausts and for major industries including steel plant, cement plant, glass factory, brick plant, nitric and sulphuric acid plant and paper mills.

A4.4.4 Emission load

Various emission inventories have been compiled for Iran. The major sources of SO_2 emissions are combustion of fuels in power plants, chemical factories, households, and vehicles. Major sources of NOx are the transport sector and power generation. Major sources of SPM are industrial activities, power generation, vehicular emission, mining activities and natural dust.

A4.5 Air pollutant emissions in the Maldives

A4.5.1 Introduction

Air pollution is not a major problem in the Maldives. However, the growth in vehicle numbers and increases in other human activities, might lead to air pollution problems in the future. Unchecked growth of vehicles in the Maldives is the source of smoke, CO, HC, NOx, and particulate matter. Unpaved roads are also a source of fine dust. The government is in the process of taking various measures for air pollution prevention, control and management including the adoption of appropriate market and regulatory measures, provision of better information and raising public awareness.

A4.5.2 Policy response

The Government of Maldives has introduced the second National Environment Action Plan in 1999 to address the environmental planning and management needs for the country. This Action Plan recognizes air pollution problem due to dust, smoke and fumes from motor vehicles. It proposes action to assess environmental and health impacts, and measures to control pollution from exhaust gases and dust. It recommends the promotion of public transport systems and bicycle paths. The Ministry of Home Affairs, Housing and Environment will take the lead in implementing the Action Plan and will work with other Ministries and other regulating agencies of the Government as well as NGOs to meet the objectives of the Action Plan.

A4.5.3 National standards

To date, no standards have been developed for ambient air quality and industrial discharge.

A4.5.4 Emission load

There are no estimates available on emissions of pollutants from different sources.

A4.6 Air pollutant emissions in Nepal

A4.6.1 Introduction

Air pollution problems in Nepal can be attributed to rapid urbanization, commercialization, vehicular growth and energy consumption. Problems are found more in the urban areas such as Kathmandu Valley, Birgunj, and Biratnagar due to increasing number of vehicles and the concentration of polluting industries. The effects of air pollution are manifested in the form of deterioration of public health, especially the increase in respiratory and skin diseases in the Kathmandu Valley. Various analyses show the unacceptable levels of suspended particulate, lead and other pollutants in the major cities of Nepal that pose risks to human heath. The number of clear days per year in Kathmandu has been consistently decreasing in the past two decades. Problems of air pollution have resulted in economic losses in the form of deteriorating human health, loss of tourism and damage to cultural heritage. Effective policies need to be developed in order to address the problems of air pollution.

A4.6.2 Policy response

There is no specific legislative framework in Nepal to address air pollution, but the provisions for the control of air pollution are reflected in various Acts and laws.

A4.6.3 National standards

Nepal is in the process of developing ambient air quality standards. A set of standards for five criteria pollutants has been proposed that needs to be incorporated into Environmental Protection Guidelines. The proposed standards include SPM, CO, NO_2, SO_2 and Pb for Pokhara, Kathmandu, and Biratnagar. However, the government has set the emission standards to control vehicular emission in Kathmandu valley and has specified smoke density for diesel engines and CO emitted by petrol engine vehicles. There are currently no emission standards prescribed for industries operating in Nepal.

A4.6.4 Emission load

For the transport sector in Kathmandu Valley, a 1996 study found carbon monoxide (CO) was the major pollutant (60% of the total vehicular emissions) followed by hydrocarbons (30%) and NOx (6%). A study of pollution from industry in the valley found that the brick kilns contributed about 64% of the total pollutant emissions and that 66% of total TSP emissions were from the industrial sector.

A4.7 Air pollutant emissions in Pakistan

A4.7.1 Introduction

Air pollution in Pakistan can be attributed to increasing urbanization, industrialization, energy production and vehicular growth. Urban areas are more vulnerable to air pollution due to vehicular pollution and growth of industries in the urban cities. Thermal power plants using coal and fuel oil are also considered major sources of air pollution. Brick kilns using high sulphur coal are also acknowledged as a major source of air pollutants in peri-urban and rural areas. Air quality in urban centres is rapidly deteriorating, which would not only affect human health but also results in increasing smog formation during winter season. Incidence of respiratory and ocular diseases is reported to be increasing in the country, particularly in urban areas. The Government of Pakistan has initiated many measures to mitigate air pollution through prescribing laws, setting up of environmental standards, and other measures.

A4.7.2 Policy response

The National Conservation Strategy, introduced in 1992, is the primary national policy document for promoting sustainable development in Pakistan. One of the core themes is preventing and abating pollution including air pollution. Programmes related to air pollution included shifting to environmentally sound processes and products, retrofitting of pollution abatement equipment, upgrading refineries and providing CNG for vehicles. The Pakistan Environmental Protection Act, 1997 is the primary legislative tool for the prevention and abatement of pollution. The key features of the Act relating to air pollution include: empowering the Pakistan Environmental Protection Council (PEPC) to approve national environmental policies within the framework of the national conservation strategy; defining the functions of the PEPC to include setting up and implementing ambient air quality standards, establishing systems and procedures for surveys, surveillance, monitoring, measurement, examination, investigation, research, inspection and audit, to prevent and control air pollution; taking measures to promote research and the development of science and technology that may contribute to the prevention of air pollution, and protection of the environment; EIAs required for proposed development projects; and the Pak-EPA and the provincial EPAs have been empowered to issue an Environmental Protection Order to deal with an actual or potential adverse environmental effect following a violation of the provisions of the Act. Other policy measures to abate air pollution included a project to improve fuel efficiency in the road transport sector; encouraging the use of CNG in the transport sector; and conducting public awareness programme on air pollution.

A4.7.3 National standards

There are no ambient air quality standards prescribed in Pakistan. Emission standards were first introduced in 1993 as the National Environmental Quality Standards (NEQS) and were later revised in 1999. The standards set maximum allowable concentration for gaseous and particulate matter from industrial sources. The pollutants for which limits were set included smoke, particulate matter, hydrogen chloride, chlorine, hydrogen fluoride, hydrogen sulphide, sulphur oxide, carbon monoxide, lead, mercury, cadmium, arsenic, copper, antimony, zinc, nitrogen and oxides. For vehicle exhaust emissions, NEQS prescribed limits on smoke opacity and CO concentration. For thermal power plants, emission standards were prescribed for SO_2 and NOx.

A4.7.4 Emission load

The main sources of SO_2 emissions are combustion of coal in power plants and brick kilns; furnace oil in power plants and industries; diesel oil in power plants and transport; and fuel wood in the residential sector. SO_2 is also emitted during industrial production processes such as sulphuric acid production, paper and pulp manufacture, cement production and petroleum refining. Vehicles are the largest source of NOx emissions although fuel combustion in the power generation and industrial sectors are also important. In Pakistan, industrial process emissions of NOx are mainly due to paper and cement production and petroleum refining. Anthropogenic SPM emission results from fuel combustion in stationary and mobiles sources, industrial processes, construction and mining activities, and domestic sources.

A4.8. Air pollutant emissions in Sri Lanka

A4.8.1 Introduction

In Sri Lanka, present levels of air pollution in towns and cities are not of much concern, except the Colombo Metropolitan Region (CMR). Most air pollutants are emitted from transport, industry, power generation, commercial and household sources. In the CMR, the present level of air quality appears to be good, but rapid urbanization, commercialization, industrialization and increase in number of vehicles could result in deterioration of air quality in the coming years. The CMR contains 80% of the country’s industry and over 60% of all vehicles plying Sri Lankan roads. High sulphur diesel used in vehicles and power plants is of great concern, as is leaded gasoline used in petrol vehicles. Government has taken measures through various initiatives to control air pollution in order to protect human health and the environment.

A4.8.2 Policy response

Government has taken various policy measures to mitigate air pollution problems including:

- The National Environmental Act (NEA) of 1980 as amended in 1988 which prohibits any discharge of pollutants into the environment including emission of pollutants into the atmosphere.
- The Central Environmental Authority (CEA) is the main enforcing institution of the Ministry of Forestry & Environment (M/F&E). Responsibilities include data dissemination, co-coordinating the monitoring programme, policy recommendations, setting standards, licensing, EIA and emergency response.

- The National Environmental (Protection and Quality) Regulations of 1990 prohibits the discharge of wastes into the environment. Discharge standards have been prescribed by the CEA for liquid wastes and the Sri Lanka Standards Institution (SLSI) has prescribed emission standards for sulphuric acid plants.
- The CEA in December 1994, gazetted national ambient air quality standards for Sri Lanka. These regulations do not, however, address vehicular air pollution.
- The Environmental Impact Assessment (EIA) regulation of 1993 ensures that any new project undertaken under the prescribed list undergoes a full EIA or an Initial Environmental Examination (IEE) before a licence is issued for implementation.
- Fiscal Instrument was applied in the form of increasing annual road tax for diesel vehicles in order to restrict the growth of diesel vehicles.
- The Clean Air 2000 Action Plan (CA2AP) was introduced to restore the gradually deteriorating air quality of CMR through various control measures.

A4.8.3 National standards

The Central Environmental Authority set the national ambient air quality standard in 1994 for pollutants such as SO_2, NO_2, PM_{10}, TSP, Pb, and ozone (O_3). Under the Motor Traffic Act, an opacity standard for diesel vehicle exhaust was set in 1994. The CEA is in the process of setting industrial emission and vehicle emission standards for in-use and future import of vehicles. The Sri Lanka Standards Institute published the specifications for the major fuels such as diesel, petrol and LPG in 1995.

A4.8.4 Emission load

In 1992, the CA2AP made an initial attempt to prepare an emission inventory for the Colombo Metropolitan Region. Recently, the M/F&E prepared a greenhouse gas inventory based on the Intergovernmental Panel on Climate Change (IPCC) guidelines. Apart from these attempts, there is no co-ordinated action on a detailed emission inventory for Sri Lanka. One of the actions proposed by the M/F&E under the greenhouse gas inventory project is that the Environment Division of the Department of Census and Statistic (D/C&S) continues the process of updating the data.