The Global Atmospheric Pollution Forum Air Pollutant Emission Inventory Manual

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GLOBAL ATMOSPHERIC POLLUTION FORUM

IUAPPA · UIAPPA

Acknowledgments

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

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

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Executive summary

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

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

Inventory methods are provided for estimating emissions from the following sources: fuel combustion and transformation; fugitive emissions from fuels; industrial process emissions (non-combustion); emissions from solvent and other product use; emissions from agriculture (including savanna fires); emissions from other vegetation fires and forestry; and emissions from the treatment and disposal of wastes. The air pollutants covered are sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4), ammonia (NH_3), particulate matter (PM_{10}, $PM_{2.5}$, black carbon (BC), organic carbon (OC)) and carbon dioxide (CO_2). An Excel workbook (FORUM Workbook Version 7.5.0) has been prepared as a companion to this Manual for use as an aid and tool in preparing national emissions inventories and is available for download from https://www.sei.org/projects-and-tools/tools/gap-global-air-pollution-forum-emission-manual/

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

Acronyms and Abbreviations

ACCENT	Atmospheric Composition Change the European Network of Excellence
APINA	Air Pollution Information Network for Africa
AP-42	Common name for the US EPA's *Compilation of Air Pollutant Emission Factors*
BC	black carbon
BEIS	Biogenic Emissions Inventory System
BKB	brown coal briquettes
Btu	British thermal unit
CEC	Commission of the European Communities
CFC	chloroflourocarbon
CLRTAP	Convention on Long Range Transboundary Air Pollution
CNG	compressed natural gas
CORINE	**CO**-o**R**dination d'**IN**formation **E**nvironmentale
COG	coke oven gas
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
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
ESP	Electrostatic Precipitator
EU	European Union
FAO	United Nations Food and Agriculture Organization
FGD	flue gas desulphurization
g	gram
GAPF	Global Atmospheric Pollution Forum
Gcal	gigacalorie (one billion calories)
GCV	Gross calorific value (= higher heating value, HHV)
GEIA	Global Emissions Inventory Activity
Gg	gigagram (10^9 grams, equal to one thousand "metric tonnes" (t))
GHG(s)	greenhouse gas(es)

GIS	Geographical Information System
GJ	gigajoule (one billion Joules)
GWG	gas works gas
GWh	gigawatt-hour (= 3.6 TJ)
HFO	heavy fuel oil (also called residual fuel oil (RFO))
HHV	higher heating value (= gross calorific value, GCV)
IAM	Integrated Assessment Model
IEA	International Energy Agency
IISI	International Iron and Steel Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
IVL	Swedish Environmental Research Institute
J	joule
JRC-IES	Joint Research Centre of the European Commission - Institute for Environment and Sustainability
kcal	kilocalorie (= 4.18 kJ)
K	Kelvin
kg	kilogram (1000 grams)
kt	kilotonne (1000 metric tonnes (t) = 1 Gg)
LNB	low NO_x burner
LPG	Liquefied Petroleum Gas
LPS	large point source
LRTAP	Long Range Transboundary Air Pollution
LTO	landing and take-off cycle (for aircraft)
LULUCF	Land Use, Land-Use Change and Forestry
Mg	megagram (10^6 grams, equal to one "metric tonne" (t))
MPIC-AC	Max-Planck-Institute for Chemistry, Department of Atmospheric Chemistry, Germany
MSW	municipal solid waste
Mt	megatonne (10^6 metric tonnes (t) = Tg)
Mtoe	megatonne (Tg) oil equivalent
MW	megawatt (1000000 watts)
MW_e	megawatt (electricity)
MW_{th}	megawatt (thermal)
m^3	cubic meter

μm	micrometer (10^{-6} meter)
N	nitrogen
NAPAP	National Acid Precipitation Assessment Program
NAPSEA	nomenclature for air pollution socio-economic activity
NARSTO	A North American Consortium for Atmospheric Research in Support of Air-Quality Management
NCV	net calorific value (= lower heating value, LHV)
NGL	natural gas liquids
NH_3	ammonia
NIA	National Implementing Agency
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	nitrogen oxides ($NO + NO_2$)
O_3	ozone
OC	organic carbon
OECD	Organization for Economic Co-operation and Development
OFA	over-fire air (a form of NO_x emission control)
P	Pascal
PM	particulate matter
PM_{10}	particulate matter less than or equal to 10 micrometers in aerodynamic diameter
$PM_{2.5}$	particulate matter less than or equal to 2.5 micrometers in aerodynamic diameter
ppm	parts per million
POP	Persistent organic pollutant
RAINS-Asia	**R**egional **A**cidification **IN**formation and **S**imulation Model for Asia
RAPIDC	Regional Air Pollution in Developing Countries
RFO	residual fuel oil (also called 'Heavy Fuel Oil')
RIVM-MNP	National Institute for Public Health and the Environment - Netherlands Environmental Assessment Agency
S	sulphur
SAFARI	Southern African Regional Science Initiative
SADC	Southern Africa Development Community
SCC	Source classification code
SCR	Selective Catalytic Reduction
SEI	Stockholm Environment Institute
Sida	Swedish International Development Agency

Sm^3	Standard cubic metre (one standard cubic metre of gas is that amount of gas which occupies 1 m^3 at Standard Temperature and Pressure (0 °C and 1 atm (1.01325×10^5 Pa) pressure).
SNAP	selected nomenclature for air pollution
SO_2	sulphur dioxide
SO_x	sulphur oxides
t	tonne (metric tonne = 1000 kg = 10^6 g))
TNO-MEP	TNO Environment, Energy and Process Innovation
toe	tonne of oil equivalent (an amount of fuel equal in energy content to one tonne of oil = 10^7 kcal)
TSP	total suspended particulate matter (particles up to about 45 micrometers in aerodynamic diameter)
TTN CHIEF	Technology Transfer Network Clearinghouse for Inventories & Emissions Factors
UNECE	United Nation Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compounds
QA/QC	Quality Assurance/Quality Control

Units and Conversions

Units

The SI system of units is generally used for emission inventories in order to ensure international compatibility. The basic unit of weight is the gram (g) and the basic unit of energy is the joule (J). Units of greater magnitude can be denoted by attaching the appropriate multiple prefix.

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

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

Conversion factors for energy

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

Conversion factors for mass

To:	kg	t	Lt	st	Lb
From:	multiply by:				
Kilogramme (kg)	1	0.001	9.84×10^{-4}	1.102×10^{-3}	2.2046
Tonne (t)	1000	1	0.984	1.1023	2204.6
Long ton (lt)	1016	1.016	1	1.120	2240.0
Short ton (st)	907.2	0.9072	0.893	1	2000.0
Pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5.0×10^{-4}	1

Fuel categories[2] used in the Forum Workbook

Coking coal

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

Other Bituminous Coal & Anthracite

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

Sub-Bituminous Coal

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

Lignite/Brown Coal

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

Patent Fuel

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

Coke Oven Coke and Lignite Coke

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

Gas coke

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

Brown Coal Briquettes (BKB)

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

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

Gas Works Gas

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

Coke Oven Gas

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

Blast Furnace Gas

Blast furnace gas is produced during the combustion of coke in blast furnaces in the iron and steel industry. It is recovered and used as a fuel partly within the plant and partly in other steel industry processes or in power stations equipped to burn it.

Natural Gas

Natural gas comprises gases, occurring in underground deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing only hydrocarbons in gaseous form, and "associated" gas produced in association with crude oil as well as methane recovered from coal mines (colliery gas). Production is measured after extraction of NGL and sulphur, and excludes re-injected gas, quantities vented or flared. It includes gas consumed by gas processing plants and gas transported by pipeline.

Crude Oil

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

Natural Gas Liquids (NGL)

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

Refinery Gas

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

Liquefied Petroleum Gases (LPG)

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

butane (C_4H_{10}) or a combination of the two. They are normally liquefied under pressure for transportation and storage.

Motor Gasoline

This is light hydrocarbon oil for use in internal combustion engines such as motor vehicles, excluding aircraft. Motor gasoline is distilled between 35°C and 215°C and is used as a fuel for land based spark ignition engines. Motor gasoline may include additives, oxygenates and octane enhancers, including lead compounds such as TEL (Tetraethyl lead) and TML (tetramethyl lead).

Aviation Gasoline

Aviation gasoline is motor spirit prepared especially for aviation piston engines, with an octane number suited to the engine, a freezing point of -60°C, and a distillation range usually within the limits of 30°C and 180°C.

Gasoline type Jet Fuel

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

Kerosene type Jet Fuel

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

Kerosene

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

Gas/Diesel Oil

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

Heavy Fuel Oil (HFO)

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

Petroleum Coke

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

Other Petroleum Products

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

Primary Solid Biomass

Biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. Included are wood, vegetal waste (including wood waste and crops used for energy production), animal materials/wastes, sulphite lyes, also known as "black liquor" (an alkaline spent liquor from the digesters in the production of sulphate or soda pulp during the manufacture of paper where the energy content derives from the lignin removed from the wood pulp) and other solid biomass. This category contains only primary solid biomass. This includes inputs to charcoal production but not the actual production of charcoal (this would be double counting since charcoal is a secondary product).

Biogas

Biomass gases are derived principally from the anaerobic fermentation of biomass and solid wastes and combusted to produce heat and/or power. Included in this category are landfill gas and sludge gas (sewage gas and gas from animal slurries).

Liquid Biomass

Liquid biomass includes bio-additives such as ethanol.

Municipal Wastes

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

Industrial Wastes

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

Charcoal

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

The Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual

1.   Introduction

1.1 The need for regional cooperation on emissions inventories

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

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

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

1.2 Regional air pollution initiatives

There have been several regional air pollution initiatives in these developing regions where cooperation between countries to tackle this problem is a goal. These include the Malé Declaration in South Asia, the East Asian Network for Acid Rain Monitoring (EANET) and in Asia as a whole, the ASEAN Haze Protocol. In Africa, the Air Pollution Information Network for Africa (APINA) developed regional cooperation amongst SADC countries, and in Latin America the Inter-American Network for Atmospheric/Biospheric Studies (IANABIS) is developing scientific understanding of the air pollution issue. Developing emission inventories is one of the activities prioritised by these initiatives and some have sought help to develop the manuals and frameworks required. In response to this, emissions inventory manuals have been produced for the Malé Declaration and APINA, from activities coordinated by SEI at the University of York, as part of a Sida-funded programme on Regional Air Pollution in Developing Countries. These manuals have formed the starting point for the development of this Forum Manual.

Issues related to emission inventory development need to be addressed internationally. As pollutant emissions management has increasingly to be conducted at wider geographical scales, now including both the regional and hemispheric, the development and adoption of harmonised approaches by different regional

networks is increasingly necessary. Harmonised approaches will allow efficient transfer of information and expertise to help regions or countries with little experience in emission inventory preparation.

1.3   The Global Atmospheric Pollution Forum

The Global Atmospheric Pollution Forum (the Forum) was established in 2005, on the initiative of the International Union of Air Pollution Prevention Associations (IUAPPA) and the Stockholm Environment Institute (SEI), to support co-operation and development of common practice among scientific and policy networks concerned with the abatement of air pollution at the regional scale. The Forum emerged from a widespread recognition among regional air pollution networks of the timeliness and merit of closer consultation and co-operation. The Forum is already promoting a Global Atlas of Atmospheric Pollution and undertaking a collaborative review of Hemispheric Pollution. It is now developing a programme of collaborative development and demonstration problems on common technical issues. A project entitled 'Developing and Disseminating International Good Practice in Emissions Inventory Compilation' is among the first initiatives of this programme and this Manual and its associated Excel-based Workbook are its main products. The purpose of the manual is to present a framework for emission inventory preparation that is suitable for use in different developing and rapidly industrialising countries and which is compatible with other major emissions inventory preparation approaches such as those described in the 2016 EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2016)[3], hereafter referred to as the *EMEP/EEA Guidebook*, and Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), hereafter referred to as the *IPCC Guidelines*[4].

2.   Principles of good practice in preparing inventories

2.1 Basic inventory principles

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

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

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[3] EMEP/EEA, 2016. Air pollutant emission inventory guidebook 2016. EEA Technical report No 21/2016. Updated July 2018, European Environment Agency https://www.eea.europa.eu/publications/emep-eea-guidebook-2016
[4] IPCC, 2006. Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

aim to reflect the real annual fluctuations in emissions and not be subject to changes resulting from methodological differences.

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

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

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

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

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

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

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

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/EEA 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/EEA approach is technology-based and includes spatial allocation of emissions (point and area sources). Both systems follow the same basic principles:

- complete coverage of anthropogenic[6] emissions;

- annual source category totals of national emissions;

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

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

Considerable progress has been made in harmonizing these two approaches, to the extent that a complete EMEP/EEA inventory can be used to produce reports in both the UNFCCC/IPCC or EMEP/EEA reporting formats.

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

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

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

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

The pollutants are defined as follows:

- NO_x includes NO and NO_2 reported in NO_2 mass equivalents.
- SO_2 includes all sulphur compounds expressed in SO_2 mass equivalents.
- NMVOC means any non-methane organic compound having at 293.15 K a vapour pressure of 0.01 kP or more, or having a corresponding volatility under the particular conditions of use.
- PM_{10} includes all particulate matter with an aerodynamic diameter less than or equal to 10 microns (μm)

- $PM_{2.5}$ includes all particulate matter with an aerodynamic diameter less than or equal to 2.5 microns (µm)
- BC and OC form part of the PM (and are assumed to be less than or equal to 1.0 microns in diameter).

The commonality between the IPCC and EMEP/EEA 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/EEA and IPCC approaches are shown in Table 2.2.

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

GAPF manual	EMEP/EEA (2016) Emission Inventory Guidebook	2006 IPCC Guidelines
1 Combustion in the Energy Industries	1.A.1 Energy industries	1 Energy (1A Fuel Combustion Activities)
2 Combustion in Manufacturing Industries and Construction	1.A.2 Manufacturing industries and construction	
3 Transport	1.A.3 Transport	
4 Combustion in Other Sectors	1.A.4 Small combustion	
5 Fugitive emission from fuels	1.B Fugitive emission from fuels	1 Energy (1B Fugitive Emissions from Fuels)
6 Industrial Processes	2 Industrial processes and product use	2 Industrial Processes and Product Use
7 Solvent and Other Product Use		
8 Agriculture	3 Agriculture	3 Agriculture, Forestry and Other Land Use
9 Vegetation Fires & Forestry	11B Forest fires	
10 Waste	5 Waste	4 Waste

2.6 Completeness

The aim is to include all known sources of emissions in the inventory. If it is not possible to fill a cell with numbers, for example due to data availability, cells should be filled in using appropriate *notation keys* to increase transparency. The following notation keys are recommended:

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

2.7 Pollutants covered in this manual

2.7.1 Sulphur dioxide

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

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

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

2.7.2 Nitrogen oxides

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

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

2.7.3 Ammonia

Estimates of ammonia (NH_3) emissions are important to include in atmospheric models as ammonia can have a significant effect on the oxidation rates, and hence on the deposition rates, of acidic species. Although much less research has been done on the effects of atmospheric NH_3 compared to sulphur dioxide and nitrogen oxides, it is well known that over large areas of Europe, acid precipitation is falling in which up to 70 percent of the original acid is neutralized by NH_3 (Battye et al., 1994[7]). 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

[7] 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.

increasing importance. There is also evidence that significant NH_3 emissions come from undisturbed soils and from biomass burning.

2.7.4 NMVOCs

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

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

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

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

There are thousands of individual chemical species that can be classified as NMVOCs. For the purposes of modelling the atmospheric chemistry involved on ozone formation, it is often necessary to "speciate" VOC emissions into so-called "reactivity groups". Speciation of NMVOCs is described in more detail in Annex 2.

2.7.5 Carbon monoxide

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

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

Carbon monoxide pollution is of particular concern in urban situations where air concentration can vary widely from a background level of a few parts per million (ppm) up to 50-60 ppm, depending on the

weather and the traffic density. Although mainly of local importance, CO is also of interest to transboundary air pollution modellers because of its role in tropospheric (ground level) ozone formation.

2.7.6 Particulate matter

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

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

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

Total suspended particulate matter (TSP) is often monitored for air quality management purposes and TSP emissions are sometimes included in emissions inventories. However, this category of PM is not covered by the Forum Manual and Workbook. This is partly because it is not generally used for regional air pollution modelling and partly because many of the important anthropogenic sources of TSP, such as fugitive emissions from mining and quarrying, are not part of the emission source structure of this manual and emission inventory methodologies are often non-existing or little developed.

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

2.7.7 Methane

Methane is a potent greenhouse gas and its increased concentration in the atmosphere has caused the largest radiative forcing by any greenhouse gas after carbon dioxide. Methane concentrations have grown as a result of human activities related to agriculture, including rice cultivation and the keeping of ruminant livestock, coal mining, oil and gas production and distribution, biomass burning, municipal waste landfills and waste water treatment. Methane has a direct influence on climate, but also has a number of indirect effects including

its role as an important precursor to the formation of tropospheric ozone which damages human health and reduces crop yields. Methane is now included in this manual primarily to enable the co-benefits for near-term climate to be assessed when scenarios of emission reduction for the tradition transboundary air pollutants are modelled.

2.7.8 Carbon dioxide

Carbon dioxide (CO_2) is the most important of the anthropogenic greenhouse gases, its increase in atmospheric concentration having caused the largest radiative forcing (i.e. atmospheric warming). The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 405 ppm by 2017. The global increases in CO_2 concentration are due primarily to fossil fuel use and land use change. Carbon dioxide is now included in this manual to enable co-benefits for long-term climate to be assessed when scenarios of emission reduction for the tradition transboundary air pollutants are modelled.

2.8 Sources-sectors included

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

2.8.1 Energy

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

2.8.2 Industrial processes

This category (Sector 6 in this Manual) covers those industrial processes that generate by-product emissions (that is, process emissions) or fugitive emissions of the pollutants covered by this Manual. It specifically *excludes all combustion emissions* from industry as these are already covered in Sector 2[8]. 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. In this version of the manual, all contain volatile compounds that are sources of NMVOC emissions. This category includes the application of paint, glue and adhesives; metal degreasing and dry cleaning of fabrics; the manufacture of certain chemical products; and the use of solvents in the printing industry.

2.8.4 Agriculture

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

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

2.8.5 Vegetation fires and forestry

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

2.8.6 Waste

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

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

Table 2-3 (Continued)

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

Table 2-3 (Continued)

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

Table 2-3 (Continued)

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

Table 2-3 (Continued)

	Sector	Comments	Pollutants
6	**INDUSTRIAL PROCESSES**	Process (by-product) or fugitive emissions from industrial processes. (Emissions from fuel combustion in industry should be reported under Energy.) Emissions from coal and coke used as reducing agents are reported under this category.	
	6A Mineral products	Cement Production, Lime Production, Road Paving with Asphalt and Brick Manufacture.	SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$ (+CO_2 for cement)
	6B Chemical industry	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	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	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	All processes in food production chains that occur after the slaughtering of animals or harvesting of crops. Includes production of Meat, fish and poultry; Sugar; Margarines and solid cooking fats; Cakes, biscuits and breakfast cereals; Bread; Animal feed; Coffee roasting and Alcoholic beverage manufacture. Excludes vegetable oil extraction and tobacco	NMVOC, PM_{10}, $PM_{2.5}$
7	**SOLVENT AND OTHER PRODUCT USE**	Emissions resulting from the use of solvents and other products containing volatile compounds.	
	7A Paint Application	The application of paint in industry (including the manufacture of vehicles, ship building etc.), vehicles refinishing, construction and building, and domestic.	NMVOC
	7B Degreasing and Dry cleaning	Metal degreasing and Dry-cleaning of fabrics	NMVOC
	7C Chemical Products, Manufacture and Processing	Manufacture of Polyester resins, Polyvinylchloride, Polyurethane, Polystyrene foam, Paint and varnish, Ink, Glue, Adhesive tape and Rubber processing.	NMVOC
	7D Other Solvent Use	For example, glass/mineral wool enduction, Printing industry, the extraction of edible fat and non-edible oil and the application of glues and adhesives.	NMVOC

Table 2-3 (Continued)

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

2.9 Large points sources (LPS)

Many air pollution models include separate accounting for emissions from Large Point Sources (LPS). Accurate information about the location and height of emission for LPS sources improves the accuracy of air chemistry/transport modelling activities. Therefore, in emissions inventories, emission estimates are often provided for large individual plants or emission outlets, usually in conjunction with data on location, capacity or throughput, operating conditions, height of exhaust stacks, and other data. Reported emissions from point-

sources can be related to the source-categories above; in particular, energy and industrial processes and should always be allocated to the appropriate source-category.

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

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

2.10 Temporal allocation of emissions

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

2.11 Spatial allocation of emissions

In addition to allocation of emissions over time, modellers must also allocate emissions over "space", that is, the location or area (e.g. 1º x 1º 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:

$$\textbf{Emission = (emission factor) x (activity rate)}$$

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*[9], the *EMEP/EEA Guidebook* and the *IPCC Guidelines*.

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)[10]. 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], Smith et al (2000)[13] and Kato and Akimoto, (1992)[14]. The default NCVs, and the reference sources from which they were derived, are included in Table 3-1.

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

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[9] 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: https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors)

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

[11] *World Energy Balances,* International Energy Agency (IEA), https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=chart&dataTable=BALANCES

[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] 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

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

Fuel class	Fuel type	Default Net Calorific Value (NCV)	
		Terajoules per kilotonne (TJ/kt)[a]	Tonnes of oil equivalent per tonne (toe/t)
Coal	Coking Coal	b	b
	Other Bituminous Coal & Anthracite	b	b
	Sub-Bituminous Coal	b	b
	Lignite	b	b
	Patent Fuel	b	b
	Coke Oven Coke	b	b
	Gas Coke	b	b
	BKB (Brown coal briquettes)	b	b
	Coke Oven Gas (COG)	38.7	0.9243
	Blast Furnace Gas (BFG)	2.47	0.0593
Gas	Gas Works Gas (GWG)	38.7	0.9243
	Natural Gas	48	1.1465
Oil	Crude Oil	b	b
	Natural Gas Liquids (NGL)	b	b
	Refinery Gas	49.5	1.182
	Liquefied Petroleum Gases (LPG)	47.3	1.130
	Motor Gasoline	44.3	1.058
	Aviation Gasoline	44.3	1.058
	Gasoline type Jet Fuel	44.3	1.058
	Kerosene type Jet Fuel	44.1	1.0533
	Kerosene	43.8	1.046
	Gas/Diesel Oil	43.0	1.027
	Heavy Fuel Oil (HFO)	40.4	0.965
	Petroleum coke	32.5	0.7762
	Other Petroleum Products	40.2	0.960
Combustible renewables/ wastes	Solid Biomass and Animal Products: Wood	15.6	0.3726
	Vegetal materials and wastes	14.78[c]	0.3530
	Other (e.g. animal products/ wastes)	11.8[d]	0.2809
	Gas/Liquids from biomass/wastes (for transport: biogasoline/ biodiesel)	27	0.6449
	Gas/Liquids from Biomass/wastes (for biogas = value for methane)	50.4	1.204
	Municipal Waste	11.6	0.2771
	Industrial Waste	11.6	0.2771
	Charcoal	31[e]	0.7404

[a] From IPCC (2006) unless otherwise indicated.

[b] For coal, coal products, crude oil and natural gas liquids refer to IEA[15] or the *IPCC Guidelines*.

[c] Mean of values for mustard straw and rice straw from Smith et al. (2000).

[d] Value for dung cake from Smith et al. (2000).

[e] Bertschi et al. (2003)[16].

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

[15] *World Energy Balances,* International Energy Agency (IEA), https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=chart&dataTable=BALANCES.

[16] 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.

separately for each sub-sector. For emissions from the Transport sector, a more detailed alternative to the IPCC Tier 1-based approach is also offered in this Manual and the accompanying workbook.

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

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

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

3.2 Sector 1: Fuel Combustion in the Energy Industries

3.2.1 Introduction

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

- *Public Electricity and Heat Production* – All emissions from the combustion of fuel for generation of electricity or the production of heat for sale to the public. The power stations or utilities may be in public or private ownership. Emissions from own on-site use of fuel are included. Emissions from autoproducers[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.

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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.

- *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, the (uncontrolled) default emission factors given in the Workbook are derived from the *EMEP/EEA Guidebook* with the exception of charcoal making (emission factor for traditional earthen charcoal kiln from Bertschi et al. (2003)). Various types of control technology can be used to reduce NO_X emissions from power stations and industrial sources, and some of these may be employed in non-OECD countries. Table 3-3 lists the main NO_x control technologies applicable to power stations, along with representative values for percentage emissions reductions associated with each technology. For NO_x there is a separate worksheet (1.3.2) in the workbook for entering the NO_x emission control rates. Emission control calculators are also provided at the bottom of the worksheet for coal, oil and gas combustion and as before, the outputs of the emission control calculators are automatically carried forward into the main worksheet table.

Table 3-3:

Representative NO$_x$ emission control reductions for power stations and industrial boilers.

Technology	Representative NO$_x$ reduction (%)
Low Excess Air (LEA)	15
Overfire Air (OFA) - Coal	25
OFA - Gas	40
OFA - Oil	30
Low NOx Burner (LNB) - Coal	45
LNB - Tangentially Fired	35
LNB - Oil	35
LNB - Gas	50
LNB with OFA - coal	50
Cyclone Combustion Modification (in power stations)	40
Flue Gas Recirculation (in industrial boilers)	40
Ammonia Injection	60
Selective Catalytic Reduction (SCR) - Coal	80
SCR - Oil	80
SCR - Gas	80
Water Injection - Gas Turbine Simple Cycle	70
SCR - Gas Turbine	80

Source: Radian, 1990[18]

The particulate matter (PM$_{10}$ and PM$_{2.5}$) emission factors (controlled and uncontrolled) for fuel combustion in power station boilers are given in the *EMEP/EEA Guidebook*. 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. Emission factors for BC and OC are derived from Bond et al. (2004)[19]. 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.

For Large Point Sources in this sector, SO$_2$, NO$_x$ and PM emission control efficiencies (or controlled emission factors) for each utility will be required unless stack emissions are normally measured directly.

3.3 Sector 2: Fuel Combustion in Manufacturing and Construction

3.3.1 Introduction

For most countries, the major fuel-consuming activities in this sub-sector are iron and steel manufacture (excludes coal and coke consumed in the furnaces as these are primarily used as reducing agents), non-ferrous metal smelting, non-metallic minerals (including cement production but excluding brick manufacture), the manufacture of chemicals and petrochemicals, the pulp and paper industry, mining (excluding coal mining) and quarrying, , the construction industry and brick manufacture (not included under non-metallic minerals).

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[18] Radian Corporation (1990) *Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO$_x$, N$_2$O, CH$_4$, CO, and CO$_2$.* Prepared for the Office of Research and Development, US Environmental Protection Agency, Washington, D.C., USA

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

The combined totals for all remaining unspecified industries should be included under the "Non-specified industry" category in the Workbook. A separate category is used for fuel consumed for autoproduction of electricity within manufacturing industry.

3.3.2 Procedures and default data used in this manual

Emissions of pollutant gases are calculated in the same way as described above for the energy industries using emission factors and the rates of fuel combustion. The (uncontrolled) default emission factors given in the workbook were derived from the *EMEP/EEA Guidebook* for CO, NO_X, NMVOC and PM, from the *IPCC guidelines* for CO_2 and CH_4, from Bond et al. (2004) for BC and OC, and from Battye et al.[20] 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.

3.4 Sector 3: Transport

3.4.1 Introduction

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

3.4.2 Procedures and default data used in this manual

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

3.4.2.1 Simple method

Emissions of all pollutants are estimated in a way similar to that described above for fuel combustion in the Energy Industries and in the Manufacturing Industries and Construction (based on fuel combusted). It is similar to the IPCC Tier 1 method except that a more detailed disaggregation of fuel types is used. An average emission factor for a particular fuel, taking into account average emission controls where relevant, is multiplied by the annual fuel combustion for the entire sub-sector (civil aviation, road transport, railways, navigation or pipeline transport). The simple method is recommended for estimating all SO_2 transport emissions which depend only on the sulphur content of fuel. For the other pollutants, the simple method just gives a very approximate estimate of emissions and should only be used by countries lacking the data required

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[20] 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

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 from the *IPCC Guidelines* for CO_2 and CH_4 and from the *EMEP/EEA Guidebook* for other species apart from OC which is derived from the BC emission factor using the BC/OC ratios reported in Bond et al. (2004)[21]. 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[22].

3.4.2.2 Detailed method (preferred)

Road-transport emission factors for NO_X, CO, NMVOCs and PM vary greatly depending on the vehicle type, age, operating characteristics, emission controls, and maintenance procedures as well on fuel type and its quality and the "Simple method" does not adequately deal with all of these variables. A "Detailed method" is also offered in the workbook which addresses the differences relating to vehicle class, and to some extent, control technology (e.g. for gasoline passenger cars). This method is recommended where some transport activity data (i.e. numbers of each vehicle type is use, average annual distance travelled) are available. The vehicle categories covered are: passenger cars, light duty vehicles, heavy duty vehicles, motorcycles <50cc (2-stroke), motorcycles >50cc (2-stroke), motorcycles <50cc (4-stroke) and 3-wheelers. These categories are further subdivided by fuel type and level of emission control technology (i.e. Euro standard). The relevant activity rates are the number of vehicles in use and the average annual kilometres driven for each vehicle category. These activity data should be available from national statistical offices and, for some vehicle categories, from the International Organization of Motor Vehicle Manufacturers (OICA)[23].

The default emission factors are mainly Tier 2 values from the *EMEP/EEA Guidebook* for the different Euro standards although the Tier 1 maximum values are suggested for uncontrolled vehicles. As many non-OECD countries lack vehicle activity data disaggregated by engine size or vehicle weight, a typical engine size of 'medium' (1.4 – 2.0 litres) was assumed for passenger cars, a typical weight of 7.5 – 16 tonnes assumed for heavy duty vehicles (trucks), and engine capacities of > 50 cm^3 assumed for 2-stroke and 250-750 cm^3 for 4-stroke motorcycles. Default EFs for 3-wheelers and retro-fit compressed natural gas (CNG) passenger cars were derived from ARAI (2008)[24]. EFs for OC were derived from organic matter (OM):BC ratios in the *EMEP/EEA Guidebook* assuming that OM = 1.4 x OC.

Dust emissions from vehicles travelling on unpaved roads are an important source of both PM_{10} and $PM_{2.5}$ emissions in many developing countries and so these are also covered by this detailed method. In this method, the percentage dry days (< 0.25 mm precipitation) in a year is required as an additional input. The method is based on that proposed by Gillies et al. (2005) for unpaved rural roads in dry weather, assuming a silt content range of 4% - 7%. The PM_{10} EF = 3 x W x S g/km where S is the average speed in km/hr and W is the average vehicle weight in tonnes. The default factors suggested in the Workbook assume an average speed of 30 km for all vehicles and average weights of 0.4 t for 2-wheelers, 1 t for 3-wheelers, 1.4 t for passenger cars, 2.5 t for light commercial vehicles and 5 t for heavy duty vehicles (trucks and buses). If the average weight and/or average speed for a vehicle class differ from these assumptions then the above formula should be used to calculate revised factors. Emissions of $PM_{2.5}$ are assume to be 10% of PM_{10} emissions from unpaved public roads as suggested by the US EPA (2006)[25].

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

[22] *Energy balances of non-OECD countries,* International Energy Agency (IEA), https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=chart&dataTable=BALANCES

[23] OICA (2019) Vehicles in use by country and type 2005-2015. International Organization of Motor Vehicle Manufacturers http://www.oica.net/category/vehicles-in-use/

[24] ARAI (2008) Emission Factor development for Indian Vehicles, The Automotive Research Association of India, Pune, India, Revision-4 March 10 2008 [http://www.cpcb.nic.in/Emission_Factors_Vehicles.pdf]

[25] US EPA, 2006. Compilation of air pollution emission factors, 5th edition. Chapter 13.2.2 Unpaved roads - Final section (Revised Nov 2006) EPA AP-42, U.S. Environmental Protection Agency, Research Triangle Park, NC.

If sufficiently detailed activity data are available, existing road transport emissions estimation models such as COPERT 4[26] (used in Europe) or MOBILE6[27] (used in North America) should be used as an alternative to the detailed method offered in this Manual/ Workbook. These models require a detailed technology split of vehicles (by engine size and emission control technology) and data on driving patterns, temperature data etc. In using European default emission factors in developing countries it is important to bear in mind that actual emission levels are determined by fuel quality and vehicle maintenance. Therefore it is important to assess whether actual emissions can be higher than those generated using the default emission factors in a model. For example, the use of leaded gasoline or adulterated fuels (a common practice in some developing countries) will often prevent the catalytic converter from working properly. Vehicles imported into some developing countries may also have their catalytic converters removed to improve fuel economy. Cars converted from gasoline to LPG will usually have their catalytic converters cut out. Lastly, imported, reconditioned vehicles (especially trucks) which initially meet certain emission standards may deteriorate rapidly due to the poor state of the roads and/or poor fuel quality. In general, it may be best to assumed that reconditioned vehicles will have pre-control levels of emissions even if newly registered.

For civil aviation, the detailed method offered in this Manual is based on the Tier 1 *EMEP/EEA Guidebook* (EMEP/EEA, 2013)[28] method for jet kerosene. Emissions can be estimated for two categories of aircraft, 'Old Fleet' represented by Boeing B737-100 and 'Average Fleet' represented by Boeing B737-400. It includes both landing and take-off (LTO) cycle[29] and cruise activity emissions for domestic aircraft. For international aviation, the aircraft categories are further subdivided into 'Short distance' (500 nautical miles) and 'Long distance' (3000 nautical miles). Cruise emissions for international aircraft are not included as these mainly occur outside the country being inventoried. For activity data, only those LTO cycles occurring in the country being inventoried are counted. This detailed approach is recommended for all pollutants emitted by civil aviation (including SO_2) where annual domestic LTO data are available. 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/EEA 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) from national totals. Emissions based on the bunker sales in the country are rather estimated and included as a memo item. Nevertheless these emissions are of course important for air quality modelling. Often it can be more useful to use global datasets for the purpose rather than national inventories.

3.4.3 Application of parameters for control equipment

For the simple road transport method, 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

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https://www3.epa.gov/ttn/chief/ap42/ch13/final/c13s0202.pdf

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

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

[28] EMEP/EEA (2013) Air pollutant emission inventory guidebook. EEA Technical report No 12/2013. European Environment. Agency https://www.eea.europa.eu/publications/emep-eea-guidebook-2013

[29] 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).

not adequate (e.g. if it contains lead or is adulterated) causing catalytic converters to lose their efficiency over time if they are not replaced. Also, as is often the case in Africa for example, catalytic converters from imported vehicles may be removed to improve fuel consumption. Therefore, the assumption that use of emission controls is negligible may still be adequate even if cars with catalytic converters are being imported.

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

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 CO_2, CH_4, SO_2, NO_X, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC and OC 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[30] although data for 'primary solid biomass'[31] are not further sub-divided by type in this database. Thus, IEA data for 'Primary solid biomass' should be entered into the Forum Workbook under the category 'Unspecified primary solid biomass'. Other activity data sources for biomass fuel consumption are the United Nations Energy Statistics Yearbooks (for fuelwood, charcoal and bagasse) and FAOSTAT[32] (for wood fuel and wood charcoal). For both these reference sources, data are in cubic metres (m^3) which must be converted into mass units (for wood assume 1000 m^3 = 0.732 kilotonnes) before being entered into the Workbook (sheet 1.1.1c). Also, for the UN Energy Statistics Yearbook and FAOSTAT database, assume that consumption equals production plus imports minus exports. Official and international data sources for biomass combustion may be unreliable and underestimate the real consumption and therefore it is important to identify additional data sources (e.g. dedicated studies).

For SO_2, emission factors are calculated from the average sulphur content, sulphur retention-in-ash and Net Calorific Value (NCV) of each type of fuel. For the *Commercial/institutional* and *Agricultural or Forestry* sectors, the other default emission factors given in the Workbook were mostly derived from the *IPCC Guidelines* for CO_2 and CH_4, Battye et al.[33] for NH_3 and from the *EMEP/EEA Guidebook* for other species. The inclusion of factors for emission controls is unlikely to be applicable in this sector.

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

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

[32] FAOSTAT http://www.fao.org/faostat/en/#data/FO

[33] 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

Domestic sources such as cookstoves, although individually small, are numerous and have the potential to contribute significantly to air pollution, particularly in developing countries. Thus for the *Residential* sector, where possible, default emission factors appropriate to non-OECD countries are offered in the Workbook (i.e. sourced from the literature rather than the *EMEP/EEA Guidebook* or *IPCC Guidelines*) as summarized in Table 3.4.

Table 3.4
Default emission factors offered in the Workbook for fuels commonly used in the residential sector.

	Pollutant species									
	CO_2	CO	CH_4	NMVOC	NO_X	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
	t/TJ	kg/TJ	kg/TJ	kg/TJ	(as NO_2) kg/TJ	kg/t	kg/t	kg/t	kg/t	kg/t
Fuel										
Charcoal	92.8[a]	4328[b]	222[d]	236[b]	70[b]	0.97[b]	2.38[c]	2.38[c]	1.19[d]	0.85[d]
Wood	101.7[a]	4260[e]	663[d]	1763[b]	73[e]	0.87[a]	8.3[e]	6.64[a]	0.83[a]	2.89[a]
Vegetal wastes	100.0[f]	5730[e]	300[f]	600[g]	47[e]	1.29[b]	8.05[e]	6.44[h]	1.0[i]	3.3[i]
Animal wastes	88.9[j]	3392[j]	383[j]	2057[j]	65.5[k]	4.75[a]	3.0[j]	3.0[j]	0.12[j]	1.8[j]
Coal	94.6[f]	2610[e]	300[f]	484[g]	34[e]	1.17[l]	14.8[m]	13.3[n]	2.2[m]	5.93[m]
Natural gas	56.1[f]	26[g]	5[f]	1.9[g]	5[g]	0.01[o]	0.061[g]	0.061[g]	0.0033[g]	0.027[p]
LPG	63.1[f]	26[g]	5[f]	1.9[g]	51[g]	0.01[q]	0.32[j]	0.31[n]	0.01[j]	0.06[j]
Kerosene	71.9[f]	57[g]	10[f]	0.69[g]	25[e]	0.005[l]	0.134[e]	0.081[g]	0.017[r]	0.013[s]

[a]Derived from Akagi et al (2011); [b]Derived from Bertschi et al (2003); [c]Smith et al (2000); [d]Assume 50% of PM is BC and 50% organic matter (assuming OC=OM/1.4) Bond et al. (2004); [e]Zhang et al (2000) for household stoves in China (For vegetal wastes, average EF for wheat and maize residues); [f]IPCC (2006) Tier 1 default; [g]EMEP/EEA (2016) Tier 1 EFs; [h]Assumes $PM_{2.5}$ = 80% of PM_{10} as reported for wood and crop waste by Reddy and Venkataraman (2002a); [i]Bond et al (2004); [j]Derived from Venkataraman et al (2010) (for OC assumed = OM/1.4); [k]Derived from Keene et al (2006); [l]Li et al (2016) - value of 1.17 is for bituminous chunk coal in traditional stove (use 0.10 for advanced stove, for anthracite chunk use 0.20 (trad) and 0.08 (adv); [m]Zhi et al (2008); [n]Assume a $PM_{2.5}/PM_{10}$ ratio of 0.9 for coal and 0.964 for kerosene and LPG (Reddy and Venkataraman, 2002b); [o]Battye et al (1994); [p]Assume OC fraction is 8.33 x BC (Bond et al 2004); [q]Assume as for natural gas; [r]Assume 13% of PM10 - Bond et al (2004); [s]Assume OC = BC/3.5 (Bond et al., 2004).

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 CH_4 and NMVOC emissions in many countries. This sub-sector includes fugitive emissions of CH_4, CO_2 and NMVOC from crude oil exploration, production and transport, oil refining, the distribution and handling of gasoline (including emissions from service stations) and the production and distribution of natural gas (including venting). It also includes CH_4 emissions from underground and surface coal mining, during both mining and post-mining activities. In addition to NMVOC, CH_4 and CO_2, this subsector also includes fugitive emissions SO_2, NO_X and CO from oil refining, emissions of BC and OC from flaring during oil and gas extraction, and emissions of SO_2, NO_X, CO, NH_3, PM_{10}, $PM_{2.5}$, BC and OC from the production of coke.

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 are based on a combination of the Tier 1 *IPCC Guidelines* and *EMEP/EEA Guidebook* approaches with most of the default EFs coming from these two sources. However, fugitive NMVOC emissions from the handling and distribution of gasoline are estimated using the EMEP/EEA Guidebook Tier 2 method that takes into account annual average Reid Vapour Pressure (RVP) and annual average ambient temperature. Accounting for the effect of ambient temperature on NMVOC emissions is particularly important for countries located in the tropics. Also, the default EFs for BC (1.6 kg/103 m3) and OC (1.6 kg/103 m3) emissions during flaring are those typical of non-OECD countries provided by Klimont et al. (2017). For coke ovens, two sets of EFs based on Tier 1 *EMEP/EEA Guidelines* are provided for SO_2, NO_X, CO, NMVOC, and NH_3; those for 'Uncontrolled' traditional ovens assumed to equal the upper end of the range provided, and those for 'Controlled' ovens equal to the default (geometric mean) value. Similarly, two sets of EFs derived from Bond et al. (2004) are provided for PM_{10}, $PM_{2.5}$, BC and OC with their values for 'Uncaptured' emissions being assumed to apply to 'Uncontrolled' coke ovens.

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.[34] Other activity data will usually be obtained from the facilities themselves or from national statistical offices in each country.

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

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

4.1 Introduction

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

The industrial process emission categories covered in this Manual are:

- *Mineral Products* (Portland cement production, Lime production, Asphalt roofing   production, Asphalt for road paving),
- *The Chemical Industry* (Ammonia, Nitric acid, Adipic acid, Carbon black, Urea, Ammonium nitrate, Ammonium phosphate, Sulphuric acid, Titanium dioxide),
- *Metals Production* (Pig iron production, Aluminium production, Copper smelting (primary) as blister and other unrefined, Copper smelting (secondary), Lead smelting (primary), Lead smelting (secondary), Zinc smelting (primary), Zinc smelting (secondary),
- *Pulp and Paper Industries* (Kraft pulping + Alkaline soda pulping, Acid sulphite pulping, Neutral sulphite semi-chemical),
- Alcoholic Beverages Production (Beer, Red wine, White wine, Wine (unspecified), Malt whiskey, Grain whiskey, Brandy, Spirits (unspecified)),
- *Food Production* (Sugar (raw), Margarines and solid cooking fats, Cakes, biscuits and   breakfast cereals, Other bread, Animal feed, Coffee roasting) and
- *Fugitive emissions of PM from major construction activities.*

4.2 Procedures and default data used in this manual

The methods used are mainly from the *EMEP/EEA Guidebook*. If activity data are not available from national statistical offices or other official sources, internationally compiled data can be obtained from the USGS Minerals Yearbooks[35], the Steel Statistical Yearbook[36] (for pig iron production), the United Nations Industrial Commodity Statistics Database[37] and, for pulp/paper industries, the FAOSTAT database[38]. Trade or branch organisations may also be able to provide data.

4.3 Application of parameters for control equipment

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

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[35]   United States Geological Survey (USGS) Minerals Yearbook (Volume III: Area reports: international) https://www.usgs.gov/centers/nmic/international-minerals-statistics-and-information

[36] International Iron and Steel Institute (IISI), Steel Statistical Yearbooks https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html

[37] United Nations UN Industrial Commodity Statistics Database http://data.un.org/Explorer.aspx?d=ICS

[38] FAOSTAT http://www.fao.org/faostat/en/#data/FO

4.4 Sources of emission factor data

The default emission factors are mainly Tier 2 factors from the *EMEP/EEA Guidebook*; references for the other source documents are provided in the Workbook. 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) (Industrial, Decorative)
Paint application (water based),
Metal degreasing (open-top degreaser),
Dry cleaning of fabrics,
- *Chemical products manufacture* (Polyester processing, Polyvinylchloride, Polyurethane, Polystyrene foam, Rubber processing, Paints, inks and glues), and
Other use of solvents (Mineral wool enduction, Glass wool enduction, Printing industry [Heat set offset, Publication gravure, Packaging (small flexography)], Fat, edible and non-edible oil (solvent extraction), Application of glue and adhesives).

5.2 Procedure and default data suggested in 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 (or other official sources), industrial sources or, for commodity production data, the UN Industrial Commodity Statistics. The estimates of annual output are multiplied by the user-selected (or default) emission factors to yield estimates of total annual NMVOC emissions by process/sub-process.

5.3 Application of parameters for control equipment

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

6. Emissions from Agriculture (Sector 8)

6.1 Introduction

Several types of agricultural activity emit air pollutants including: livestock enteric fermentation (a source methane (CH_4) emissions), livestock manure management (a source of ammonia (NH_3) and CH_4 emissions) and animal housing (PM_{10} and $PM_{2.5}$), application of nitrogen-containing fertilizers (a source of both NO_x and NH_3), savanna burning and burning of agricultural crop residues both of which emits a range of air pollutants (NO_x, SO_x, NH_3, CO, CH_4, NMVOC and particulate matter), and rice cultivation (CH_4 emissions).

In general, agricultural emissions are calculated by multiplying an activity rate by an emission factor. Activity data such as the numbers of livestock present, the amount of fertilizer applied, annual crop production (for crop residue burning) and area of savannah burnt are available on the internet from the FAOSTAT database[39].

6.2 Procedures suggested for use in this Manual

6.2.1 Sources of emissions covered

- **Manure management**: This source covers emissions of ammonia (NH_3), nitric oxide (NO, expressed as NO_2) and methane (CH_4) from the storage and disposal of livestock manures from 11 categories of livestock (Dairy cattle, Other cattle, Buffalo, Pigs, Sheep, Goats, Horses, Mules and asses, Poultry, Fur animals and Camels). Emissions are a function of the number of animals and, for NH_3 emissions, the way in which manures are handled.

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

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

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

- **Emissions from savanna burning**: Savannas are intentionally burned during the dry season, primarily for agricultural purposes such as ridding the grassland of weeds and pests, promoting nutrient cycling, and encouraging the growth of new grasses for animal grazing. Burning of savannas takes place every one to four years on average and is a potential source of combustion-related emissions of CO, NO_x, CH_4, NMVOCs, particulate matter (including BC and OC), SO_2, and NH_3. Estimation of these emissions involves consideration of the area burned, the biomass fuel load, the fraction of biomass burned, and emission factors for each pollutant.

- **Emissions from burning of agricultural residues**: Disposal of agricultural residues by on-field burning can result in releases of CO, NO_x, CH_4, NMVOCs, particulate matter (including BC and OC), SO_2, and

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[39] FAOSTAT: Livestock numbers:- http://faostat3.fao.org/download/Q/QA/E; N-fertilizer application:- http://www.fao.org/faostat/en/#data/RFB; Savanna burning :- http://www.fao.org/faostat/en/#data/GH; Crop production:- http://www.fao.org/faostat/en/#data/QC.

NH_3. Estimation of these emissions requires estimation of crop production, the amount of residue produced per unit crop production, the amount of residue burned, and emission factors.

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

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

Emissions of NH_3, NO_X and CH_4 from livestock manure management and CH_4 from enteric fermentation depend on the average number of each type of livestock in the inventory year (e.g. as given by FAOSTAT[40]) and a set of emission factors. The emission factors for NH_3 from manure vary by management system and the Tier 1 EMEP/EEA (2016) defaults offered in the workbook for cattle and pigs are for solid systems (with alternatives for slurry systems given in footnotes). Also, the default NH_3 emission factor is for laying hens (with alternatives for chicken broilers, turkeys, ducks and geese given in the Workbook footnotes). Table 6-1 presents the types of livestock included and the suggested default emission factors.

For CH_4 emissions from manure management, the default emission factors (IPPC, 2006)[41] offered in the Workbook are for the Indian subcontinent assuming 26 °C annual average temperature. For other temperatures, other Asian countries or other regions, the user should consult the tables (taken from IPCC (2006), Vol 4, Tables 10.14 and 10.15) provided at the bottom of the relevant worksheet (Sheet 4.1) in the Workbook accompanying this manual.

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

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

Emissions of particulate matter from livestock housing are calculated from an estimate of the number of each type of animal reared, the time spent within the housing system and a set of emission factors. Tier 1 emissions factors from EMEP/EEA (2016) for PM_{10} and $PM_{2.5}$ emissions are given in the Workbook. For time spent in animal housing, EMEP/EEA (2016) default values are offered if local data are unavailable: 49% for cattle and horses, 38% for buffalo, and 100% for pigs and poultry.

6.2.4 Procedure for estimating emissions of ammonia and nitric oxide from fertilizer use

Emissions of ammonia (NH_3) and nitric oxide (NO) from fertilizer use are a function of the tonnes of nitrogen fertilizer applied by type of fertilizer (activity data in FAOSTAT[42]) and the emission factors. For NO, the Tier 1 EMEP/EEA (2016) emission factors are offered in the Workbook with emissions subsequently converted to the equivalent weight of NOx (as NO_2). For NH_3, the Tier 2 EMEP/EEA (2016) emission factors appropriate for temperate countries (annual ambient average temperature 15-25 °C) are offered in the Workbook. For cooler (< 15 °C) or warmer (>25 °C) countries, the user is referred to alternative values given

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[40] http://faostat3.fao.org/download/Q/QA/E
[41] IPCC (2006) https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf
[42] FAOSTAT http://www.fao.org/faostat/en/#data/RFB

in EMEP/EEA (2016)[43] (Section 3.D Crop production and agricultural soils, Table 3.3). To account for the increased rate of volatilization that occurs when ammonium sulphate and combined ammonium phosphates are used on calcareous soils, NH_3 emission factors for these two fertilizers are also offered for soils having pH greater than 7.0. Information on the extent and distribution of calcareous soils can be obtained from agricultural institutes in the relevant country.

6.2.5 Procedure for estimating emissions from burning of savannas

The IPCC Guidelines (1996)[44] describe emissions from prescribed burning of savannas as follows:

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

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

- Estimation of the amount of biomass burned (dry weight) based on the area of savanna burned in kilohectares (kha) during the inventory year, the fuel load biomass (not the same as total above ground biomass), and the fraction of this biomass that is actually burnt.
- Estimation of emissions of CO, NOx, SO_2, NMVOCs, particulate matter (PM_{10}, $PM_{2.5}$, BC and OC), NH_3 and CH_4 by multiplying the amount of biomass burned by emission factors for each pollutant.

Default factors [and reference source] included in the Workbook for use in these calculations are as follows:
- Fuel load biomass before burning (as dry tonnes/hectare): 4.9 [IPCC, 1996]
- Fraction of biomass actually burnt: 0.85 [IPCC, 1996]
- CO emission factor (kg/tonne biomass burned): 68 [Sinha et al., 2003][45]
- NO_x emission factor (kg (as NO_2)/tonne biomass burned): 5.1 [Sinha et al., 2003]
- SO_2 emission factor (kg/tonne biomass burned): 0.43 [Sinha et al., 2003]
- NMVOC emission factor (kg/tonne biomass burned): 3.4 [Sinha et al., 2003]
- PM_{10} emission factor (kg/tonne biomass burned): 10 [Sinha et al., 2003]
- $PM_{2.5}$ emission factor (kg/tonne biomass burned): 5.4 [Andreae and Merlet, 2001][46]
- BC emission factor (kg/tonne biomass burned): 0.39 [Sinha et al., 2003]
- OC emission factor (kg/tonne biomass burned): 2.3 [Sinha et al., 2003]
- NH_3 emission factor (kg/tonne biomass burned): 0.26 [Sinha et al., 2003]
- CH_4 emission factor (kg/tonne biomass burned): 1.7 [Sinha et al., 2003]

The default source of activity data (burned area of savannah + woody savannah) is the FAOSTAT online database[47].

6.2.6 Procedure for estimating emissions from burning of agricultural wastes

The procedure is adapted from the *EMEP/EEA Guidelines* methodology and includes the following:

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[43]https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/4-agriculture/3-d-crop-production-and/view

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

[45] Sinha, P., Hobbs, P.V., Yokelson, R.J., Bertschi, I.T., Blake, D.R., Simpson, I.J., et al., 2003. Emissions of trace gases and particles from savanna fires in southern Africa. *Journal of Geophysical Research* 108(D13), 8487, doi:10.1029/2002JD002325, 2003.

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

[47] FAOSTAT Area savannah burned http://www.fao.org/faostat/en/#data/GH

- Enter the amount (kilotonnes per year) of each crop produced (rice, wheat, millet, soya, maize, potatoes, jute, cotton, groundnut, sugarcane, rapeseed and mustard),

- For each crop, calculate of the amount of crop residue biomass burned (kt dry matter) based on the above crop production together with the residue to crop ratio, 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.

- For Maize, Rice, Sugarcane and Wheat, the dry matter biomass burned (tonnes) can be obtained directly from the FAOSTAT database[48].

- Estimation of emissions of SO_2, NO_X, CO, NMVOCs, CH_4, NH_3, PM_{10}, $PM_{2.5}$, BC and OC by multiplying the amount of crop residue burned by the emission factors for each pollutant.

In the Workbook, Tier 1 default values from EMEP/EEA (2016) are provided for dry matter fractions, fractions oxidised and most of the residue-to-crop ratios. EMEP/EEA (2016) Tier 2 default emission factors are offered for most pollutants apart from CH_4 and OC which came from Andreae and Merlet (2001), and SO_2 from Reddy and Venkataraman (2002). Also, crop-specific default residue-to-crop ratios, appropriate for LMICs, were sourced from TFAC (1991) and Tyagi (1989). The default source of activity data (crop production) is the FAOSTAT database[49].

6.2.7 Procedure for estimating emissions of methane from rice cultivation

The procedure is based on Tier 1 IPCC (2006) methodology and includes the following steps:

- Estimate the annual area of rice fields harvested (ha/yr) subdivided according to 3 types of rice ecosystem: *Irrigated* (fields are flooded for a significant period of time and water regime is fully controlled), *Rainfed and deep water* (fields are flooded for a significant period of time and water regime depends solely on precipitation) or *Upland*[50] (fields are never flooded for a significant period of time).

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

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

- As a starting point, a *baseline default emission factor* of 1.30 kg CH_4 ha^{-1} day^{-1} (from IPCC, 2006) for situations where: a) the paddy fields are not flooded during the 180 days prior to cultivation, b) they are continuously flooded during the cultivation period and c) there is no use of organic amendments.

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

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

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

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

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[48] FAOSTAT Crop residue dry matter biomass burned http://www.fao.org/faostat/en/#data/GI
[49] FAOSTAT Crop production quantity (tonnes) http://www.fao.org/faostat/en/#data/QC
[50] Note that for *Upland* rice cultivation, CH_4 emissions are zero even with organic amendments. This category is only included to enable the user to check that the total area under rice cultivation has been estimated correctly.

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

6.3 Sources of emission factors in literature and their limitations

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

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

7.1 Introduction

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

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

7.2 Procedures for estimating emissions from vegetation fires

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

- Enter the annual land area burnt in thousands of hectares (kha) for each vegetation category. These data can be obtained from the FAOSTAT online database as the element 'Burned Area' under the category 'Burning – Biomass'[51]

- The amount of biomass actually burned (Biomass consumption) in each applicable vegetation type is then estimated by multiplying the area burned by the biomass consumption rate (tonnes biomass burnt per hectare) after entering either locally-estimated or IPCC default values[52].

- Emissions of SO_2, NOx, CO, CH_4, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC and NH_3 are calculated by multiplying the biomass consumption by emission factors expressed as kg pollutant per tonne biomass burnt.

7.3 Sources of emission factor data

The emission factors for vegetation fires offered in the workbook are from Andreae and Merlet (2001)[53] for all pollutant species.

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[51] FAOSTAT http://www.fao.org/faostat/en/#data/GI

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

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

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

8.1 Introduction

Methods for treating and disposing of wastes include incineration/burning, disposal of wastes in landfills, and aerobic and/or anaerobic treatment of municipal sewage. The incineration and other burning of municipal solid wastes (MSW) and other industrial and commercial wastes constitutes a source of combustion-related emissions of SO_2, NO_X, CO, CH_4, NMVOC, NH_3 and particulate matter. Anaerobic decomposition of organic material within solid waste disposal sites (SWDS), commonly called 'landfill' sites, can be a major source of CH_4 emissions. 'Methane from domestic water' covers CH_4 emissions from the treatment and discharge of domestic wastewater (sewage).   Also, the storage of human excreta in latrines (simple dry toilets built outside the house) is often a significant source of NH_3 emissions.

8.2 Procedure selected for use in this Manual

8.2.1 Procedure for estimating emissions from combustion of solid wastes

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

- Estimate total amount of Municipal Solid Waste (MSW) generated by multiplying the population whose waste is collected (i.e. the urban population) by a per capita MSW generation rate (country specific values are given by the World Bank[54]).

- Estimate the fraction of total MSW which is disposed of by burning in incinerators. (Some country-specific data are included in Annex 2A.1 of the 2006 IPCC guidelines[55].)

- Estimate the fraction of total MSW which is disposed of by open-burning in back-yards, roads or open (unmanaged) dumps. [Unless better information is available, in poorer developing countries, it can be assumed that all MSW generated is available to be open-burnt in one way or another, approximately 60% of which is actually burnt in the open (Wiedinmyer, Yokelson and Gullett, 2014[56])]

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

- Estimation of emissions of SO_2, NO_X, CO, CH_4, NMVOCs, PM_{10}, $PM_{2.5}$, BC, OC and NH_3 by multiplying the amount of waste burned for each waste incinerator type by emission factors (locally-derived or default values) for each pollutant. For MSW, the default EFs are mainly from Akagi et al. (2011) for open burning and EMEP/EEA (2016) for incinerators (Tier 1 for modern and Tier 2 for uncontrolled plant). For industrial/commercial waste, default emission factors are mainly EMEP/EEA Tier 1 defaults for modern plant and US EPA (1995) defaults for uncontrolled plant.

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

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

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[54] Hoornweg, D, Bhada-Tata, P., 2012. What a waste: A global review of solid waste management. Annex J – MSW generation by country.   http://documents.worldbank.org/curated/en/302341468126264791/pdf/68135-REVISED-What-a-Waste-2012-Final-updated.pdf

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

[56] Wiedinmyer, C., Yokelson, R. J., & Gullett, B. K. (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. *Environmental Science and Technology*, 48(16), 9523–9530. https://doi.org/10.1021/es502250z

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

- Estimate the per capita Municipal Solid Waste (MSW) generation rate (country specific values are given by the World Bank as described above for MSW combustion).

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

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

- Enter default or country-specific values for **MCF** (methane correction factor) - which accounts for the effect of SWDS management practice; **DOC** (degradable organic carbon) – the fraction of organic carbon that is degradable; DOC_F – the fraction of DOC that decomposes under anaerobic conditions; **F** (fraction of methane in generated landfill gas); **R** (recovered CH_4) - the proportion of methane generated in the SWDS that is recovered and combusted in a flare or energy device; and **OX** (oxidation factor) – which reflects the amount of CH_4 from the SWDS that is oxidised in the soil or other material covering the waste. Ranges of values are offered in the Workbook for the default fraction MSW disposed to SWDS and for the DOC fraction with footnotes directing users to the relevant IPCC (2006) tables to find country- or region-specific values.

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

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

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

8.2.4 Procedure for estimating ammonia emissions from latrines

The suggested procedure for the estimation of annual emissions of ammonia from latrines is based on the EMEP/EEA (2016) 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 an assumption that during storage of excreta in latrines for one year, about 30 percent of the nitrogen is emitted as ammonia. In certain developing countries, a significant proportion of the rural populations may simply defecate and urinate outside in the open fields or bush. Bouwman et. al. (1997) present typical 'meadow' ammonia-N annual losses of 15 percent for cattle, buffalo, camels and horses in developing country regions (compared with 28- 36 percent for animal housing). In the absence of a specific emission factor, it may be assumed that the ammonia-N loss rate for human open defecation/urination is also reduced by approximately half and that the appropriate default emission factor is therefore 0.8 kg NH_3 per year per person.

8.3 Application of parameters for control equipment

For waste incinerators, switching activity (waste burnt) in spreadsheet from uncontrolled to modern plant will achieve reduced 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. For methane emissions from MSWD (landfill) and from wastewater treatment, the amount of methane recovered for energy use or flared is explicitly accounted for.

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.* [57].

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

- Power plants with thermal input capacity >=300 MW

- Refineries

- Sulphuric acid plants

- Nitric acid plants

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

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

- 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

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[57] 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.

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 1º x 1º grid code)

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

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

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

- *Measured pollutant emissions* (where available)

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

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

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

9.3   Temporal aspects of modelling large point sources

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

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

10. Guide to use of Excel Workbook for emissions compilation

10.1 Introduction

In order to provide a standardized structure for use in compiling inventories of air pollutants, an Excel workbook template is provided. This workbook, entitled **FORUM Workbook Version 7.5.0**, is intended to provide a structure for input activity data and emission factors, areas for calculation of intermediate and final emissions, areas for tabular reporting of results, and areas for annotations of data sets, as well as tools for moving from place to place within the workbook and for accomplishing inventory preparation functions. The workbook is designed to be flexible enough to accommodate the range of emissions situations and modelling requirements that exist across the countries of the region. Also, because it is a workbook template rather than a dedicated piece of software, the workbook can be modified (albeit carefully) by users in order to conform to data availability and modelling needs (for example) in each individual country. However, to edit areas other than data input cells (e.g. if the user needs to add another row) the worksheet will have to be 'unprotected' using a password ("RAPIDC") After inserting a row, any green calculation areas will then have to be filled with the appropriate calculation formulae, usually by dragging down the fill handle of the cell immediately above. The sheet should then be protected again after the editing session. ***Only experienced Excel spreadsheet users should attempt to unprotect and modify worksheets.*** Backup copies should be made of the Workbook, both initially and regularly during inventory construction, in case any major and irretrievable errors occur during such editing sessions. The remainder of this Chapter provides an overview of the structure and main elements of the workbook.

10.2 General structure of the workbook

10.2.1   Division into worksheets

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

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,**

[Back to Main Menu]   **Manufacturing Industries and Construction,**
Transport, and
Other Sectors

1.1 General fuel combustion worksheets

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[GO] Sheet: 1.7.2 Ammonia (NH_3) combustion emissions (tonnes)

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

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

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

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

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

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

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

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

Back to Main Menu

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

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

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

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

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

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

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

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

Back to Main Menu

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

GO Sheet 1.9.2 Emissions for LTO activities of international aviation.

GO Sheet 1.9.3 Mobile emissions for on-road vehicles.

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

Sector 6. Industrial processes (non-combustion) emissions

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

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

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

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

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

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

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

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

Sector 7. Solvent and Other Product Use

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

Box 10-7: Menu 6 - Agriculture

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

GO Sheet: 4.2 Particle emissions from animal housing

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

GO Sheet: 4.4 Savanna burning.

GO   Sheet 4.4.1 Temporal distribution of savanna burning emissions

GO Sheet: 4.5 Emissions from agricultural residue burning.

GO Sheet: 4.6 Methane emissions from rice cultivation.

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

Sector 9. Vegetation fires and Forestry.

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

Box 10-9: Menu 8 – Waste

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GO Sheet: 6.1 Emissions from waste incineration

GO Sheet: 6.2 Ammonia emissions from human excreta

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

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

Box 10-11: Menu 9 – Large Point Sources

Large Point Sources

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

GO Sheet 8.1.1 Large point source combustion emissions - sulphur dioxide (SO2)

GO Sheet 8.1.2 Large point source combustion emissions - nitrogen oxides (NOx)

GO Sheet 8.1.3 Large point source combustion emissions - carbon monoxide (CO)

GO Sheet 8.1.4 Large point source combustion emissions - NMVOCs

GO Sheet 8.1.5 Large point source combustion emissions - PM_{10}

GO Sheet 8.1.6 Large point source combustion emissions - $PM_{2.5}$

GO Sheet 8.1.7 Large point source combustion emissions - ammonia (NH3)

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

GO Sheet 8.2.1 Large point source process (non-combustion) emissions, sulphur dioxide (SO2).

GO Sheet 8.2.2 Large point source process (non-combustion) emissions, nitrogen oxides (NOx).

GO Sheet 8.2.3 Large point source process (non-combustion) emissions, carbon monoxide (CO).

GO Sheet 8.2.4 Large point source process (non-combustion) and fugitive emissions, NMVOCs.

GO Sheet 8.2.5 Large point source process (non-combustion) and fugitive emissions, particulate matter, (PM_{10} and $PM_{2.5}$).

GO 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. **CAUTION**: If you enter data into the wrong cell(s), **do not use 'cut and paste' within the worksheets** to shift data into correct cells as you will destroy the cell references for the linked green calculation cells. So if you enter data into the wrong cell(s), you may 'copy and paste' into the correct cell(s) and then go back and delete the wrong data entries,
or simply type data into the correct cells and then delete the wrong data entries.

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

Reference sources for the activity data should be entered into the table at the bottom of the worksheet. For other types of data (such as sulphur content and Net Calorific Values (NCVs) of fuels, emission factors), default values or ranges are generally offered in the worksheets. The default values are mostly from U.S. or European sources although some are more specific to non-OECD regions (e.g. South African emission factors for savanna burning, domestic biomass fuel combustion). Default data and factors are included so that users lacking country- or regionally-specific data or factors can still produce an emissions inventory without having to wait for the data/factors to become available. Internationally available sources of activity data are also suggested, where possible, in case more reliable nationally sourced data are not readily available.

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

10.2.3   General data output/report areas

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

10.2.4   Summary results worksheet and graphs

The emissions summary sheet (**Summary 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.

Results from the summary sheet are also aggregated into 17 sub-sectors in a **Summary table for graphs** which then links to subsequent worksheets showing various graphs of all emissions by sector and of individual pollutant species by sector.

Box 10-10: Summary worksheet (Sheet 9)

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

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

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Annex 1: Emissions from Natural Sources

A1.1 Introduction

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

Natural sources include:

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

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

- **Biogenic emissions of NH₃ 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 NH₃ 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 SO₂ 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/EEA approach, biogenic NMVOC emissions from living trees in managed forests are considered to be 'natural' for the purposes of the Forum Manual and are therefore, not to be formally inventoried

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

A1.4 Biogenic emissions of NH₃ 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)[58]. 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	NH₃ emission factor (tonnes/km²/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 NOₓ from non-agricultural soils (Forests and grasslands)

Although this source is not covered in the IPCC (2006) Guidelines, two methods are offered in the EMEP/EEA (2016) Guidebook. In the simple method, a background emission rate of 0.1 ng NO-N m^{-2} s^{-1} is assumed in addition to 0.3% of applied N (returned to the atmosphere as NO) from animal manure and atmospheric deposition for non-agricultural areas . This method is only appropriate where N-deposition estimates are available. The detailed methodology is based on the Biogenic Emissions Inventory System (BEIS-2) 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.

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

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[59] have shown that high concentrations of alkaline dust are an important feature of the atmosphere in large parts of China, and that base cation deposition must be taken into account when discussing the possible effects of acidic deposition on soils and vegetation. There are two main sources of base cation deposition: the uplift and transportation of soil dust in the atmosphere and particulates emitted from anthropogenic sources. The relative importance of industrial sources will depend on the extent of dust control technology used.

Base cation emission and deposition related to wind-blown dust are not currently accounted for by international inventory-building methodologies such as those described by EMEP/EEA 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[60]) 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

[59] Larssen, T and G.R. Carmichael (2000) Acid rain and acidification in China: The importance of base cation deposition. *Environmental Pollution*, **110**:89-102.
[60] 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.

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[61] and others. Gillette estimated the uplift of dust to be:

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

Where:

Qa is the dust flux from the surface

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

u is the wind speed, and

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

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[62,63] and in Asia by Chang et al[64]. 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[65] estimated the percent calcium (associated with carbonate) to be 5 to 10 percent.

[61] 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.

[62] 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.

[63] 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.

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

[65] 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: Speciation of pollutant emissions

A2.1 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.

A2.2 The need for speciation of VOC

Ground level ozone is a secondary pollutant that results primarily from photochemical interactions between volatile organic compounds (VOCs), carbon monoxide (CO) 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.

A2.3 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)[66]. The EMEP ozone model uses a simplified mixture with seven "representative compounds" chosen to represent the normal range of ozone creating potential for most organic pollutants. The EMEP representative compounds are: ethane, ethanol, *n*-butane, *o*-xylene, propene, ethene and "unreactive".

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

A2.4 Sources of speciation factors in the literature

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[66] 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.

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

A2.5 Speciation models

A convenient model for the speciation of VOC/NMVOC emissions is called 'SPECIATE' and is available from the USEPA[67]. SPECIATE is a software system for speciating organic compounds and particulate matter that was developed to:

- create speciated emissions inventories for regional haze, PM, greenhouse gas (GHG), and photochemical air quality modelling;
- estimate hazardous air pollutant (HAP) and toxic air pollutant (TAP) emissions from PM and organic gas primary emissions;
- provide input to the Chemical Mass Balance (CMB) receptor model; and,
- verify profiles derived from ambient measurements by multivariate receptor models (e.g., factor analysis and positive matrix factorization).

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[67] https://www.epa.gov/air-emissions-modeling/speciate