METHODOLOGIES FOR GHG EMISSIONS INVENTORIES AND PARIS AGREEMENT REPORTING: A PRACTICAL HANDBOOK

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Methodologies for GHG Emissions Inventories and Paris Agreement Reporting: A Practical Handbook

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ACRONYMS

BOD – biochemical oxygen demand

BOD5 – 5-day biochemical oxygen demand

HFCs – hydrofluorocarbons

HFC-23 – trifluoromethane

HCFC-22 – chlorodifluoromethane

LULUCF – land use, land use change and forestry

HWP – harvested wood products

FOD – first order decay

IGCE – Yu.A. Izrael Institute of Global Climate and Ecology

MSW – municipal solid waste

NMVOC – non-methane volatile organic compounds

IPCC – International Panel on Climate Change

DOM – dead organic matter

INDC – individual nationally determined contribution

GHG – greenhouse gases

IPPU – industrial processes and product use

PFCs – perfluorocarbons

UNFCCC – United Nations Framework Convention on Climate Change

C – carbon

SWDS – solid waste disposal sites

TFT-FPD – thin-film-transistor flat panel display

FAO – UN Food and Agriculture Organization

FCs – fluorinated compounds

PV – photovoltaics

COD – chemical oxygen demand

TFI – Task Force on National Greenhouse Gas Inventories

CH_4 – methane

CO – carbon monoxide

CO_2 – carbon dioxide

CRF – common reporting format

HNO_3 – nitric acid

N – nitrogen

N_2O – nitrous oxide

Na_2CO_3 – sodium carbonate

NAI – non-Annex I national communication reporting tables

NH_3 – ammonia

NO_x – nitrogen oxides

SF_6 – sulfur hexafluoride

SO_2 – sulfur dioxide

TiO_2 – titanium dioxide

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INTRODUCTION

The development of **A Practical Handbook on Methodologies for GHG Emissions Inventories and Paris Agreement Reporting** was made possible through the ESCAP regional project on Supporting countries in Asia-Pacific to meet commitments to the Paris Agreement funded by the Russian Federation.

The text of the book is a print version (in Russian and English) of an online tool, which is intended to support the estimation of GHG emissions and the preparation of national inventories by Central Asian and other countries, which are non-Annex I parties under the UNFCCC. An interactive version of the tool is available upon registration at: http://escap.igce.ru/

The target audience includes the personnel of organizations responsible for the estimations and preparation of national GHG reports (inventories).

The Guidance contains recommendations for each sector and a description of source categories included in each sector, as well as references, clarifications, and useful tips to support the estimation and inventory efforts. All leaks in the interactive version lead directly to the required section pages, original data sources, or useful supplementary resources (see Figure 1).

All the recommendations and methodological approaches to estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol build on the methodology provided in the 2006 IPCC Guidelines and additional

methodologies coordinated with the UNFCCC Conference of Parties. Where appropriate, approaches to, and examples of, using national methodologies which best reflect the national circumstances are provided, on condition that such methodologies are consistent with the IPCC Guidelines, scientifically based and properly documented.

Today, non-Annex I parties are not required to follow the 2006 IPCC Guidelines, but the methodological approaches to reporting greenhouse gas (GHG) emissions and removals under the Paris Agreement are expected to be broadly similar to those currently used by Annex I parties to the UNFCCC in their national GHG emissions and removals inventories.

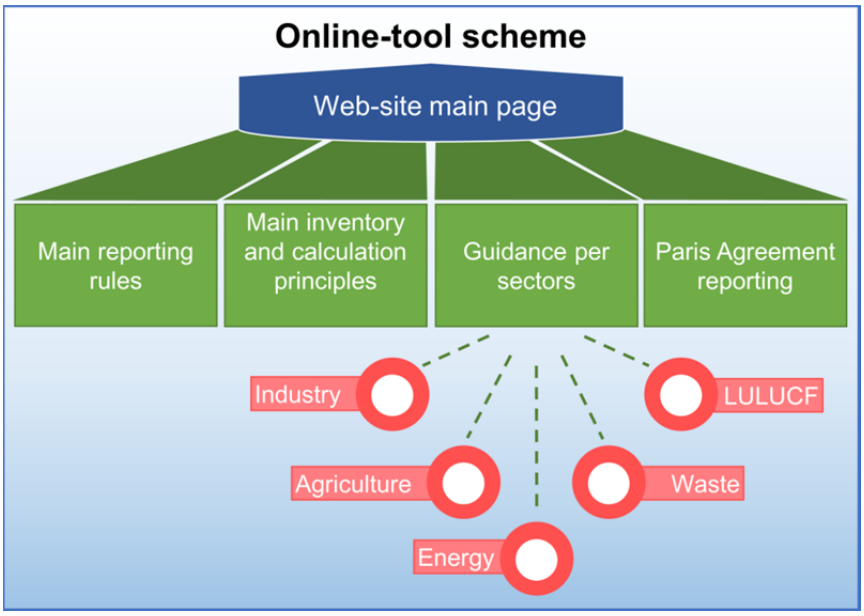

Figure 1. Information presentation outline as per the Guidance and pages outline at http://escap.igce.ru/

Each section of the Guidance, which describes a particular sector, provides a description of the source categories; methodological approaches to estimating GHG emissions and/or removals; approaches to selecting activity data and estimation parameters; cross-cutting issues; completing the reporting tables; quality control and uncertainty estimates; recommendations for how to address typical problems; availability of a refinement for a specific source category in 2019 Refinement to the 2006 IPCC Guidelines.

The final section discusses the decisions of the Paris Agreement on the national greenhouse gas inventories, including the methodological issues; formats and schedules for submitting the national inventories; procedures and schedules for reviewing the inventories; and the flexibility framework for the developing countries.

The materials were finalized based on two training seminars: one for experts from Kazakhstan (in November 2020) and the other for experts from five Central Asian countries (in May 2021).

GENERAL PRINCIPLES FOR ESTIMATING EMISSIONS

I. Methodological issues

Methodologies that are to be used for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol and for preparing national inventories are provided in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). According to the decision made by the Conference of Parties, the IPCC Guidelines are mandatory for the preparation of national inventories by Parties included in Annex I to the UNFCCC.

Along with the mandatory 2006 IPCC Guidelines, the UNFCCC Conference of Parties recommended voluntary use of 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC, 2014) for the preparation of inventories.

Another methodological development by IPCC, namely, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019), is yet to be reviewed and adopted by the Conference of Parties as guidelines for the preparation of national inventories.

Greenhouse gas emissions and removals are estimated for individual **categories** or sub-categories and are grouped by 5 sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture; Land Use, Land Use Change and Forestry (LULUCF); and Waste.

Key categories are those that have a significant influence on a country's total greenhouse gas emission in terms of emissions/removals level, trend (change in time), or uncertainty. Methodological approaches to the determination of key categories are provided in the IPCC Guidelines. Key categories should be given a higher priority in terms of resource allocation for the preparation of national inventories, including data collection, summarizing, quality assurance/quality control, and reporting. Methodologies that ensure a higher accuracy of emissions/removals estimates should be used for the key categories.

Good practice is a set of methodological approaches, actions, and procedures that are used for the preparation of national inventories. Inventories that are in line with good practice are those that do not, as far as can be judged, over- or underestimate emissions or removals, and in which uncertainties are minimized as practicable. The IPCC Guidelines provide good practice guidance for specific categories and for general sections of inventories.

The IPCC Guidelines provide 2 or 3 methodologies for estimating emissions or removals for each specific category; these methodologies differ in complexity and requirements for baseline information. They are called **Tier 1, 2, and 3** methodologies and are ranked in increasing complexity from Tier 1 to Tier 3. The choice of methodology is determined by specific national circumstances. Guidance on the methodological choice is provided in the IPCC Guidelines. One example of such choice is shown in Figure 2.

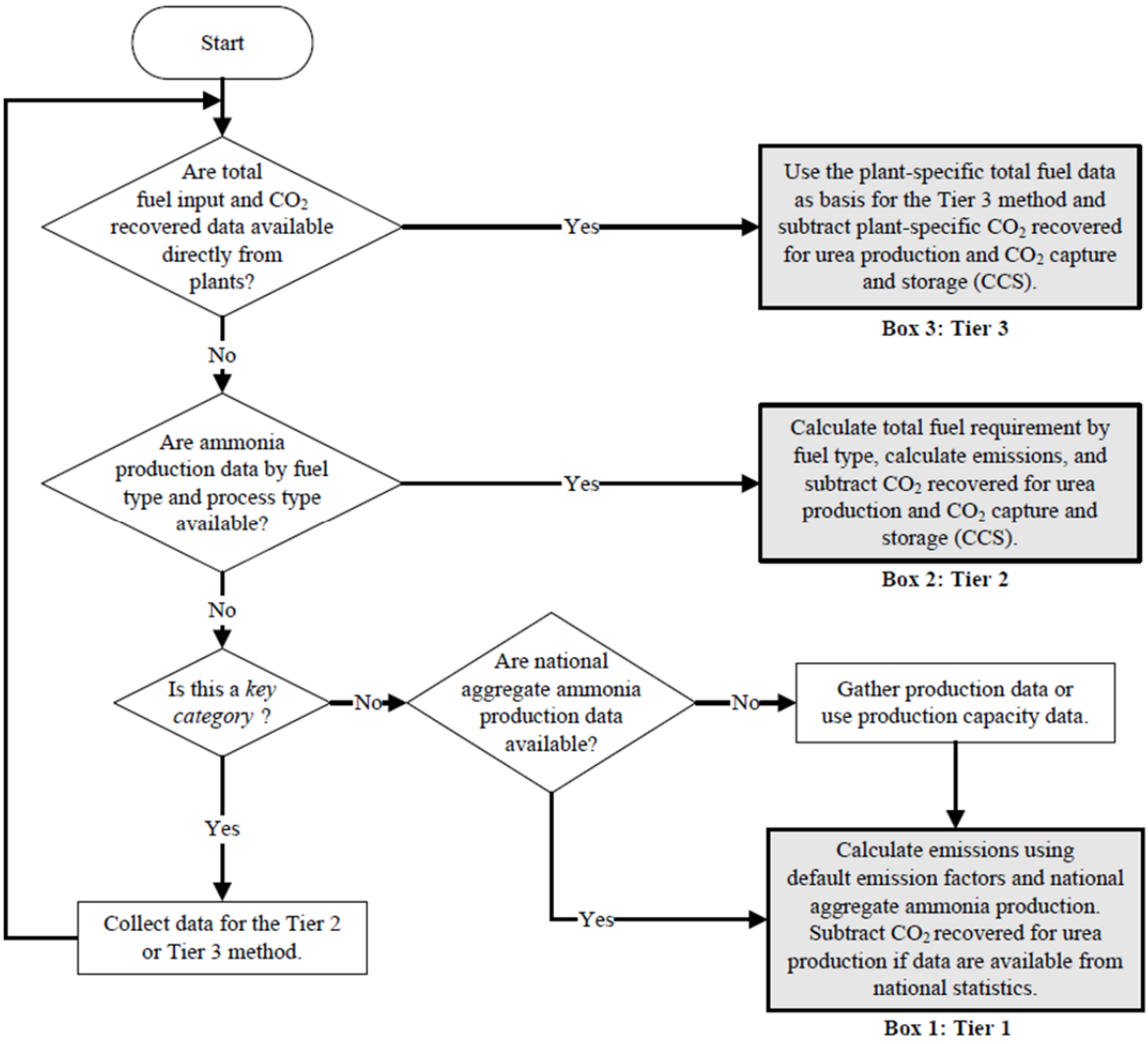

Figure 2. Decision tree for estimation of CO2 emissions from ammonia production (IPCC, 2006)

The IPCC Guidelines provide **recalculation** methods for previous estimates of emissions and removals (such recalculations are made by inventory developers, as needed, for some years covered by the inventory or for the entire time series). The IPCC Guidelines also provide methods for inventory **quality assessment / quality control**.

Figure 3 (IPCC, 2006) illustrates the annual inventory development cycle.

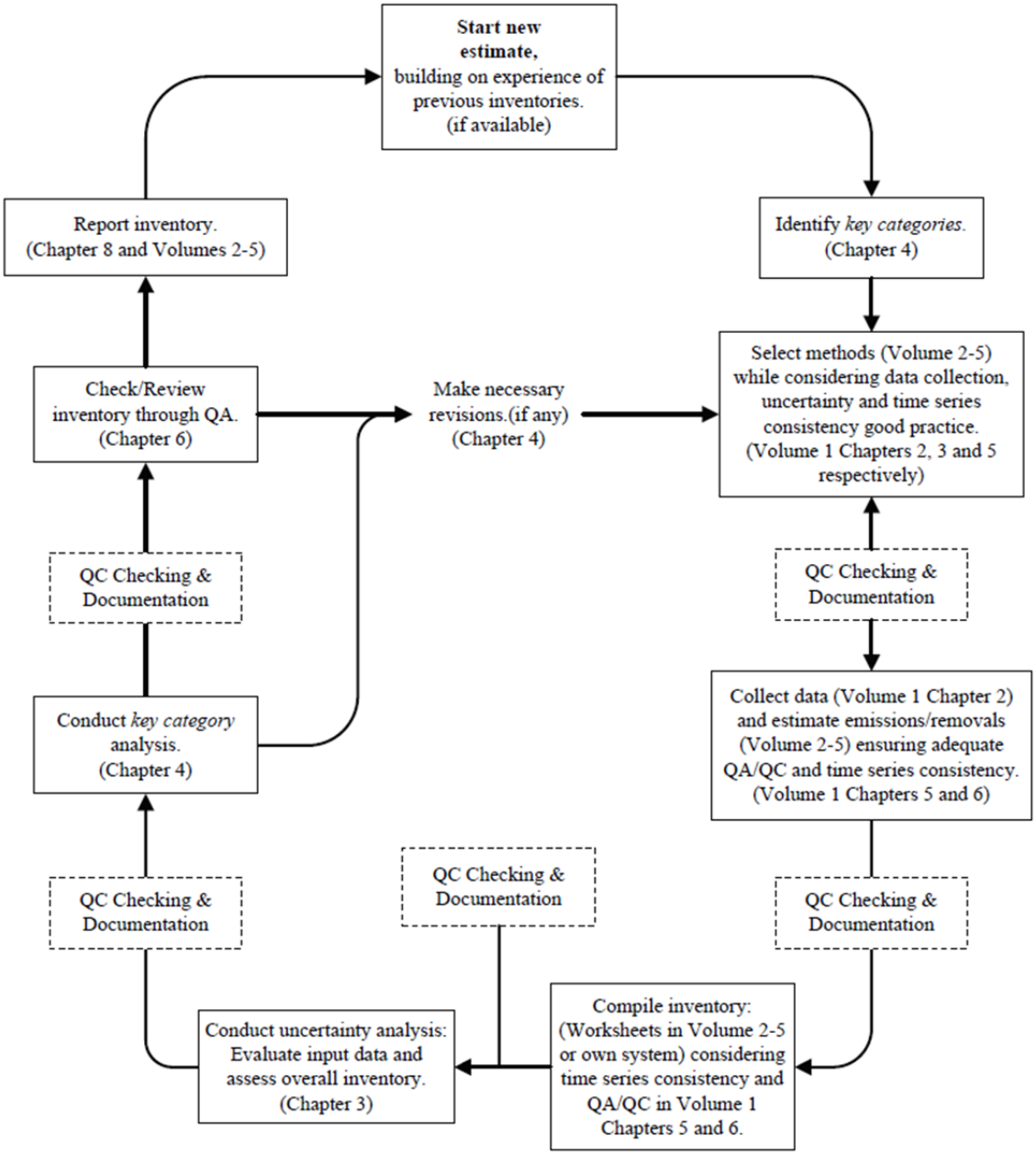

Figure 3. Inventory development cycle (terms 'volume' and 'chapter' refer to relevant volumes and chapters of the IPCC Guidelines (IPCC, 2006)

II. IPCC software for greenhouse gas emission estimation

Task Force on National Greenhouse Gas Inventories (TFI)[1] has developed IPCC Inventory Software, a special tool for greenhouse gas emission estimation. The purpose of this tool is to assist in using the methodologies provided in the IPCC Guidelines either for the preparation of complete national inventories or for the estimation of emissions and removals for separate categories or groups of categories. This IPCC Inventory Software is available free of charge for non-commercial purposes; an updated version can be downloaded from the TFI website.[2,3]

[1] https://www.ipcc-nggip.iges.or.jp
[2] https://www.ipcc-nggip.iges.or.jp/software/index.html

This software has not been subject to formal IPCC review process yet, therefore, whilst the information contained therein is believed to be true and accurate, the IPCC and its Task Force on National Greenhouse Gas Inventories cannot accept any legal responsibility or liability for any error or omission. In other words, users are fully responsible for the use of this software.

IPCC Inventory Software includes a database and a number of software modules to estimate emissions and removals and develop final reports in accordance with the IPCC Guidelines. If need be, this tool can be used also for the estimation of emissions/removals and for the preparation of reports using the methodology provided in the earlier Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). IPCC Inventory Software implements Tier 1 methods for all sectors and Tier 2 methodologies for most source categories for Energy; Industrial Processes and Product Use; Waste; Agriculture; and Land Use under the 2006 IPCC Guidelines. Currently, TFI is working to improve the software and expand the list of categories covered therein.

The primary target groups of users of IPCC Inventory Software are greenhouse gas inventory compilers, trainers and trainees on national GHG inventory compilation, and Parties not included in Annex I of the Convention having limited resources without their own GHG inventory systems. The default language of the software is English, yet users can use a special module for translation and switch between languages.

IPCC Inventory Software User Manual (IPCC, 2020) was developed to assist the users.

The basic approach of the software is to facilitate filling out the IPCC Guidelines category worksheets with the activity and emission factor data. For this purpose the database contains default data from the IPCC Guidelines, which, however, can be replaced with national factors and parameters, if need be. All activity data can be imported as MS Excel or XML files.

In addition, IPCC Inventory Software supports many other functions related to database administration, quality control, data export/import, as well as data reporting.

In addition to doing calculations for GHG emission reporting tables for Annex I Parties in accordance with the IPCC Guidelines, the software helps:

- estimate uncertainties;
- make key category analysis;
- use Notation Keys;
- develop user's tables of activity data, parameters, emission factors, and GHG emission estimates;
- present the values of selected parameters by years in the form of graphs.

[3] Any publication of results obtained with this software shall acknowledge its use as follows: IPCC Inventory Software (Version X.XX). Produced by IPCC Task Force on National Greenhouse Gas Inventories.

The activity data used and the results obtained can be exported as MS Excel or XML files.

In addition, IPCC Inventory Software allows for the calculation and export of non-Annex I (NAI) national communication reporting tables. NAI reporting tables format corresponds to Tables 1 and 2 from the Annex to Decision 17/CP.8 of the Conference of Parties (Guidelines for the preparation of national communications from Parties not included in Annex I to the Convention).

IPCC Inventory Software allows for the sharing of the database for simultaneous and joint work on all inventory sectors (or groups of categories) by providing a safe and simple method of data exchange between the users.

TFI and its Technical support unit provide continuous support to the software and the users, including by organizing:

- annual meetings and expert training;
- user support service[4];
- a forum to discuss current issues concerning IPCC Inventory Software.[5]

[4] ipcc-software@iges.or.jp
[5] https://discussions.zoho.com/ipccinventorysoftware/

KEY REPORTING RULES

I. General issues of inventory preparation and submission

National inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol (hereinafter referred to as inventories) are developed by all Parties included in Annex I to the UNFCCC (hereinafter referred to as the Parties) annually and are submitted to the UNFCCC within the time frame set by the Conference of Parties. The inventories include two parts: National Inventory Reports (NIR) and Common Reporting Format (CRF) tables. The Parties that are also Parties to the Kyoto Protocol include additional information in their inventories to comply with the requirements of the Kyoto Protocol.

Requirements for the preparation and submission of the inventories are specified in the UNFCCC Guidelines approved by the 19th Conference of Parties (UNFCCC, 2013). The Guidelines also include requirements for national inventory arrangements to ensure the timely development of **complete, consistent, comparable, and transparent** annual inventories.

In the context of the UNFCCC Guidelines:

- **Completeness** means that the inventory covers at least all sources and sinks, as well as all gases for which the 2006 IPCC Guidelines (hereinafter referred to as the IPCC Guidelines) (IPCC, 2006) present methodologies, or for which the UNFCCC Conference of Parties has agreed on additional methodologies. Completeness also means full geographical coverage of sources and sinks in the territories of the Parties;
- **Consistency** means that the inventory ought to be internally consistent across all reporting years in all its elements by sector, category, and gas. An inventory is consistent, if the same

methodologies are used for the base year and all subsequent years, and if consistent datasets are used to estimate emissions by sources or removals by sinks. Under certain circumstances[6], an inventory prepared using different methodologies for different years can be considered consistent, if it has been transparently recalculated as directed by the IPCC Guidelines;

- **Comparability** means, that estimates of emissions and removals reported by the Parties in their inventories should be comparable across the Parties. To this end, while making assessments and developing inventories the Parties should use methodologies and formats agreed upon by the Conference of Parties to the UNFCCC. The order of presenting source/sink **categories** is to be in line with the CFR tables at the level of summary tables and sectoral tables;
- **Transparency** means that data sources, assumptions and methodologies used in the inventories should be clearly explained to facilitate the reproduction and evaluation by users of the information presented in the inventories. The use of the CRF tables and preparation of a structured NIR contribute to the transparency of information and facilitate the review of national and international inventories;
- **Accuracy** means that estimates of emissions and removals should be accurate in the sense that, as far as could be judged, they do not systematically over- or underestimate true emissions or removals, and that the estimation uncertainties are reduced as practicable.

II. Methodological issues

To estimate anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, the Parties should use the methodologies presented in the IPCC Guidelines, unless otherwise specified in the UNFCCC Guidelines, and any additional methodologies agreed upon by the Conference of Parties to the UNFCCC, as well as by other relevant decisions adopted by the Conference of Parties. In addition, national methodologies can be used, which the Parties believe best reflect their national circumstances, providing that such methodologies are compatible with the IPCC Guidelines, are properly documented and scientifically based.

[6] These circumstances are specified in the UNFCCC Guidelines.

Greenhouse gas emissions and removals are divided into main sectors which are groupings of relevant processes, sources, and sinks:

- ***Energy (the energy sector includes emissions from all types of fossil fuel combustion, regardless of the sectors or processes where such combustion takes place. The energy sector also includes fugitive emissions, which are process emissions, gaseous leaks of fuel into the atmosphere, and fuel combustion for purposes other than energy production, including gas flaring)***
- ***Industrial processes and product use (IPPU)***
- ***Agriculture***
- ***Land Use, Land Use Change and Forestry (LULUCF)***
- ***Waste***
- ***Other (if applicable)***

Each sector comprises individual categories (e.g., transport) and sub-categories (e.g., railroad transport).

With regard to the categories[7] which were determined by the IPCC Guidelines as **key categories**, every effort should be made to use the IPCC recommended method for estimating emissions/removals. Every effort should also be made to develop and/or select emission factors (EFs) and to collect and select activity data (AD) in accordance with IPCC **good practice**. Where national circumstances do not allow for the use of the method recommended by IPCC, the reasons why the Party was unable to use it shall be specified in the inventory.

For each source or sink category, the IPCC Guidelines provide two or more methodologies (Tiers) for estimating greenhouse gas emissions or removals. **Tier 1 methodologies** are the simplest and require the least resources to collect the required data and to estimate emissions. **Tier 2 and 3 methodologies**, in addition to directly calculating emissions/removals, can use approaches, such as compilation of a mass balance, collection of the necessary information from companies, etc. Looking to ensure the correct approach to selecting methodologies, the IPCC Guidelines include decision-making plans ("decision trees").

The IPCC Guidelines provide default methodologies, which include default emission factors and, in some cases, default activity data for specific categories. Such methodologies fall into Tier 1. Since the assumptions implicit in these methods, factors, and data may not be appropriate for specific national circumstances, the Parties should use their own national emission factors and activity data, where available, providing those were developed in accordance with the IPCC Guidelines and are considered more accurate, than the IPCC defaults. Where such country-specific information is not available, emission factors or other parameters provided in the IPCC emission

[7] The term 'categories' refers both to sources and sinks.

factor database (if any) may be used,[8] providing that the Party can demonstrate that these parameters are appropriate for its specific national context and are more accurate than the IPCC defaults. The inventory should include a transparent explanation of which data, factors, or parameters were used.

The inventory ought to include the results of key category identification for the base year and the latest inventory year. Key categories are determined by the level and trend of emissions and removals, including and excluding land use, land use change and forestry (LULUCF).

The Parties are required to quantitatively estimate the uncertainty of the data used for all source and sink categories using at least **Approach 1** of the IPCC Guidelines and report such estimates in the inventory for at least the base year and the latest inventory year. Uncertainty estimates for the trend between these two years shall also be reported in the inventory. It is recommended to use **Approach 2** or a hybrid of Approaches 1 and 2 presented in the IPCC Guidelines, because Approach 1 has certain technical limitations. Quantitative uncertainty of the data should be discussed in the NIR for all categories, and above all for categories that were identified as key categories.

For the whole time-series, including the base year and all subsequent years, inventory estimates should be made using the same methodologies, and corresponding AD and EFs should be obtained and used in a consistent manner to ensure that changes in emission trends do not stem from changes in estimation methods or assumptions in a time-series of estimates.

Emissions and removals need to be recalculated to improve the accuracy and/or completeness of the inventory. The grounds for recalculations are discussed in more detail in the IPCC Guidelines. In particular, the Parties should assess the need for recalculations for the key categories. When making recalculations, it is important to ensure the consistency of time-series. If the methodology or manner of collection of corresponding AD and EFs changes, the inventory is to be recalculated for the base year and subsequent years of the time-series. Methodologies for recalculations are provided in the IPCC Guidelines.

In some instances it may be impossible to use the same methods and consistent datasets for all years because of the lack of AD, EFs or other parameters directly used to obtain emission estimates for some historic years, including the base year. In such cases, it may be necessary to recalculate emissions or removals using alternative methods. Such methods are provided in the IPCC Guidelines. Information about the methods used should be documented and included in the inventories.

[8] https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

Each Party develops a quality assurance / quality control (QA/QC) plan for the inventory and implements general quality control procedures in accordance with this plan following the IPCC Guidelines. In addition, category-specific quality control procedures should be applied for the key categories and for those individual categories in which significant methodological changes and/or data revisions have been made. In addition, the Parties are required to conduct basic expert peer reviews of their inventories in accordance with the IPCC Guidelines; such reviews are also part of the quality control procedures.

The UNFCCC Guidelines include requirements for **national inventory arrangements.** In particular, they include requirements to the development and operation of systems that support emissions and removals estimation, to work planning, and to the preparation and management of inventories.

In accordance with these requirements the Parties shall:

- Establish and maintain the necessary institutional, legal, and procedural arrangements between the government agencies and other entities;
- Ensure that the necessary resources and qualified personnel are recruited for the timely development of inventories in compliance with the requirements specified in the IPCC Guidelines;
- Designate a single national authority with overall responsibility for the national inventory;
- Prepare annual national inventories in a timely manner in compliance with the IPCC Guidelines and relevant decisions of the Conference of Parties and submit relevant information in its entirety;
- Carry out planning and preparation of the inventory in compliance with the list of required procedures (as specified in the IPCC Guidelines).

III. Content of inventories and UNFCCC submission requirements

Each inventory should include complete time-series which start with the base year and end in (X-2) year, where X is the year of the inventory submission.[9]

In accordance with the UNFCCC Guidelines, inventories shall include data on anthropogenic emissions by sources and removals by sinks of at least the following greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). In addition, the Parties may include information on the following precursor gases: carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), and sulfur oxides (SO_x). As a memo

[9] For example, the inventory to be presented to the UNFCCC in 2021 should include data from the base year to 2019.

item,[10] the Parties may include indirect N_2O emissions in their inventories, excluding emissions from the Agriculture and LULUCF sectors. The Parties may also include information on indirect CO_2 emissions in their inventories; total national emissions should then be calculated including and excluding indirect CO_2 emissions. Emissions should be reported in units of mass.

Emissions and removals are to be reported in inventories separately for each gas. Emissions by sources should be reported separately from removals by sinks, unless it is technically impossible (in the LULUCF sector). For PFCs and HFCs, which are groups of gases, data for each gas should be reported separately.

The Parties are to include total national emissions and removals expressed in CO_2 equivalent ($CO_{2eq.}$) in their inventories. Conversion factors from emissions of individual gases into $CO_{2eq.}$ (these factors are called **global warming potentials**) are provided in the Annex to UNFCCC Guidelines.[11]

Emissions from fuel used by international aviation and maritime transport (also known as international **bunker fuel** emissions) are not to be included in national total emissions. The Parties should calculate these emissions, yet the values ought to be reported separately as memo items.

It is important to clearly indicate how feedstocks and non-energy use of fuels are accounted for in the inventory under the energy or industrial processes sector.[12]

Emissions and removals should be reported in the inventory at the most disaggregated level of each source/sink category,[13] however, a minimum level of aggregation may be used to protect confidential business and military information.

Where methodological or data gaps exist in inventories, information on these gaps should be presented in a transparent manner. It is important to clearly indicate the sources and sinks which are not considered in the inventories but which are included in the IPCC Guidelines, and explain the reasons for such exclusion. The Parties should indicate the parts of their geographical areas, if any, not covered by their inventories and explain the reasons for their exclusion.

The following notation keys should be used to fill in the blanks in all CRF tables: NO (not occurring), NE (not estimated), NA (not applicable), IE (included elsewhere), C (confidential). The specifics of the use of the symbols are described in the UNFCCC Guidelines. If a Party considers that a disproportionate amount of effort would be required to estimate emissions/removals under a

[10] Data included in the inventories as memo items are not to be taken into account by Parties when estimating their total national emissions.

[11] Reporting under the Paris Agreement will use global warming potential values that are different from those currently used in the inventories.

[12] Relevant methodological aspects are considered in the IPCC Guidelines.

[13] In practice, this requirement means that it is necessary to use the structure of categories as presented in the CFR tables.

specific category that would be insignificant in terms of the overall level and trend in national greenhouse gas emissions, it may choose to decline estimating for this category. In such cases the notation key "NE" shall also be used in the CRF tables. The criteria for insignificant categories are provided in the UNFCCC Guidelines.

The Parties shall estimate the contributions from the key categories to their national total emission levels and trends and include these estimates in their inventories. The methods for determining the key categories and estimating their contributions are provided in the IPCC Guidelines.

For the purposes of verification of emission estimates, the Parties shall compare in the inventories their emissions from fuel combustion with the estimates obtained using the IPCC reference approach. A description of the reference approach is included in the IPCC Guidelines.

Estimated uncertainties of emissions/removals shall be provided in the NIR; in addition, the methods used and the underlying assumptions shall also be provided. Uncertainty estimates are used to prioritize efforts to improve the accuracy of subsequent inventories in the future and to guide decisions on methodological choice.

Recalculations of previously submitted estimates of emissions and removals as a result of changes in methodologies, changes in the manner in which EFs and AD are obtained and used, or the inclusion of new sources or sinks which have existed since the base year but were not reported in the earlier inventories, shall be reported for the base year and for all subsequent years of the time series. A discussion on the impact of the recalculations on the trend in emissions should be included in the NIR at the category, sector, and national total level, as appropriate.

The results of the recalculations shall be integrated in the NIR along with explanatory information including, inter alia, a justification for the recalculations. Information on the procedures used for the recalculations, changes in the calculation methods, EFs and AD used, and the inclusion of sources or sinks not previously covered should be provided for the recalculated categories.

Any other changes in the estimates of emissions and removals compared with previously submitted inventories shall be also included in the NIR. It is important to clearly indicate the reason for such changes (e.g. error correction, statistical reason or reallocation of emissions/removals between categories).[14]

The NIR should include information on the QA/QC plan and QA/QC procedures already implemented or to be implemented in the future. In addition, it is recommended to report on any peer review of the inventory (which was carried out independently from the UNFCCC review).

[14] Minor changes, for example, as those resulting from rounding, do not count as re-calculation.

Each Party shall submit to the Conference of Parties (through the UNFCCC Secretariat) a NIR containing detailed and complete information on its inventory. The NIR should ensure transparency and contain sufficiently detailed information to enable the review of the inventory. This information should cover the base year, the most recent 10 years and any previous years since the base year ending with 0 or 5 (1990, 1995, 2000, etc.).

A complete and updated NIR shall be electronically submitted each year. Mandatory requirements to the NIR content are specified in the UNFCCC Guidelines, and the overall structure of NIR is provided in the Annex to the UNFCCC Guidelines.

The CRF tables are designed to ensure that the Parties report quantitative data in a standardized format and to facilitate comparison of national emissions/removals levels and trends. Qualitative information should be mainly provided in the NIR.

CRF tables, same as the NIR, shall be electronically submitted on an annual basis in their entirety to the UNFCCC Conference of Parties through the UNFCCC Secretariat.[15, 16] Specially developed CRF Reporter software is used to fill in the CRF tables; the access to the software is provided to the Parties by the UNFCCC Secretariat.

Mandatory requirements to filling in the CRF tables are specified in the UNFCCC Guidelines, and CRF formats as approved by the Conference of Parties are provided in the UNFCCC website.[17]

IV. Record keeping and archives. Inventory technical review

The Parties should collect and keep all relevant inventory information for each year of the reported time series. This requirement also refers to recalculations. This information should allow for the reconstruction by the UNFCCC expert review teams of the national inventories submitted by Annex I Parties. Record keeping and archive requirements are specified in more detail in the UNFCCC Guidelines and IPCC Guidelines.

Technical review by UNFCCC expert review teams of the inventories submitted by the Parties takes place mainly on the annual basis. The review is carried out in person (including a visit of experts to the country whose inventory is to be reviewed) or in absentia. The rules and procedures of the technical review are provided in relevant UNFCCC Guidelines (UNFCCC, 2014).

[15] Unlike NIR, CRF tables shall contain complete continuous data series which start with the base year and end in (X-2) year, where X is the year of the inventory submission.

[16] Parties are not required to submit their NIR and CRF at the same time; however, both NIR and CRF shall be submitted no later than the deadline set by the relevant decisions of the Conference of Parties to the UNFCCC. Currently, NIR and CRF are to be submitted no later than April 15 of each year.

[17] https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements

DESCRIPTION BY SECTORS

Energy Sector

Greenhouse gas emissions from fuel combustion for energy purposes, i.e. for energy recovery (heat, electrical, or mechanical), should be reported in the Energy Sector regardless of the sectors or companies where such combustion takes place. The Energy Sector also includes greenhouse gas emissions from fuel leaks and evaporation (fugitive emissions), including emissions from the extraction, storage, processing, transport, and consumption of oil, coal, and gas, and also from fuel combustion without energy recovery.

1A EMISSIONS FROM FUEL COMBUSTION – SECTORAL APPROACH

- Category description

Sector 1A includes emissions from stationary and mobile fuel combustion. For inventory purposes, *combustion* may be defined *as the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process or for use away from the apparatus. This definition aims to separate the combustion of fuels for distinct energy use from the*

heat released from the use of hydrocarbons in industrial processes or from the use of hydrocarbons as industrial products. It is *good practice* to apply this definition as fully as possible, but there are cases where demarcation with the Industrial Processes and Product Use (IPPU) sector is needed.

- Methodological approaches to emission estimation

The key method for estimating emissions from fuel combustion is by economic sectors; it is called the sectoral approach. In addition, an independent verification for completeness and accuracy of the estimates obtained by using the sectoral approach can rely on the reference (top-down) approach with a focus on total fuel and energy consumption in a country.

Methodological approaches to estimating emissions under the sectoral approach differ for stationary fuel combustion (categories 1A1, 1A2, 1A4, 1A5) and mobile fuel combustion (category 1A3 'Transport'). Therefore, hereinafter the methodological recommendations will be separated into stationary and mobile combustion.

It should be noted, that category 1A4c 'Agriculture/Forestry/Fishing/Fish Farms' of the stationary categories is broken down into stationary and mobile sources. Where this is the case, the method described in the 'Off-road transport' section should be used for mobile sources. On the contrary, emissions from 1A3e 'Other Transportation/Pipeline Transport' in the Transport category are estimated using the methodology for stationary sources, because they cover emissions from stationary combustion facilities that are used for pipelines maintenance.

If waste is incinerated in installations where the combustion heat is used as energy, this waste must be treated as a fuel, and greenhouse gas emissions should be reported in the Energy Sector. Overall (total) national emission only includes CO_2 emissions from the combustion of fossil fuel wastes, but not CO_2 from biogenic material, which is reported separately as an information item. The emissions of CH_4 and N_2O from the combustion of biomass are estimated and included in the Energy Sector and national totals. For more detail about the principles of biomass accounting in the Energy Sector see Section 2.3.3.4, *Chapter 2, Volume 2, 2006 IPCC Guidelines.* The methodology for estimating emissions from waste incineration is provided in the *'Waste'* section, and for more detail see *Volume 5, 2006 IPCC Guidelines.*

Emissions from fuel used in international aviation and maritime transport (*bunker fuels*) are estimated separately from national greenhouse gas emission totals and are included in the inventory as information items. The methodology for estimating emissions from bunker fuels correlates with the methodology for estimating national emissions from aviation and maritime transport and is provided in the relevant sections.

2006 IPCC Guidelines also describe *carbon capture and storage processes*, which imply the capture and storage of carbon dioxide that would otherwise be emitted to the atmosphere, and the

transfer of this carbon dioxide for indefinite long-term storage in geological reservoirs, such as oil and gas fields or deep saline aquifers. CO_2 capture systems from stationary combustion sources and the approaches to accounting for these systems in emission estimation in the Energy Sector are described in Section 2.3.4, *Chapter 2, Volume 2, 2006 IPCC Guidelines*. Fugitive emissions produced by carbon dioxide transportation from the capture place to the geological storage and emissions from the storage reservoirs per se are described in *Chapter 5, Volume 2, 2006 IPCC Guidelines*. There are also other industrial methods for capturing CO_2 from process flows; these are described in *Volume 3, 2006 IPCC Guidelines*. The technology and methodology for estimating emissions and removals related to carbon capture and storage are not considered here, for they are not widely practiced in Central Asian countries.

Reporting tables for the sectoral approach also contain sections to report emissions that are not included in the national totals, the so-called *Memo items*. These include emissions from *International bunker fuels (Aviation, Maritime transport); Multilateral operations; CO_2 emissions from biomass combustion; CO_2 capture (For domestic storage; For export)*.

Data on *Waste incineration with energy recovery (Biogenic waste, Abiogenic waste),* which ought to be already included in the reporting tables by categories, are also provided separately as information items.

Methodological approaches to estimating emissions in the *Memo items* categories should be applied based on the type of sources and are provided in the relevant sections and in *2006 IPCC Guidelines*.

STATIONARY COMBUSTION (CATEGORIES 1A1, 1A2, 1S4, 1A5)

- Categories description

For the inventory purposes, greenhouse gas emissions from the stationary combustion of various fuels are estimated for a number of economic activities (Table 2.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines*). A distinction is made between stationary combustion in *energy industries (1.A.1)*, *manufacturing industries and construction (1.A.2)* and *other sectors (1.A.4)*. Although these distinct subsectors are intended to include literally all stationary combustion, an additional category *(1.A.5)* is available for *any emissions* that cannot be allocated to one of the other subcategories. Emissions from heat and energy generation for producers' own use should be assigned to the source category which includes the key product produced by the plant. Subcategories 1.A.4 and 1.A.5 also include emissions from mobile sources (such as agricultural or construction machinery). The methods to be used for estimating emissions from these sources are described in the second part of

the methodological recommendations on mobile sources, while the emissions are reported for the relevant subcategory 1A 'Stationary Combustion'.

- Methodological approaches to estimating emissions

It is recommended that a methodology based on the characteristics of combusted fuel be used to estimate greenhouse gas emissions. Emissions of greenhouse gases from all combustion sources can be estimated by using data on the amounts and types of combusted fuel and corresponding emission factors. Total greenhouse gas emissions from a sector are calculated by summing up GHG emissions over the source categories, gases, and fuels. Division into liquid, solid, and gaseous fuels is not based on the aggregate state of the secondary fuels, but on that of the primary fuels these are produced from. Peat is considered to be a fossil fuel and emissions from peat combustion are included in the national total. A list of fuels that are accounted for in the estimations of greenhouse gas emissions is provided in Table 1.1 *(Chapter 1, Volume 2, 2006 IPCC Guidelines)*. In order to ensure transparency and comparability of the estimations and obtained results, a consistent classification scheme for fuel types needs to be used, as well as consistent measurement units, activity data sources, and time series.

- Tiers of estimation

Based on the activity data availability, specificities of combusted fuels, the combustion technologies used, and the contributions of the source categories to the total greenhouse gas emission in the region, there are three tiers for estimating emissions:

Tier 1 is based on the fuels combustion statistics by source categories and IPCC-recommended average emission factors (*Equation 2.2, Chapter 2, Volume 2, 2006 IPCC Guidelines*).

Tier 2, like Tier 1, is based on the fuel combustion statistics, yet instead of IPCC-recommended emission factors it uses country-specific emission factors (*Equation 2.2, Chapter 2, Volume 2, 2006 IPCC Guidelines)*.

Tier 3 is based on either estimated or measured emissions at the facility level (*Equation 2.3-2.5, Chapter 2, Volume 2, 2006 IPCC Guidelines)*.

For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ashes, etc.) are relatively unimportant. Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the average carbon content of the fuels. Emission factors for methane (CH_4) and nitrous oxide (N_2O) depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time.

For each source category and greenhouse gas, the inventory compiler has a choice of applying different methods. The inventory compiler can use different tiers for different source categories, depending on the importance of the source category (its contribution to the national total, *see the Key Categories section*) and the availability of resources in terms of time, work force, sophisticated models, and budget. To perform a key category analysis, it is important to develop an inventory (using Tier 1 or higher methods) for at least one year. Further on, the key category analysis should be updated to comply with the most relevant emission estimates. A decision as to which tier method for estimating emissions should be applied can be made for each of the fuel combustion activities and for each of the gases; different tier methods can also be used under each source category. It is important to ensure the accounting of all emission sources and the consistency of activity data, i.e. to check the balance of fuels on a per-mass basis.

- Activity data

Data on the amount and types of combusted fuel can be obtained from national statistics agencies, relevant ministries, individual enterprises and companies, fuel suppliers (sellers), and from fuel sales statistics. Tier 1 or 2 estimations typically use data obtained from the national statistics; statistical reports submitted by individual enterprises are normally used for Tier 3 estimations, but can also be used for Tier 1 or 2 estimations; yet if this is the case, it is important to check them for completeness and consistency with the national statistical reporting. Approaches to activity data collection and summarization are described in *Chapter 2, Volume 1, 2006 IPCC Guidelines*, and approaches to using the data from individual enterprises for national inventories are described in *2019 Refinement to the 2006 IPCC Guidelines (*Section 2.3, *Chapter 2, Volume 2).*

When working with fuel consumption data, it is recommended to use, where possible, the quantities of fuel combusted, rather than the quantities of fuel delivered, and to check data obtained from various sources for completeness and comparability. It is not recommended to use the data obtained from fuel suppliers, because such data cannot help identify fuel end-uses. The use of fuel combustion statistics rather than fuel delivery statistics is key to avoid double counting in emission estimates for the Energy Sector, Waste Sector, or Industrial Processes and Product Use. For more detail about the activity data description see Section 2.3.3, *Chapter 2, Volume 2, 2006 IPCC Guidelines*.

It is not always possible to make a distinction in the energy statistics between fuels combusted by mobile and stationary sources. For some source categories (for example, combustion in Agriculture Sector), there may be some difficulty in separating fuel used in stationary equipment from fuel used in mobile machinery. Given the different emission factors for non-CO_2 gases of these two sources, good practice is to derive shares of energy use for each of these sources by using

indirect data (for example, number of pumps, average consumption, needs for water pumping, etc.). If it is not possible to draw a demarcation line between mobile and stationary combustion, the emissions may be assigned to the source category which is responsible for the larger part of the emissions.

- Estimation parameters

Fuel combustion releases most of the carbon into the atmosphere as carbon dioxide. Some carbon is released into the atmosphere as carbon monoxide, methane, or non-methane volatile organic compounds. Most of the carbon emitted as non-CO_2 species eventually oxidizes to CO_2 in the atmosphere. In the case of fuel combustion, the emissions of non-CO_2 gases contain very small amounts of carbon compared to CO_2. Therefore, at Tier 1, CO_2 estimates are based on the total amount of carbon in the fuel. This is done in order to account for the whole amount of carbon in the fuel and avoid emission underestimation.

Emission factors (for CO_2) mainly depend upon the carbon content in the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ashes. etc.) are relatively unimportant. Emission factors for CH_4 and N_2O depend on the combustion technology and equipment operation conditions and may vary significantly between individual combustion installations and sometimes over time. Table 1.3 (*Chapter 1, Volume 2, 2006 IPCC Guidelines)* provides recommended values for carbon content for all categories of stationary combustion and for all fuels, and *Tables 2.2-2.5* (*Chapter 2, Volume 2, 2006 IPCC Guidelines*) give default emission factors for CO_2, CH_4, and N_2O for various categories of stationary combustion to be used for Tier 1 estimations. The default carbon oxidation factor is 1.

Tier 2 or 3 estimations may use emission factor values from the IPCC Emission Factor Database which contains country-specific data, or develop national emission factors and/or facility-specific emission factors (*reference to the approaches described in Volume 1, 2006 IPCC Guidelines*). It is also possible to use national percentage of combustion inefficiency, net calorific value by fuels, and other estimation parameters.

Emission factor defaults provided in *2006 IPCC Guidelines* for stationary combustion sources are mostly in kg gas/TJ. Where activity data statistics are available in physical units (tons, m^3, etc.) or in other energy units (tons of coal equivalent, tons of oil equivalent, etc.), these should be converted to TJ (*Box 1.1, Chapter 1, Volume 2*).

Conversion of these data to common energy units requires net calorific values of the fuels used in a country. Default conversion factors, as recommended in *2006 IPCC Guidelines,* Table 1.2, *Chapter 1, Volume 2,* can be used for those fuels, for which national data are not available. If national conversion factors are used, it is important to ensure time series consistency.

- Cross-cutting issues

The use of fuel combustion statistics, rather than fuel delivery statistics, is key to avoid double counting in emission estimates. Fuel combustion data, however, are very seldom complete, therefore, national inventories will generally contain a mixture of combustion data for larger sources and delivery data for other sources. Inventory compilers must take care to avoid both double counting and omission of emissions when combining data from multiple sources. Double counting may take place either between the Energy Sector categories, or with other sectors, such as Industrial Processes and Products Use, Waste, or LULUCF. Some of the categories and subcategories where fossil fuels are used and between which double counting of fossil fuel carbon could, in principle, occur, are listed in Section 2.3.3.3, *Chapter 2, Volume 2, 2006 IPCC Guidelines* and are specified in the sections of these guidelines for each source category.

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels. It is essential to understand, that secondary fuels relate to the fuels from which they are produced. For example, gas coke should be treated as a solid fuel, and liquefied petroleum gas as a liquid fuel in the reporting tables.

- Quality control procedures; uncertainties

Standard quality assurance / quality control procedures include checks of data input for accuracy; for latent emission factor values; for fuel consumption consistency by fuels and across the category; and for activity data and greenhouse gas emission trends.

Uncertainties are estimated using the information on the activity data uncertainties and emission factor uncertainties in compliance with the method described in Section 1.5, *Chapter 1, Volume 2.*

STATIONARY COMBUSTION SUBCATEGORY SPECIFICITIES

1A1 Energy Industries

- Category description

This category includes emissions from fuel combustion for electricity and heat production, fuel mining, and from the electricity and heat sector industries. Emissions are estimated for three subcategories: *1A1a 'Main Activity Electricity and Heat Production', 1A1b 'Petroleum Refining', 1A1c 'Manufacture of Solid Fuels and Other Energy Industry'.*

- Methodological approaches to emissions estimation

Methodological approaches to estimating emissions in this category are the same as for stationary combustion. There are 3 tier approaches (see Section *Emissions from fuel combustion – sectoral approach*); for more detail about the methodological approaches see Section 2.3.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines.*

- Activity data

Activity data include the amount of fuel combusted by the types of fuel used by plants within the source category:

1A1a 'Main Activity Electricity and Heat Production'

Activity data include the amount of fuel combusted by Main Activity Electricity and Heat Producers, whose primary activity is to supply the public. These include emissions from electricity and heat production, combined heat and power generation, and generation by heat plants. Where the activity data are available, it is essential to distinguish between *1A1ai 'Electricity generation'* (only electricity generation companies) *1A1aii 'Combined Heat and Power Generation'* (combined cycle producers), *1A1aiii 'Heat Plants'* (only heat producers). The producers may be in the public or private ownership. Emissions from own on-site energy production should also be included.

1A1b 'Petroleum Refining'

This subcategory includes all combustion activities supporting the refining of petroleum products, including on-site combustion for the generation of electricity and heat for own use.

1A1c 'Manufacture of Solid Fuels and Other Energy Industry'

This subcategory covers combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels, including production of charcoal. Emissions from on-site own use should be included. Also includes emissions from fuel production for own use. Combustion for on-site own use electricity and heat production in the above sectors should also be included. Where the activity data are available, it is essential to distinguish between *1.A.1ci 'Manufacture of Solid Fuels'* (emissions arising from fuel combustion for the production of coke, brown coal briquettes, and patent fuel), *1.A.1cii 'Other Energy Industries'* (includes emissions from fuel combustion for energy purposes for coal mining, oil and gas extraction, and the processing and upgrading of natural gas). Combustion emissions arising from the energy-producing industries' own energy use, for which separate activity data are not available, broken down by subcategories or not mentioned in any of the above categories (for example, own use for the production of charcoal, saw dust, cotton stalks and carbonizing of biofuels).

- Estimation parameters

Tier 1 estimations use default emission factors provided in the 2006 IPCC Guidelines (Section 2.3.3, Table 2.2, *Chapter 2, Volume 2*).

- Cross-cutting issues

1A1a 'Main Activity Electricity and Heat Production'. Emissions from autoproducers (undertakings which generate electricity/heat wholly or partly for their own use, as an activity that supports their primary activity) should be assigned to the sector where they were generated and not to the category 1.A.1.a. Autoproducers may be in public or private ownership.

1A1b 'Petroleum Refining'. Does not include fugitive emissions occurring at the refinery. These emissions should be reported separately under 1.B.2.a.

1A1c ii 'Other Energy Industries'– 'Manufacture of Solid Fuels and Other Energy Industries'. Combustion emissions from pipeline transport should be reported under 1.A.3.e.

- Refinement: No.

1A2 'Manufacturing Industries and Construction'

- Category description

This category includes emissions from fuel combustion for energy purposes by manufacturing industries and construction enterprises. Emissions from the generation of electricity and heat by energy plants of industrial enterprises wholly or partly for their own use are also included in this category. Emissions are estimated separately for the following subcategories: *1A2a – Iron and Steel (cast iron and steel production), 1A2b – Non-ferrous metals, 1A2c – Chemicals, 1A2d – Pulp, Paper, and Print, 1A2e – Food Processing, Beverages, and Tobacco, 1A2f – Non-Metallic Minerals (glass, ceramics, cement, etc.), 1A2g – Transport Equipment, 1A2h – Machinery, 1A2i – Mining (excluding fuels) and Quarrying, 1A2j – Wood and Wood Products, 1A2k – Construction, 1A2l – Textile and Leather, 1A2m – Non-Specified Industry.* For more detail about the category description see Section 2.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines*. Some of the specificities of individual subcategories are described below.

- Methodological approaches to emission estimation

Methodological approaches to estimating emissions in this category are the same as for stationary combustion. There are 3 tier approaches (see Section *Emissions from fuel combustion – sectoral approach*); for more detail about the methodological approaches see Section 2.3.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines.*

- Activity data

Activity data include the amount of fuel combusted by the types of fuel used by plants within the source category. For example, emissions from fuel combustion in coke ovens within the iron and steel industry should be reported in *1A1 – Energy Industries*, rather than in *1A2a – Iron and Steel.*

- Estimation parameters

Tier 1 estimations use default emission factors provided in the 2006 IPCC Guidelines (Section 2.3.3, Table 2.3, *Chapter 2, Volume 2*).

- Cross-cutting issues

Energy used within the industry for all transport activity should not be reported here, but under *1.A.3 Transport.* Emissions arising from off-road transport in industry should, if possible, be broken out as a separate subcategory and estimated using the method for off-road transport as described in Section *Mobile combustion* and in more detail in Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

It is important to avoid double counting in *1A2a* with *1A1c – Manufacture of Solid Fuels (including coke)* and *2C1 – Iron,* steel and metallurgical coke production. It is important to cross-check the estimates and activity data with all of the above categories. The key principle is to avoid double counting or omissions in these categories. The overall approach to disaggregating the activity data requires that combustion emissions be reported in the Energy Sector, whereas emissions from the conversion of feedstock should be reported in the Industrial Processes and Product Use.

In order to avoid double counting with *4.4 – Iron and Steel (2c),* natural gas that is used for direct reduced iron production and also natural gas used in blast furnaces for steel and sinter production should be excluded from the Sectoral Approach estimates. The volume of natural gas excluded from estimations under the *Energy Sector* should be evaluated as described in the Industrial Processes methodology and in *Volume 3, 2006 IPCC Guidelines.*

Other categories between which double counting of fossil fuel carbon could, in principle, occur are listed in Section 2.3.3.3, *Chapter 2, Volume 2, 2006 IPCC Guidelines.*

- Quality control procedures; uncertainties

The quality control procedure in this category is specific in that it requires a check for possible double counting of emissions with the IPPU sector. To this end, it is recommended to check the fuels balance (coke, natural gas) and fuels distribution by the inventory categories.

- Filling in Reporting Tables

To fill in the reporting tables (Common Reporting Format, CRF), data for categories 1A2g – Transport Equipment, 1A2h – Machinery, 1A2i – Mining (excluding fuels) and Quarrying, 1A2j – Wood and Wood Products, 1A2k – Construction, 1A2l – Textile and Leather, 1A2m – Non-Specified Industries should be summed up and filled in the CRF reporting category 1A2g – Other. Where sufficient activity data are available, CRF can be supplemented with additional source categories, and data should be input individually for each manufacturing industry ensuring time series consistency.

- Recommendations for verification: problems related to calculations and common mistakes

The main issue in estimating emissions under this category is to avoid potential double counting with the Industrial Processes and Product Use (IPPU) Sector. The problem is that statistics may not separate fuel combustion from fuel use as feedstock in iron and steel production, or such distinction may be incorrect. For example, this may be the case in coke use for cast iron production; natural gas use for direct reduced iron production and in blast furnaces; pulverized coal use for coke production; or in blast furnace gas use. Energy Sector and IPPU experts need to compare the data on the emissions reported in the IPPU Sector with the fuels used as feedstock and with the information on fuels combusted for energy. Where detailed statistical data are not available, an expert judgment on the distinction between fuels used as feedstock and as sources of energy may be a potential solution to avoid double counting or omissions of emission. If it is not possible to obtain an expert judgment, it is important to explicitly specify the Energy Sector or IPPU category, in which the emissions were reported. In either case, the method for disaggregating the activity data between the two sectors and the relevant assumptions should be described in the NIR in every detail.

- Refinement 2019

Distinction between stationary combustion and leakage categories in the Energy Sector and Industrial Processes and Product Use categories has been amended. For a description of these amendments see *Refinements 2019, Volume 3.*

1A4 Other Sectors

- Category description

Other Sectors category deals with combustion emissions, including combustion for electricity and heat production for own use in three subcategories: *1A4a 'Commercial / Institutional'* (includes emissions from fuel combustion in commercial and public buildings)*, 1A4b 'Residential'* (includes emissions from fuel combustion in the residential sector, excluding centralized heat and power generation), *1A4c 'Agriculture/Forestry/Fishing/Fish Farms'*. If activity data are available, emissions in 1A4c subcategory should be broken down into *1A4ci Stationary, 1A4cii Off-Road Vehicles and Other Machinery* (emissions from fuels combusted in traction vehicles on farm land and in forests), *1A4ciii Fishing* (emissions from fuels combusted for inland, coastal and deepsea fishing. Fishing should cover vessels of all flags that have re-fuelled in the country (including international fishing). It should be noted, that all emissions arising from fuel use by agricultural vehicles on paved roads (for example, trucks that carry agricultural products and belong to agricultural enterprises) should not be reported in category 1A4c, but in category *1A3b – Road Transportation*.

- Methodological approaches to emissions estimation

Methodological approaches to estimating emissions in this category are the same as for stationary combustion, except for subcategories *1A4cii 'Off-Road Vehicles and Other Machinery'* and *1A4ciii 'Fishing'*. There are 3 tier approaches (see Section *Emissions from fuel combustion – sectoral approach*); for more detail about the methodological approaches see Section 2.3.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines.* Methodological approaches to estimating emissions from categories 1A4cii and 1A4ciii are described in Section *Emissions from Mobile Sources,* for more detail see Section 3.3 *and* Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Activity data

Activity data include the amount of fuel combusted by the types of fuel used by plants within the source category. It is important to separate, where possible, fuel combusted by stationary and mobile sources, because the methods for estimating emissions from these sources are different.

- Estimation parameters

Tier 1 estimations for stationary emission sources use default emission factors provided in the 2006 IPCC Guidelines (Section 2.3.3, Tables 2.4-2.5, *Chapter 2, Volume 2*). Estimation parameters for mobile sources (categories 1A4cii and 1A4ciii) are provided in Section *Emissions from Mobile Sources,* for more detail see Section 3.3 *and* Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Cross-cutting issues

The main issue is to ensure that double counting of agricultural and off-road vehicles is avoided. In the residential sector, inventory compilers may also encounter some difficulty in separating diesel oil used in stationary equipment (space heating systems, diesel generators, etc.) and gasoline used in stationary equipment (gasoline-fired household and gardening machinery), which are to be reported in *1A4b 'Residential',* from fuel used in private cars, which is to be reported in *1A3b 'Road Transportation'*. These fuel uses can be separated by using indirect estimation methods, such as those based on the density of population, the number of households, etc. It is important to observe the overall diesel oil and gasoline consumption balance within the source category and the country as a whole and provide transparent explanations in the National Inventory Report for the methods and assumptions used to distinguish between the activity data in different sectors.

- Quality control procedures; uncertainties

The quality control procedure in this category is specific in that it requires a check for possible double counting of emissions from motor fuel (gasoline, diesel oil) uses between road transportation and residential categories; agricultural vehicles and off-road transportation; stationary

and mobile combustion in 1A4c 'Agriculture/Forestry/Fishing/Fish farms'. To this end, it is recommended to check the fuels balance and fuels distribution by the inventory categories.

- Recommendations for verification: problems related to calculations and common mistakes

The key recommendations deal with the issues of activity data disaggregation between the sectors and the correct use of emission factors for stationary and mobile combustion categories, which are described above in detail (see sections *Activity data, Estimation parameters,* and *Cross-cutting issues.*

- Refinement: No

1A5 Non-Specified

- Category description

The 'Non-Specified' category includes all remaining emissions from fuel combustion that are not specified elsewhere, broken down into *1A5a 'Stationary'* (emissions from fuel combustion in stationary sources that are not specified elsewhere) and *1A5b 'Mobile'* (emissions from vehicles and other machinery, marine and aviation (not included in 1A4cii or elsewhere). The category *1A5b 'Mobile'* includes emissions from fuel delivered to the country's military, as well as fuel delivered within that country but used by the militaries of other countries that are not engaged in multilateral operations. If sufficient data are available, the category *1A5b 'Mobile'* is broken down into *1A5bi 'Mobile (aviation component)', 1A5bii 'Mobile (water-borne component)',* and *1A5biii 'Mobile (other)'*.

Emissions from fuels used in multilateral operations pursuant to the Charter of the United Nations, including emissions from fuel delivered to the military in the country and delivered to the military of other countries, are reported separately under the *'Multilateral operations'* as information items and are not included in the national totals.

- Methodological approaches to emission estimation

Methodological approaches to estimating emissions in this category are the same as for stationary combustion, except for subcategory *1A5b 'Mobile'*. There are 3 tier approaches for stationary combustion categories (see Section *Emissions from fuel combustion – sectoral approach*); for more detail about the methodological approaches see Section 2.3.1, *Chapter 2, Volume 2, 2006 IPCC Guidelines.* Methodological approaches to estimating emissions from categories 1.A.5.b are described in Section *Emissions from Mobile Sources,* for more detail see Section 3.3 *and* Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Activity data

Activity data include the amount of fuel combusted by the types of fuel used by plants within the source category. It is important to separate, where possible, fuel combusted by stationary and mobile sources, because the methods for estimating emissions from these sources are different.

- Estimation parameters

Tier 1 estimations for stationary emission sources use default emission factors provided in the 2006 IPCC Guidelines (Section 2.3.3, *Chapter 2, Volume 2*). Selection of the category with a specified default emission factor depends on the type of source assigned to the *'Non-Specified'* category. Estimation parameters for mobile sources (category 1A5b) are provided in Section *Emissions from Mobile Sources,* for more detail see Section 3.3 *and* Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Cross-cutting issues

The category *'Non-Specified'* often includes emissions from processes which cannot be split by the types of economic activity. For example, when energy is recovered from waste combustion, the associated greenhouse gas emissions are reported in the *Energy Sector* under stationary combustion; however, it is sometimes difficult to assign these emissions to this or that stationary combustion category. If this is the case, the CO_2 emission from the fossil-carbon part of the waste can be included in the fuel category *'Other fuels'* within the *Non-Specified'* category. If it is known that waste incineration with energy recovery takes place in a specific sector (for example, commercial and public buildings, or household combustion, or centralized heat and power supply), then the relevant emissions should be reported in the corresponding category.

It is important to check the overall balance of fuels used in a country for energy purposes and, if there are no alternatives, to account remaining fuels, that were not previously accounted elsewhere, in the category *'Non-Specified'*. Effort should be made to minimize the data reported in the category *'Non-Specified'* by assigning the activity data, as much as practicable, to other inventory categories in accordance with the types of economic activities.

- Quality control procedures; uncertainties

The quality control procedure in this category is specific in that it requires a check for possible double counting of fuel uses with other categories. To this end, it is recommended to check the fuels balance and fuels distribution by the inventory categories.

- Recommendations for verification: problems related to calculations and common mistakes

Key recommendation for this category is to avoid potential double counting with other categories and to choose the correct estimation parameters for the different types of sources that may be assigned to this category. At that, estimations should be done separately for each type of

sources. For example, emissions from waste incineration should be estimated in compliance with the methodology for the *Waste Sector,* which is described in *Chapter 5, Volume 5, 'Waste', 2006 IPCC Guidelines* and in the *section 'Waste'* in this methodological guidance.

- Refinement: No

MOBILE COMBUSTION (CATEGORIES 1A3, 1A4CII, 1A4CIII, 1A5B, MEMO ITEMS: BUNKER FUEL, MULTILATERAL OPERATIONS)

Mobile sources produce direct greenhouse gas emissions, namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the combustion of various fuels, as well as several other pollutants, such as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), particulate matter (PM), and oxides of nitrate (NOx).

Greenhouse gas emissions from mobile combustion are most easily estimated by major transport activity, i.e., road, off-road, railways, air, and water-borne navigation.

1A3a 'Civil Aviation'

- Category description

Greenhouse gas emissions from civil aviation come from the combustion of fuel (jet kerosene and jet gasoline) by aircraft engines. Emissions from aviation mostly consist of carbon dioxide and water vapor. N_2O and CH_4 emissions are small or missing, yet should be reported.

Greenhouse gas emissions depend on the number of aircraft operations; the types and operation parameters of the aircraft engines; the fuel used; and the length of flight.

This source category only includes emissions from the civil aviation. All emissions from fuel uses in the international aviation (bunker fuel) and in multilateral operations should be excluded from the national totals and accounted separately, and they should be provided as information items.

For more detail about the category description see Section 3.6, Chapter 3, Volume 2, 2006 IPCC Guidelines.

- Methodological approaches to emission estimation

This source category includes emissions from all civil commercial use of airplanes, including civil and general aviation (e.g. agricultural airplanes, private jets, helicopters etc.). For the inventory purposes, a distinction is to be made between domestic and international aviation.

Three methodological tiers for estimating emissions of CO_2, CH_4 and N_2O from aviation are presented. Tier 1 and Tier 2 methods use fuel consumption data. Tier 1 is purely fuel-based, while Tier 2 method is based on the number of landing/take-off cycles (LTOs) and fuel use. Tier 3 uses movement data for individual flights.

The 2006 IPCC Guidelines allow it to refer to methodologies, such as EMEP/CORINAIR (EEA 2016, *https://www.eea.europa.eu/ru/publications/rukovodstvo-emep-eaos-po-inventarizacii*) for more detail about the estimation methods and emission factors.

For more detail about the methodology description see Section 3.6.1.1, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Activity data

Tier 1 method is based on the total amount of fuel used by the aviation (LTO cycle and cruise phase) multiplied by average emission factors.

Tier 2 method is only applicable for jet fuel use in jet aircraft engines. Operations of aircraft are divided into LTO and cruise phases. To use Tier 2 method, the number of LTO operations must be known for both domestic and international aviation, preferably by aircraft type.

Tier 3 methods are based on actual flight movement data, either: for Tier 3A origin and destination (OD) data or for Tier 3B full flight trajectory information.

Likely sources of fuel consumption and flight hours data are listed below:

- airlines;
- national air transport agencies;
- territorial branches of national energy statistical agencies;
- airport records.

Information on fuel consumption may not always be available at the country level; data on flight hours and average fuel consumption per flight hour for each type of aircraft can be used for indirect estimations of fuel consumption.

For more detail about the required activity data see Section 3.6.1.3, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Estimation parameters

CO_2 emission factors for Tier 1 estimations are based on the fuel type and carbon content, and the *default values are given in* Table 3.6.4, Section 3.6.1.2, *Chapter 3, Volume 2, 2006 IIPCC Guidelines*. National emission factors for CO_2 should not deviate much from the default values, because the quality of jet fuel is well defined.

Default values for CH_4 and N_2O for Tier 1 estimations *are provided in* Table 3.6.5, Section 3.6.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines.* Different types of aircraft/engine combinations have specific emission factors, and these factors may also vary according to the distance flown.

For Tier 2 method, it is good practice to use emission factors that differ by aircraft models and landing/take-off cycles and are given in Table 3.6.9, Section 3.6.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

Tier 3A emission factors may be found in the EMEP/CORINAIR emission inventory guidebook, while Tier 3B uses emissions factors contained within the models necessary to employ this methodology. Inventory compilers should check that these emission factors are in fact appropriate.

For more detail about the emission factors used see Section 3.6.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Cross-cutting issues

Emissions from international aviation are reported in this sector and are provided as an information item in the Memo Items category (International Bunker Fuel).

- Quality control procedures; uncertainties

Regardless of the method used, it is important to account for all fuel sold to aviation.

It is good practice to conduct quality control checks and expert review of the emission estimates when using Tier 2 or 3 methods. Comparison of emission estimates using alternative approaches helps determine whether these estimates are correct; any anomaly between the emission estimates should be explained.

The accuracy of estimations is determined by the accuracy of the activity data and correction factors. The uncertainty in the reporting will be strongly influenced by the accuracy of the data collected on domestic aviation separately from international aviation. For more detail about the uncertainties see Section 3.6.1.7, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following fuel categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels.

- Recommendations for verification: problems related to calculations and common mistakes

Inventory compilers are required to report emissions from international aviation separately from domestic aviation and exclude international aviation from national totals. Comparison of emission estimates using alternative approaches helps determine whether these estimates are correct; any anomaly between the emission estimates should be explained.

- Refinement: No

1A3b Road Transportation

- Category description

The mobile source category 'Road Transportation' includes all types of light-duty vehicles, such as automobiles and light trucks, and heavy-duty vehicles such as tractor trailers and buses, and on-road motorcycles (including mopeds, scooters, and three-wheelers). These vehicles operate on many types of liquid and gaseous fuels. In addition to emissions from fuel combustion, emissions associated with catalytic converter use in road vehicles (e.g., CO_2 emissions from catalytic converters using urea) are also addressed in this section.

For more detail about the category description see Section 3.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

Estimated emissions from road transport can be based on two independent sets of data: fuel consumption (Tier 1 and 2) and vehicle kilometers (Tier 3, activity data).

Emissions of CO_2 are best calculated on the basis of the amount and type of fuel combusted and its carbon content. The Tier 1 method is based on the amount and type of the fuel combusted and recommended average CO_2 emission factors. The Tier 2 approach is the same as Tier 1, except that country-specific emission factors that are based on the actual carbon content of fuels consumed in the country during the inventory year are used. There is no Tier 3, as it is not possible to produce better results for CO_2 than by using the Tier 2.

Emissions of CH_4 and N_2O are more difficult to estimate accurately, than those for CO_2 because emission factors depend on vehicle technology, fuel, and operating characteristics. Therefore, the most accurate estimates will be obtained through a Tier 3 method. However, distance-based activity data and disaggregated data on average speed and technical condition of vehicles may be considerably less certain, than overall fuel consumption.

Where data in sufficient detail are not available for Tier 2 or 3 estimations, the IPCC Guidelines allow for the use of emission models or fleet models that enable a range of vehicles and emission control technologies to be considered, as well as fleet models to estimate vehicle kilometers travelled by each vehicle type. More detailed modelling tools are available for estimating emissions from road vehicles using Tier 3 methodology – COPERT model *(http://www.emisia.com/copert)* and EMEP/EEA emission inventory guidebook (*http://www.eea.europa.eu/ru/publications/emep-eea*).

For more detail about the methodology description see Section 3.2.1.1, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Activity data

Tier 1 estimations require information on the fuel sold to road transport in a country; however, these data may be unavailable or unreliable, for they can only provide limited information on fuel consumption by transport, particularly road transport. If this is the case, fuel consumption estimates should be based on the size and structure of vehicle fleet registered in the country. Tier 2 method differs from Tier 1 in that it estimates fuel consumption by vehicle types.

The Tier 3 approach requires detailed data to generate vehicle activity-based emission factors for vehicle subcategories and may involve model runs. Tier 3 requires data on average annual vehicle kilometers travelled for each vehicle subcategory disaggregated by average vehicle age, emission class, fuel, engine capacity, average speed, etc.

For more detail about the required data see Section 3.2.1.1, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Estimation parameters

At Tier 1, the emission factors should assume that 100 percent of the carbon present in fuel is oxidized during or immediately following the combustion process (for all fuel types in all vehicles) and *default emission factors are provided in* Table 3.2.1, Section 3.2.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*. At Tier 2, the CO_2 emission factors may be adjusted to take account of un-oxidized carbon or carbon emitted as non-CO_2 gases (using country-specific emission factors).

If CH_4 and N_2O emissions from mobile sources are not a key category, default CH_4 and N_2O emission factors presented in Table 3.2.2, Section 3.2.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines* may be used; for Tier 2 estimates, country-specific emission factors should be used.

More detailed modelling tools are available for estimating emissions from road vehicles using Tier 3 methodology – COPERT model (*http://www.emisia.com/copert*) and EMEP/EEA emission inventory guidebook (*http://www.eea.europa.eu/ru/publications/emep-eea*).

- Cross-cutting issues

In this sector, it is important to take account only of the fuel that was used as transport fuel. For greenhouse gas emission estimation purposes, all fuel used in the industrial, commercial, residential, and other sectors, can be assigned to subcategory 1A3b – Road Transportation. However, greenhouse gas inventory compilers may split transport fuel use between transport and stationary sources based on the information available. They only need to ensure that fuel double counting is avoided. It is also essential to separate fuel used by on-road and off-road transportation, which is reported in category 1A3e.

Emissions from lubricants that are intentionally mixed with fuel and combusted in road vehicles (typically, in two-stroke engines) should be captured as mobile source emissions. Other uses of lubricants are covered in the IPPU Sector.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks and expert review of the emission estimates when using Tier 2 or 3 methods. Comparison of emission estimates using alternative approaches helps determine whether these estimates are correct; any anomaly between the emission estimates should be explained.

When data collection and accounting procedures, emission estimation methodologies or models are revised, it is good practice to recalculate the complete time series.

CO_2, N_2O, and CH_4 contribute typically around 97, 2-3 and 1 percent of emissions from the road transportation sector, respectively. Therefore, although uncertainties in N_2O and CH_4 estimates are much higher, CO_2 dominates the emissions from road transport. Use of locally estimated data can reduce uncertainties, particularly with bottom-up estimates. For more detail about the uncertainties see Section 3.2.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following fuel categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels.

- Recommendations for verification: problems related to calculations and common mistakes

In this sector, it is important to take account only of the fuel that was used as transport fuel. It is key to ensure that fuel double counting is avoided. It is also essential to separate fuel used by on-road and off-road transportation, as the latter is reported in category 1A3e.

- Refinement: No

1A3c Railways

- Category description

This section only deals with emissions from diesel locomotives operation. Electric locomotives are powered by electricity generated at stationary power plants, as well as other sources. The emissions from stationary power plants are covered under the Stationary Combustion chapter.

For a more detailed category description see Section 3.4, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

There are three methodological options for estimating CO_2, CH_4, and N_2O emissions from railways.

For Tier 1, emissions are estimated using fuel-specific default emission factors, assuming that for each fuel type the total fuel is consumed by a single locomotive type.

For Tier 2, emissions are estimated using country-specific data on the carbon content of the fuel.

Tier 3 methodology is used if the data are available. Tier 3 methods use modelling of fuel usage for each type of engine and train, which take account of the dependence of emission factors on load. The data needed include the fuel consumption which can be further stratified according to typical journey (e.g., freight, intercity, regional) and kilometres travelled by type of train. A number of modelling tools are available for estimating locomotive emissions (e.g., RAILI *http://lipasto.vtt.fi/railie/index.htm* or NONROAD *http://www.epa.gov/otaq/nonrdmdl.htm*).

Tier 3 method is not used for estimating CO_2 emissions.

For more detail about the methods see Section 3.4.1.1, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Activity data

National level fuel consumption data are needed for estimating CO_2 emissions for Tier 1 and Tier 2 approaches. For estimating CH_4 and N_2O emissions using Tier 2 methods, locomotive category level data are needed. Tier 3 approaches require activity data for operations (for example, gross tonne kilometre (GTK) and duty cycles) at specific line haul locomotive level. These methods also require other locomotive-specific information, such as source population (with age and power ranges), mileage per train tonnage, annual hours of use and age-dependent usage patterns, average rated horse power (with individual power distribution within given power ranges), load factor, section information (such as terrain topography and train speeds).

For more detail about the required activity data see Section 3.4.1.3, *Chapter 3, Volume 2, 2006 IPCC Guidelines*.

- Estimation parameters

Default emission factors for CO_2, CH_4, and N_2O emissions and their uncertainty ranges for Tier 1 are provided in Table 3.4.1, Section 3.4.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*. To estimate CH_4 and N_2O emissions, inventory compilers are encouraged to use country-specific emission factors for locomotives, if available (Tier 2 methods). Tier 3 requires the use of emission factors for specific types of locomotives.

- Cross-cutting issues

Emissions from electric locomotives that are powered by electricity generated at stationary power plants are covered under the Stationary Combustion chapter.

- Quality control procedures; uncertainties

Emissions of CH_4 and N_2O depend on engine type and technology. Unless technology-specific emission factors have been developed, it is good practice to use the same fuel-specific set of emission factors for all years.

To reduce uncertainty, a comprehensive approach is needed for both emission factors and activity data, especially where bottom-up activity data are used. The use of representative locally estimated data is desirable to improve the accuracy, although the uncertainties may remain quite large.

For more detail about the uncertainties see Section 3.4.1.6, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following fuel categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels.

- Recommendations for verification: problems related to calculations and common mistakes (if any)

There are potential overlaps with other source sectors. Some statistical data do not include fuel used in other activities, such as stationary railway sources; off-road machinery, vehicles and track machines in railway fuel use. Their emissions should not be included here, but in the relevant non-railway categories, such as stationary sources, off-road, etc. If this is not the case and it is impossible to separate these other uses from the locomotives, then it is good practice to note this in all inventory reports or in emission reporting tables.

- Refinement: No

1A3d Water-borne navigation

- Category description

Carbon dioxide is the key greenhouse gas that is emitted from fuel combustion in water-borne navigation. Water-borne navigation causes emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), particulate matter (PM), and oxides of nitrogen (NOx). CH_4

and N_2O are produced in much smaller quantities, than CO_2 and their emissions are mainly determined by the engine operation mode.

Greenhouse gas emissions should be estimated separately for domestic and international water-borne navigation. The international/domestic split should be determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship.

For more detail about the category description see Section 3.5, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

There are two methodological tiers for estimating CO_2, CH_4, and N_2O emissions from water-borne navigation. The Tier 1 method is the simplest, for it requires fuel consumption data and default specific emission factors.

The Tier 2 method also relies on fuel consumption by fuel type, but requires country-specific emission factors with greater specificity in the classification of modes, fuel type, engine type, etc.

In applying Tier 2, the inventory compilers should note that the EMEP/CORINAIR emission inventory guidebook (EEA, 2005) offers a detailed methodology for estimating ship emissions based on engine and ship type and ship movement data. The ship movement methodology can be used when detailed ship movement data and technical information on the ships are both available and can be used to differentiate emissions between domestic and international water-borne navigation

- Activity data

Tier 1 and 2 estimations require data on fuel consumption by fuel type and engine type (for N_2O and CH_4). Emissions from domestic and international water-borne navigation should be reported separately, which requires disaggregating the activity data to this level.

Several likely sources of fuel consumption data are listed below:

- port and marine authorities;
- customs service;
- national statistical agencies;
- annual surveys of shipping companies, fuel suppliers, port authorities; fishing companies.

It may be important to combine these data sources to get full coverage of shipping activities.

For more detail about the required activity data see Section 3.5.1.3, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Estimation parameters

For CO_2, Tier 1 default emissions factors are provided in Table 3.5.3, Section 3.5.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines;* they are based on the fuel type and carbon content

and take account of 100 percent oxidized carbon. CH_4 and N_2O emission factors for Tier 1 method are on a very general level provided in Table 3.5.3, Section 3.5.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

Tier 2 emission factors should be country-specific and, if possible, derived by in-country testing of fuels and combustion engines. The EMEP/Corinair Emission inventory guidebook (EEA, 2013) can be a source for NOx, CO, and NMVOC emission factors for both Tier 1 and Tier 2 calculations.

- Cross-cutting issues

All fugitive emissions from transport of fossil fuels should be estimated and reported under the category 'Fugitive emissions'. Most fugitive emissions occur during loading and unloading and are therefore accounted under that category. Emissions during travel are considered insignificant.

- Quality control procedures; uncertainties

It is good practice to determine fuel consumption using the same method for all years. If this is not possible, data collection should overlap sufficiently in order to check for consistency in the methods employed.

According to expert judgment, CO_2 emission factors for fuels are generally well determined as they are primarily dependent on the carbon content of the fuel. Much of the uncertainty in water-borne navigation emission estimates is related to the difficulty of distinguishing between domestic and international fuel consumption.

For more detail about the uncertainties see Section 3.5.1.7, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following fuel categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels.

- Recommendations for verification: problems related to calculations and common mistakes

Estimates of water-borne emissions should include not only fuel for marine shipping, but also for passenger vessels, ferries, recreational watercraft, other inland watercraft, and other gasoline-fueled watercraft.

- Refinement: No

1A3e Other Transportation

This category includes other transport that is not taken into account in other categories. Therefore, methodological approaches to emission estimation are based on the data available to the inventory compilers and specific vehicle activities.

1A3ei Pipeline Transport

1A3eii Off-road

- Category description

Other transportation may include, for example, off-road transport. This off-road category includes vehicles used in the agriculture, industry (including construction and maintenance), residential, and sectors such as airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles, haul trucks, etc.

Engine types typically used in the off-road equipment include diesel engines, motor gasoline engines, 2-stroke engines, and motor gasoline 4-stroke engines.

For more detail about the category description see Section 3.3, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

There are three methodological options for estimating CO_2, CH_4, and N_2O emissions from combustion in off-road mobile sources.

For Tier 1, emissions are estimated using fuel-specific default emission factors, with all off-road machinery split by types.

For Tier 2, emissions are estimated using country-specific emission factors which, if available, are specific to broad type of vehicle or machinery.

For Tier 3, if data are available, the emissions can be estimated from annual hours of use and equipment-specific parameters, such as rated power, load factor, and emission factors based on the use of neutralizers for various types of machinery.

Tier 3 method is not used for estimating CO_2 emissions.

Inventory compilers may wish to consult methodologies such as EMEP/CORINAIR 2013 or USEPA for emission factors, noting that responsibility remains with the inventory compilers to ensure that emission factors taken from these sources are applicable to national circumstances. It is also acceptable to use methodologies such as NONROAD, 2005 (*http://www.epa.gov/otaq/nonrdmdl.htm*) and COPERT (*http://www.emisia.com/copert*).

- Activity data

Comprehensive top-down activity data on off-road vehicles are often unavailable, and where this is the case statistical surveys will be necessary to estimate the share of transport fuel used by off-road vehicles. It is important to separate fuel consumption by off-road transport from that by road transport. It is often difficult to do, for corresponding data are not available from the national statistics. Therefore, it is essential to check the fuel consumption balance using off-road machinery activity data, such as hours of use and average hourly fuel consumption. It is also useful to collect data on off-road equipment from large industrial facilities (companies), airports, public utilities, etc.

- Estimation parameters

At Tier 1, CO_2 default emission factors assume that 100 percent of the carbon present in fuel is oxidized during or immediately following the combustion process (for all fuel types and vehicles) and *default emission factors are provided in* Table 3.3.1, Section 3.3.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines*. At Tier 2, the CO_2 emission factors may be adjusted to take account of un-oxidized carbon or carbon emitted as non-CO_2 gases (using country-specific emission factors).

If CH_4 and N_2O emissions from mobile sources are not a key category, default CH_4 and N_2O emission factors presented in Table 3.3.2, Section 3.3.1.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines* may be used; for Tier 2 estimates, country-specific emission factors should be used.

More detailed modelling tools are available for estimating emissions from off-road machinery using Tier 3 methodology – COPERT model (*http://www.emisia.com/copert*) and EMEP/EEA emission inventory guidebook (*http://www.eea.europa.eu/ru/publications/emep-eea*) or NONROAD, 2005 (*http://www.epa.gov/otaq/nonrdmdl.htm*) model.

- Cross-cutting issues

It is important to review the source of the activity data to ensure applicability and relevance to the category. Where possible, the inventory compiler should compare the data to historical activity data or model outputs to detect possible anomalies. Where surveys data have been used, the sum of on-road and off-road fuel usage should be consistent with total fuel used in the country.

- Quality control procedures; uncertainties

It is essential to avoid double counting of on-road and off-road machinery. It is good practice to determine activity data (for example, fuel use) using the same method for all years. It is good practice to conduct quality control checks and expert review of the emission estimates with additional checks when using Tier 2 or 3 methods.

Greenhouse gas emissions from off-road sources are typically much smaller than those from road transportation, but activities in this category are diverse and are thus typically associated with higher uncertainties because of the additional uncertainty in activity data. The types of equipment

and their operating conditions are typically more diverse than those for road transportation, and this may give rise to a larger variation in emission factors and thus to larger uncertainties.

For more detail about the uncertainties *see* Section 3.3.2, *Chapter 3, Volume 2, 2006 IPCC Guidelines.*

- Filling in Reporting Tables

The level of detail is the key difference between the reporting tables and the worksheets. For the reporting tables it is important to sum up activity data and emissions across the following fuel categories: liquid fuel; solid fuel; natural gas; peat; biofuels; other fuels.

- Recommendations for verification: problems related to calculations and common mistakes

A key difficulty in estimating emissions from off-road transportation is the availability of the fuel balance activity data. Where surveys data have been used, the sum of on-road and off-road fuel usage should be consistent with the total fuel used in the country.

- Refinement: No.

1A FUEL COMBUSTION (THE REFERENCE APPROACH)

- Category description

The Reference Approach is a top-down approach which estimates CO_2 emissions from the combustion of various fossil fuels based on the total fuel consumption in a region. The Reference Approach is a method that can be applied on the basis of relatively easily available energy supply statistics. The Reference Approach is one of the procedures to verify the completeness and accuracy of the inventory estimates obtained using the Sectoral Approach. It is good practice to apply both a Sectoral Approach and the Reference Approach to estimate a country's emissions from fuel combustion and to compare the results of these two independent estimates. Significant differences may indicate possible problems with the activity data, net calorific values, carbon content, and excluded carbon calculation. National total emissions are determined using the estimates obtained through the Sectoral Approach.

The Reference Approach is designed to calculate the emissions of CO_2 from fuel combustion, starting from high level energy supply data. The assumption is that carbon is conserved, so that, for example, carbon in crude oil is equal to the total carbon content of all the derived products.

The Reference Approach does not distinguish between different source categories within the Energy Sector and only estimates total CO_2 emissions from the category 'Fuel Combustion'. Emissions derive both from combustion in the energy sector, where the fuel is used as a heat source in oil refining or producing power, and from combustion in final consumption of the fuels.

- Methodological approaches to emission estimation

The Reference Approach methodology breaks the calculation of carbon dioxide emissions from fuel combustion into 5 steps:

Step 1: Estimate Apparent Fuel Consumption in Original Units.

Step 2: Convert to Common Energy Units.

Step 3: Compute the Total Carbon Using the Emission Factors.

Step 4: Compute the Excluded Carbon.

Step 5: Correct for Carbon Un-oxidized and Convert to CO_2 Emissions.

To estimate '*total apparent fuel consumption*' in a country, the following data are required for each fuel and inventory year:

- the amounts of primary fuels produced;
- the amounts of primary and secondary fuels imported;
- the amounts of primary and secondary fuels exported;
- the amounts of primary and secondary fuels used in international bunkers (fuel used by international aviation and sea-borne navigation);
- the net increases or decreases in stocks of primary and secondary fuels.

In order to avoid double counting it is important to distinguish between primary fuels, which are natural fossil fuels, such as coal, crude oil, and natural gas, and secondary fuels, i.e. fuel products, such as gasoline, lubricants, etc., which are derived from primary fuels. A complete list of fuels that are taken into account for CO_2 emission estimations is provided in Table 1.1, *Chapter 1, Volume 2, 2006 IPCC Guidelines*.

The 'apparent' consumption of *primary fuels* is therefore calculated from the above data as:

'Apparent' Consumption = Production + Imports – Exports – International Bunkers – Stock Change

An increase in fuel stocks over a year reduces apparent consumption, while a stock reduction causes an increase in total consumption, thus resulting in negative numbers for stock change in the fuel balance. The total 'apparent' consumption of all primary fuels will be the sum of the total consumptions for each primary fuel.

Total 'apparent' consumption of secondary fuels should be added to the total apparent consumption of primary fuels. The production of secondary fuels should be ignored in the carbon balance calculations, because the carbon in these fuels is already included in the supply of primary fuels from which they were derived. For instance, the estimate for total consumption of crude oil already contains the carbon from which gasoline would be refined. Total 'apparent' consumption of a secondary fuel is calculated as follows:

Total 'Apparent' Secondary Consumption = Imports – Exports – International Bunkers – Stock Change

Total 'apparent' consumption of individual secondary fuels can result in negative numbers. This is possible and indicates a net export or stock increase of that fuel in the country. The total 'apparent' consumption of secondary fuels will be the sum of the apparent consumptions for each secondary fuel.

Step 4: Compute the excluded carbon is about excluding from the total carbon the amount of carbon which does not lead to fuel combustion emissions, because the aim is to provide an estimate of fuel combustion emissions. Carbon excluded from fuel combustion is either accounted for in another sector of the inventory (for example as an industrial process emission) or is stored in a product manufactured from the fuel.

The main flows of carbon concerned in the calculation of excluded carbon are those used as feedstock, reductant in the industrial sector, or as non-energy products. Table 6.1, *Chapter 6, Volume 2, 2006 IPCC Guidelines* sets out the fuels in each group. The method for estimating emissions arising from the use of fuels as feedstock, reductants, or as non-energy products is addressed in detail in *Industrial Processes and Product Use* chapter. If a country has other fossil fuel carbon products which should be excluded, they should be taken into consideration and documented. The quantity of carbon to be excluded from the estimation of fuel combustion emissions is calculated according to *Equation 6.4, Chapter 6, Volume 2, 2006 IPCC Guidelines*. Activity data for each product are given in Table 6.2, *Chapter 6, Volume 2, 2006 IPCC Guidelines*.

Step 5. Correct for Carbon Un-oxidized. A small part of the fuel carbon entering combustion escapes oxidation, but is later oxidized in the atmosphere. It is assumed that the carbon that remains un-oxidized (for example, as soot or ash) is stored indefinitely. For the purposes of the Reference Approach, unless country-specific information is available, a default value of 1 (full oxidation) should be used.

For more detail about the Reference Approach methodology for emission estimation see *Chapter 6, Volume 2, 2006 IPCC Guidelines.*

- Activity data

The Reference Approach is a method that can be applied on the basis of relatively easily available energy supply statistics. Statistical data on fuels production, imports, exports, and stock changes are required. The Reference Approach also requires activity data on the consumption of fuels used as feedstock or for non-energy purposes, where carbon may be emitted through activities not covered, or only partly covered, under the Fuel Combustion Sector.

The amounts of primary fuels produced. Production of natural gas is measured after purification and extraction of NGLs and sulphur. Extraction losses and quantities re-injected, vented or flared are not included. Production of coal includes the quantities extracted or produced calculated after any operation for removal of inert matter. Production of oil includes marketable production and excludes volumes returned to formation. The production of secondary fuels and derived products should be ignored in the calculations to avoid double counting, because the carbon in these secondary fuels and derived products is already included in the carbon supply of primary fuels.

- Estimation parameters

The carbon content of the fuel may vary considerably both among and within primary fuel types. Since the carbon content is closely related to the energy content of the fuel, the variability of the carbon content is small when the activity data are expressed in energy units.

Since carbon content varies by fuel type, data should be used for detailed categories of fuel and product types. The default values for carbon content given in Table 1.3, *Chapter 1, Volume 2, 2006 IPCC Guidelines* are suggested only if country-specific values for carbon content in fuels are not available. When selecting a country-specific value for carbon content for the Reference Approach based on detailed consumption values, good practice suggests that a weighted average be used. For some fuels (for example, coal), carbon content may vary over time. In this instance, different values for carbon emission factors may be used in different years. In order to minimize the discrepancies between the Reference Approach and the Sectoral Approach estimations it is recommended that comparable values for carbon content factors be used.

- Cross-cutting issues

The reporting of non-energy and feedstock use of fuels in the fuel combustion sector and the IPPU Sector using the Reference Approach should be coordinated between these two sectors.

- Quality control procedures; uncertainties

In the Reference Approach estimations, standard quality control procedures are applicable, including checks of data input for accuracy; of values for latent emission factors; for fuel consumption consistency by fuel types and across the category; and for activity data and greenhouse gas emission trends. Uncertainties are not estimated for the Reference Approach, unless the Reference Approach is the only method for estimating national total emissions.

- Filling in Reporting Tables

When filling in the reporting forms, it is important to specify in the Common Reporting Format tables (Table 1.A(d)) the inventory source category, or more often the IPPU sector, under which emissions from non-energy use of fuels that were excluded from the Energy Sector are reported.

- Recommendations for verification: problems related to calculations and common mistakes

When preparing data for the Reference Approach it may be difficult to estimate the excluded carbon, i.e. carbon which is not emitted from fuel combustion, but is included in the derived product or reported under other inventory sectors. It is essential to ensure that non-energy fuel use reported in the *Energy Sector* is consistent with the fuel use reported in the *Industrial Processes and Product Use*. Corresponding data should be reflected in the National Inventory Report and in the Common Reporting Format Tables (Table 1.A(d)).

- Comparison between the Reference Approach and the Sectoral Approach

The Reference Approach estimations are used, for example, to assess the completeness and accuracy of the Sectoral Approach estimations. The Reference Approach and the Sectoral Approach often have different results, because the Reference Approach is a top-down approach using a country's energy supply data, but has no detailed information on how individual fuels are used in each sector. Typically, the gap between the two approaches is relatively small (5 percent), when compared to the total carbon flows involved. When significant discrepancies and/or large time series deviations do occur, it is important to explore the possible reasons for such discrepancies and provide a detailed description in the National Inventory Report. Potential reasons for the discrepancies between the Reference Approach and the Sectoral Approach estimations are discussed in Section 6.8, *Chapter 6, Volume 2, 2006 IPCC Guidelines*.

- Refinement: No.

1B FUGITIVE EMISSIONS FROM FUEL

Sources of greenhouse gas emissions in this sub-sector include oil and gas extraction and refining and coal mining and handling. These sources produce direct emissions of the following greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), as well as non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), and oxides of nitrate (NOx).

1B1 Solid Fuels

- Category description

The 'Solid Fuels' category covers all coal handling operations, including other emissions. It covers emissions from underground and surface coal mines and post-mining coal handling operations, including methane utilization. It also covers emissions from solid fuels conversion arising from uncontrolled combustion at coal mines. Methane and carbon dioxide emissions are reported in this category.

- Activity data

Emissions from solid fuels (the main category is 1B1a) are estimated using activity data on the underground and surface mining and post-mining coal handling.

Data on the underground and surface coal mining should be adjusted for methane utilization: the amount of recovered methane should be subtracted from the total emissions from underground coal mining and reported separately. The application of factors to estimate emissions from solid fuels conversion requires information on coalfields with uncontrolled combustion.

- Estimation parameters

Tier 1 estimations are based on the country-specific data on the underground and surface coal mines, methane recovery, the number of sealed mines, and on the IPCC default values for emission factors.

Tier 2 methods are based on the information about underground and surface coal mined in the country and **country-specific emission factors** that account for country- or basin-specific data, such that **to take into account** the **gas content**, **national basin-specific** emission parameters, and the number of coal mines.

Tier 3 estimations use the information about underground and surface coal mined in the country and the emission factors based on direct measurements on a mine-specific basis.

1B1a1 Underground Mines

Emissions from underground coal mining without adjustment for methane recovery[18], estimated using the Tier 1 method:

$$\text{Emissions} = ADa \times \text{Efa} \times \text{c} \quad (1)$$

Emissions are greenhouse gas emissions from underground coal mines (Gg);

AD_a is raw coal production from underground mines (Mln tons);

EF_a is emission factor for underground coal mining (m^3/ton);

C is coal into gaseous fuel conversion factor; conversion of the mined coal volume into the mass of CH_4 (Gg 10^{-6} m^{-3}) is taken equal to 0.67.

Emissions from post-mining coal handling:

$$\text{Emissions} = ADb \times \text{Efb} \times \text{c} \quad (2)$$

Emissions are greenhouse gas emissions from post-mining coal handling (Gg);

AD_b is raw coal production from underground mines (Mln tons);

EFb is emission factor for post-mining handling of coal from underground mines (m^3/ton);

C is coal into gaseous fuel conversion factor; conversion of the mined coal volume into the mass of CH_4 (Gg 10^{-6} m^{-3}) is taken equal to 0.67.

[18] Emissions from underground coal mines are estimated with adjustment for methane recovery; the volume of methane recovered should be subtracted from the total emission from underground coal mines.

Tier 2 estimations of emission from underground coal mines require emission factors that account for country-specific gas content of coal basins.

Tier 3 method for estimating emissions from underground coal mines is based on mine-specific data, ventilation air measurements and degasification system measurements for individual coalfields, and so provides more detailed actual emissions on a mine-by-mine basis, than using emission factors.

According to the Kazakhstan inventory, emissions from abandoned coal mines are not estimated, because in Kazakhstan they use the mine sealing (flooding) technology, which cuts off emissions from underground coal mines.

1B1a2 Surface Mines[19]

$$\text{Emissions} = ADa \times \text{EFc} \times \text{c} \quad (3)$$

EF_c is emission factor for surface coal mining (m^3/ton);

C is coal into gaseous fuel conversion factor (Gg 10^{-6} m^{-3}); conversion of the mined coal volume into the mass of CH_4 is taken equal to 0.67.

$$Emissions = AD_a \times \text{Ef}_\text{d} \times \text{c} \quad (4)$$

Emissions are CH_4 emissions (Gg);

AD_b is raw coal production from surface mines (Mln tons);

EF_d is emission factor for post-mining handling of coal mined from surface mines (m^3/ton);

C is coal into gaseous fuel conversion factor (Gg 10^{-6} m^{-3}); conversion of the mined coal volume into the mass of CH_4 is taken equal to 0.67.

$$Emissions = AD_b \times \text{Ef}_\text{d} \quad (5)$$

Emissions are CH_4 emissions (Gg);

ADb is raw coal production from surface mines (Mln tons);

EFd is emission factor for post-mining handling of coal mined from surface mines (m^3/ton);

C is coal into gaseous fuel conversion factor (Gg 10^{-6} m^{-3}); conversion of the mined coal volume into the mass of CH_4 is taken equal to 0.67.

1B2 Oil and Natural Gas

- Category description

The 'Oil and Natural Gas' category covers fugitive emissions from oil and natural gas systems. This category includes fugitive equipment leaks (1B2a and 1B2b) and emissions from

[19] Methane which is recovered (from ventilation air) should be accounted for based on the utilization method: if it is utilized or flared for own use, it should be subtracted from the total emission arising from coal mining. If the recovered methane is emitted to atmosphere, rather than utilized, then in Tier 2 estimation method it is already accounted for in the coal mining emissions.

blow-outs and flaring (1.B.2.c). Direct emissions of greenhouse gases from this sub-sector include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) (from combustion and exploration), as well as non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), and oxides of nitrate (NOx).

Greenhouse gas emissions in this sub-sector are estimated using activity value activity data for each hydrocarbon fuel. It is important to check the units of measure and the conditions for which required activity data are reported, because the emissions estimates should be brought to the consistent estimation parameters of the IPCC Guidelines. So as to bring the estimates to consistent conditions, average-weighted country-specific hydrocarbons densities should be used for emissions estimations.

- Estimation parameters

Tier 1 estimations are based on the country-specific activity data for the specified hydrocarbon fuel and on the IPCC default values for emission factors.

Tier 2 methods are based on the country-specific activity data for each hydrocarbon fuel and **country-specific emission factors** that account for the fuel's composition and activity values for the oil and natural gas systems in a country.

The Tier 3 approach uses direct measurements of the parameters of hydrocarbon feedstock on the facility-specific basis and accounts for the specificities of the facilities' operations.

Emissions from oil and natural gas operations:[20]

$$Emissions = AD_a \times \mathrm{Ef_d} \qquad (6)$$

Emissions are CH_4 emissions (Gg);

AD_a is activity value;

EF_d is emission factor for operations with hydrocarbon feedstock (Gg/activity value).

Emissions in this sub-sector can be estimated using activity data about the type of operation, which is determined by the sub-category within the sub-sector: extraction, transmission, combustion, blow-off, or venting. Activity value activity data should be collected with an account of potential discrepancies between agencies regarding the activity values and units of measure. Emissions estimates are based on the number of mines, pipelines length, etc.

[20] Emissions from the whole 'Oil and Natural Gas' sub-sector should be estimated using one and the same formula, which requires that the activity value for a hydrocarbon fuel be multiplied by the emission factor for that activity, taking account of the units of measure for this fuel and the type of operation (transmission, extraction, combustion, blow-off, preparation, exploration, or distribution).

Emission factors for the use in greenhouse gas emissions estimations from the whole sub-sector can be found in Tables 4.2.4 and 4.2.5 for the developed and developing countries and economies in transition. For more detail see *Sub*section 4.2.2.2, *Chapter 4, 2006 IPCC Guidelines.*

When blow-off and flaring volumes are known, emissions from these operations should be estimated using the emission factors specified in the notes to Tables 4.2.4 and 4.2.5.

Emissions from combustion for own use should be separated from emissions from flaring and reported in category 1.A.

1B2ab 'Oil' and 'Natural Gas'

Estimations of emissions from oil and gas operations (leakage): leakage is viewed as unintentional emission through equipment leaks; blowdowns are intentional, or engineered, emissions related to the field development process. Many companies do not distinguish between these parameters and report aggregated emission data in the 'system losses' column.

There are three tiers to estimate emissions from oil and natural gas operations.

Tier 1 methods for estimating emissions use default emission factors from Tables 4.2.4 and 4.2.5 of the IPCC Guidelines and activity values by hydrocarbon fuels.

Tier 2 emission estimates are based on country-specific emission factors that account for weighted average compositions of hydrocarbons extracted nationally; aggregated losses from the oil and gas equipment (if country-specific representative data are available from measurements or other research carried out at oil and gas facilities); and the parameters of loss sources.[21]

A Tier 3 method for estimating emissions requires data obtained through direct measurements of losses and hydrocarbons parameters at the deposits and oil and gas systems. Data obtained through the use of the Tier 3 approach can then be used to back-calculate Tier 2 emission factors.

Data on the gas mix total process loss are collected from all oil systems in the Russian Federation, and based on these data emissions from leaks in oil operations are estimated using the Tier 2 methodology.

1B2 c Venting and Flaring (illustrated with an example of associated gas and process loss)

Emissions in this sub-sector are estimated using Tier 1, 2, and 3 approaches.

Tier 1 methodology requires the use of one and the same formula to estimate emissions from all oil and gas operations using the emission factors as specified in the notes to Tables 4.2.4 and 4.2.5.

[21] Joint research was carried out by Gazprom and Ruhrgas (Dedikov et al., 1999) at Russian natural gas facilities and included measurements of equipment leaks from gas transmission and from natural gas production and processing facilities, taking account of methane losses.

Tier 2 methodology for estimating emissions from flaring requires the development of **country-specific emission factors** that account for:

- Weighted average compositions of hydrocarbons extracted nationally;
- Flaring parameters (percentage of combustion inefficiency) and volume; standard densities of the components of hydrocarbons extracted in a country and their molar masses;
- The conditions for which activity data are obtained on the country level;
- Compositions of hydrocarbons from individual deposits and activity values by operations (flaring, extraction, etc.).

Tier 2 estimations of emissions from blowdowns account for national average weighted parameters of extracted hydrocarbons and intentional, or process, losses of hydrocarbon mixtures for each stage of oil and gas extraction.

Tier 3 methods require direct measurements at the facility level, including losses, flaring parameters, hydrocarbon mixture extraction and on-site flaring volumes.

Estimating emissions from associated gas flaring

Tier 1 methodology implies the use of IPCC default emission factors (Tables 4.2.4 and 4.2.5) for estimating emissions from associated gas flaring. When the flaring volumes are known, the emission factors specified in the notes to these tables marked as 'Flaring' should be used.

Tier 2 method requires that, when estimating emission factors for the components of the associated gas flared on-site in a country, it is important to account for the percentage of combustion inefficiency and the associated gas carbon content, which can be estimated using standard densities of the associated gas components and their mole fractions. The emission factor for carbon dioxide can be estimated based on the values obtained. The emission factor for methane can be estimated using the data on the percentage of combustion inefficiency at flares and the fraction of methane in the associated gas.

Tier 3 estimations imply direct measurements of the composition of flared gas mixture and accounting for the associated gas flaring parameters.

INDUSTRIAL PROCESSES AND PRODUCT USE

According to the IPCC Guidelines, the Industrial Processes and Product Use sector (hereinafter referred to as IPPU) covers emissions occurring from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuels (*Volume 3, 2006 IPCC Guidelines*).

Greenhouse gas emissions are produced from a wide variety of industrial activities. The main emission sources are releases from industrial processes that chemically or physically transform materials (for example, the blast furnace in the iron and steel industry, ammonia and other chemical products manufactured from fossil fuels used as chemical feedstock, and the cement industry are notable examples of industrial processes that release a significant amount of CO_2). During these processes, many different greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), can be produced.

General guidance in terms of reporting and documentation requirements, as well as requirements for filling out the reporting tables, is provided in *Chapter 8, Volume 1, 2006 IPCC Guidelines*. The level of data disaggregation is the key difference between the reporting tables and the worksheets. Category codes as used in the reporting tables are specified in Table 8.1, Section 8.2.5, *Chapter 8, Volume 1*. In order to avoid rounding error accumulation it is recommended to export the CRF tables the from CRF Reporter software, which can be found at the UNFCCC

website (https://unfccc.int/crfapp/view/listSubmission.jsf), fill in the data from the local worksheets and then import the tables back to the software. Access to CRF Reporter can be obtained by applying to the *UNFCCC Secretariat*.

For the sake of brevity, references like 'see Section 2.2, *Chapter 2, Volume 3*' further in the text should be taken as references to the chapter and volume of the 2006 IPCC Guidelines.

2A Mineral Industry

This subsector outlines methodologies for estimating carbon dioxide (CO_2) emissions resulting from the use of carbonate raw materials in the production of a variety of products:

- Cement Production (2A1);
- Lime Production (2A2);
- Glass Production (2A3);
- Other Process Uses of Carbonates (2A4):
  - Ceramics (2A4a);
  - Other Uses of Soda Ash (2A4b);
  - Non Metallurgical Magnesia Production (2A4c);
  - Other (2A4d);
- Other (2A5).

Limestone and other carbonate materials are also consumed in a variety of other industries (for example, carbonates are used as fluxes and slagging agents), therefore, emissions from the use of limestone, dolomite, and other carbonates should be assigned to the industrial source category where they are emitted (for example, iron and steel production).

It is important to ensure that there is no double counting of CO_2 emissions between the Energy (combustion-related emissions) and IPPU (process-related emissions) Sectors, and that CO_2 emissions from other mineral-related activities that are not covered by the above subcategories are also taken into account if they can be estimated.

2A1 Cement Production

- Category description

In cement manufacture, CO_2 is produced during the production of clinker (a nodular intermediate product) that is then used to produce hydraulic (typically portland) cement. Cement may be made entirely from imported clinker, in which case the cement production facility may be considered to have zero process-related CO_2 emissions. Emissions associated with the lime from the production of masonry cement should be accounted for in category 2A2 (Lime Production). For more detail about the category description see Section 2.2, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

Based on the activity data level of detail available to the inventory compilers, there are 3 tier methodologies, which are described in detail in Section 2.2.1.1, *Chapter 2, Volume 3*.

- Activity data

The Tier 1 method requires data on the types of cement produced and the clinker contents of cement to enable estimations of national clinker production volumes. Clinker fractions in various cement types are shown in Table 2.2, *Chapter 2, Volume 3*. In Tier 2, emissions are estimated directly from clinker production data. Activity data for Tier 1 or 2 estimations can be collected from national statistics or, preferably, from individual plants. The type of activity data required for Tier 3 estimations are likely available only at individual plants. It is important to remember that cement and/or clinker production data from national statistics may not be complete in some countries where a substantial part of production comes from numerous small kilns, particularly vertical shaft kilns. For more detail about the activity data see Section 2.2.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

Tier 1 methodology requires the use of default emission factors (Table 2.1, Section 2.1, *Chapter 2, Volume 3*). The basic emission factor was not corrected for cement kiln dust emissions or for additives. The Tier 2 method estimates a country-specific CO_2 emission factor for clinker (for more detail see Section 2.2.1.2, *Chapter 2, Volume 3*), if country-specific data on CaO content of clinker and inputs of non-carbonate CaO sources are available. For more detail about the choice of emission factors see Section 2.2.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

In order to avoid double counting inventory compilers should review statistics used to estimate emissions from source category 2A4 'Other Process Uses of Carbonates' to ensure that emissions reported in that source category do not result from the use of these carbonates in cement production. Where carbonates are used for cement production, the emissions in category 2A1 'Cement Production' should only include process-related emissions. Combustion-related emissions should be accounted for in the Energy Sector.

- Quality control procedures; uncertainties

Tier 1 estimations require a correction for imports and exports of clinker. If this is not done, then based on the situation it would result in an over- or underestimation of emissions from cement production. Quality control specificities in this source category include comparisons of emissions estimates using different tiers; review of emission factors; and site-specific activity data check (for more detail see Section 2.2.3, *Chapter 2, Volume 3*). Standard quality control procedures should be applied in compliance with the recommendations provided in *Chapter 6, Volume 1*. Uncertainty

estimates for cement production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainty related to the emission factor for clinker (for more detail see Section 2.2.2, *Chapter 2, Volume 3*). For Tier 1, the major uncertainty component is the clinker fraction of the cement(s) produced; under Tier 2, the major source of uncertainty is associated with determining the CaO content in clinker. Standard procedures for estimating the uncertainties are described in *Chapter 3, Volume 1*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

In most cases, source category 2A1 'Cement Production' is a key category, and so requires a Tier 2 method. Where a Tier 1 methodology is applicable for country-specific conditions, it is important to make a correction for imports and exports of clinker to avoid an over- or underestimation of emissions from cement production.

- Refinement: No.

2A2 Lime Production

- Category Description

Calcium oxide (CaO or quicklime) is formed by heating limestone up to high temperatures to decompose the carbonates, and the process releases CO_2. The consumption of lime as a product may in some cases not result in net emissions of CO_2 to the atmosphere. Any recarbonation may be calculated and reported only where proven and validated methods are used to calculate the amount of CO_2 that reacts with lime to re-form calcium carbonate. Where these conditions are met, the resulting amount of CO_2 can be reported in the category 2.H 'Other'. For more detail about the category description see Section 2.3, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

As is the case for emissions from cement production, there are three basic methodologies for estimating emissions from lime production: Tier 1 is an output-based approach that relies on default values; Tier 2 is an output-based approach that estimates emissions from CaO and CaO·MgO production and country-specific information for correction factors; and Tier 3 is an input-based carbonate approach. For more detail about the methodologies see Section 2.3.1.1, *Chapter 2, Volume 3*.

- Activity data

The Tier 1 method is based on applying a default emission factor to any one of the following variables: the types of lime produced and/or the proportion of hydrated lime produced. Data on

stoichiometric ratios, the ranges of CaO and CaO·MgO contents, and the resulting default emission factors for the main lime types produced are given in Table 2.4, Section 2.3, *Chapter 2, Volume 3*. The Tier 1 method for lime production does not incorporate a correction for lime kiln dust. Tier 2 methodology requires disaggregated data for the following three key types of non-hydrated lime: high calcium lime, dolomitic lime, and hydraulic lime, because they have different emission factors; and also data on all non-carbonate sources of CaO. Correction for lime kiln dust in the Tier 2 and Tier 3 methods is analogous to cement kiln dust in cement production. Activity data for estimating CO_2 emissions from lime production may be obtained from the national statistics or industrial plants. For more detail about the activity data see Section 2.3.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

Tier 1 methodology requires that an emission factor be multiplied by the total quantity of lime produced. The emission factor is based on the default stoichiometric ratios provided in the 2006 IPCC Guidelines (Table 2.4, Section 2.3.1.2, *Chapter 2, Volume 3*). Unlike Tier 1, Tier 2 requires the use of national-level data on lime production by type. A correction factor for hydrated lime should be included in the Tier 2 estimation equation and, if the data are available, also in the Tier 1 estimations. For more detail about the choice of factors see Section 2.3.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

It is recommended to take caution in order to avoid double counting or omissions between the emissions from source category 2A2 and emissions from limestone and dolomite consumption, as well as from hydrated lime production. The latter can be double counted, if lime production was corrected for hydrated lime without first establishing whether the lime used to produce hydrated lime was included in total lime production. In order to avoid underestimation of emissions in category 2A2 it is suggested that inventory compilers identify potential industries where non-marketed lime may be produced (for example, metallurgy, pulp and paper, sugar refining, precipitated calcium carbonate, water softeners) and take account of these data. Emissions from lime production at sugar mills should be reported in category 2A2 ‘Lime Production’, whilst emissions from dolomite calcinations apart from lime production should be reported in category 2A4d ‘Other’.

- Quality control procedures; uncertainties

The potential exists to exclude some lime sources from the national inventory due to problems with obtaining the activity data on lime use or lime production as a non-marketed intermediate product (see Sections 2.3.1.4 and 2.3.2.2, *Chapter 2, Volume 3*). Therefore, the Tier 1 method could considerably underestimate emissions if these issues are not carefully considered. Since for Tiers 1 and 2, the stoichiometric ratio is an exact number, the emission factor uncertainty is mostly determined by lime composition uncertainties, in particular by the uncertainty related to the share of

hydraulic lime (for more detail see Section 2.3.2, *Chapter 2, Volume 3*). The uncertainty for the activity data is determined by problems related to lime data collection (see Section 2.3.1.4, *Chapter 2, Volume 3*). Corrections for hydrated lime and lime kiln dust involve additional uncertainties.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

For this category, it is difficult to take account of all of the small lime production facilities, as well as of internal technologies within these facilities which may consume lime for the process needs (not as feedstock or end-product). It is important to account this consumption to the maximum degree in order to avoid underestimation of emissions.

- Refinement: No.

2A3 Glass Production

- Category description

The glass industry can be divided into four main categories: containers, flat (window) glass, fibre glass, and specialty glass. Category 2A3 also covers emissions from glass wool (a category of mineral wool) production. Based on how feedstock for the glass industry is obtained (extraction of carbonates, which are typically limestone ($CaCO_3$), dolomite Ca, Mg $(CO_3)_2$, and soda ash (Na_2CO_3), or production of feedstock through the carbonation of a hydroxide) there are processes with or without CO_2 emissions. For more detail about the category description see Section 2.4, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

There are three methodologies for estimating emissions in category 2A3: the Tier 1 method applies a default emission factor to the total glass production statistics; the Tier 2 method applies default emission factors to each glass manufacturing process and takes account of cullet; the Tier 3 methodology is based on accounting for facility-specific data on the consumption of carbonates and on the development of corresponding emission factors. For more detail about the methodologies description see Section 2.4.1.1, *Chapter 2, Volume 3*.

- Activity data

Activity data for the Tier 1 method include national statistics for glass production by weight, as well as correction for the quantity of cullet used in glass production. The Tier 2 method requires the collection of national level data on the quantity of glass produced using various technologies (where possible, data should be collected on a plant-specific basis and aggregated to the national

level). Data for glass should be converted into tonnes. Activity data can be obtained from the national statistics or from industrial plants. For more detail about the activity data description see Section 2.4.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

Tier 1 applies a default emission factor, based on a 'typical' raw material mixture, to national glass production data. The Tier 2 method relies on applying default emission factors and cullet ratios to the various types of glass produced in the country as given in Table 2.6, Section 2.4.1.2, *Chapter 2, Volume 3*. Where country-specific or plant-specific data are available, it is recommended to use these data to supplement or replace the defaults provided in the table. For more detail about the choice of emission factors and ratios see Section 2.4.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

Inventory compilers are encouraged to ensure that there is no double counting of emissions between source categories 2A3 and 2A4b 'Other Uses of Soda Ash', specifically no double counting of emissions from soda ash used in glass manufacturing. Based on the type of production emissions from soda ash can be reported either in source category 2A3 'Glass Production' or 2A4b 'Other Uses of Soda Ash' (see sections 2.4 and 2.5, *Chapter 2, Volume 3*). Emissions from mineral wool (including natural rock- and slug-based wool) are covered in sub-category 2A5 'Other'. The re-melting of slag to make mineral wool does not involve significant process-related emissions and does not need to be reported. Emissions related to slag production should be reported in the relevant metallurgical source category.

- Quality control procedures; uncertainties

It is important to make sure that all types and sources of different carbonate feedstock are included in the emission estimations. There may be a number of smaller producers of specialty glass that are not accounted for in the national inventory, for it is difficult to obtain data on their glass production volumes, so quality control procedures should ensure complete coverage of the glass industry. Uncertainty associated with the use of the Tier 1 emission factors and cullet ratio is the highest; for Tier 2 the uncertainty is based on the amount of glass produced. If activity data have to be converted to mass, this may result in additional uncertainty. For more detail about the uncertainty assessment see Section 2.4.2, *Chapter 2, Volume 3*. Standard quality assurance and quality control procedures include checks of input data for accuracy, control sums for consistency, etc., in accordance with the methodology described in Section 1.4, *Chapter 1, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

Activity data for category 2A3 'Glass Production' are often provided in a variety of units: square meters (for construction glass), cubic meters (for fibre glass), economic units (number of bottles). If correct estimates of emissions are to be obtained, it is important to accurately convert the data to a common unit.

Refinement: No.

2A4 Other Process Uses of Carbonates

- Category description

Carbonates (limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), magnesium carbonate $MgCO_3$ and ferrous carbonate $FeCO_3$, etc. are used in a number of industries: in metallurgy (iron and steel), agriculture, construction and environmental pollution control (for example, flue gas desulphurisation.). The calcination of carbonates at high temperatures yields CO_2 (see Table 2.1, Section 2.1, *Chapter 2, Volume 3*). Some uses of carbonates do not result in the release of CO_2 and do not need to be included in the national GHG inventory (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*). Emissions from the consumption of carbonates should be accounted in the source category where the carbonates are consumed and the CO_2 emitted. There are four broad source categories: ceramics, other soda ash use, non-metallurgical magnesia production, and other carbonate uses. For more detail about the category description see Section 2.5, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

There are two primary methodologies for estimating emissions from source category 2A4 (Tier 1 and 2). In practice, the Tier 3 method is used only for a few sub-categories. A hybrid approach can be used for all sub-categories of category 2A4 depending on the country-specific conditions and data availability; this means that a Tier 1 or 2 method can be used for the categories with limited data availability, whilst a Tier 3 method is applied for other subcategories, where data are available for all uses of carbonates that are emissive. For more detail about the methods description see Section 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

In the Tier 1 method, it is essential to collect activity data for total carbonate consumption for emissive uses (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*). It is suggested that inventory compilers ensure that data on carbonates reflect pure carbonates and not carbonate rock. Tier 2 requires the collection of activity data to illustrate the total quantity of carbonates consumed in each end-use sector. Where such data are not available for each end-use sector, national-level activity data for limestone and dolomite consumed should be collected. Activity data can be obtained from

the national statistics or from industrial plants. For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factor for the Tier 1 and Tier 2 methodologies is based on the mass of CO_2 released per mass of carbonate consumed (see Table 2.1, Section 2.1, *Chapter 2, Volume 3*). The distinction between Tier 1 and Tier 2 is in the activity data. An assumption is made that only limestone and dolomite are used as carbonate input in industry, and Tier 1 method allows for the use of default fractions of limestone and dolomite consumed, whilst in Tier 2 the fractions are assessed by analyzing the consumption of carbonates. The Tier 3 method requires complete accounting of all types of carbonates and their sources, so the emission factor represents the weighted average of the emission factors of the individual carbonates. For more detail about the emission factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

It is essential to report emissions from the consumption of carbonates in the source category where the carbonates were consumed and the CO_2 emitted. So where limestone is used for the liming of soils, emissions should be reported in the respective source category of the Agriculture, Forestry and Other Land Use (AFOLU) Sector. Where carbonates are used as fluxes or slagging agents (in iron and steel, chemicals, or for environmental pollution control, etc.) emissions should be reported in the respective source categories where the carbonates were consumed. In particular, national limestone statistics should be carefully examined to determine whether the data also contain consumption of limestone in the iron and steel or other industry. Specific source categories described further (ceramics, other soda ash uses, and non-metallurgical magnesium production) are covered in the subcategories of category 2A4 'Other Carbonate Uses', and it is essential to avoid double counting of emissions which were already accounted for in other source categories.

- Quality control procedures; uncertainties

For category 2A4 'Other Carbonate Uses' it is challenging to ensure that all carbonate inputs are accounted for in industries where carbonates are consumed (calcined), because there is a chance of under- or overestimation. The uncertainty associated with the emission factor for this source category should be relatively low, as the emission factor is the stoichiometric ratio reflecting the amount of CO_2 released upon calcination of the carbonate (for more detail see Section 2.5.2, *Chapter 2, Volume 3*). Quality control procedures for this category include the comparison of estimates obtained by using different Tier methods (assuming that the same fraction of calcination achieved is used for all Tiers, and that limestone and dolomite are likely to contribute the greatest

percentage of emissions for these sources); and activity data checks at the plant level (for more detail see Section 2.5.3, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2A4a Ceramics

- Category description

Category 2A4a 'Ceramics' covers emissions from the production of bricks, roof tiles, vitrified clay pipes, wall and floor tiles, table and ornamental ware (household ceramics), sanitary ware, etc., that result from the calcination of carbonates of the raw material (shales, fire clay, ball clay and other types of clay, limestone, dolomite and witherite) from the use of additives and the use of limestone as a flux. For more detail about the category description see Section 2.5, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

The methodologies applied are the same for all processes of subcategories within the source category 2A4. For more detail about the methodology description see Section 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

Tier 1 estimations require that for all clays used in the ceramics industry the inventory compilers should collect national production data for bricks, roof tiles, vitrified clay pipes, and refractory products and calculate the amount of clay consumed by multiplying production with a default loss factor. The Tier 2 method requires the collection of activity data to illustrate the total quantity of carbonates consumed in each end-use sector or national-level activity data for limestone and dolomite consumed. In Tier 3 estimations for clay use in the ceramics industry, the inventory compilers should collect clay consumption data for all ceramics products. The activity data may be available from the national statistics or from industrial plants. Caution should be taken not to assume that all limestone and dolomite consumed in the country results in the release of CO_2 emissions, because not all carbonate uses are emissive (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*). For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factors applied are similar for all processes of subcategories within the source category 2A4. For more detail about the choice of emission factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

Emissions from other carbonate consumption processes should be reported in the source category where the carbonates are consumed, and so emissions should be accounted for in the sectors where they take place. When allocating emissions to source category 2A4a 'Ceramics', it is important to avoid double counting of emissions which were already recorded in other source categories.

- Quality control procedures; uncertainties

The uncertainty associated with the emission factor for this source category should be relatively low, as the emission factor is the stoichiometric ratio (for more detail see Section 2.5.2, *Chapter 2, Volume 3*). Quality control procedures for this category include the comparison of estimates obtained by using different Tier methods; and activity data checks at the plant level (for more detail see Section 2.5.3, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

Activity data for category 2A4a 'Ceramics' are often provided in a variety of units. If correct estimates of emissions are to be obtained, it is important to accurately convert the data to a common unit of weight.

- Refinement: No.

2A4b Other Uses of Soda Ash

- Category description

Category 2A4b 'Other Uses of Soda Ash' includes emissions from the use of soda ash (sodium carbonate, Na_2CO_3) in areas such as soaps and detergents, chemicals, pulp and paper, etc. Emissions from soda ash use are reported in the respective end-use sectors: in category 2A3 'Glass Production' if it is used in glass production; or in category 2A4b if it is used in other industries. For more detail about the category description see Section 2.5, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

The methodologies applied are the same for all processes of subcategories within source category 2A4. For more detail about the methodology description see Section 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

In the Tier 1 method, it is essential to collect activity data for total carbonate consumption for emissive uses (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*). For category 2A4b, the inventory compilers should collect national or plant-level data on the total quantity of soda ash used. It is essential to consider the chemical purity of the raw material. Tier 2 requires the collection of activity data to illustrate the total quantity of carbonates consumed in each end-use sector. Where such data are not available for each end-use sector, national-level activity data for limestone and dolomite consumed should be collected. Activity data can be obtained from the national statistics or from industrial plants. For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factor for the Tier 1 and Tier 2 methodologies is based on the mass of CO_2 released per mass of carbonate consumed (see Table 2.1, Section 2.1, *Chapter 2, Volume 3*). The Tier 1 method for soda ash does not require the use of default fractions. Emissions are estimated by multiplying the quantity of soda ash consumed on the national level by the default emission factor for sodium carbonate (see Table 2.1, Section 2.1, *Chapter 2, Volume 3*). The Tier 3 method requires the full accounting of carbonates (species and sources), therefore the emission factor represents the weighted average of the emission factors of the individual carbonates. CO_2 emissions from soda ash use are estimated taking account of national exports and imports of soda ash. For more detail about the choice of factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

Emissions from soda ash production are reported in category 2B7 in the 'Chemical Industry' sub-sector. Emissions from the use of soda ash are reported in the respective end-use sectors; for example, emissions from the use of soda ash in glass production are accounted for in category 2A3 'Glass Production'.

- Quality control procedures; uncertainties

The uncertainty associated with the emission factor for this source category should be relatively low, as the emission factor is the stoichiometric ratio (for more detail see Section 2.5.2, *Chapter 2, Volume 3*). Quality control procedures for this category include the comparison of

estimates obtained by using different Tier methods; and activity data checks at the plant level (for more detail see Section 2.5.3, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2A4c Non Metallurgical Magnesia Production

- Category description

Source category 2A4c 'Non Metallurgical Magnesia Production' should include emissions from magnesia (MgO) production that are not included elsewhere in the inventory. Magnesia is produced by calcining magnesite ($MgCO_3$) which results in the release of CO_2 (see Table 2.1, Section 2.1, *Chapter 2, Volume 3*). There are three major categories of magnesia products: calcined magnesia (used in many agricultural and industrial applications, for example, as feed supplement to cattle, fertilisers, electrical insulations and flue gas desulphurization), deadburned magnesia (used predominantly for refractory applications), and fused magnesia (used in refractory and electrical insulating markets). Where magnesia is produced for use as a fertiliser these emissions should be reported under the appropriate section of the Chemical Industry sub-sector. For more detail about the category description see Section 2.5, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

The methodologies applied are the same for all processes of subcategories within source category 2A4. For more detail about the methodology description see Section 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

The Tier 1 methodology requires the collection of activity data on the total magnesite or other carbonates consumption that releases CO_2 (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*). It is suggested to ensure that data on carbonates reflect the amount of pure carbonates and not of carbonate rock. The Tier 2 method is based on the collection of data on the total raw materials consumed for non-metallurgical magnesia production, as well as on the accounting of the fraction of calcination achieved and of average carbonate (most often magnesite, $MgCO_3$) content in the raw material. These data can be obtained from the national statistics or from industrial plants. For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factor for the Tiers 1 and 2 methodologies is calculated similarly to the other carbonate uses (see category 2A4, Table 2.1, Section 2.1, *Chapter 2, Volume 3*). For more detail about the choice of emission factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

Where magnesia is produced for use as a fertilizer, the emissions should be reported under the appropriate category of the Chemical Industry Emissions sub-sector. Emissions from other carbonate uses for magnesia production should be reported in the source category where the carbonates are consumed, and so the emissions are accounted for where they take place. When allocating emissions to source category 2A4c 'Non-Metallurgical Magnesia Production' it is important to be careful not to double count emissions already recorded in other source categories.

- Quality control procedures; uncertainties

The uncertainty associated with the emission factor for this source category should be relatively low (for more detail see Section 2.5.2, *Chapter 2, Volume 3*). Quality control procedures for this category include the comparison of estimates obtained by using different Tier methods; and activity data checks at the plant level (for more detail see Section 2.5.3, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2A4d Other

- Category description

Source category 2A4d 'Other' covers CO_2 emissions that may take place in the production of minerals not considered elsewhere, for example, the use of dolomites as refractory products. When allocating emissions to this category it is particularly important to avoid double counting with other source categories. For more detail about the category description see Section 2.5, *Chapter 2, Volume 3*.

- Methodological approaches to emission estimations

The methodologies applied are the same for all processes of subcategories within source category 2A4. For more detail about the methodology description see Section 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

The activity data can be obtained from the national statistics or from industrial plants. For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factors are similar to the other processes covered by sub-categories within category 2A4. For more detail about the choice of emission factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

Emissions from other carbonate uses should be reported in the source category where the carbonates are consumed, and so the emissions are accounted for in the sectors where they occur. When allocating emissions to source category 2A4d 'Other' it is important to avoid the double counting of emissions already recorded in other source categories.

- Quality control procedures; uncertainties

Quality control procedures for this category include all the main procedures to minimize the omissions and avoid double counting of emissions from the use of carbonates in the minerals production (for more detail see Section 1.4, Chapter 1, and Section 2.5.3, *Chapter 2, Volume 3*). The uncertainty associated with the emission factor for this source category should be relatively low (for more detail see Section 2.5.2, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2A5 Other

- Category description

The source category 'Other' should cover the emissions that are not included in any of the key categories (2A1-2A4) specified in Table 2.7 (see Table 2.7, Section 2.5, *Chapter 2, Volume 3*).

- Methodological approaches to emission estimations

Tier 1, 2, or 3 methodologies can be used depending on the type of carbonate feedstock used, on how CO_2 is released from the carbonates, and on the country-specific conditions and data availability. General methods for estimating CO_2 emissions from the use of carbonates in the minerals production are discussed in Sections 2.1 and 2.5.1.1, *Chapter 2, Volume 3*.

- Activity data

If plant-level information is not available or scarce, data obtained from the national statistics or reporting should be used. For more detail about the activity data description see Section 2.5.1.3, *Chapter 2, Volume 3*.

- Estimation parameters

The emission factor for the Tiers 1 and 2 methodologies is calculated similarly to the other carbonate uses (see category 2A4, Table 2.1, Section 2.1, *Chapter 2, Volume 3*). For more detail about the choice of emission factors see Section 2.5.1.2, *Chapter 2, Volume 3*.

- Cross-cutting issues

When allocating emissions to source category 2A5 'Other', it is important to avoid double counting of emissions, which were already recorded in other source categories.

- Quality control procedures; uncertainties

Quality control procedures for this category include all the main procedures to minimize the omissions and avoid double counting of emissions from the use of carbonates in the minerals production (for more detail see Section 1.4, Chapter 1, and Section 2.5.3, *Chapter 2, Volume 3*). For more detail about the uncertainty associated with the emission factor see Section 2.5.2, *Chapter 2, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B Chemical Industry

For the Chemical Industry sub-sector, greenhouse gas emissions are estimated for the production of the following organic and inorganic chemicals:

- Ammonia Production (2B1);
- Nitric Acid Production (2B2);
- Adipic Acid Production (2B3);
- Caprolactam, Glyoxal, and Glyoxylic Acid Production (2B4);
- Carbide Production (2B5);
- Titanium Dioxide Production (2B6);
- Soda Ash Production (2B7);
- Petrochemical and Carbon Black Production (2B8);
- Fluorochemical production (2B9).

CO_2 emissions resulting from carbon's role as process reactant and as a heat source to drive the chemical reactions involved in the chemical processes can be closely related. This may result in mistakes in CO_2 emissions estimation, which are driven by:

- double counting of carbon dioxide (CO_2) emissions in the IPPU and Energy Sectors;
- underestimation of CO_2 emissions.

Therefore, it is essential to take caution while determining CO_2 emission sources and assessing the accuracy of the estimates. Should CO_2 capture technology be installed at a chemical plant, the CO_2 captured should be deducted in emissions calculation.

2B1 Ammonia Production

- Category description

The production of ammonia represents a significant non-energy source of industrial CO_2 emissions. Ammonia (NH_3) is a major industrial chemical and the most important nitrogenous material produced. Ammonia gas is used as a fertiliser, in paper pulping, nitric acid and nitrates manufacture, nitric acid ester and nitro compound manufacture, explosives of various types, and as a refrigerant. Amines, amides, and miscellaneous other organic compounds, such as urea, are made from ammonia. For more detail about the category description see Section 3.2.1, *Chapter 3, Volume 3*.

- Methodological approaches to emission estimations

There are 3 tier methodologies, for more detail about the methodological approaches see Section 3.2.2, *Chapter 3, Volume 3*.

- Activity data

Tier 1 estimations require data on the ammonia production in the country. These data can be obtained from the national statistics or directly from the ammonia plants located in the country. The Tier 2 methodology is based on plant-level data on ammonia production classified by fuel type and production process. Data on the ammonia production, the fuel type and the fuel requirement per unit of output for individual ammonia production units and for process types can be obtained from the industrial producers and ammonia plants. All Tiers estimations also require data on the amount of CO_2 recovered for further use in other processes (urea production, CO_2 capture and storage), which can be obtained from producers. For more detail about the activity data description see Section 3.2.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

Tier 1 estimations are based on default emission factors as given in Table 3.1, Section 3.2.2.2, *Chapter 3, Volume 3*. For emission factors to be used in Tier 2 or 3 estimations see Section 3.2.2.2, *Chapter 3, Volume 3*.

- Cross-cutting issues

In order to avoid double counting, the total quantities of oil or gas used (fuel plus feedstock) in ammonia production must be subtracted from the quantity reported under energy use in the Energy Sector. In addition, while estimating emissions from ammonia production the quantity of CO_2 recovered for downstream use in urea production must be subtracted from the total quantity of CO_2 generated. Emissions of CO_2 from urea use should be accounted for in the corresponding sectors. In particular, emissions from urea use as fertiliser should be included in the Agriculture, Forestry, and Other Land Use (AFOLU) Sector. Emissions from urea use in automobile catalytic converters should be accounted for in category 2D3. Emissions from any other chemical products manufactured using CO_2 recovered from the process (for example, emissions from carbonic acid use) are covered by the methodology suggested in the Chemical Industry and should not be accounted for in other IPPU sections or in other sectors.

- Quality control procedures; uncertainties

The quality control procedure in this category is specific in that it requires a check for possible double counting of CO_2 emissions from fossil fuel non-energy use with the Energy Sector and Agriculture, Forestry, and Other Land Use Sector. Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors in accordance with the methodology described in *Chapter 3, Volume 1*. Uncertainties for default emission factors are given in Table 3.1, Section 3.2.2.2, *Chapter 3, Volume 3*. Default emission factor uncertainties reflect variations between plants across different locations. Activity data obtained from producers are highly accurate (with just 2% uncertainty). This will include uncertainty estimates for fuel use, for ammonia production, and for CO_2 recovered. Data that are obtained from national statistical agencies usually do not include uncertainty estimates. It is *good practice* to consult with national statistical agencies to obtain information on any sampling errors. Where uncertainty values are not available from other sources, a default value of ±5 percent can be used (Section 3.2.3, *Chapter 3, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

In order to avoid double counting the total quantities of oil or gas used (fuel plus feedstock) in ammonia production must be subtracted from the quantity reported under energy use in the Energy Sector.

- Refinement: No.

2B2 Nitric Acid Production

- Category description

Nitric acid is used as a raw material mainly in the manufacture of nitrogenous-based fertilisers and can also be used in the production of adipic acid and explosives (for example, dynamite), for metal etching and in the processing of ferrous metals. During the production of nitric acid (HNO_3), nitrous oxide (N_2O) is generated as an unintended by-product of the high temperature catalytic oxidation of ammonia (NH_3). For more detail about the category description see Section 3.3.1, *Chapter 3, Volume 3*.

- Methodological approaches to emission estimations

There are 3 Tier methodologies, for more detail see Section 3.3.2, *Chapter 3, Volume 3*.

- Activity data

Tier 1 estimations are based on the data on national production of nitric acid. These data can be obtained from the national statistics or directly from plants or industrial companies that produce nitric acid. The Tier 2 method requires nitric acid production data disaggregated by technology type and abatement system type. In this case, data are obtained from nitric acid producers. For more detail about activity data description see Section 3.3.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

When applying the Tier 1 method default emission factors shown in Table 3.3, Section 3.3.2.2, *Chapter 3, Volume 3*, should be used. Emissions factors for Tier 2 and 3 estimations are described in Section 3.3.2.2, *Chapter 3, Volume 3*. Activity data should be based on 100 percent HNO_3. This can be done by multiplying the amount of nitric acid in the monohydrate by $\frac{63}{81}$ according to the molar ratios.

- Cross-cutting issues: No.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors in accordance with the methodology described in *Chapter 3, Volume 1*. Uncertainties for default emission factors are given in Table 3.3, Section 3.3.2.2, *Chapter 3, Volume 3*. Where activity data are obtained from plants, uncertainty estimates can be obtained from producers. Data that are obtained from national statistical agencies usually do not include uncertainty estimates. Where uncertainty values are not available from other sources, a default value of ±2 percent can be used. To reduce uncertainty, it is *good practice* to ensure that all activity data are for 100 percent HNO_3. It is important to once again point out, that the entire amount of nitric acid should be taken into account, including both the nitric acid that enters into commerce and

that is integrated as part of larger production processes. Where national statistics only account for the production of nitric acid for commerce, the activity data uncertainties may be much higher.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It should be noted that nitric acid statistics may be underestimated by omitting a substantial proportion of the data, namely, by failing to account for the production of weak (low-concentration) nitric acid that is used by plants to produce other products. The production of marketable weak nitric acid and of high-strength nitric acid is fully taken into account. Weak nitric acid is typically used within the plant and is hardly ever transported. Nitric acid production capacities are balanced with the processing capacities, namely, with the production of ammonium nitrate or compound fertilizers which are produced by reacting phosphate feedstock with nitric acid or nitric and sulfuric acids, or for other purposes. Therefore, while working with the data it is important to determine whether all of the produced volumes have been included. If need be, the amount of weak nitric acid that is produced to be used for fertilizers production can be estimated indirectly from the data on mineral fertilizers production. This can be done by using national production data for mineral fertilizers and nitric acid consumption rate to determine 100 percent nitric acid consumption for the production of these fertilizers.

- Refinement

Default emission factors for the Tier 1 methodology have been revised. For more detail about the revisions see *Refinements 2019*.

2B3 Adipic Acid Production

- Category description

Adipic acid is used in the manufacture of a large number of products including synthetic fibres, coatings, plastics, urethane foams, elastomers and synthetic lubricants. The production of nylon accounts for the bulk of adipic acid use. At the same time, a substantial fraction of the adipic acid is further processed to give hexamethylene diamine, which is an important monomer used in the chemical industry. A further small fraction of the adipic acid is converted into di-octyl (di-2-ethylhexyl) or di-hexyl esters for use as plasticizers in flexible grades of PVC, or as a high boiling point component of synthetic motor oils. Adipic acid industry is a large N_2O emitter.

- Methodological approaches to emission estimations

There are 3 Tier approaches. For more detail about the methodologies see Section 3.4.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 method requires national data on adipic acid production. The data can be obtained from the national statistics or directly from adipic acid plants and producers. The Tier 2 method uses plant-level adipic acid production data categorized by the abatement technology type employed. For more detail about the activity data see Section 3.4.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

Tier 1 estimations are based on default emission factors shown in Table 3.4, Section 3.4.2.2, *Chapter 3, Volume 3*. Emission factors for Tier 2 and 3 estimations are given in Section 3.4.2.2, *Chapter 3, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors in accordance with the methodology described in *Chapter 3, Volume 1*. Uncertainties for default emission factors are given in Table 3.4, *Chapter 3, Volume 3*. In general, adipic acid default emission factors are well known, because they are derived from the stoichiometry of an intended chemical reaction (nitric acid oxidation) and N_2O-specific abatement systems. Given the small number of adipic acid plants, the uncertainty in national production data (Tier 1) is the same as for plant-level data, namely, ±2 percent.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the description of category 2B.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B4 Caprolactam, Glyoxal and Glyoxylic Acid Production

This section addresses the production of three chemicals – caprolactam, glyoxal, and glyoxylic acid – that are potentially important sources of nitrous oxide (N_2O) emissions. Almost all of the production of caprolactam ($C_6H_{11}NO$) is consumed as the monomer for nylon-6 fibres and plastics, with a substantial proportion of the fibre used in carpet manufacturing. Glyoxal is used as a crosslinking agent for acetate/acrylic resins, disinfectant, gelatine hardening agent, textile finishing agent, wet-resistance additive. Glyoxylic acid is used for the production of synthetic aromas, agrochemicals and pharmaceutical intermediates.

- Methodological approaches to emission estimations

The methodology for estimating emissions from caprolactam production is described in detail in Section 3.5.2, *Chapter 3, Volume 3*. It can also be applied for estimating emissions from glyoxal and glyoxylic acid production.

- Activity data

The Tier 1 method requires national data on caprolactam, glyoxal and glyoxylic acid production. Tier 2 estimations are based on plant-level caprolactam, glyoxal and glyoxylic acid production data disaggregated by technology type and default emission factors classified by technology type. Data on the production of caprolactam, glyoxal and glyoxylic acid can be obtained from national statistical agencies or directly from plants. For more detail about the activity data description see Section 3.5.2, *Chapter 3, Volume 3*.

- Estimation parameters

Tier 1 estimations are based on default emission factors for caprolactam, glyoxal and glyoxylic acid as provided in Table 3.5, Section 3.5.2.1, *Chapter 3, Volume 3* (for caprolactam) and in Table 3.6, Section 3.5.3, *Chapter 3, Volume 3* (for glyoxal and glyoxylic acid). Tier 2 estimations are also based on default emission factors where plant-specific data are not available.

- Cross-cutting issues

No.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1, 2006 IPCC Guidelines*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors in accordance with the methodology described in *Chapter 3, Volume 1*. Uncertainties for default emission factors are given in Table 3.5, Section 3.5.2.1, and in Table 3.6, Section 3.5.3, *Chapter 3, Volume 3*. It is good practice to obtain uncertainty estimates for caprolactam at the plant level. They should be lower than uncertainty values associated with default values. Where activity data are obtained from plants, uncertainty estimates can be obtained from producers. Data that are obtained from national statistical agencies usually do not include uncertainty estimates. Where uncertainty values are not available from other sources, a default value of ±2 percent can be used.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B5 Carbide Production

- Category description

Production of silicon carbide (SiC) and calcium carbide (CaC_2) is associated with greenhouse gas emissions. The production of carbide can result in emissions of carbon dioxide (CO_2) and methane (CH_4). Silicon carbide is a significant artificial abrasive. It is produced from silica sand and petroleum coke. Calcium carbide is used in the production of acetylene, cyanamide (a minor historical use). It is made from two carbon-containing raw materials: calcium carbonate (limestone) and petroleum coke. The use of carbon-containing raw materials in the production processes results in emissions of CO_2. The presence of hydrogen-containing volatile compounds and sulphur in the petroleum coke may cause formation and emission to the atmosphere of CH_4.

- Methodological approaches to emission estimations

The methodology for estimating emissions from carbide production is described in detail in Section 3.6.2, *Chapter 3, Volume 3*.

- Activity data

Tier 1 estimations are based on country-specific data for petroleum coke consumption or carbide production. The Tier 2 method requires plant-level data on production of carbide and the amount of carbon contained in the product. For CaC_2, data on the use of calcium carbide for the production of acetylene used in welding applications are also required. For more detail about the activity data see Section 3.6.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

The Tier 1 method uses default emission factors provided in Tables 3.7 and 3.8, Section 3.6.2.2, *Chapter 3, Volume 3*. Where data on petroleum coke consumption are used, values for carbon content factor and carbon oxidation factor for petroleum coke can be taken from *Chapter 1, Volume 2*, and the results should be multiplied by 44/12 to convert carbon to CO_2.

Similarly to the Tier 1 method, the Tier 2 method uses default emission factor values, except for the amount of C contained in the product, where plant-level data are required.

- Cross-cutting issues

To avoid double counting, CO_2 emission from combusting CO gas generated in the process of calcium carbide production should be accounted in the IPPU Sector, rather than in the Energy Sector. Petroleum coke used in the production process should be deducted from the Energy Sector as a non-energy use of petroleum coke.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors; corresponding values are provided in Section 3.6.3, *Chapter 3, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

CO_2 emissions from combusting carbon monoxide generated in the process of calcium carbide production should be accounted in the IPPU Sector, rather than in the Energy Sector.

- Refinement: No.

2B6 Titanium Dioxide Production

- Category description

Titanium dioxide (TiO_2) is one of the most commonly used white pigments; it is used in paint manufacture, as well as in the manufacture of plastics, rubber, ceramics, fabrics, floor covering, printing ink, and many other miscellaneous uses. CO_2 emissions in TiO_2 production take place as a result of carbon oxidation in the production of titanium slag, coal oxidation in the process of producing synthetic rutile using the Becher process, and petroleum coke oxidation in the process of producing rutile TiO_2 via the chloride route.

- Methodological approaches to emission estimations

The general approach for calculating CO_2 emissions from titanium dioxide production is the same irrespective of the TiO_2 type, because the emissions are based on the quantity of reducing agent or carbothermal input. The choice of a good practice method depends on the national data available for estimating emissions from titanium dioxide production. The methodology for estimating emissions from titanium dioxide production is described in Section 3.7.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 method requires country-specific data on the production of titanium slag, synthetic rutile and rutile TiO_2, which can be obtained from the national statistical agencies or directly from plants and industrial companies that produce titanium dioxide. The Tier 2 method relies on plant-level data for the quantities of reducing agent and carbothermal input. For more detail about the activity data description see Section 3.7.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

Where plant-level information is scarce or not available, default emission factors as shown in Table 3.9, Section 3.7.2.1, *Chapter 3, Volume 3*, should be used. These defaults are based on the

international practice and their values, according to the IPCC's expert judgment, represent global averages. The defaults were derived from the estimates of reductant or carbothermal input per unit of output assuming complete conversion of the carbon content to CO_2, which reflects a conservative approach and results in some overestimation of the emission estimates.

- Cross-cutting issues

In order to avoid double counting, the quantities of electrode carbon, coal used as a reductant, and petroleum coke used in the chloride route process, must be subtracted from the quantity reported under energy and non-energy use in the Energy Sector.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors in accordance with the methodology described in *Chapter 3, Volume 1*. Uncertainties for default emission factors are given in Table 3.9, Section 3.7.2.1, *Chapter 3, Volume 3*. Where activity data are obtained from plants, uncertainty estimates can be obtained from producers. Data that are obtained from national statistical agencies usually do not include uncertainty estimates. Where uncertainty values are not available from other sources, a default value of ±5 percent can be used.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B7 Soda Ash Production

- Category description

Soda ash (sodium carbonate, Na_2CO_3) is one of the key products in the chemical industry. It is used as a raw material in a large number of industries, including glass manufacture, soap and detergents, pulp and paper production, iron and steel and non-ferrous metals industries, etc. Carbon dioxide (CO_2) is emitted from the use of soda ash and these emissions are accounted for as a source under the relevant using industry. CO_2 is also emitted during production of soda ash, and the quantity emitted is dependent on the industrial process used.

- Methodological approaches to emission estimations

Carbon dioxide emissions can be estimated using an output-based approach (emissions per unit of output), or an input-based approach (emissions per unit of input). It is recommended that the

input-based method be used where data are available. The methodology for estimating emissions from soda ash production is described in Section 3.8.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 method requires country-specific data for the Trona input or natural soda ash output which can be obtained from national statistical agencies or directly from soda ash plants. To use the Tier 2 method, it is necessary to gather data on Trona consumption or natural soda ash production for each of the plants along with plant-specific emission factors for the Trona input or soda ash output. For more detail about the activity data description see Section 3.8.2.1, *Chapter 3, Volume 3*.

- Estimation parameters

The Tier 1 method uses the default emission factors presented in Equation 3.14, Section 3.8.2.1, *Chapter 3, Volume 3*. The Tier 2 method requires plant-level emission factors per unit of Trona input or per unit of natural soda ash output. Plant-level emission factors should reflect the fractional purities of the Trona (raw material) input and natural soda ash (product) output. It is good practice to ensure that the fractional purities are taken into account in the derivation of plant-level emission factors.

- Cross-cutting issues

In order to avoid double counting CO_2 emissions generated in the process of soda ash production should be accounted in the IPPU Sector, rather than in the Energy Sector. Coke used in the Solvay production process should be deducted from the Energy Sector as a non-energy use of coke.

- Quality control procedures; uncertainties

The Solvay ammonia soda ash production process is a chemical industry activity, therefore emissions should be reported under the IPPU Sector. Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors, the values for which are given in Section 3.8.2.2, *Chapter 3, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B8 Petrochemical and Carbon Black Production

- Category description

The petrochemical industry uses fossil fuels (for example, natural gas) or petroleum refinery products (for example, naphtha) as feedstocks. This section provides guidance for estimating CO_2 and CH_4 emissions from the production of methanol, ethylene and propylene, ethylene dichloride, ethylene oxide, and acrylonitrile, as well as from the production of carbon black, which is not considered to be a petrochemical, yet the carbon black production process uses petrochemical feedstocks. For more detail about the category description see Section 3.9.1, *Chapter 3, Volume 3*.

- Methodological approaches to emission estimations

The emissions from petrochemical and carbon black production vary both with the process used and the feedstock used. The choice of method should thus be repeated for each product, process, and feedstock used. Three methodological tiers are provided depending on the availability of activity data. The methodology for estimating emissions from petrochemical and carbon black production is described in Section 3.9.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 methodology is applied to estimate CO_2 emissions based on activity data for the amount of each petrochemical product produced in a country, which can be obtained from national statistical agencies or directly from petrochemical plants. The Tier 2 method is a feedstock-specific and process-specific carbon balance approach. This approach is applicable in cases where activity data are available for both feedstock consumption and primary and secondary product production and disposition. Activity data for all carbon flows are required to implement the Tier 2 methodology. The Tier 2 method calculates the difference between the total amount of carbon entering into the production process as primary and secondary feedstock and the amount of carbon leaving the production process as petrochemical products. CH_4 emissions from petrochemical processes may be fugitive emissions and/or process vent emissions. Fugitive emissions are emitted from flanges, valves, and other process equipment. Emissions from process vent sources include incomplete combustion of waste gas in flare and energy recovery systems. The Tier 1 method for estimating CH_4 emissions requires primary product production data or feedstock consumption data for the petrochemical process in a country, which can be obtained from national statistical agencies or directly from petrochemical plants. The Tier 2 methodology which is based on total feedstock carbon mass balance method is not applicable to estimation of CH_4 emissions. For more detail about activity data description see Sections 3.9.2.1 and 3.9.2.3, *Chapter 3, Volume 3*.

- Estimation parameters

IPCC default emission factors for CO_2 and CH_4 are provided in Tables 3.12-3.24, Section 3.9.2.2, *Chapter 3, Volume 3*. If country-specific emission factors are available, they should be used for the estimations instead of the IPCC default emission factors. In the event that no activity data are available concerning the specific processes and feedstocks used within a country to produce the petrochemical, the default process identified in Table 3.11, Section 3.9.2.2, *Chapter 3, Volume 3*, should be used to estimate the emissions.

- Cross-cutting issues

Within the petrochemical industry and carbon black production, primary fossil fuels (natural gas, petroleum, coal) are used for non-fuel purposes in the production of petrochemicals and carbon black. Combustion emissions from fuels obtained from the feedstocks should be allocated to the source category in the IPPU Sector. Where the fuels are not used within the source category but are transferred for combustion elsewhere, the emissions should be reported in the appropriate Energy Sector source category. Energy statistics may include total combustion of fossil fuels (including natural gas, oil, and coal) and also secondary fuels (such as industrial process off-gases) for energy production. It is important to investigate if fuels used in petrochemical industries are included in national energy statistics. If this is the case, emissions from petrochemical processes should be subtracted from the calculated Energy Sector emissions to avoid double counting. This is particularly relevant for ethylene and methanol, where primary fuel (for example, natural gas, ethane, propane) feedstock consumption may be reported in national energy statistics. In this source category it is important to take account of carbon dioxide (CO_2) capture technologies. Petrochemical processes may utilise CO_2 captured elsewhere as a feedstock; and CO_2 may also be captured from petrochemical processes. To avoid double counting the CO_2 captured should be subtracted from CO_2 emissions from the process.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors. Uncertainty ranges for emission factors and activity data are given in Table 3.27, Section 3.9.3, *Chapter 3, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2B9 Fluorochemical Production

2B9a HFC-23 Emission from HCFC-22 Production

- Category description

Trifluoromethane (HFC-23 or CHF_3) is generated as a by-product during the manufacture of chlorodifluoromethane (HCFC-22 or $CHClF_2$). Materials such as HFC-23 (and other HFCs, PFCs and SF_6) are not significantly removed by aqueous (acidic, neutral or alkaline) scrubbing processes and are released into the atmosphere.

- Methodological approaches to emission estimations

The Tier 1 method involves the multiplication of a default emission factor by the quantity of HCFC-22 produced. Where detailed plant-specific information on HFC-23 capture and destruction is not available, the conservative assumption is that all of the estimated HFC-23 production is released into the atmosphere. The Tier 2 methodology estimates HFC-23 emissions based on detailed plant-level information on the production of HCFC-22, capture of associated HFC-23, as well as on carbon and fluorine (HCFC-22) efficiency. The methodology for estimating emissions from fluorochemical production is described in Section 3.10.1.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 method for estimating HFC-23 emissions requires data on the total HCFC-22 production by all plants in the country, which can be obtained directly from HCFC-22 producers. The Tier 2 methodology estimates HFC-23 emissions based on detailed plant-level information on the production of HCFC-22, capture of associated HFC-23, as well as on carbon and fluorine (HCFC-22) efficiency. Where for some reason it is not possible to obtain data from the producers, HCFC-22 national production data can be used as obtained from the national statistical agencies. If this is the case, only Tier 1 emission estimations can be made. For more detail about the activity data description see Section 3.10.1.2, *Chapter 3, Volume 3*.

- Estimation parameters

If plant-specific information to enable the estimation of emission factors or data on the scale of associated HFC-23 emissions capture and destruction are not available, then default emission factors should be used as given in Table 3.28, Section 3.10.1.2, *Chapter 3, Volume 3*. In the Tier 2 methodology, the HFC-23 emission factor is derived from carbon and fluorine balance efficiencies. For more detail about the estimation parameters see Section 3.10.1.2, *Chapter 3, Volume 3*.

- Cross-cutting issues: No.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity

data and emission factors, the values for which are provided in Section 3.10.1.3, *Chapter 3, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

The methodology for estimating by-product HFC-23 emissions from HCFC-22 production was insignificantly amended, but with no practical impact on the emission estimates. For the description of the amendments see *Refinements 2019*.

2B9b Emissions from Production of Other Fluorinated Compounds

- Category description

A large number of fluorine containing greenhouse gases can be produced as by-products of fluorochemical manufacture and emitted into the atmosphere. Emissions of chemicals occur during their production and destruction or as by-products during the production of related chemicals. There may also be emissions of the material that is being produced – the so-called 'fugitive emissions'. Both by-product and fugitive emissions are calculated in the same way.

- Methodological approaches to emission estimations

In the Tier 1 methodology, a default emission factor should be multiplied by the total production of fluorinated greenhouse gas. Tier 2 and 3 methodologies are described in Section 3.10.2.2, *Chapter 3, Volume 3*.

- Activity data

The Tier 1 method requires data on the annual mass of the desired fluorochemical that is produced. These data can be obtained from industrial companies and plants. For more detail about the activity data description see Sections 3.10.2.2, *Chapter 3, Volume 3*.

- Estimation parameters

For sources that are not significant subcategories under the key category, fugitive and by-product emissions can be estimated using the Tier 1 methodology and 0.5 percent default emission factor. For more detail about the emission factors see Section 3.10.2.2, *Chapter 3, Volume 3*.

- Cross-cutting issues: No.

- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors, the values for which are provided in Section 3.10.2.3, *Chapter 3, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

The methodology for estimating emissions from the production of other fluorinated compounds was substantially revised. The Tier 1 method was revised, and new default emission factors were obtained. Tier 2 and 3 methodologies were developed anew. For the description of the amendments see *Refinements 2019*.

2C Metal Industry Emissions

This sub-sector gives guidance for estimating greenhouse gas emissions that typically result from the production of metals:

- iron and steel, and metallurgical coke production (2C1);
- ferroalloy production (2C2);
- aluminium production (2C3);
- magnesium production (2C4);
- lead production (2C5);
- zinc production (2C6);
- other (2C7).

Care should be taken to avoid double counting of carbon dioxide (CO_2) emissions in both this chapter and in the Energy Sector, or in omitting CO_2 emissions, since CO_2 emissions resulting from carbon's role as process reactant and as a heat source involved in the metallurgical processes may be closely related.

Should CO_2 capture technology be installed and used at a metals production facility, the CO_2 captured should be deducted in a higher tier emissions calculation. Any methodology taking into account CO_2 capture should consider that CO_2 emissions captured in the process may be both combustion- and process-related.

2C1 Iron and steel, and metallurgical coke production

- Category description

Iron and steel production includes a large variety of processes, such as metallurgical coke production, sinter production, pellet production, iron ore processing, iron making, steelmaking, steel casting and very often combustion of blast furnace and coke oven gases for these and other purposes. The main processes may occur under what is referred to as an 'integrated' facility and typically include blast furnaces and basic oxygen steelmaking furnaces, or in some cases open hearth furnaces. It is also common for parts of the production to be off-site under the responsibility of another operator, such as an off-site coke production facility. For more detail about the category description see Section 4.2, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three tiers for calculating CO_2 emissions and two tiers for calculating CH_4 emissions from metallurgical coke, iron and steel, direct reduced iron, sinter and pellets production. The Tier 1 method is to multiply default emission factors by tons of the material produced. The Tier 2 method is based on the national activity data for the consumption of raw materials, including reducing agents. The Tier 2 method for estimating CO_2 emissions distinguishes between on-site and off-site coke production. The Tier 3 method requires plant-specific CO_2 emissions data and plant-specific CH_4 emissions data, or plant-specific activity data. Emissions from metallurgical coke production should be reported in the Energy Sector, however, the methodology is presented in the IPPU Sector, because the activity data used to estimate emissions from energy and non-energy fuel use in integrated iron and steel production have significant overlap. For more detail about the methodologies description see Section 4.2.2, *Chapter 4, Volume 3*.

- Activity data

The Tier 1 method for calculating CO_2 and CH_4 emissions is based on national production data and default emission factors. It may lead to errors due to its reliance on assumptions rather than actual data for the quantity of inputs into the sinter production and iron and steel production sector that contribute to CO_2 emissions. Therefore, the Tier 1 is appropriate only if iron and steel production is not a key category. The Tier 2 method for estimating CO_2 emissions from iron and steel production is based on the national industry-wide data for the consumption of raw materials, including reducing agents. It uses a mass balance approach and material-specific carbon contents. The Tier 2 method is not applicable to estimating CH_4 emissions. The Tier 3 method requires plant-specific emissions or activity data aggregated to the national level for estimating CO_2 and CH_4 emissions. For more detail about the required activity data see Section 4.2.2, *Chapter 4, Volume 3*.

- Estimation parameters

For Tier 1 estimations, default emission factors for coke, sinter, pellet, iron, and steel production are presented in Tables 4.1 and 4.2, Section 4.2.2.3, *Chapter 4, Volume 3*. The Tier 2 method uses a mass balance approach and material-specific carbon contents. Default carbon contents are given in Table 4.3, Section 4.2.2.3, *Chapter 4, Volume 3*. They should be used if the information on conditions in iron and steel-making facilities and coke production facilities is not available, but there are disaggregated activity data for the process materials and off-site transfers.

- Cross-cutting issues

In estimating emissions from coke production (Energy) and iron and steel production (IPPU), there is a risk of double counting or omission in either the IPPU or the Energy Sector. Since the primary use of carbon sources (predominantly coke, but also coal, oil, natural gas, limestone, etc.) is to produce pig iron, the CO_2 and CH_4 emissions from iron and steel production, including sinter production, are considered industrial process emissions and should be reported in the IPPU Sector. The CO_2 and CH_4 emissions from coke production (both fuel consumption and conversion losses) are categorised as energy production and should be reported as such. However, for integrated production of iron and steel with on-site coke production, there may be flows of by-products (such as coke oven gas, blast furnace gas, coke oven by-products) between the coke production facility and the iron and steel production facility, creating potential double counting issues. Therefore, inventory compilers need to work together to take into account both coke consumption and production data.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. Emissions from coke production, sinter production, and iron and steel production should be calculated using the same method for every year in the time series. Inventory compilers should compare national emission factors and carbon contents with the IPCC default factors in order to determine which emission factors should be used, the national EF or the IPCC defaults. Activity data quality assurance requires that inventory compilers examine data from different plants and how these data were collected; in the case of any inconsistencies between data from different plants it is important to determine the reasons, whether these reflect errors, different measurement techniques, operational conditions or technology, etc. The default emission factors for coke production and iron and steel production used in Tier 1 estimates have an uncertainty of ±25 percent. It is believed that Tier 2 material-specific carbon contents have an uncertainty of 10 percent.

For Tier 1, the most important type of activity data is the amount of steel produced using each method. It can be assumed that national statistics are likely to have an uncertainty of ±10 percent. For Tier 2, the uncertainty related to the total amount of reducing agents and process materials used for iron and steel production is likely to be within 10 percent. Table 4.4, Section 4.2.3, *Chapter 4, Volume 3*, provides the uncertainties for emission factors, carbon contents, and activity data.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

In estimating emissions from coke consumption (Energy Sector) and iron and steel production (IPPU Sector), there is a risk of double counting in the IPPU or the Energy Sector. This double count can be avoided by examining the national statistics and the energy balance. If need be, the coke used in category 2C1 'Iron and Steel, and Metallurgical Coke Production' should be deducted from the total coke consumption in the country (as reported by the national statistics).

- Refinement

Whilst the methodologies for estimating CO_2 and CH_4 emissions remained the same, new default emission factors were developed for Tier 1 estimations for some sources, and some default parameters for Tier 2 estimations were amended. Flaring of blast furnace and converter gas was added as a new source of N_2O emissions. A method and emission factors were developed for estimating N_2O emissions. A description of the amendments is discussed in *Volume 3, Refinements 2019*.

2C2 Ferroalloy Production

- Category description

Ferroalloy is the term used to describe concentrated alloys of iron and one or more metals, such as silicon, manganese, chromium, molybdenum, vanadium, and tungsten. Ferroalloy production involves a metallurgical reduction process that results in significant carbon dioxide emissions. The carbonaceous reductants are usually coal and coke, but bio-carbon (charcoal and wood) is also commonly used as a primary or secondary carbon source. Electric submerged arc furnaces with graphite electrodes or consumable Søderberg electrodes are used for ferroalloy production. In the electric arc furnace, heat is produced by the current passing through graphite electrodes suspended in a cup-shaped, refractory-lined steel shell. Carbon reduction of the metallic oxides occurs as both coke and graphite electrodes are consumed. The carbon in the electrodes captures the oxygen from the metal oxides to form CO, while the ores are reduced to molten base metals. The component metals then combine in the solution. The CO gas produced in open or semi-closed furnaces is burnt to CO_2 above the charge level. Any CO emitted to the atmosphere is

assumed to be converted to CO_2 within days afterwards. For more detail about the category description see Section 4.3, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three different methodologies for calculating CO_2 and CH_4 emissions from ferroalloy production.

CO_2 emissions:

For practical purposes, this section adopts a mass balance approach where all CO emitted is reported as emitted CO_2. The Tier 1 method calculates emissions from general emission factors applied to a country's total ferroalloy production. The Tier 1 method is very simple and may lead to errors due to its reliance on assumptions rather than actual data. Therefore it is appropriate only when ferroalloy production is not a key category. The Tier 2 method calculates emissions from a known consumption of reducing agents, preferably from plant-specific consumption data, but alternatively from industry-wide data using emission factors similar to those used to estimate combustion emissions. The Tier 3 method is based on facility-specific emissions data.

CH_4 emissions:

The Tier 1 methodology is similar to that for CO_2 emission estimations. The Tier 1 method calculates emissions from general emission factors applied to a country's total ferroalloy production. The Tier 2 method calculates emissions from operation- and technology-specific emission factors. The Tier 3 method uses facility-specific emissions data. The errors associated with estimates or measurements of N_2O emissions from the ferroalloys industry are very large, and thus no methodology for N_2O emissions estimation is provided. For more detail about the methodologies see Section 4.3.2.1, *Chapter 4, Volume 3*.

- Activity data

The simplest estimation method (the Tier 1 method for CH_4 and N_2O) is to multiply default emission factors by ferroalloy product type; therefore, the activity data include nation-wide amounts of ferroalloys produced by product type. Tier 2 estimations of CO_2 emissions require activity data for the consumption of reducing agents. It is also essential to obtain activity data for other raw materials and products used (ores, slag forming materials, etc.) and their carbon contents. The producers use coal and coke with different contents of ash, fixed carbon and volatiles. Further, the amounts of carbon in carbonate ores and slag forming materials varies. Therefore, CO_2 emissions are most accurately estimated using the Tier 3 method, which is based on the total amount of carbon in reducing agents, electrode paste, ores, slag forming materials and products; and this calculation should be carried out for each ferroalloy produced. Tier 2 estimations of CH_4 emissions require plant-specific data for the ferroalloy production technology (continuous or periodic loading of

charge, etc.). Tier 3 estimations of CH_4 emissions are based on plant-specific measurements. For more detail about the activity data description see Section 4.3.2.1, *Chapter 4, Volume 3*.

- Estimation parameters

For the Tier 1 method, CO_2 and CH_4 default emission factors for ferroalloys are given in Tables 4.5 and 4.7, Section 4.3.2.2, *Chapter 4, Volume 3*. The Tier 2 methodology for estimating CO_2 emissions uses a mass balance approach and the carbon content values for individual materials. The emission factors for the reducing agents used in the production of manganese and silicon alloys are given in Table 4.6, Section 4.3.2.2, *Chapter 4, Volume 3*. The Tier 2 method is also based on emission factors, but unlike the Tier 1 method, these factors are operation-specific and provided in Table 4.8, Section 4.2.2.3, *Chapter 4, Volume 3*.

- Cross-cutting issues

In estimating CO_2 emissions from this source category, there is a risk of double counting or omission in either the IPPU Sector or the Energy Sector. Since the primary use of carbon sources (coal, coke, limestone, dolomite, etc.) is to produce ferroalloys, the emissions are considered to be industrial process emissions and should be reported as such. It should be noted that the risk of double counting is particularly high for the Tier 1 approach.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1*, and an expert review of the emissions estimates. Emissions from ferroalloys production should be calculated using the same method for every year in the time series. Inventory compilers should compare national emission factors and carbon contents with the IPCC default factors in order to determine which emission factors should be used, the national EF or the IPCC defaults. Plant-level activity data quality assurance requires that inventory compilers examine data from different plants and how these data were collected; in the case of any inconsistencies between data from different plants it is important to determine the reasons, whether these reflect errors, different measurement techniques, operational conditions or technology, etc. Uncertainties for ferroalloy production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainties related to the emission factor. Table 4.9, Section 4.3.3.2, *Chapter 4, Volume 3,* presents uncertainty ranges for the emission factors and activity data.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2C3 Primary Aluminium Production

- Category description

Worldwide, primary aluminium is produced by the Hall-Heroult electrolytic process. In this process, electrolytic reduction cells differ in the form and configuration of the carbon anode and alumina feed system and belong to one of four technology types: Centre-Worked Prebake (CWPB), Side-Worked Prebake (SWPB), Horizontal Stud Søderberg (HSS), and Vertical Stud Søderberg (VSS). The most significant process emissions are:

- carbon dioxide (CO_2) emissions from the consumption of carbon anodes in the reaction to convert aluminium oxide to aluminium metal;
- perfluorocarbons (PFCs) emissions of CF_4 and C_2F_6 during anode effects. Also emitted are smaller amounts of CO, SO_2, and NMVOC process emissions. For more detail about the category description see Section 4.4.1, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three tiers methodologies for CO_2 emissions calculation, and the production data requires technology differentiation as Søderberg or Prebake. There is no need for further differentiation as to the specific type of Søderberg or Prebake technology. The Tier 1 method for calculating CO_2 emissions uses only broad cell technology characteristics (Prebake or Søderberg), because it is a lower order estimate of CO_2 emissions from aluminium production. In the Tier 2 or 3 methodologies, for both the Prebake and Søderberg processes CO_2 emissions are calculated using a mass balance approach that assumes that the carbon content of net anode consumption or paste consumption is ultimately emitted as CO_2. In estimating emissions from Prebake cells technology it is essential to estimate CO_2 emissions associated with anode baking furnaces – the combustion of volatile matter released during the baking operation and the combustion of baking furnace packing material (coke). For more detail about CO_2 emission estimation methodologies see Section 4.4.2.1, *Chapter 4, Volume 3*.

During electrolysis, alumina (Al_2O_3) is dissolved in a fluoride melt comprising about 80 weight percent cryolite (Na_3AlF_6). Perfluorocarbons (PFCs hereinafter stand for CF_4 and C_2F_6) are formed from the reaction of the carbon anode with the cryolite melt during a process upset condition known as an 'anode effect'. An anode effect occurs when the concentration of alumina in the electrolyte is too low to support the standard anode reaction. The Tier 1 method for estimating PFC emissions uses technology-based default emission factors for the four main production technology types (CWPB, SWPB, VSS and HSS). Both Tier 2 and Tier 3 methods for PFCs are based on plant-specific process data for anode effects, which are regularly collected. For Tier 2 or 3 estimations of PFC emissions there are two different equations, and both are based on the

relationship between anode effect and performance. These are the slope and overvoltage coefficient equations. Both types of coefficients are based on direct measurements of PFCs. Tier 2 method makes use of an average coefficient from measurements at several facilities, while Tier 3 methodology is based on measurements at the individual facility. For more detail about the PFCs emissions calculation methods see Section 4.4.2.3, *Chapter 4, Volume 3*.

- Activity data

The Tier 1 method for calculating CO_2 emissions uses only aluminium production technology characterizations (Prebake or Søderberg) and the amount of aluminium produced for each of the technologies. The Tier 2 methods for estimating CO_2 emissions for both these processes make use of typical industry values for impurities, while the Tier 3 methods use actual concentrations of impurities. The choice of method between the Tier 2 and Tier 3 methodologies depends on whether anode or paste composition data are available at the individual plant level. For more detail about the required activity data for CO_2 emissions see Section 4.4.2.1, *Chapter 4, Volume 3*. The Tier 1 method for estimating PFCs emissions from aluminium production requires activity data for annual production by technology. Tier 2 and 3 methods for PFC emissions with an established relationship between anode effect process data and PFC emissions, process data collected on an on-going basis can be used to calculate PFC emissions in lieu of direct measurement of PFCs (anode effect minutes per cell-day or anode effect overvoltage). The choice between the two estimation relationships depends on the process control technology in use (recording anode effect in minutes per cell-day or recording overvoltages). For more detail about the activity data required for CO_2 emissions estimation see Section 4.4.2.3, *Chapter 4, Volume 3*.

- Estimation parameters

For Tier 1 calculations, default emission factors for CO_2 emissions from aluminium production are given in Table 4.10, Section 4.4.2.2, *Chapter 4, Volume 3*. Emission parameters for Tier 2 and 3 calculations of CO_2 emissions should be collected from individual operating facilities. Tier 3 is based on the use of specific operating facility data, whereas Tier 2 is based on default values listed in Tables 4.11 - 4.13, Section 4.4.2.2, *Chapter 4, Volume 3*. Emission factors for Tier 1 PFC emission estimations are given in Table 4.15, Section 4.4.2.4, *Chapter 4, Volume 3*. The Tier 2 and 3 methods for estimating PFC emissions are based on using either technology specific slope or overvoltage coefficients for the applicable reduction cell and process control technology. The Tier 3 method is based on facility-specific data, and calculation coefficients for the Tier 2 method are provided in Table 4.16, Section 4.4.2.5, *Chapter 4, Volume 3*.

- Cross-cutting issues: No.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1*, and an expert review of the emissions estimates. It is good practice to sum up emissions estimates from all facilities to arrive at total national emissions. The quality control procedure also includes checking facility-level CO_2 emission factors per tonne of aluminium against the range of CO_2 specific emissions values. There are major differences in the uncertainty for PFC emissions depending on the choice of Tier 1, Tier 2, or Tier 3 methods. The differences in uncertainty resulting from the choice of method for CO_2 emissions are much smaller than for PFC emissions. There is no basis for country differences in emissions resulting from aluminium production other than the differences that result from the specific type of production technologies and work practices in use in the country. Tables 4.10 – 4.16 in Sections 4.4.2.2 – 4.4.2.4 and 4.4.3, *Chapter 4, Volume 3,* present uncertainty ranges for the emission factors and activity data.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

The methodology for estimating PFC emissions from primary aluminium production (2C3) was totally revised. New emission factors and emission estimation parameters were developed for different tiers methodologies. For a description of the changes introduced see *Refinements 2019, Volume 3*.

2C4 Magnesium Production

- Category description

Magnesium production is a potential source of greenhouse gas emissions. The amount and type of emissions from the magnesium industry will reflect the raw material used for primary magnesium metal production and/or the type of cover gas mixture used in the casting and recycling foundries to prevent oxidation of molten magnesium. Primary magnesium can be produced either by electrolysis or a thermal reduction process. Processing of carbonate raw materials (magnesite and dolomite) releases CO_2 during manufacturing. Secondary magnesium production includes the recovery and recycling of metallic magnesium from a variety of magnesium containing scrap materials. All molten magnesium spontaneously burns in the presence of atmospheric oxygen. The amount and type of GHG emissions from metallic magnesium casting is determined by the protection methods used for liquid magnesium. In addition to emissions of the active protection compound (SF6, HFC-134a or FK 5-1-12) in the cover gas itself there may be emissions of various fluorinated decomposition products (for example, PFCs)

and potentially also the carrier gas (depending on the choice of air and/or CO_2 or N_2). For more detail about the category description see Section 4.5.1, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three tier methodologies for estimating CO_2 emissions from magnesium production. The choice of a good practice method for inventory preparation of CO_2 emissions from the primary magnesium (raw material) production segment depends on the national circumstances. The Tier 1 method relies on national primary production data and knowledge of raw materials used in the country. The Tier 2 method for determining CO_2 emissions from primary magnesium involves collecting company/plant-specific empirical emission factors, in addition to company specific production data. The Tier 3 methodology is applied where data are available from individual facilities; these data are then summed up to account for national CO_2 emissions. The choice of a good practice method for inventory preparation of SF_6 emissions from magnesium casting process segment also depends on the national circumstances. The Tier 1 method for estimating SF_6 emissions is based on the total amount of magnesium casting or handling in the country. Like the Tier 1 method, the Tier 2 methodology also assumes that all SF_6 consumed is subsequently emitted into atmosphere. However, instead of the amount of magnesium casting the Tier 2 method uses data on national (or sub-national) consumption of SF_6 in the magnesium industry as reported by the industry or available from other sources. If actual measured emission data are available from individual magnesium processing facilities (Tier 3), these data can be summed up to obtain national emissions estimates. Both HFC-134a and FK 5-1-12 are less thermodynamically stable than SF_6. If individual plants have little historic data on actual emissions of these other fluorinated compounds and if GHG emission from the use of these magnesium cover gases is a national key category, it is good practice to collect direct measurements of HFC-134a and FK 5-1-12 emissions. For more detail about methods for estimating emissions see Section 4.5.2.1, *Chapter 4, Volume 3*.

- Activity data

The Tier 1 method for estimating CO_2 emissions relies on national primary production data and knowledge of raw materials used in the country (magnesium production from dolomite or magnesite). Failing other data, it may be possible to estimate primary magnesium production from annual national magnesium metal sales. This method has increased uncertainty, since it does not account for magnesium used in national product manufacturing. Tiers 2 and 3 methods for estimating CO_2 emissions also require data on primary production, but they also rely on calculation factors. Tier 1 methodology for estimating CF_6 emissions requires activity data for the total amount of magnesium casting or handling in the country. Tier 2 estimates of SF_6 emissions are based on data from all individual users of the gas in the magnesium industry. If no direct data are available,

an alternative but a less accurate method is to estimate the share of annual national SF_6 consumption attributable to the magnesium industry. This requires collecting annual data on national SF_6 sales. Tier 3 estimations require activity data from individual plants. For more detail about the required activity data for CO_2 emissions see Section 4.2.2.1, *Chapter 4, Volume 3*.

- Estimation parameters

As previously mentioned, the Tier 1 method calculates CO_2 emissions from default emission factors applied to a country's total primary magnesium production. Default emission factors are provided in Table 4.19, Section 4.5.2.2, *Chapter 4, Volume 3*. The Tier 2 method for estimating CO_2 emissions from primary magnesium production involves collecting company/plant-specific empirical emission factors, whereas the Tier 3 methodology requires plant-level emission factors. Emission factors for Tier 1 estimations of SF_6 emission from all magnesium casting processes are given in Table 4.20, Section 4.5.2.2, *Chapter 4, Volume 3*. Tier 2 and 3 estimations of CF_6 emissions require plant- or company-level data for gas consumption.

- Cross-cutting issues

Inventory compilers should take caution to avoid double counting of emissions from calcination of magnesium carbonate raw materials during primary magnesium production and those emissions associated with calcining limestone, dolomite, and other carboneous minerals (category 2A). All emissions associated with the calcination of carbonates for primary magnesium production should be reported as GHG emissions from magnesium production.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. Inventory compilers should involve magnesium industry experts in a thorough review of the inventory estimate, with due consideration of potential confidentiality issues. At the plant level, there should be information about raw material type/composition, as well as tonnage magnesium produced. Directly-reported activity data, which are required for Tier 2 and 3 methods for all gases, are typically accurate to within less than 5 percent for CO_2 emissions from primary production. At the national inventory level, the accuracy of magnesium production activity and emission data is comparable to that of other national production statistics (i.e., ±5 percent). For more detail about the uncertainties see Section 4.5.3, *Chapter 4, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2C5 Lead Production

- Category description

There are two primary processes for the production of rough lead bullion from lead concentrates. The first type is sintering/smelting, the second type is direct smelting. In the sintering/smelting process, the initial sintering blends lead concentrates with recycled sinter, lime rock and silica, oxygen, and high-lead-content sludge to remove sulphur and volatile metals via combustion. This process results in the emission of sulphur dioxide (SO_2) and energy-related carbon dioxide (CO_2) from the natural gas used to ignite the lead oxides. Lead smelting is the reduction of the lead oxide which produces CO_2 emissions. The direct smelting process offers significant environmental and potential cost saving benefits through the avoidance of the sintering process. The secondary production of refined lead amounts to the processing of recycled lead to prepare it for reuse. The vast majority of this recycled lead comes from scrapped lead acid batteries. As with the furnaces used for primary lead bullion production, these furnaces generate different levels of CO_2 emissions from their use of differing types and quantities of reductants. For more detail about the category description see Section 4.5.1, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three methods for calculating CO_2 emissions from lead production. The choice of a good practice method depends on the national circumstances. The Tier 1 method calculates emissions from national emission factors applied to a country's total lead production; this method is the least accurate and appropriate only when lead production is not a key category. The Tier 2 method uses country-specific process material data for both primary and secondary production processes multiplied by the appropriate carbon contents of process materials. The Tier 3 method requires facility-specific measured activity or emissions data. For more detail about the methods used for estimating emissions see Section 4.6.2, *Chapter 4, Volume 3*.

- Activity data

The Tier 1 method requires only the amount of lead produced in the country, and if available, lead production by different types of furnaces. These data may be available from governmental agencies responsible for manufacturing statistics, business or industry trade associations, or individual lead companies. Tier 2 methodology is based on the total use of reducing agents and other process materials used for lead production in a country. These data may also be available from governmental agencies responsible for manufacturing or energy statistics, business or industry trade associations, or individual lead companies. The Tier 3 method requires that plant level emission or activity data be collected, compiled, and summed up. For more detail about the required activity data for CO_2 emission estimations see Section 4.6.2.1, *Chapter 4, Volume 3*.

- Estimation parameters

When the only data available are national lead production statistics, it is good practice for Tier 1 estimations to use default emission factor. If information on the amounts of lead produced from primary and from secondary materials is available, emissions should be calculated using the appropriate factors as provided in Table 4.21, Section 4.6.2.2, *Chapter 4, Volume 3*. The Tier 2 method offers the opportunity to adjust default emission factors based on plant-specific data for the carbon content of these materials and on the furnace type. The default carbon contents are shown in Table 4.22, Section 4.6.2.2, *Chapter 4, Volume 3*; they should be used if an inventory compiler does not have information on conditions in lead facilities, but has disaggregated activity data for the process materials. The Tier 3 method is based on aggregated emission estimates or the application of the Tier 2 method at the plant-level.

- Cross-cutting issues

In estimating emissions from this source category, there is a risk of double counting or omission in either the IPPU or the Energy Sector. As a general guide, all process emissions from lead production should be reported in the IPPU Sector.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. Emissions from lead production should be calculated using the same method for every year in the time series. Inventory compilers should compare national emission factors and carbon contents with the IPCC default factors in order to determine if the national factor is reasonable relative to the IPCC default. For site-specific activity data, it is essential to review data from a variety of plants and explore how these data were collected; if there are inconsistencies between sites, it is important to establish whether they reflect errors, different measurement techniques, operational conditions, or technology. Uncertainty estimates for lead production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainties related to the emission factor. For more detail about the uncertainties see Section 4.6.3.2, *Chapter 4, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2C6 Zinc Production

- Category description

There are three different types of primary zinc production. The first method is a metallurgical process called electro-thermic distillation. The second method of zinc production is a pyrometallurgical process involving the use of an Imperial Smelting Furnace, which allows for the simultaneous treatment of lead and zinc concentrates. The third zinc production method is the electrolytic process, which is a hydrometallurgical technique. All primary zinc production methods result in the release of non-energy carbon dioxide (CO_2) emissions. There are more than 40 hydrometallurgical and pyrometallurgical technologies that can be used to recover zinc metal from various materials. The preferred method for a given situation depends on the zinc source (contamination level and zinc concentration) and the desired end use for the recovered zinc. For more detail about the category description see Section 4.7.1, *Chapter 4, Volume 3*.

- Methodological approaches to emission estimations

There are three methods for calculating CO_2 emissions from zinc production. The Tier 1 method calculates emissions from general emission factors applied to a country's total zinc production; this is the least accurate method. It should only be used when zinc production is not a key category. The Tier 2 method uses country-specific emissions factors for both primary and secondary production processes. The Tier 3 method may be used if facility-specific measured emissions data are available. For more detail about the emission estimation methods see Section 4.7.2.1, *Chapter 4, Volume 3*.

- Activity data

The Tier 1 method requires only the amount of zinc produced in the country, and if available, the process type. These data may be available from governmental agencies responsible for manufacturing statistics, business or industry trade associations, or individual zinc companies. CO_2 emissions are then calculated by multiplying these amounts by default emission factors. The Tier 2 method requires the calculation of a country-specific emission factor based on the total amount of reducing agents and other carbon containing process materials used for zinc production in the country. The Tier 3 method requires collection, compilation, and aggregation of facility-specific measured emissions data, if any. For more detail about the required activity data for CO_2 emissions estimation see Section 4.7.2.3, *Chapter 4, Volume 3*.

- Estimation parameters

When the only data available are national zinc production statistics, it is good practice to use default emission factors for Tier 1 estimations. The emission factor for the pyrometallurgical process (Imperial Smelting Furnace) is an aggregate, weighted emission factor encompassing both

primary and secondary zinc production in Europe. This and other factors for different zinc production processes are given in Table 4.24, Section 4.7.2.2, *Chapter 4, Volume 3*. The Tier 2 method requires the calculation of a country-specific emission factor based on the total amount of reducing agents and other carbon containing process materials used for zinc production in the country. The Tier 3 method requires collection, compilation, and aggregation of facility-specific measured emissions data, if any.

- Cross-cutting issues

In estimating CO_2 emissions from this source category, there is a risk of double counting or omission in either the IPPU Sector or the Energy Sector. It is important to note that the Tier 1 emission factor assumes that the CO_2 emissions from the combustion of various fuels used for the production of heat in the calcining, sintering, leaching, purification smelting, and refining processes are captured within the CO_2 from fossil fuel combustion emission category. Double counting can be avoided by using the Tier 2 or 3 methodologies. Emissions from coke production may become the largest source of potential double counting; these should be reported in the Energy Sector.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1*, and an expert review of the emissions estimates. Emissions from zinc production should be calculated using the same method for every year in the time series. Where data are not available to support a Tier 3 method for some of the years in the time series, these gaps should be recalculated according to the guidance provided in *Chapter 5, Volume 1*. Inventory compilers should compare national emission factors and carbon contents with the IPCC default factors in order to determine if the national factor is reasonable relative to the IPCC default. For site-specific activity data, it is essential to review data from a variety of plants and explore how these data were collected; if there are inconsistencies between sites, it is important to establish whether they reflect errors, different measurement techniques, operational conditions, technology, etc. Uncertainty estimates for zinc production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainties related to the emission factors. For more detail about the uncertainties see Table 4.25, Section 4.7.3, *Chapter 4, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2C7 Other

This source category comprises emissions that are not reported in other categories.

2D Non-Energy Products From Fuels And Solvent Use

This sub-section provides guidance for estimating greenhouse gas emissions from the use of solvents and non-energy products from fuel use under the following categories:

- Lubricant Use (2D1);
- Paraffin Wax Use (2D2);
- Solvent Use (2D3);
- Other (2D4).

This sub-section provides methods for estimating emissions from the first use of fossil fuels as a product for primary purposes other than a) combustion for energy purposes, and b) use as feedstock or reducing agent. Emissions from the latter two uses are described in chapters on the chemical industry (*Chapter 3, Volume 3*) and on metal industry (*Chapter 4, Volume 3*).

Emissions from further uses or disposal of the products after use (i.e., the combustion of waste oils and lubricants) are to be reported in the Waste Sector when incinerated or in the Energy Sector when energy recovery takes place.

Generally, the methods for calculating carbon dioxide (CO_2) emissions from non-energy product uses follow a basic formula, in which the emission factor is composed of a carbon content factor and a factor that represents the fraction of fossil fuel carbon that is Oxidised During Use (ODU), for example, actual fraction of lubricants that slips into the combustion chamber of an engine.

Methane (CH_4) emissions from the activities are considered to be minor, or non-existent, or are not accounted for in the guidelines.

2D1 Lubricant Use

- Category description

Lubricants are mostly used in industrial and transportation applications. It is difficult to determine which fraction of the lubricant consumed in machinery and in vehicles is actually combusted and thus directly results in CO_2 emissions, and the fraction not fully oxidised that results firstly in NMVOC and CO emissions (except for the use in 2-stroke engines). In the case of 2-stroke engines, where the lubricant is mixed with another fuel and thus on purpose co-combusted in the engine, the emissions should be estimated and reported as part of the combustion emissions in the Energy Sector. Therefore, for calculating CO_2 emissions the total amount of lubricants lost during their use is assumed to be fully combusted and these emissions are directly reported as CO_2

emissions. Waste oil handling emissions are to be reported in the Waste Sector (or in the Energy Sector when energy recovery takes place). For more detail about the category description see Section 5.2, *Chapter 5, Volume 3*.

- Methodological approaches to emission estimations

There are two methodological tiers for determining CO_2 emissions from the use of lubricants. Tier 1 and Tier 2 rely on essentially the same analytical approach, which is to apply emission factors to activity data on the volume of lubricant consumption in a country. The Tier 2 method requires data on the quantities of different types of lubricants (excluding the amount used in 2-stroke engines) and type-specific Oxidised During Use (ODU) factors, preferably country-specific, while the Tier 1 method relies on applying default ODU factors to total lubricant activity data. For more detail about emissions estimation methodologies see Section 5.2.2.1, *Chapter 5, Volume 3*.

- Activity data

Data on the non-energy use of lubricants are required to estimate emissions, with activity data expressed in energy units (TJ). Basic data on non-energy products used in a country may be available from production, import and export data and on the energy/non-energy use split in national energy statistics. Additional information may need to be collected to determine the amount of lubricants being used in 2-stroke engines, which should be excluded from the Tier 2 calculation in this source category. For the Tier 2 method, the individual quantities applied as motor oil/industrial oils and as greases need to be separately known. For more detail about the required activity data for CO_2 emissions estimation see Section 5.2.2.3, *Chapter 5, Volume 3*.

- Estimation parameters

If only total consumption data for all lubricants (i.e., no separate data for oil and grease) are available, the weighted average ODU factor for lubricants as a whole can be used in the Tier 1 method. Assuming that 90 percent of the mass of lubricants is oil and 10 percent is grease, applying these weights to the ODU factors for oils and greases yields an overall ODU factor of 0.2. This ODU factor can then be applied to an overall carbon content factor (which may be country-specific or the default value) for lubricants to determine national emission levels from this source when activity data on the consumption of lubricants is known. Tier 2 estimations use these country-specific or default ODU factors which can then be multiplied by the country-specific carbon content factors or the single default IPCC carbon content factor for lubricants to determine national emission levels. For more detail about the emission factors to be used in calculations see Section 5.2.2.2, *Chapter 5, Volume 3*.

- Cross-cutting issues

Emissions from the use of lubricants in 2-stroke engines should be accounted for in the Energy Sector. Any emissions that occur due to post-use combustion or degradation after disposal should be accounted for separately in the Waste Sector (or in the Energy Sector, if combustion is used for energy recovery). To avoid double counting and to ensure completeness, it is essential to cross-check the proper allocation of those emissions not related to the non-combustion usage of lubricants in the Energy and Waste Sectors.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. Emissions from lubricants should be calculated using the same method for every year in the time series. It is good practice to check the consistency of the total annual consumption figure with the production, import and export data. In addition, it is recommended to compare the amounts discarded, recovered, and combusted and the amount used in 2-stroke engines with total consumption figures in the calculation to ensure the internal consistency of activity data and ODU factors used in the calculation of different source categories across sectors. Expert judgment suggests using a default uncertainty of 50 percent. The carbon content uncertainty range is estimated at about ±3 percent.

Much of the uncertainty in emission estimates is related to the difficulty in determining the quantity of non-energy products used in individual countries. A 5 percent default uncertainty may be used in countries with well-developed energy statistics and 10-20 percent in other countries, based on expert judgment of the accuracy of energy statistics. For more detail about the uncertainties description see Section 5.2.3, *Chapter 5, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2D2 Paraffin Wax Use

- Category description

This category, as defined here, includes products, such as petroleum jelly, paraffin waxes and other waxes, including ozokerite. Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Paraffin waxes are categorised by oil content and the amount of refinement. Emissions from the use of waxes derive primarily when the waxes or derivatives of

paraffins are combusted during use (for example, candles), and when they are incinerated with or without heat recovery or in wastewater treatment (for surfactants). For more detail about the category description see Section 5.2, *Chapter 5, Volume 3*.

- Methodological approaches to emission estimations

There are two methodological tiers for determining CO_2 emissions from the use and storage of paraffin waxes. Tiers 1 and 2 rely on essentially the same analytical approach, which is to apply emission factors to activity data for the amount of paraffin waxes consumed in a country (in energy units, for example, in TJ). The Tier 2 method relies on determining the actual use of paraffin waxes and applying a country-specific ODU factor to activity data, while the Tier 1 method relies on applying default emission factors to activity data. For more detail about the emissions estimation methodologies see Section 5.3.2.1, *Chapter 5, Volume 3*.

- Activity data

Data on the use of paraffin waxes are required to estimate emissions; the activity data should be expressed in energy units (TJ). To convert consumption data in the units of mass (for example, in tonnes) into common energy units (for example, in TJ, on a Lower Heating Value basis), calorific values are required (for specific guidance see Section 1.4.1.2, *Chapter 1, Volume 2 (Energy)*. Basic data on non-energy products used in a country may be available from production, import and export data and on the energy/non-energy use split in national energy statistics. If the reported national statistics do not contain this information as a separate source category but instead only show it as part of an aggregated 'other oil products' category, the national statistical agency should be approached, since the oil product statistics are often collected at a more detailed level. For more detail about the required activity data for CO_2 emissions see Section 5.3.2.3, *Chapter 5, Volume 3*.

- Estimation parameters

The values for carbon content and default ODU factor for Tier 1 estimations are provided in Section 5.3.2.2, *Chapter 5, Volume 3*. For Tier 2 estimations, those countries with specific details on the uses of paraffin waxes in the country can determine their own country-specific ODU factors for waxes based on national knowledge of the combustion. These factors can be combined with either the default carbon contents or country-specific carbon contents, if any are available.

- Cross-cutting issues

Emissions from incineration (without energy recovery) of wax-coated boxes fall under the Waste Sector. Any emissions from paraffin waxes that are produced due to energy recovery should be reported in the Energy Sector.

- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. Emissions from paraffin waxes should be calculated using the same method for every year in the time series. It is good practice to check the consistency of the total annual consumption figure with the production, import and export data. The default emission factors are highly uncertain, because knowledge of national circumstances of paraffin wax uses is limited. Ideally, a Tier 2 method should be employed in which national data on the use and fates of waxes can be used instead of determining the quantities destined for emissions and those destined to be stored. For more detail about the uncertainties see Section 5.3.3.1, *Chapter 5, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2D3 Solvent Use

- Category description

Direct greenhouse gas emissions, for example, CO_2 or CH_4, associated with these categories are negligible compared to the emissions of non-methane volatile organic compounds (NMVOC), and so are not reported. This sub-sector covers the following categories: solvent use (the use of colouring agents, degreasing and cleaning solvents), asphalt production for roofing materials, and asphalt use for road-paving applications. Emissions from these source categories are negligible, and no estimation methodologies are provided in the 2006 IPCC Guidelines; however, these Guidelines allow it to use the methodology described in EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2013 *https://www.eea.europa.eu/publications/emep-eea-guidebook-2013*) to estimate the emissions from these categories. Further in the text only methodological approaches for the 'solvent use' category will be described. The use of solvents manufactured using fossil fuels as feedstocks can lead to evaporative emissions of various non-methane volatile organic compounds (NMVOC), which are subsequently further oxidised in the atmosphere. Fossil fuels used as solvent are notably white spirit and kerosene (paraffin oil). For more detail about the category description see Section 5.5.1, *Chapter 5, Volume 3*.

- Methodological approaches to emission estimations

The 2006 IPCC Guidelines refer to, and allow for the use of, the methodology described in EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2013) for estimating NMVOC emissions from solvent use. Solvent use is treated as a separate category because the nature of this source

requires a somewhat different approach to emissions estimation than that used for calculating other emission categories. This is also a reason why solvent use is treated as a separate sub-category in the 2006 IPCC Guidelines. For more detail about the emissions estimation methodology see Section 5.5.1, *Chapter 5, Volume 3*.

- Activity data

Emissions from this source category can be estimated using either a production-based or consumption-based approach. If total domestic sales figures of paints, etc. are not available, apparent national consumption can be inferred from production, imports and exports. However, if trade statistics are not complete, this may introduce a significant uncertainty in the activity data. Thus, it is recommended that inventory compilers try to ensure that all significant evaporative uses of solvent and other product use are addressed by NMVOC emission estimates. For more detail about the activity data for NMVOC emissions estimation see Section 5.5.2, *Chapter 5, Volume 3*.

- Estimation parameters

General recommendations for choosing the calculation factors are provided in Section 5.5, *Chapter 5, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

It is good practice to conduct quality control checks as outlined in *Chapter 6, Volume 1* and an expert review of the emissions estimates. For this source category only small annual changes can be expected. However, when environmental policies are implemented to replace more toxic volatile compounds in solvents, both NMVOC emissions and the fossil carbon content of the NMVOC emissions may change over time. The uncertainty of the NMVOC emissions is typically large, i.e. about ±50 percent, except for countries that have developed a detailed inventory for these sources (in these countries the uncertainty may be 25 percent). The default fossil carbon content fraction of NMVOC is 60 percent by mass, based on limited published national analyses of the NMVOC profile. The fossil carbon fraction may vary between 50 and 70 percent by mass, so the uncertainty is about ±10 percent. Country-specific fractions of fossil carbon should have a lower uncertainty, for example, ±5 percent. For more detail about the uncertainties see Section 5.5.4, *Chapter 5, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2D4 Other

This source category comprises emissions that are not reported in other categories.

2E Electronics Industry

- Category description

Fluorinated compounds (FCs) are used in many processes in modern electronics industry for plasma etching intricate patterns, cleaning reactor chambers, and temperature control. Some of the electronic industry sectors include semiconductor, thin-film-transistor flat panel display (TFT-FPD), and photovoltaic (PV) manufacturing. The electronics industry currently emits FCs, including CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, nitrogen trifluoride (NF_3), and sulfur hexafluoride (SF_6). These are used in two important steps of electronics manufacturing: plasma etching silicon-containing materials, and cleaning chemical vapour deposition (CVD) tool chamber-walls; they are emitted as a result of inefficient use of the FCs during the etching or the cleaning process. In addition, a fraction of the FCs used in the production process can be converted into by-product CF_4 and in some instances into other FCs, such as C_2F_6, CHF_3, and C_3F_8.

Additional FCs emissions occur as evaporative losses from the use of heat transfer fluids. Electronics manufacturers use FCs for temperature control during certain processes as heat transfer fluids; these FCs are liquids at room temperature and have appreciable vapour pressures. Therefore, the production process involves evaporative losses of FCs during cooling of certain process equipment, during testing of packaged semiconductor devices and during vapour phase reflow soldering of electronic components to circuit boards. Evaporative losses do not occur when liquid FCs are used to cool electronic components or systems during operation, if the liquid FCs are contained in closed systems throughout the life of the product or system. For more detail about the category description see Section 6.1, *Chapter 6, Volume 3*.

- Methodological approaches to emission estimations

Etching and CVD cleaning for semiconductors, liquid crystal displays, and photovoltaics

The structure and intensity of emissions vary according to the gases used in manufacturing different types of electronic devices, the process used (or process type, for example, CVD or etch), the brand of FCs emission control equipment; and the efficacy of FC emission control equipment depends on operating and maintaining the equipment according to the manufacturer's specifications.

The Tier 1 method uses IPCC emission factors and does not account for the use of emission control technology. The Tier 2a and 2b methods can be combined to obtain more accurate estimates than by using the Tier 2a methodology alone. However, the Tier 1 method is not to be combined

with other methods. Tier 1 estimations are based on IPCC emission factors for each sector of electronic products being manufactured (semiconductors, TFT-displays and PV-cells). The Tier 2a method calculates emissions for each FC used on the basis of company-specific data for gas consumption and for emission control technologies. To use the Tier 2a method inventory compilers must have direct communication with industry to gather data and ensure that emission control technologies are installed and in use. The Tier 2b method requires data on the aggregate quantities of each gas fed into all etching processes and all cleaning processes. Thus, this method distinguishes only between broad process types (etching versus CVD chamber cleaning), but it does not distinguish among the many possible individual processes or small sets of processes. For more detail about the emissions estimation methodologies see Section 6.2, *Chapter 6, Volume 3*.

Heat transfer fluids

Tier 1 estimations rely on the emission factor that expresses the average emissions per unit of silicon consumed during semiconductor manufacturing. The Tier 2 method is a mass-balance approach that accounts for FC usage over an annual period. It is appropriate when company-specific data are available. Over the course of a year, liquid FCs are used to fill newly purchased equipment and to replace FC fluid loss from equipment operation through evaporation. The Tier 2 method neglects fluid losses during filling new or existing equipment or when decommissioning old equipment. Inventory compilers should obtain from companies the chemical composition of the fluids for which emissions are estimated. For more detail about the emissions estimation methodologies see Section 6.2, *Chapter 6, Volume 3*.

- Activity data

Activity data for the electronics industry consist of data on gas sales and use or the annual amount of electronics substrate processed (for example, m^2 of silicon processed for semiconductors). For the Tier 2 methods, plant- or company-level data are required. For the Tier 1 methods, inventory compilers will need to determine the total surface area of electronic substrates processed for a given year in a country. It is recommended that the following information sources be used:

- National statistical agencies;
- Corresponding plants and companies.[22]

For more detail about the activity data see Section 6.2.3, *Chapter 6, Volume 3*.

[22] For estimating silicon consumption, the IPCC Guidelines recommend data published in World Fab Watch (WFW) periodical issued quarterly by Semiconductor Equipment & Materials International (SEMI). This database contains a list of plants (production as well as R&D, pilot plants, etc.) worldwide, with information about location, design capacity, wafer size, and much more. Similarly, SEMI's 'Flat Panel Display Fabs on Disk' database provides an estimate of glass consumption for global TFT-displays manufacturing.

- Estimation parameters

IPCC default emission factors for Tier 1 estimations are provided in Sectoin 6.2.2, Table 6.2, *Chapter 6, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Standard quality control procedures should be consistent with the recommendations given in *Chapter 6, Volume 1*. Uncertainty estimates should be derived from the uncertainties for the activity data and emission factors, the values for which are provided in Section 6.3, *Chapter 6, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

Methods, emission factors, and estimation parameters for calculating the emissions of fluorinated compounds were completely revised. This was determined by the changes in production processes that took place in the electronics industry over the past 13 years, and by a large amount of experimental data accumulated over the same period. For a description of the revisions see *Refinements 2019*.

2F Product Uses as Substitutes for Ozone Depleting Substances

This sub-sector covers the methods for estimating emissions of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), which serve as alternatives to ozone depleting substances (ODS) being phased out under the Montreal Protocol. The application areas of HFCs and PFCs include:

- refrigeration and air conditioning;
- fire suppression and explosion protection;
- aerosols;
- solvent cleaning;
- foam blowing;
- other applications.

The use of HFCs and PFCs in some applications can lead to the development of long-lived banks of material; this specifically refers to rigid foam (typically closed-cell foam), refrigeration and fire suppression systems. The emission patterns from these uses can be particularly complex, so methods employing disaggregated data sets are essential to generate accurate emissions estimates. This statement

also applies to applications with high numbers of sub-applications (refrigeration, foam). Even if few sub-applications exist, estimating emissions by sub-application is still preferable owing to the differences in emission patterns, chemical use, data gathering methodologies, and/or data availability. Therefore, it is important early on in the estimation process to decide how and where data can be collected.

When collecting data on HFC and PFC consumption, it is essential to take care to include those HFCs in blends, but to avoid including those components of a blend which are not required to be reported (for example, hydro- and chlorofluorocarbons (CFCs and HCFCs)). Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*, gives an overview of the most important HFCs and PFCs. Data on domestic HFCs and PFCs sales are most often not captured by national statistics. These data can partially be obtained from plants that use these chemicals to manufacture equipment, materials, and other products (facilities that produce household refrigerators, foamed plastics, etc.). These chemicals can also be used by companies that install and maintain refrigerating equipment and equipment for air conditioning and fire protection. There can be a large number of such companies, and collection of data on HFCs and PFCs sales in a country is often quite difficult. Data on markets, which are data on equipment or product sales at the sub-application level, will be imperfect; they should also include equipment or product manufacture, exports and imports. Along with various HFCs and PFCs, the same sub-applications can use other compounds that are not greenhouse gases and therefore are not to be reported in the National greenhouse gas emissions inventory. Thus, data often need to be accompanied by an estimate of the share of the market that uses a particular chemical that must be reported in the inventory.

One of the major barriers to reliable emissions estimates at the national level has been the confidentiality of data at the level of many plants. In order to resolve this issue, there has been an effort to develop global and regional databases which provide information on historic and current activity (chemical consumption) data at the country level for specific applications and sub-applications (further in the text these mean the key current and projected HFCs and PFCs consumption groups), see Box 7.1, Section 7.1.2.1, *Chapter 7, Volume 3*. Importantly, in many applications ODS substitutes are contained (for example, air conditioning), while in other applications they are meant to be emitted (for example, an aerosol propellant). These differences are important to understand, so that the year in which emissions occur can be accurately assessed, and hence actual emissions can be accurately estimated. Emissions of ODS substitutes can be assessed using different tier methodologies, but the Tier 3 method, which is based on actual monitoring and measurement of emissions from point sources, is technically possible for specific sub-applications, yet is rarely, if ever, employed, because the individual point sources are widely disparate. Accordingly, Tier 3 methods are not addressed for category 2F. For more detail about the general principles and HFCs and PFCs applications see Section 7.1, *Chapter 7, Volume 3*.

2F1 Refrigeration and Air Conditioning

- Category description

Refrigeration and air-conditioning (RAC) systems covered in category 2F1 may be classified into six categories or sub-application domains (although less sub-applications are typically used at a single country level): household refrigeration; commercial refrigeration including different types of equipment (from vending machines to centralised refrigeration systems in supermarkets); industrial processes (including chillers, cold storage, and industrial heat pumps); transport refrigeration (including equipment and systems used in refrigerated trucks, containers, reefers, and wagons); stationary air conditioning (including air-to-air systems, heat pumps, and chillers for building and residential applications); mobile air-conditioning systems (used in passenger cars, truck cabins, buses, and trains). The most common blends containing HFCs and/or PFCs that are used in RAC applications are shown in Table 7.8, Section 7.5.1, *Chapter 7, Volume 3*. For more detail about the category description see Section 7.1, *Chapter 7, Volume 3*.

- Methodological approaches to emission estimations

Tier 1 and 2 methods result in estimates of actual emissions for category 2F1, and these estimates account for the lag between consumption and emissions, which is particularly important for the RAC sectors because of the potentially long retention of refrigerants in products and equipment, which results in bank establishment per sub-applications. For subcategories covered by RAC it is acceptable to use a hybrid Tier 1a/b approach which back-calculates the development of banks of a refrigerant. Where activity data at the sub-application level and national or global emission factors are available, emissions can be estimated using Tier 2a or 2b method. For more detail about the methodologies see Section 7.5.2, *Chapter 7, Volume 3*. The mass balance approach is particularly applicable to RAC applications, because maintenance of RAC equipment is associated with substantial chemical consumption. For more detail about the selection between the mass balance approach and the emission factors approach see Section 1.5, *Chapter 1, Volume 3*.

- Activity data

Activity data for Tier 1a/b emission estimations include: sales of a specific refrigerant in the year to be reported; year of introduction of the refrigerant; growth rate in sales of new equipment (usually assumed linear across the period of assessment); assumed percentage of new equipment exported; assumed percentage of new equipment imported. In countries that produce refrigerant chemicals, annual sales of new refrigerant should be estimated using information provided by chemical manufacturers. Data on imported chemicals should be collected from customs statistics, importers or distributors. Required activity data can be obtained from equipment manufacturers/importers. For some applications it is necessary to collect information on historical

net consumption patterns, which can lead to the development of long-lived banks of material. If national data cannot be analyzed on the country level, verified global data can be used (see Table 7.9, Section 7.5.2.2, *Chapter 7, Volume 3*). The composition of blends (containing HFCs or PFCs) can be specified by using data from Table 7.8, Section 7.5.1, *Chapter 7, Volume 3*; refrigerant manufacturers can help obtain data for the technologies and chemical use (particularly for blends).

- Estimation parameters

A composite emission factor is required for Tier 1 estimations. Since the sub-applications within the RAC application are relatively heterogeneous, the validity of any single composite emission factor must be in doubt, unless it takes into consideration the research undertaken in the country. Tier 2 estimations rely on the emission factors obtained from country-specific data, which are based on information provided by equipment manufacturers, service providers, disposal companies, and independent studies. If national data are unavailable, default emission factors shown in Table 7.9, Section 7.5.2.2, *Chapter 7, Volume 3*, should be used. If the collected data cannot be broken down into the sub-applications, expert judgment should be used to estimate the relative share of each type of equipment, and calculate composite emission factors weighted according to that relative share (as proposed for Tier 1a/b), or use the emission factor appropriate to the most common type(s) of equipment. Box 7.3, Section 7.5.2.3, *Chapter 7, Volume 3*, sets out an algorithm for adequate estimation of imports and exports of refrigerants and equipment. For more detail about choosing the calculation factors see Sections 7.5.2 and 7.5.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Completeness for the Tier 1a/b method can be achieved if data for new refrigerants and refrigerants in equipment that is retired in the current year, are available. For the Tier 2a and 2b methods, completeness depends on a thorough accounting of the existing equipment banks. Generally, disaggregated methods (Tier 2) have less uncertainty, than Tier 1 methods, because of the heterogeneous nature of the sub-applications. Table 7.8, Section 7.5.1, *Chapter 7, Volume 3*, presents emission factor ranges that highlight the uncertainty associated with this sector. For more detail about the uncertainty assessment for the RAC category (2F1) see Section 7.5.3, *Chapter 7, Volume 3*. Quality control procedures in this category include all the key procedures designed to minimize omissions and avoid double counting of emissions, in particular, verification of supply and demand assessment and calculation of annual refrigerant market (for more detail see Sections 7.1.4 and 7.4.4, *Chapter 7, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It is recommended to balance consumption of HFCs used in different categories based on the national circumstances and available activity data. For example, HFC-134a can be used in categories 2F1, 2F2, 2F3, and 2F4. This balancing will help avoid data omissions or double counting. Because of the substantial branching and heterogeneity of category 2F1 and its sub-categories, which are determined by the variety of refrigeration and air conditioning systems used in the world and by the large number of various fluorinated substitutes of ozone depleting substances, it is recommended to obtain expert judgment in order to avoid incorrect accounting.

- Refinement

Some estimation parameters required for the Tier 2 method were added to category 2F1 'Refrigeration and Air Conditioning'. In addition, the results of research devoted to the emissions of fluorinated substitutes for ODS from various refrigeration and air conditioning equipment undertaken in different countries were reported.

2F1a – Refrigeration and Stationary Air Conditioning

- Category description

Sub-category 2F1a (Refrigeration and Stationary Air Conditioning) covers the emissions of HFC and PFC or their blends from stationary air conditioning and refrigeration.

- Methodological approaches to emission estimations

There are two tier approaches (see Emissions of Fluorinated Substitutes for Ozone Depleting Substances Section); for more detail about the methodological approaches see Section 7.5.2, *Chapter 7, Volume 3*.

- Activity data

Activity data are based on the information obtained from chemical importers, distributors or manufacturers, manufacturers/importers of equipment, customs statistics, verified global data (see Table 7.9, Section 7.5.2.2, *Chapter 7, Volume 3*). For more detail about the activity data see Section 7.5.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

Emission factors and other estimation parameters are provided in detail in the description of category 2F1 'Refrigeration and Air Conditioning', see Sections 7.5.2 and 7.5.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Quality control procedures and uncertainty estimates for sub-category 2F1a 'Refrigeration and Stationary Air Conditioning' are similar to those for category 2F1 'Refrigeration and Air

Conditioning'. For more detail about the uncertainty estimates see Section 7.5.3, *Chapter 7, Volume 3*; for quality control procedures see Sections 7.1.4 and 7.4.4, *Chapter 7, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

Because of the substantial branching and heterogeneity of category 2F1 and its sub-categories, which are determined by the variety of refrigeration and air conditioning systems used in the world and by the large number of various fluorinated substitutes of ozone depleting substances, it is recommended to obtain expert judgment in order to avoid incorrect accounting.

- Refinement

For more detail about the assessment of the potential impact of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (*Refinement 2019*) see category 2F1.

2F1b – Mobile Air Conditioning

- Category description

Sub-category 2F1b 'Mobile Air Conditioning' covers emissions from mobile air conditioners that are used in passenger cars, tractor cabins, buses, and trains.

- Methodological approaches to emission estimations

There are two tier approaches (see Emissions of Fluorinated Substitutes for Ozone Depleting Substances Section); for more detail about the methodological approaches see Section 7.5.2, *Chapter 7, Volume 3*, and for an example of a Tier 2a calculation for mobile air conditioning see Box 7.4, Section 7.5.2.4, *Chapter 7, Volume 3*.

- Activity data

The required bank of activity data for sub-category 2F1b can be developed using the car statistics (for example, the car population by type, age, and air conditioner availability), and also information which may be available from chemical importers, distributors or manufacturers, manufacturers/importers of equipment, customs statistics, verified global data (see Table 7.9, Section 7.5.2.2, *Chapter 7, Volume 3*). For more detail about the activity data see Section 7.5.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

Emission factors and other estimation parameters are provided in detail in the description of category 2F1 'Refrigeration and Air Conditioning', see Sections 7.5.2 and 7.5.2.2, *Chapter 7, Volume 3*. Example of the application of a Tier 2a calculation for mobile air conditioning (see Box

7.4, Section 7.5.2.4, *Chapter 7, Volume 3*) shows, that pure approaches and methods are very rarely applied in practice. In practice, the mass balance approach can be combined with the emission factor approach, as well as with the national and global data.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Quality control procedures and uncertainty estimates for sub-category 2F1b (Mobile Air Conditioning) are similar to those for category 2F1 (Refrigeration and Air Conditioning). For more detail about the uncertainty estimates see Section 7.5.3, *Chapter 7, Volume 3*; for quality control procedures see Sections 7.1.4 and 7.4.4, *Chapter 7, Volume 3*. Typically, one method, approach, or data set is used to cross-check the other method, approach, or data set (see Section 7.1.2.1, *Chapter 7, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

Because of the substantial branching and heterogeneity of category 2F1 and its sub-categories, which are determined by the variety of refrigeration and air conditioning systems used in the world and by the large number of various fluorinated substitutes of ozone depleting substances, it is recommended to obtain expert judgment in order to avoid incorrect accounting.

- Refinement

For more detail about the assessment of the potential impact of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (*Refinement 2019*) see category 2F1.

2F2 Foam Blowing Agents

- Category description

Category 2F2 (Foam Blowing Agents) covers emissions from HFCs use in foams and insulation applications. HFCs included in this category are shown in Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*, and the processes and applications for which these HFCs are being used are shown in Table 7.4, Section 7.4.1, *Chapter 7, Volume 3*. Foams are divided into open-cell foams (which are used for applications such as furniture, mattresses, automotive seating, etc.) and closed-cell foams (which are used for insulating applications). For open-cell foam, emissions of HFCs used as blowing agents occur during the manufacturing process and shortly thereafter. In closed-cell foam, emissions extend into the in-use phase and can occur over a period of 50 or more years from the date of manufacture. Therefore, the use of HFCs in some applications may result in long-lived banks of material, particularly of rigid foam. Emission profiles for these sources may be complex, so more rigorous estimates can be obtained through methods that use disaggregated data.

- Methodological approaches to emission estimations

The approaches to estimating HFCs emissions from open-cell and closed-cell foams are different: in the case of open-cell foams, the first-year loss emission factor is 100 percent; in the case of closed-cell foams, the accumulated datasets and service life are taken into account. Emission profiles vary substantially by sub-application within the overall foam application, so a Tier 2 method should be used wherever possible. If it is not possible to disaggregate foams by sub-application and global activity data are not available, then the Tier 1a method should be applied. An additional characteristic of foam inventories is that a large part of emissions occur from foam blowing agent banks (that have accumulated over the previous years) or from closed cell foam at the point of decommissioning or thereafter. The latter option requires that inventory compilers should carefully research decommissioning practices and any foam recovery and destruction practices in the country. It is also important to subtract exported closed-cell foams from the calculations of annual banks and decommissioning losses, since the in-use emissions will occur in the importing country. Similarly, it is essential to include imported closed-cell foams in the calculations of banks and decommissioning losses. Emissions from imported products should be included in the total estimates of annual emissions from accumulated HFCs bank in foams. Importantly, the mass balance approach is inappropriate for foams, since there is no mechanism by which such products are serviced in practice. For more detail about the methodological approaches see Section 7.4.2, *Chapter 7, Volume 3*.

- Activity data

Two types of activity data are needed in order to prepare the emissions estimates: 1) the amount of chemical used in foam manufacturing in a country and not subsequently exported, and 2) the amount of chemical contained in foam imported into the country. Data collection issues related to these two areas differ. In the first case, estimates should include both domestically produced and imported HFCs. Data on domestic chemical sales to the foam industry should be available directly from chemical suppliers or foam manufacturers at the application level (Tier 1a) or at the sub-application level (Tier 2a). As with other ODS substitute applications, imported chemical data may be available from customs officials or chemical distributors. For open-cell foam, all emissions will occur during manufacture, with the exception of the OCF sub-sector. Thus, it is necessary to determine the share of chemical associated with the manufacture of open-cell foam through an end-use survey. In the second case, it is important to make foam export/import corrections to annual data banks and decommissioning losses. Data on the chemical charge of exported closed-cell foam may be available from large manufacturers. Data on foam blowing agents contained in imported closed-cell foam products are difficult to obtain, and in countries where emissions occur only from imported closed-cell foam it is necessary to use expert judgment in

estimating these data (see *Chapter 2, Volume 1* and *Chapter 3, Volume 1*). For more detail about the activity data see Section 7.4.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

If no country-specific information is available at the sub-application level (Tier 2 method), default emission factors (see Tables 7.6 and 7.7, Section 7.4.2.2, *Chapter 7, Volume 3*) or values from the Emission Factor Database (EFDB) can be used. Use of these factors will require data on chemical sales at the sub-application level for both current and historic consumption in order that the bank of chemical in equipment/products for these sub-applications is properly considered. If only aggregated chemical sales data for closed-cell foam are available and information on specific foam types cannot be obtained, the general default emission factors shown in Table 7.5, Section 7.4.2.2, *Chapter 7, Volume 3*, can be used in support of a Tier 1a method. No emission factors are provided for open-cell foams, because all emissions occur during the first year. For more detail about the choice of emission factors see Sections 7.4.2 and 7.4.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

For completeness, inventory compilers should determine whether HFC blowing agents (five potential chemical substances) are used in each of the 16 sub-applications being practised in their countries, which suggests up to 80 theoretically possible combinations (see Table 7.4, Section 7.4.1, *Chapter 7, Volume 3*). At this stage, there is no explicit description of the use of blends; in theory, this should be covered in the chemical-by-chemical assessment. In order to ensure completeness, it is essential to develop historical data banks from the very start. Any recalculation of estimates should be done according to the guidance provided in *Chapter 5, Volume 1*. Category 2F2 is characterized by low accuracy of estimates and high uncertainties, which depend fundamentally on the accuracy of historic consumption data. Since decommissioning will be the trigger for the majority of emissions in many cases, the product end-of-life assumptions may introduce the greatest degree of uncertainty (for more detail see Section 7.4.3, *Chapter 7, Volume 3*). Quality control checks should be conducted as outlined in *Chapter 6, Volume 1*, and an expert review of the emissions estimates.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It is recommended to balance consumption of HFCs used in different categories based on the national circumstances and available activity data. For example, HFC-134a can be used in categories 2F1, 2F2, 2F3, and 2F4. This balancing will help avoid data omissions or double counting.

- Refinement: No.

2F3 Fire Protection

- Category description

Category 2F3 'Fire Protection' covers emissions from the use of HFCs and/or PFCs in two major types of fire protection (fire suppression) equipment: portable (streaming) equipment, and fixed (flooding) equipment. Current emissions from sub-application 2F3 are quite small, but growing. This results in an accumulating bank of future potential emissions. HFCs and PFCs that are involved in fire protection are shown in Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*. For more detail about the category description see Section 7.6.1, *Chapter 7, Volume 3*.

- Methodological approaches to emission estimations

As with application 2F1 'Refrigeration And Air Conditioning', application 2F3 'Fire Protection' offers the possibility of using both emission-factor approach and mass-balance approach. Sub-applications within this category are less numerous and more homogeneous, so Tier 1a or 1b methods may be sufficient to provide appropriate emissions reporting. The inclusion of end-of-life emissions would normally warrant a Tier 2 approach. Since HFCs and PFCs in fire protection are emitted over a period longer than one year, it is important to represent emissions from equipment charged during previous years, which leads to the accumulation of data banks. For more detail about the methodological approaches see Section 7.6.2, *Chapter 7, Volume 3*.

- Activity data

Data come from countries that produce fire protection agents or systems, with the exception of data on destruction. In order for the producer country to decrease the amount credited toward that country from production of agent, bulk exports must be demonstrated; bulk exports reduce the producer countries' installed base and at the same time serve as activity data for importing countries to determine their installed base. For category 2F3, just like for foams and air conditioning, it is important to consider accumulating banks, i.e. a historical time series of country-specific or globally or regionally derived activity data is required dating back to the introduction of any new HFC or PFC. For more detail about the activity data see Section 7.6.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

In order to avoid overestimation of end-of-life emissions, it is essential to collect from relevant industries information on recovery that may occur due to legislation, Industry Codes of Practice or other measures. For countries that do not have a national Industry Code of Practice, it should be assumed that the agent will not be recovered and is emitted. For more detail about the choice of calculation factors see Sections 7.6.2 and 7.6.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues

No.

- Quality control procedures; uncertainties

Gas recovered from fire protection systems can be destroyed or recycled. Therefore, the default assumption of zero end-of-life recovery may overestimate end-of-life emissions. It is important to make sure that all greenhouse gases used in the fire protection industry are included in the emissions estimate and to consider the time dependence of emissions starting from the first year when greenhouse gases–fire protection agents were used in a country. Emission estimate uncertainty is determined by a small error built into the method, as importing and exporting of filled systems is not included in the method. For more detail about the uncertainty estimates see Section 7.6.3, *Chapter 7, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Sections 7.1.4 and 7.6.4, *Chapter 7, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It is recommended to balance consumption of HFCs used in different categories based on the national circumstances and available activity data. For example, HFC-134a can be used in categories 2F1, 2F2, 2F3, and 2F4. This balancing will help avoid data omissions or double counting.

- Refinement: No.

2F4 Aerosols

- Category description

Category 2F4 'Aerosols' covers emissions from the use of HFCs as propellants or solvents in aerosol packages. Emissions from aerosols usually occur shortly after production, as 100 percent of the chemical is emitted; however, the period between manufacture and sale can vary significantly depending on the sub-application involved. There are 5 main sub-applications: Metered Dose Inhalers (medical aerosols); Personal Care Products (deodorant, shaving cream); Household Products (air-fresheners, oven and fabric cleaners); Industrial Products (for example, special cleaning and lubricating sprays, special-purpose aerosols); Other General Products (tyre inflators, klaxons). The HFCs currently used as propellants are shown in Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*. For more detail about the category description see Section 7.3, *Chapter 7, Volume 3*.

- Methodological approaches to emission estimations

For category 2F4, emissions are considered *prompt* because all the initial charge escapes within the first year or two after manufacture, typically six months after sale for most sub-applications. Therefore, to estimate emissions it is necessary to know the total amount of aerosol initially charged in product container prior to sale. There are two tier approaches, for more detail

see Section 7.3.2.1, *Chapter 7, Volume 3*. The choice of the method depends on data availability at the sub-application level. On very rare occasions (for example, when stockpiled product becomes out-of-date) there is a need to account for recovery, recycling or destruction (depending on the national practices).

- Activity data

Activity data can be collected at the application or sub-application level using either a supplier-based or a user-based approach, depending on the availability and quality of the data. The user-based approach requires data on the number of aerosol products sold and imported at the application or sub-application level (for example, the number of individual metered dose inhalers, hair care products, and tyre inflators) and the average charge per container. This may require globally or nationally derived activity data for some sectors of use. In producer countries, it is important to account for annual imports and exports of aerosol products. For countries that import 100 percent of aerosol products, activity data are equal to imports. These data can be available from customs officials and chemical distributors. For more detail about activity data see Section 7.3.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

In Tier 1 estimations, the size of charge for emission factor for aerosol use is taken equal to default values. Alternative emission factors should only be used when empirical evidence is available for the majority of aerosol products at either the application level (Tier 1a) or the sub-application level (Tier 2a). The percentage emission factors should in general sum up to 100 percent over the time during which it is assumed that the charge will escape. Importantly, the observations show that for category 2F4 the consistently emissive nature of aerosols makes the distinction between country-specific and the default emission factor for applications and sub-applications less influential on overall emissions estimates, than is the case in other application areas. Therefore, the benefit of following a more disaggregated Tier 2a approach instead of a Tier 1a approach is less pronounced in the case of aerosols. For more detail about the choice of calculation factors see Section 7.3.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues

Category 2F4 ‘Aerosols’ covers emissions from aerosols, including those containing solvents; therefore, it is important that solvents in aerosol containers be reported in this category, rather than in category 2F5 ‘Solvents’.

- Quality control procedures; uncertainties

In order to avoid incorrect emissions reporting under category 2F4 it is important to check domestic HFC sources to confirm the list of chemical substances used in the country. For countries that do not produce any aerosol products, a special attention should be paid to the imports statistics in order

to avoid any underestimation (for more detail see *Chapters 2* and *3, Volume 1*), particularly with reference to the propellants and solvents contained. If reliable country-specific data for the general aerosol sector are not available, this might lead to the over- or underestimation of emissions estimates and thus increase the level of uncertainty. The situation can be improved through additional (bottom-up) data collection activities and the development of national databases which can be compiled through a specific study on a country basis through local industry experts, whose advice should be sought on uncertainties (the description is provided in *Chapter 3, Volume 1*). Quality control checks should be conducted as outlined in *Chapter 6, Volume 1*, and Section 7.3.4, *Chapter 7, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

HFC-43-10mee is used as a solvent, but is counted as an aerosol when delivered through aerosol canisters. It is also recommended to balance consumption of HFCs used in different categories based on the national circumstances and available activity data. For example, HFC-134a can be used in categories 2F1, 2F2, 2F3, and 2F4. This balancing will help avoid data omissions or double counting.

- Refinement: No.

2F5 Solvents

- Category description

This category covers the use of fluorinated gases in solvent applications. HFC/PFC solvent uses occur in four main areas: Precision Cleaning; Electronics Cleaning; Metal Cleaning; Deposition applications. HFCs are typically used in the form of an azeotrope or other blend. PFCs have little use, as they are essentially inert and have very little power to dissolve oils, except for fluoro-oils and fluoro-greases. Emissions from aerosols containing solvents should be reported under category 2F4 'Aerosols', rather than under this one. Emissions from the use of other solvents should be reported under category 2D3 'Solvent Use'. For more detail about the category description see Section 7.2, *Chapter 7, Volume 3*.

- Methodological approaches to emission estimations

For category 2F5, emissions are considered prompt emissions, because 100 percent of the chemical is typically emitted within two years of initial use. In order to estimate emissions, it is necessary to know the total amount of each HFC or PFC chemical sold in solvent products each year. Information about ODS substitutes that are used in solvent applications is provided in Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*. There are two tier approaches, for more detail see Section 7.2.2.1, *Chapter 7, Volume 3*.

- Activity data

Activity data should be collected directly from the suppliers of solvent or the users in support of either Tier 1a or 2a methods. Where this is not possible, globally derived activity data at the application or the sub-application level can be used. Depending on the character of the national solvent industry, data from suppliers (show the amount of solvent sold or imported annually into a country) can be cross-checked with data from users (include the number of pieces of equipment or canisters containing solvent and their charge). Data on solvent imports can be obtained from exporters, or by using the imports statistics obtained from the customs or distributors of imported solvents. Activity data for estimating HFCs and PFCs emissions from solvent use may be available from the national statistical agencies. For more detail about the activity data see Section 7.2.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

Emission factor is the fraction of chemical emitted into atmosphere from solvent use in the reported year. The product lifetime is assumed to be two years, thus any amount not emitted during the first year is assumed by definition to be emitted during the second year. In Tier 1 estimations, where country-specific data at the sub-application level are not available, emission factor for solvent use is taken equal to default values. The Tier 2 method requires calculation of emissions of each HFC/PFC in each end use, using sales data at the sub-application level, and the development/use of country-specific emission factors, taking into account the use of new equipment with lower leak rates. For more detail about the choice of calculation factors see Section 7.2.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues

For category 2F5 ‘Solvents’ there is a potential for double counting with HFC and PFC use in category 2E ‘Electronics Industry’; this can be avoided if care is taken to identify previous ODS consumption patterns. Care should also be taken where HFCs and PFCs acting as solvents are contained in aerosols. In order to avoid problems in making distinctions between solvents and propellants where one chemical acts in both roles, the emissions should be reported in category 2F4 ‘Aerosols’. Additional research is to be carried out on the national producers’, importers’, and distributors’ market to confirm that no HFCs or PFCs other than those listed in Table 7.1, Section 7.1.1, *Chapter 7, Volume 3*, are being used for solvent applications.

- Quality control procedures; uncertainties

The magnitude of the error caused by the default assumption will depend on the solvent usage patterns in the country. In general, this assumption will over-estimate emissions for a given year, although not on a cumulative basis. Activity data should be reliable at the sub-application level

because of the small number of chemical manufacturers, the high cost of the solvent, and the assumption that in most applications 100 percent of HFCs and PFCs are emitted with time. For more detail about the uncertainty estimates see Sections 7.1.3 and 7.2.3, *Chapter 7, Volume 3*. Quality control checks should be conducted as outlined in *Chapter 6, Volume 1*, with an account of the correctness and completeness of data for solvent uses and composition in the country (see Section 7.1.4 and 7.2.4, *Chapter 7, Volume 3*).

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

In most cases, emissions in this category are insignificant. It is important to account for country-specific potential imports and exports of substances that are typically used in solvent applications.

- Refinement: No.

2F6 Other Applications

- Category description

Other applications include sterilisation equipment, tobacco expansion applications, plasma etching of electronic chips (PFC-116), and as solvents in the manufacture of adhesive coatings and inks. Industries that have a potential for using HFCs and PFCs include electronics testing, heat transfer, dielectric fluid, medical applications, and potentially new applications not yet developed. For more detail about the category description see Section 7.7.1, *Chapter 7, Volume 3*.

- Methodological approaches to emission estimations

The choice of methods depends on the national circumstances and assumes the use of Tier 1 or 2 approach either by treating each of the other applications as a separate application or addressing them as a group. The first option will lead to the use of Tier 2 methods, while the latter will lead to a single Tier 1 approach. Since the end users for these applications may be extremely diverse, it is suggested that these applications be divided into highly emissive (solvents and aerosols) and less emissive applications (closed-cell foam and refrigerators). For more detail about the methodological approaches see Section 7.7.2, *Chapter 7, Volume 3*.

- Activity data

Activity data are typically difficult to establish; and in qualifying sub-applications much will depend on the co-operation of chemical suppliers. Since HFCs and PFCs market is further developing, the key challenge will be to keep updated with end-use applications as shown in Table 7.10, Section 7.5.4.2, *Chapter 7, Volume 3*. For more detail about the activity data description see Section 7.7.2.3, *Chapter 7, Volume 3*.

- Estimation parameters

Emission factors for the sub-applications with prompt emissions will follow similar selection criteria to those for category 2F4 'Aerosols' and 2F5 'Solvents' (see Sections 7.2.2.2 and 7.3.2.2, *Chapter 7, Volume 3*). Emission factors for less emissive applications will depend on the particular nature of that sub-application, so if a series of sub-applications is fairly homogeneous in nature, it may be possible to work with a composite emission factor and adopt a Tier 1a method. Availability of separate emission factors allows for the adoption of a Tier 2a method. For more detail about the choice of calculation factors see Sections 7.7.2 and 7.7.2.2, *Chapter 7, Volume 3*.

- Cross-cutting issues

There is a need to avoid double counting with category 2E 'Electronics Industry' (see *Chapter 6, Volume 3*), including electronics testing, heat transfer and dielectric applications. Other double counting is possible in the coverage of solvents or where HFCs and/or PFCs are contained as solvents in industrial aerosols. This is where the delineation between what is acting as an ODS substitute and what is not can be very fine. To avoid confusion, *Chapter 7, Volume 3* has taken the approach that only those technology transitions which occur directly from ODSs to HFC and/or PFC technologies should be considered.

- Quality control procedures; uncertainties

The key challenge related to the completeness of data will be to keep updated with new other applications as they emerge. Since there may be a wide range of diverse applications, which fall into this category, it is not possible to give default uncertainties for these sources. However, manufacturers can assess levels of uncertainty in accordance with the methodology outlined in *Chapter 3, Volume 1*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Sections 7.1.4 and 7.7.4, *Chapter 7, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G Other Product Manufacture and Use

This subsector outlines methods for estimating emissions of sulphur hexafluoride (SF_6), nitrous oxide (N_2O), and perfluorocarbons (PFCs) from the manufacture and use of electrical equipment and a number of other products. At the time of writing of the 2006 IPCC Guidelines, little was known about the emissions of 'other halogenated gases', but it is possible that these gases

may be used and emitted in the future. In most applications, SF_6, PFC, or N_2O are deliberately incorporated into the product to exploit their physical properties, such as the high dielectric strength (SF_6), the stability (PFCs), and the anaesthetic effect (N_2O). The applications have a wide range of emission profiles, ranging from immediate and unavoidable release of all of the chemical (for example, the use of PFCs as atmospheric tracers) to largely avoidable, delayed release from leak-tight products after 40 years of use (for example, manufacture and use of sealed-pressure electrical equipment). For more detail about this subsector see Section 8.1, *Chapter 8, Volume 3*.

2G1 Electrical Equipment

- Category description

Category 2G1 'Electrical Equipment' covers emissions of sulphur hexafluoride (SF_6) where it is used for electrical insulation and current interruption in equipment used in the transmission and distribution of electricity, and PFCs which can be used for retrofitting transformers, as dielectrics and heat transfer fluids in power transformers. Electrical equipment is the largest consumer and the most important use of SF_6, globally. However, the importance of this source varies considerably from country to country. The emissions from this category depend not only on the installed (banked) or consumed quantities of SF_6, but also very much on the tightness of the products and the handling processes applied. Henceforth in this category, 'SF_6' will be used to denote 'SF_6 and/or PFCs.' For more detail about the category description see Section 8.2.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

There is a Tier 1 method (the default emission factor approach), a Tier 2 method (the country-specific emission-factor approach), and a Tier 3 method (a hybrid that can use either the mass-balance or the emission-factor approach for different life cycle stages, depending on country-specific circumstances). The tier selected will depend on the data availability and whether or not the category is key. The Tier 2 method uses the basic equation (same as Tier 1), but requires country-specific emission factors for each life cycle stage instead of default emission factors. If data for equipment retirement are available, emissions due to retirement can be estimated more accurately. A Tier 3 method is the most detailed; it accommodates a wide range of national circumstances and includes separate equations for each phase of the life cycle of equipment, including equipment manufacture, installation, use, and disposal. Depending on the type of equipment, the life cycle stage, and country-specific circumstances, either a mass-balance approach or country- (or facility-) specific emission factors may be used. It is acceptable to use the hybrid approach, which permits the use of the mass-balance approach for some processes and life cycle stages and the emission-factor approach for other processes and life cycle stages. Some SF_6 emissions occur after the chemical is recovered and include emissions associated with recycling and destruction of SF_6. (Emissions

associated with the shipment of SF_6 to off-site recyclers or destruction facilities are considered negligible). It is recommended to develop country-specific emission factors for recycling and destruction that are based on full consideration of country-specific logistics and practices. For more detail about the methodological approaches see Section 8.2.2, *Chapter 8, Volume 3*.

- Activity data

The activity data necessary to carry out the various estimation methods may be obtained from chemical manufacturers, equipment manufacturers, equipment users, and equipment disposers and/or their industry associations in the country. The best source(s) of data vary depending upon the method and national circumstances. For more detail about the activity data see Section 8.2.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

In the Tier 1 method, SF_6 emissions are estimated by multiplying default emission factors by the SF_6 consumption of equipment manufacturers and/or by the nameplate SF_6 capacity of the equipment at each life cycle stage. Installation emissions are believed to be zero (for closed-pressure equipment) or installation emissions are included in the emission factor for emissions from manufacturing or use. Default emission factors are provided in Tables 8.2-8.4, Section 8.2.2.2, *Chapter 8, Volume 3*. Emission factors for the Tier 2 method are developed on the basis of data collected from representative manufacturers and utilities that track emissions by life cycle stage, essentially using the Tier 3 (mass-balance method) for at least one year. In Tier 3 estimates, emission factors are only used when emission rates from processes are quite low or when electrical equipment has only recently been introduced into a country, and so emission factors for this method may be difficult to measure using a mass-balance approach. To estimate Tier 3 emission factors engineering studies may be used (to identify potential leak points and loss mechanisms and assign probabilities and emission rates to these). For more detail about the choice of calculation factors see Sections 8.2.2 and 8.2.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

SF_6 recycling emissions from chemical producers will be accounted for under category 2B9 'Fluorochemical Production' (see Section 3.10, *Chapter 3, Volume 3*) and should not be included in category 2G1.

- Quality control procedures; uncertainties

A combination of approaches (the hybrid approach) enhances accuracy, but also introduces opportunities for double counting or overlooking emissions. Table 8.1, Section 8.2.2.1, *Chapter 8, Volume 3*, provides examples of potential measures to avoid double counting and omissions. Completeness for source category 2G1 requires accounting for emissions during the manufacture,

use, and disposal of equipment, and during the recycling or destruction of SF_6 (for more detail see Section 8.2.2.4, *Chapter 8, Volume 3*). Uncertainties for Tier 1 default emission factors are shown in Table 8.5, Section 8.2.3, *Chapter 8, Volume 3*. A Tier 3 method will be more accurate; for more detail see Section 8.2.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.2.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

In subsector 2G 'Other Product Manufacture and Use', no significant amendments were made to the methodology, emission factors or other estimation parameters for the sources included in the *2006 IPCC Guidelines*. Two more sources of fluorinated compounds emissions were added: the use of fluorinated compounds to waterproof electronic circuits and the use of fluorinated compounds for the treatment of textile, carpet, leather, and paper. An emission estimation methodology was only developed for the first source.

2G1a Manufacture of Electrical Equipment

- Category description

Sub-category 2G1a 'Manufacture of Electrical Equipment' covers emissions of sulphur hexafluoride (SF_6) from the activities associated with the manufacture of electrical equipment. For more detail about the category description see Sections 8.1 and 8.2, *Chapter 8, Volume 3, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimations

The tier selected (1, 2 or 3) will depend on the data availability and whether or not the category is key (see *Chapter 4, Volume 1* and the comment about limited sources in Section 4.1.2). The general decision tree and tier selection outline is provided in Figure 8.1, Section 8.2.2.1, *Chapter 8, Volume 3*. In this sub-category, emissions can be estimated using either a pure mass-balance approach or a hybrid of a mass-balance approach for some processes and an emission factor-based approach for others. When choosing an approach it is recommended to use emission factors to estimate emissions from the processes with very low emission rates and to use the mass-balance approach to estimate emissions from the other manufacturing processes. For more detail about the methodological approaches see Section 8.2.2.1, *Chapter 8, Volume 3*.

- Activity data

SF_6 consumption by equipment manufacturers can be estimated using information from the manufacturers on their purchases of SF_6, their returns of SF_6 to chemical producers, and changes in their inventory of SF_6 in containers. If information from equipment manufacturers is unavailable or incomplete, information from chemical producers and/or distributors on their sales to equipment manufacturers (less any returns) may be used. For the sake of complete accounting it is important to have information on the imports and exports of equipment, which can be obtained from equipment manufacturers/importers, customs services, reporting. For more detail about the activity data see Section 8.2.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

Default emission factors which are used for Tier 1 estimations are provided in Tables 8.2-8.4, Section 8.2.2.2, *Chapter 8, Volume 3*. It is recommended to choose default emission factors from countries with similar equipment designs and SF_6-handling practices. The development of a country-specific emission factor for manufacturing relies on total emissions (from the survey of manufacturers) and total SF_6 consumption of surveyed manufacturers. This emission factor is then applied to the manufacturing sector as a whole, using national SF_6 consumption by manufacturers. Emission factors used in the Tier 3 approach are applied at a more aggregated level, i.e. to equipment manufacturing in general. For more detail about the choice of calculation factors see Sections 8.2.2 and 8.2.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

Emissions from chemical producers that are associated with SF_6 recycling should be accounted for in category 2B9 'Fluorochemical Production' (see Section 3.10, *Chapter 3, Volume 3*) and should not be considered in category 2G1.

- Quality control procedures; uncertainties

Completeness for sub-category 2G1a requires due consideration of all significant SF_6 consumers (manufacture of gas-insulated switchgear, automated gas switches, high voltage gas-insulated lines, gas-insulated instrument transformers, etc.; for more detail see Section 8.2.2.4, *Chapter 8, Volume 3*). Sources of uncertainty in this sub-category may include SF_6 exports/imports by equipment manufacturers; SF_6 returned to foreign recycling facilities, etc.; for more detail see Section 8.2.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.2.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

For more detail about the assessment of the potential impact of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (*Refinement 2019*) see category 2G1 'Electrical Equipment'.

2G1b Use of Electrical Equipment

- Category description

Sub-category 2G1b 'Use of Electrical Equipment' covers emissions of sulphur hexafluoride (SF_6) from the use of electrical equipment. For more detail about the category description see Sections 8.1 and 8.2, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

The tier selected (1, 2 or 3) will depend on the data availability and whether or not the category is key (see *Chapter 4, Volume 1*, and the comment about limited sources in Section 4.1.2). The general decision tree and tier selection outline is provided in Figure 8.1, Section 8.2.2.1, *Chapter 8, Volume 3*. Emissions from the equipment installation and use can be estimated using either a mass-balance approach or an emission factor-based approach. The first one is preferable, except where emission rates are very low. The second approach is more accurate for all sealed-pressure systems and all types of equipment in countries where electrical equipment has been in use for less than 10-20 years. A hybrid approach is also acceptable. For more detail about the methodological approaches see Section 8.2.2.1, *Chapter 8, Volume 3*.

- Activity data

SF_6 consumption from the use of equipment may be estimated using the information obtained from equipment manufacturers/distributors/importers, equipment users, customs services, and reporting. At the national level, trade associations for equipment manufacturers and utilities can be very helpful in obtaining information for Tier 3 estimations. For more detail about the activity data see Section 8.2.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

Default emission factors which are used for Tier 1 estimations are provided in Tables 8.2-8.4, Section 8.2.2.2, *Chapter 8, Volume 3*; it is recommended to choose default emission factors from countries with similar equipment designs and SF_6-handling practices. The development of a country-specific emission factor for equipment use relies on total emissions (from the survey of users) and total SF_6 consumption of surveyed users. This emission factor is then applied to the equipment-use sector as

a whole. The emissions from recycling and destruction of the recovered gas occur both on site and downstream of the utility/user, therefore, they must be accounted for separately. Emission factors used in the Tier 3 approach are applied at an aggregated level to equipment use (includes installation, operation, and disposal), rather than to each lifecycle stage. For more detail about the choice of calculation factors see Sections 8.2.2 and 8.2.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Completeness for sub-category 2G1b requires due consideration of all electrical equipment distribution chains from producers/distributors to end users, account for leakage, refill, maintenance, equipment failures, etc.; for more detail see Section 8.2.2.4, *Chapter 8, Volume 3*. Sources of uncertainty in this sub-category may include data on the emission factors; time lag between emissions and servicing; lifetime of the equipment, etc.; for more detail see Section 8.2.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.2.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

The main difficulty in this source category relates to the difficulty in collecting information from different plants and facilities. It may result in the under- or overestimated emissions.

- Refinement

For more detail about the assessment of the potential impact of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (*Refinement 2019*) see category 2G1 'Electrical Equipment'.

2G1c Disposal of Electrical Equipment

- Category description

Sub-category 2G1c 'Disposal of Electrical Equipment' covers emissions of sulphur hexafluoride (SF_6) from the disposal and final use of electrical equipment. For more detail about the category description see Sections 8.1 and 8.2, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

The tier selected (1, 2 or 3) will depend on the data availability and whether or not the category is key (see *Chapter 4, Volume 1* and the comment about limited sources in Section 4.1.2). The general decision tree and tier selection outline is provided in Figure 8.1, Section 8.2.2.1, *Chapter 8, Volume 3*. In this sub-category, emissions can be estimated using either a pure mass-

balance approach or a hybrid approach, depending on the national circumstances. In the pure mass-balance approach, emissions from sealed-pressure equipment are estimated using a mass-balance equation. In the hybrid approach, emissions from sealed-pressure equipment are estimated using emission factors. It is important to pay particular attention to the fraction of retiring equipment whose SF_6 is recovered and to the fraction of the charge that is recovered ('recovery efficiency'). For more detail about the methodological approaches see Section 8.2.2.1, *Chapter 8, Volume 3*.

- Activity data

Activity data for this sub-category may be estimated using the information obtained from equipment manufacturers/distributors/importers, equipment disposers, reporting. For more detail about the activity data see Section 8.2.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

The emission factor for disposal should account for three factors: the recovery frequency (the fraction of equipment whose charge is recovered), the recovery efficiency (the fraction of charge recovered when recovery is performed), and the emissions from recycling and destruction of the recovered gas. The latter reflects emissions that occur both on site and downstream of the utility/user and so must be accounted for separately. Disposal emissions are extremely sensitive to recovery frequencies and to recovery efficiencies, so these should be regularly monitored before establishing disposal emission factors. For more detail about the calculation factors see Sections 8.2.2 and 8.2.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

Complete accounting for sub-category 2G1c requires due consideration of all disposal chains, disposal of discarded electrical equipment, etc. (for more detail see Section 8.2.2.4, *Chapter 8, Volume 3*). Sources of uncertainty in this sub-category may include data on the equipment lifetime, fraction of charge remaining at retirement, etc.; for more detail see Section 8.2.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.2.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It is recommended to give special attention to the lifetime of electrical equipment and identify the equipment which should already be accounted in this category.

- Refinement

For more detail about the assessment of the potential impact of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Refinement 2019) see category 2G1 'Electrical Equipment'.

2G2 SF_6 and PFCs from Other Product Uses

- Category description

Category 2G2 'SF_6 and PFCs from Other Product Uses' covers the following sources (applications): SF_6 and PFCs used in military applications; SF_6 used in university and research particle accelerators or in industrial and medical particle accelerators; adiabatic applications; SF_6 used in sound-proof windows; PFCs used as heat transfer fluids in commercial and consumer applications; PFCs used in cosmetics/medical applications; and other uses. For more detail about the category description see Section 8.3.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

Depending on the data availability and the type of SF_6 and PFCs application, there are three tier approaches. For more detail about the methodological approaches see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Activity data

Activity data vary greatly based on the application and SF_6 and PFC source category. For more detail about the activity data for each sub-category see Sections 8.3.2.1 and 8.3.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

In category 2G2 'SF_6 and PFCs from Other Product Uses' for the source categories that contribute substantially to a country's SF_6 and PFCs emissions, it is recommended to develop country-specific emission factors based on occasional surveys of representative subsets of sources. For more detail about the choice of calculation factors see Sections 8.3.2.1 and 8.3.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

The following emission sources should not be included in category 2G2 'SF_6 and PFCs from Other Product Uses': production of SF_6 and PFCs (accounted for in category 2B9, see Section 3.10, *Chapter 3, Volume 3*), production and use of electrical equipment (accounted for in category 2G1, see Section 8.2, *Chapter 8, Volume 3*), primary and secondary production of magnesium and aluminium (accounted for in categories 2C3 and 2C4, see Section 4, *Volume 3*), semiconductor and flat panel display manufacturing (accounted for in categories 2E1 and 2E2, see *Chapter 6, Volume 3*).

- Quality control procedures; uncertainties

In order to avoid problems with data accounting, it is recommended to make regular checks to see if all SF_6 and PFC producers and distributors are identified, that end users do not import gas (in large containers), and that imports of SF_6 and PFCs containing products are not large. For more detail about the uncertainty estimates see Section 8.3.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.3.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G2a Military Applications

- Category description

Sub-category 2G2a 'Military Applications' covers a wide range of SF_6 uses in the military equipment, for example as an insulating medium in the radar systems of military reconnaissance planes of the Boeing E-3A type (AWACS). Most emissions occur during the pressure-balancing process on ascent, but emissions from system leakage can also occur during other phases of flight or during time on the ground. PFC heat transfer fluids are used in ground and airborne radar (klystrons), avionics, missile guidance systems, ECM (Electronic Counter Measures), sonar, amphibious assault vehicles, other surveillance aircraft, lasers, SDI (Strategic Defense Initiative), and stealth aircraft. PFCs may also be used to cool electric motors in ships and submarines. The specific PFCs used in these applications are believed to be similar to those identified as heat transfer fluids in electronics manufacturing (see *Chapter 6, Volume 3*). For more detail about the category description see Section 8.3.2, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

SF_6 emissions from AWACS can be estimated using the Tier 2 mass-balance method (if detailed data on the acquisitions and disbursements are available) or the Tier 1 method relying on per plane emissions (see Table 8.7, Section 8.3.2.1, *Chapter 8, Volume 3*). SF_6 emissions from other military applications can be estimated by using Tier 1, 2 or 3 methods depending on the data availability and whether or not they can be obtained from the responsible agencies. For equipment with different emission profiles (for example, with prompt emissions), corresponding equations from Section 8.2, *Chapter 8, Volume 3*, can be used. The largest emission sources include equipment manufacture, use, and particularly disposal. For more detail about the methodological approaches see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Activity data

All the activity data for this sub-category for Tier 2 and 3 estimations are difficult to obtain, require detailed information about the use of equipment and military machinery, and are typically top-secret information. If no published data are available, information should be requested from the corresponding agencies. For more detail about the activity data see Sections 8.3.2.1 and 8.3.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

The emission factors and default data used for the Tier 1 approach (to estimate SF_6 emissions from AWACS) are given in Tables 8.7 and 8.8, Section 8.3.2.1, *Chapter 8, Volume 3*. The Tier 2 method relies on the mass-balance method. Emission factors for other military applications depend on the country-specific circumstances, availability of detailed activity data, the type of equipment which determines the equation for estimations. The estimation methodology is similar to that used for estimating emissions from the electrical equipment (see Section 8.2, *Chapter 8, Volume 3*). For more detail about the choice of calculation factors see Sections 8.3.2.1 and 8.3.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

Potential double counting with other categories is described in detail in the corresponding section for Category 2G2 'SF_6 and PFCs from Other Product Uses'.

- Quality control procedures; uncertainties

If gas consumption data are not available, uncertainties regarding the number and usage of AWACS become important. SF_6 emissions from AWACS and related uncertainty are substantially dependent on the number of sorties. For more detail about the uncertainty estimates see Section 8.3.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.3.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

It is recommended to make an official enquiry to the national defense/military agency about the use of SF_6 in military equipment. This would allow it to make a decision whether or not this category should be considered and included in the inventory.

- Refinement: No.

2G2b Accelerators

- Category description

Sub-category 2G2b 'Accelerators' covers emissions of SF_6, which is used as an insulating gas, from university and research-operated particle accelerators, and particle accelerators in industrial (low- and high-voltage) and medical applications. SF_6 losses occur primarily during gas recovery and transfer, when pressure relief valves are actuated, and through slow leaks. For more detail about the category description see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

The Tier 1 method (country-specific approach) is used where it is impossible to obtain data from individual users of particle accelerators. The Tier 2 method relies on the accelerator/user-level emission factors. Equations for Tier 1 and 2 estimations of emissions from university and research accelerators are not the same as those from industrial and medical accelerators. The Tier 3 method uses disaggregated data on the acquisition and consumption and the accelerator/user-level mass-balance approach (calculation equations are similar for all types of accelerators). For more detail about the methodological approaches see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Activity data

Activity data for this source category can be obtained from the statistical or reporting documentation of related industries or agencies. In addition, more disaggregated information can be requested directly from the manufacturers/suppliers/distributors of particle accelerators, client service companies, end users, and perhaps national control agencies. For more detail about the activity data see Sections 8.3.2.1 and 8.3.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

The emission and charge factors that are used in Tier 1 and 2 equations for industrial and medical accelerators are different from those of university and research accelerators. Average SF_6 charge in accelerators by process description is shown in Table 8.9, Section 8.3.2.1, *Chapter 8, Volume 3*. Emission factors for each accelerator type that are used for the Tier 2 method are given in Table 8.10, Section 8.3.2.1, *Chapter 8, Volume 3*. Tier 3 estimations rely on the accelerator-level mass-balance method. For more detail about the choice of calculation factors see Sections 8.3.2.1 and 8.3.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

Potential double counting with other categories is described in detail in the corresponding section for Category 2G2 'SF_6 and PFCs from Other Product Uses'.

- Quality control procedures; uncertainties

If gas consumption data are not available, uncertainties regarding the number and usage of accelerators will be substantial. For accelerators, the total SF_6 charge and leak rate determine the amount of emissions and associated uncertainty. For more detail about the uncertainty estimates see Section 8.3.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.3.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G2c Other

- Category description

Sub-category 2G2c 'Other' covers emissions from other SF_6 and PFCs uses not included in the previous subcategories. Some of the earlier mentioned uses include adiabatic applications (car tyres, sport shoe soles, tennis balls); sound-proof windows; heat transfer fluids in commercial and consumer applications (cooling for supercomputers, telecommunication, airport radar systems, drive units (rectifiers) on high-speed trains; cosmetics/medical applications (anti-wrinkle creams, storage of tissues for transplantation, eye surgery, pneumonectomy, etc.), and other uses. Since the applications are very diverse, there may be a long delay between the purchase of the SF_6 or PFC and the release of the chemical. In some cases, the chemical is fairly well contained during the life of the equipment or product, and most emissions are associated with the manufacture and disposal of the product. For more detail about the category description see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

Estimations of emissions from the use of SF_6 and partially PFCs in adiabatic systems and sound-proof windows rely on the equations provided in Section 8.3.2.1, *Chapter 8, Volume 3*. Tier 1, 2 or 3 methods (see the methodology for category 2G1, Section 8.2, *Chapter 8, Volume 3*) can be used for estimations of emissions from the use of PFCs as heat transfer liquids in commercial and consumer applications. Emissions from the use of PFCs in cosmetics, medical and other applications are estimated assuming that PFCs are fully emitted within a year of their purchase, and so the emissions are considered prompt. For more detail about the methodological approaches see Section 8.3.2.1, *Chapter 8, Volume 3*.

- Activity data

Activity data for this sub-category can be obtained by identifying and contacting all gas producers/distributors to identify SF_6 and PFC users and to investigate the gas consumption of source categories other than those mentioned above. Since SF_6 and PFCs applications differ substantially depending on the country-specific circumstances, activity data can be obtained from the statistical sources, agency or industry reporting, customs service, from equipment manufacturers/suppliers/distributors, etc. For more detail about the activity data see Sections 8.3.2.1 and 8.3.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

Different methods and emission factors are used for different SF_6 and PFCs applications. For more detail about the choice of calculation factors see Sections 8.3.2.1 and 8.3.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

Potential double counting with other categories is described in detail in the corresponding section for Category 2G2 'SF_6 and PFCs from Other Product Uses'.

- Quality control procedures; uncertainties

The uncertainty in emissions estimates will be small when the uses are all prompt emissions or if the survey of domestic sales per application by national producers and distributors was complete. In case of delayed emission applications the uncertainties may amount to 50 percent. For more detail about the uncertainty estimates see Section 8.3.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.3.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G3 N_2O from Product Uses

- Category description

N_2O emissions accounted for in category 2G3 can arise from the use of medical products; propellants in aerosols (mostly in the food industry); oxidising agents and etchants used in semiconductor manufacturing; oxidising agents used, with acetylene, in atomic absorption spectrometry; production of sodium azide; fuel oxidants and oxidising agents in blowtorches, etc. Typically,

medical applications and use as a propellant in aerosol products are likely to be the largest emission sources. For more detail about the category description see Section 8.4.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

It is not possible to specify different tiers of estimation for this source of N_2O emissions, for no reliable estimation methods are available. Emissions are to be estimated using the equation in Section 8.4.2.1, *Chapter 8, Volume 3*. For more detail about the methodological approaches see Section 8.4.2, *Chapter 8, Volume 3*.

- Activity data

Activity data for estimating N_2O emissions in this category may be obtained based on N_2O supply data that should be requested from manufacturers and distributors of N_2O products, hospitals and medical practices. Where national statistical service is good, data can be obtained from statistical reports or from reports or research by corresponding agencies or industries. For more detail about the activity data see Section 8.4.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

In most N_2O applications, the emission factor is assumed equal to 1.0, because the gas is not chemically changed and is returned to the atmosphere. However, in some cases this value may not correlate with the actual emission factor, and it is important to calculate reasonable emission factors based on the country-specific circumstances and application practices. For more detail about the calculation factors see Sections 8.4.2 and 8.4.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

It is recommended to check regularly if all distributors, data per application on imports, exports, and consumption have been accounted for, and that no N_2O is imported directly (in bulk) by end users. In general, the uncertainties in quantity of N_2O supplied by application type obtained from manufacturers and distributors of N_2O products may vary widely from country to country. For more detail about the uncertainty estimates see Section 8.4.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.4.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G3a Medical Applications

- Category description

Sub-category 2G3a 'Medical Applications' covers N_2O emissions from anaesthetic use as an anaesthetic/analgesic and as a carrier gas for volatile fluorinated hydrocarbon anaesthetics. Different anaesthesia applications involve different quantities of N_2O, and obviously produce different emissions. N_2O is not used as an analgesic in countries with very cold climate, so it is mandatory to make a correction for country-specific circumstances. In a similar way N_2O is used in veterinary. For more detail about the category description see Section 8.4.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

Typically, N_2O emissions are estimated from data on quantity of N_2O supplied according to Equation 8.24 (see Section 8.4.2.1, *Chapter 8, Volume 3*). For medical applications, it is assumed that N_2O-containing products will be used in one year. Different tiers could not be defined for this source category, because there are no other reliable estimation methods. It is acceptable to derive estimations from the numbers of anaesthetics given, number of surgical beds or hours of anaesthesia, but these methods are likely to be inaccurate. For more detail about the methodological approaches see Section 8.4.2.1, *Chapter 8, Volume 3*.

- Activity data

Total quantity of N_2O supplied by application type should be obtained from manufacturers and distributors of N_2O products. For medical applications, quantity of N_2O usage may be obtained from individual hospitals that have records of the number and capacity of N_2O cylinders purchased per annum. Depending on the data availability in the country, the required data can be obtained from statistical reports or from reports and research by healthcare agencies. For more detail about the activity data see Section 8.4.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

The flow of N_2O (l/min) may vary during the course of surgery between zero and 6 l/min. Because of this considerable variability, estimates of consumption based on duration of anaesthesia are inaccurate. The proportion of anaesthetics in which N_2O is used varies between countries and between individual anaesthetists in a given country. More accurate factors can be obtained through an additional research in the country. For this sub-category it is assumed that none of the N_2O inhaled by a patient is chemically changed by the body, and all is returned to the atmosphere; so the emission factor is taken to be 1.0. For more detail about the choice of calculation factors see Sections 8.4.2 and 8.4.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.

- Quality control procedures; uncertainties

It is important to the maximum degree to account for the data required for the estimation of N_2O emissions, in particular, data per application on import, export and consumption from national N_2O manufacturers and distributors. For this purpose it is essential to identify all N_2O manufacturers, domestic consumers, and imports and exports in products. Any error arising from the assumption that the emission factor is equal to 1.0 is small in comparison with other uncertainties. The largest uncertainty relates to the activity data and is determined by the difficulties in the accounting for the quantities of N_2O supplied per application. For more detail about the uncertainty estimates see Section 8.4.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.4.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G3b Propellant for Pressure and Aerosol Products

- Category description

Sub-category 2G3b 'Propellant for Pressure and Aerosol Products' covers the emissions of N_2O which is used as a propellant in aerosol products, primarily in the food industry. Typical usage is to make whipped cream, where cartridges filled with N_2O are used to blow the cream into foam. For more detail about the category description see Section 8.4.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

N_2O emissions are estimated from data on quantity of N_2O supplied according to Equation 8.24 (see Section 8.4.2.1, *Chapter 8, Volume 3*). For this sub-category, it is assumed that supplied N_2O-containing products will be used in one year. Equation 8.24 covers more than one year because both supply and use are assumed to be continuous over the year (that is, N_2O supplied in the middle of year t-1 is not fully used and emitted until the middle of year t). For more detail about the methodological approaches see Section 8.4.2.1, *Chapter 8, Volume 3*.

- Activity data

Total quantity of N_2O supplied by application type should be obtained from manufacturers and distributors of N_2O products. Potential sources of activity data include statistical reports, research and reporting by industry agencies. For more detail about the activity data see Section 8.4.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

For this sub-category it should be noted that N_2O used as a propellant in pressurized and aerosol food products is not reacted during the process, and all of it is emitted to the atmosphere resulting in an emission factor of 1.0 for this source. For more detail about the choice of calculation factors see Sections 8.4.2 and 8.4.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

In order to avoid underestimation, it is essential to identify all N_2O manufacturers, domestic consumers, and imports and exports in products. N_2O used as a propellant in aerosols is not reacted during the process (the emission factor is 1.0), which results in a relatively small error compared to other uncertainties related to the activity data. For more detail about the uncertainty estimates see Section 8.4.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.4.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G3c Other

- Category description

Sub-category 2G3c 'Other' covers the emissions of N_2O used as an oxidising agent and etchant for the manufacture of semiconductors; an oxidising agent used, with acetylene, in atomic absorption spectrometry; for production of sodium azide, fuel oxidants, blowtorches, etc. For more detail about the category description see Section 8.4.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

In this sub-category, like in the other sub-categories of category 2G3, N_2O emissions are estimated from data on quantity of N_2O supplied using Equation 8.24 (see Section 8.4.2.1, *Chapter 8, Volume 3*). Depending on the N_2O application, there can be different time delays between manufacture, delivery, and use, and these delays should be included in the equation when making calculations. For more detail about the methodological approaches see Section 8.4.2, *Chapter 8, Volume 3*.

- Activity data

Activity data for N_2O emission estimations in this category are dependent on the N2O application and can be obtained (based on N_2O supply data) from manufacturers and distributors of

N_2O products, industrial plants, or from end users; statistical reports, research and reporting by corresponding agencies or industries can also be used.

- Estimation parameters

For other applications, like in sub-categories 2G3a and 2G3b, the emission factor of 1.0 may not correspond to the actual value. Typically, sub-category 2G3c requires calculation of reasonable national emission factors based on literature data or measurements. For more detail about the choice of calculation factors see Sections 8.4.2 and 8.4.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues: No.
- Quality control procedures; uncertainties

It is important to the maximum degree to account for the data required for the estimation of N_2O emissions, in particular, data per application on import, export and consumption from national N_2O manufacturers and distributors. For this purpose it is essential to identify all N_2O manufacturers, domestic consumers, and imports and exports in products. Uncertainty estimates for emission factors in this sub-category require an individual approach and analysis. For more detail about the uncertainty estimates see Section 8.4.3, *Chapter 8, Volume 3*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Section 8.4.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement: No.

2G4 Other

- Category description

Category 2G4 'Other' covers methods for estimating SF_6, PFCs, and N_2O emissions which are not covered in other Sections of *Chapter 8, Volume 3*. For more detail about the category description see Section 8.1, *Chapter 8, Volume 3*.

- Methodological approaches to emission estimations

The applications of category 2G4 have a wide range of emission profiles, ranging from immediate and unavoidable release of all of the chemical to largely avoidable, delayed release from leak-tight products after decades of use. The estimation methods should be tailored to reflect these differences in emission profiles and can borrow methods used for categories 2G1-2G3. For more detail about the methodological approaches see Sections 8.2.2, 8.3.2, 8.4.2, *Chapter 8, Volume 3*.

- Activity data

Activity data for other SF_6, PFCs, and N_2O applications are typically difficult to obtain and analyse, and much depends on the cooperation with manufacturers/suppliers/distributors of both chemical and equipment. In general, in addition to special requests and inquiries, it is essential to consider data sources such as national and industry-wide reports and reports by different agencies and industries. For more detail about the activity data see Sections 8.2.2.3, 8.3.2.3, 8.4.2.3, *Chapter 8, Volume 3*.

- Estimation parameters

The emission factors applied and a possibility to outline different tiers (Tier 1, 2 or 3 methods) are determined by the SF_6, PFCs, and N_2O application and by how the entire chemical is released. For more detail about the choice of calculation factors see Sections 8.2.2.2, 8.3.2.2, 8.4.2.2, *Chapter 8, Volume 3*.

- Cross-cutting issues

Double counting with other categories may occur depending on the SF_6, PFCs or N_2O application considered.

- Quality control procedures; uncertainties

The key challenge related to the completeness of data will be the difficulty in obtaining information for other SF_6, PFCs or N_2O applications and the need to keep updated with new other applications as they emerge. Since there may be a wide range of diverse applications, which fall into this category, it is not possible to give default uncertainties for these sources. However, the level of uncertainty can be estimated in accordance with the methodology described in *Chapter 3, Volume 1*. Quality control checks should be made as outlined in *Chapter 6, Volume 1*, and in explanations given in Sections 8.2.4, 8.3.4, and 8.4.4, *Chapter 8, Volume 3*.

- Filling in Reporting Tables

General recommendations for filling in Reporting Tables are provided in the sector description.

- Recommendations for verification: estimation problems and common mistakes

No.

- Refinement

In subsector 2G ‘Other Product Manufacture and Use’, no significant amendments were made to the methodology, emission factors or other estimation parameters for the sources included in the *2006 IPCC Guidelines*. Two more sources of fluorinated compounds emissions were added: the use of fluorinated compounds to waterproof electronic circuits and the use of fluorinated compounds for the treatment of textile, carpet, leather, and paper. An emission estimation methodology was only developed for the first source.

2H Other

Sub-sector 'Other' covers the emissions of non-methane volatile organic compounds (NMVOC), NO_x, CO, SO_2 from the pulp and paper industry (2H1) and NMVOC emissions from the food industry and in the production of alcoholic beverages (2H2).

Methodologies for estimating the emissions of precursors (NO_x, NMVOC, CO, SO_2, and NH_3) are not provided in the 2006 IPCC Guidelines. Emissions from the pulp and paper industry, food industry, and production of alcoholic beverages can be estimated using the methodology provided in *1996 IPCC Guidelines, Part 2*. Countries are also encouraged to use *EMEP/EEA Air Pollutant Inventory Guidebook 2016*.

Estimations of NMVOC, NO_x, CO, SO_2 emissions from the pulp and paper industry rely on pulp production volumes, which can be obtained from the national statistical agencies. Default emission factors are provided in Tables 2.23 and 2.24, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Part 2*.

Estimations of NMVOC from the food industry rely on food production volumes, which can be obtained from the national statistical agencies. Default emission factors are provided in Table 2.26, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Part 2*.

Estimations of NMVOC from the production of alcoholic beverages rely on the production volumes for various alcoholic beverages, which can be obtained from the national statistical agencies. Default emission factors for each type of alcoholic beverages are provided in Table 2.25, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Part 2*.

AGRICULTURAL SECTOR

The Agricultural Section deals with greenhouse gas emissions from animal husbandry and crop production.

Emissions from animal husbandry include methane (CH_4) emissions from livestock enteric fermentation and from manure management. This category also includes nitrous oxide (N_2O) emissions from manure management systems.

For crop production processes the following emissions are taken into account:

- N_2O emissions from managed soils;
- CH_4 emissions from rice fields;
- Greenhouse gas emissions from on-site burning of agricultural crop residues;
- CO_2 emissions from lime and urea application.

For a detailed description of greenhouse gas emissions estimation methodology see the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 'Agriculture, Forestry, and Other Land Use':*

Chapter 2, Generic Methodologies Applicable to Multiple Land-Use Categories;

Chapter 5, Cropland;

Chapter 10, Emissions from Livestock and Manure Management;

Chapter 6, Grassland;

Chapter 11, N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application.

Greenhouse gas emission estimation methodology was supplemented and verified in *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use, Chapter 10, 'Emissions from Livestock and Manure Management', Chapter 11, 'N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application'.*

3A LIVESTOCK ENTERIC FERMENTATION

- Category description

This category includes methane (CH_4) emissions which are produced by herbivores as a by-product of enteric fermentation (a digestive process). For many regions, cattle are major sources of CH_4 emissions because of the large population and because ruminant gut structure fosters extensive enteric fermentation of their diet. The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed. For a more detailed category description see Section 10.3, *Chapter 10.*

- Methodological approaches to emission estimation

Estimates of methane emissions from enteric fermentation can be obtained through the following steps:

- - Divide the livestock population into subgroups and characterize each subgroup as described in Section 10.2, *Chapter 10.* It is recommended that annual averages estimated with consideration for the impact of production cycles and seasonal influences on population numbers be used;
- - Estimate emission factors for each subgroup;
- - Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.

These steps can be performed at varying levels of detail and complexity: Tier 1 is a simplified approach that relies on default emission factors; Tier 2 is a more complex approach that requires detailed country-specific data; Tier 3 is acceptable for countries for which livestock emissions are particularly important and includes additional country-specific information.

For a more detailed description of methods to estimate methane emissions from enteric fermentation see Section 10.3.1, *Chapter 10.*

- Activity data

Input data include official statistics on livestock and poultry population by species. A basic livestock characterisation (for example, dairy cattle, other cattle, buffalo, sheep, goats, camels, deer, horses, rabbits, mules and asses, swine, and poultry) is sufficient for Tier 1 estimations. The Tier 2 methodology relies on a more detailed characterization of livestock population seeking to define animals, animal productivity, diet quality, and management circumstances. For more detail about livestock population characteristics for Tier 1 and 2 see Section 10.2.2*, Chapter 10.*

- Estimation parameters

Tier 1 methodology relies on default emission factors presented for each of the livestock population subgroups. For a detailed description of how to estimate emissions from enteric fermentation under Tier 1 methodology see Section 10.3.2*, Chapter 10.* The Tier 2 method for emissions estimation is applied to more disaggregated livestock population categories and used to calculate emission factors, as opposed to default values. Emission factors by livestock categories are estimated using gross energy consumption and methane conversion factors. For more detail about emission factors and methane conversion factors estimation see Section 10.3.2, *Chapter 10,* gross energy consumption estimation is provided in Section 10.2.2, *Chapter 10.*

- Quality control procedures; uncertainties

Accurate estimation of greenhouse gas emissions from livestock enteric fermentation can be ensured through taking account of all key country-specific livestock categories. For more detail about quality control procedures see Section 10.3.5, *Chapter 10.*

Quality control procedures for this category are specific in that they require a consistent livestock population time series. Livestock population data should be cross-checked for consistency with the statistics published by FAO. Feed intake estimates for ruminants should be verified. The resulting dry matter intake (kg/day) should not exceed 3% of the body weight of the animals for all years throughout the estimation period.

Uncertainties are estimated using the activity data and emission factors uncertainties obtained in accordance with the methodology. For a more detailed description of uncertainties estimation see Section 10.3.4, *Chapter 10.*

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets. When filling out Reporting Tables it is important to provide activity data and emissions by livestock categories (cattle, dairy cattle, sheep, goats, buffalo, etc.), as well as total emissions by categories.

- Problems related to estimation and typical mistakes

Major estimation problems may be related to the underestimation of all livestock subcategories in a country.

- Refinement: Yes

3B LIVESTOCK AND POULTRY MANURE MANAGEMENT SYSTEMS

3B1 CH_4 emissions from livestock and poultry manure management systems

- Category description

This category includes the emissions of methane produced during the storage and treatment of manure deposited by animals on pastures. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock. The decomposition of manure under anaerobic conditions produces methane. These conditions occur most readily when animals are managed in a confined area (e.g., dairy farms, swine and poultry farms, and beef feedlots), and where manure is disposed of in liquid-based systems.

Emissions of CH4 related to manure handling and storage are reported under 'Manure Management.'

For a more detailed category description see Section 10.4, *Chapter 10.*

- Methodological approaches to emission estimation

In order to estimate CH_4 emissions from manure handling, storage, and use it is important to:

- - develop a complete list of livestock populations and characterize each category as described in Section 10.2, *Chapter 10.* It is recommended that estimates of average annual populations be used with an account of impacts from production cycles and seasonal variations;
- use default values or develop country-specific emission factors for each livestock subcategory in terms of kilograms of methane per animal per year;
- multiply the livestock subcategory emission factors by the subcategory populations to estimate subcategory emissions, and sum across the subcategories to estimate total emissions.

There are three tier approaches to estimate emissions. Tier 1 is a simplified method of estimating CH_4 emissions that only requires livestock population data by categories and climate regions or temperatures, and IPCC default emission factors. Tier 2 is a more complex method for estimating CH_4 and should be used where a particular livestock species/category represents a significant share of a country's emissions. Tier 3 is used by countries for which livestock emissions are particularly important.

For more detail about the approaches description see Section 10.4.1, *Chapter 10.*

- Activity data

Estimation of CH_4 emissions from manure management systems requires the same livestock population data from the national statistics, as for the 3A category, with an account of the approach described in Section 10.2, *Chapter 10*. It is important to note, that the level of disaggregation in the livestock population data required to estimate emissions from manure management may differ from the levels used for other emission sources, such as enteric fermentation. In addition, estimation of CH_4 emissions from manure management requires data on the application of manure management systems. For more detail about the activity data see Section 10.4.3, *Chapter 10.*

- Estimation parameters

When using the Tier 1 method, default emission factors by livestock category or subcategory are used as shown in Tables 10.14, 10.15, and 10.16, Section 10.4.2, *Chapter 10* and in Tables 10A-4 through 10A-9, *Annex 10A.2, Chapter 10.* When using the Tier 2 method, account is taken of country-specific manure management circumstances. Estimation of emission factors under the Tier 2 method accounts for manure characteristics, such as the amount of volatile solids (VS) produced in the manure and the maximum amount of methane that can be produced from that manure (Bo). It is also important to take account of the characteristics of manure management systems, namely, the types of systems used to manage manure and a system-specific methane conversion factor (MCF). A more detailed description of manure management systems is provided in Table 10.18, Section 10.4.2, *Chapter 10*; methane conversion factor (MCF) defaults are shown in Table 10.17, Section 10.4.2, *Chapter 10*. For more detail about the estimation parameters see Section 10.4.2, *Chapter 10*.

- Cross-cutting issues

The emissions associated with the burning of dung for fuel are to be reported for the Energy Sector (*Volume 2, 'Energy')* or for the Waste Sector (*Volume 5, 'Waste'),* if burned without energy recovery.

- Quality control procedures; uncertainties

Quality control procedures for this category are similar to those for 3A 'Methane emissions from livestock enteric fermentation'. A more detailed description of the quality control procedures is provided in Section 10.4.5, *Chapter 10.*

Uncertainties are estimated using the activity data and emission factors uncertainties obtained in accordance with the methodology. For a more detailed description of uncertainties estimation see Section 10.4.4, *Chapter 10.*

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets. When filling out Reporting Tables it is required to provide activity data and emissions by livestock categories (cattle, dairy cattle, sheep, goats, buffalo, etc.), as well as total emissions by categories.

- Problems related to estimation and typical mistakes

Major estimation problems may be determined by the underestimation of all livestock subcategories in a country or with inaccurate definition of manure management systems.

- Refinement: Yes

3B2 N_2O emissions from livestock and poultry manure management

- Category description

This category includes N_2O emissions produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Nitrification is a necessary prerequisite for the emission of N_2O from stored animal manures.

Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NOx. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time, and to a lesser degree on temperature.

For a more detailed description of direct and indirect N_2O emissions from manure collection, storage, and use see Section 10.5, *Chapter 10.*

- Methodological approaches to emission estimation

Selection of the approach to estimating N_2O emissions from manure management systems and the level of detail depend on the country-specific circumstances.

Three tier approaches are used to calculate direct and indirect N_2O emissions from manure management systems. The Tier 1 method entails multiplying the total amount of nitrogen excretion (from all livestock subcategories) in each type of manure management system by a default emission factor for that type of manure management system (*Chapter 10, Annex 10A.2,* Tables 10A-4 to 10A-8 for direct and indirect N_2O emissions, and for the estimation of indirect emissions see Section 10.5.4, *Chapter 10,* Table 10.22 (to account for default fractions of nitrogen losses from manure management systems due to volatilization)).

A Tier 2 approach would include the use of country-specific data. A Tier 3 method utilizes alternative estimation procedures based on a country-specific methodology.

For a detailed description of each approach see Section 10.5.1, *Chapter 10.*

- Activity data

The data on livestock population as described in the 3A category, and the data on manure management systems that are used to estimate methane emissions under the 3B1 category, are used for the estimation of N_2O emissions from manure management systems. Livestock population data should be obtained using the approach described in Section 10.2, *Chapter 10.* Data on manure management systems used for the estimation of N_2O emissions should be similar to those used for the estimation of CH_4 emissions from manure management. Major types of livestock and poultry manure management systems are described in Table 10.18, Section 10.4.4, *Chapter 10.*

The best means of obtaining manure management system distribution data is to consult regularly published national statistics; if such statistics on the use of the above systems in a country are unavailable, defaults from Tables 10A-4 to 10A-8, *Chapter 10, Annex 10A.2* should be used.

A Tier 2 estimation of emissions requires national statistics on nitrogen intake and retention for livestock categories.

For more detail about the input data selection see Section 10.5.3, *Chapter 10.*

- Estimation parameters

A Tier 1 estimation of direct N_2O emission requires that annual nitrogen excretion rates be determined for each livestock category defined by the livestock population characterisation. Country-specific rates may be taken from documents or reports available in a country. If country-specific data cannot be obtained, default data as presented in Table 10.19, Section 10.5.2, *Chapter 10,* can be used, as well as data from Tables 10A-4 through 10A-8, *Chapter 10, Annex 10A-2*.

For a Tier 2 estimation nitrogen intake can be calculated from data on feed and crude protein intake in accordance with Section 10.2, *Chapter 10.* Default nitrogen retention values are provided in Table 10.20, Section 10.5.2, *Chapter 10.*

The best emission estimate would be obtained using country-specific emission factors. If country-specific emission factors are unavailable, default emission factors presented in Table 10.21, Section 10.5.2, *Chapter 10,* can be used.

For indirect emission estimations default nitrogen losses in the form of NH_3 and NOx are provided in Table 10.22, Section 10.5.2, *Chapter 10.*

For more detail about the estimation parameters used for assessing direct and indirect N_2O emissions from manure management systems see Section 10.5.2, *Chapter 10.*

- Cross-cutting issues

The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil, and are reported under the category 'N_2O Emissions from Managed Soils'. For a detailed category description see Section 11.2, *Chapter 11*.

The emissions associated with the burning of dung for fuel are to be reported under the 'Fuel Combustion' category (see *Volume 2: Energy*), or under 'Waste Combustion' (see *Volume 5: Waste*), if burned without energy recovery.

- Quality control procedures; uncertainties

Quality control procedures for this category are similar to those for 3A 'Methane emissions from livestock enteric fermentation'. In addition, complete inventories should estimate N_2O emissions from all systems of manure management for all livestock categories.

For more detail about quality control procedures see Section 10.5.6, *Chapter 10*.

Uncertainties are estimated using the activity data and emission factors uncertainties obtained in accordance with the methodology. For a more detailed description of uncertainties estimation see Section 10.5.5, *Chapter 10*.

- Filling out Reporting Tables

There are no fundamental differences between filling out Reporting Tables and Worksheets. When filling out Reporting Tables it is important to submit activity data and emissions for each livestock category (cattle, dairy cattle, sheep, goats, buffalo, etc.) and other input data used for the estimations, as well as emission totals by categories.

- Problems related to estimations and typical mistakes

Double counting of emissions associated with the application of managed manure should be avoided, as well as manure associated with pasture and grazing operations; in this latter case, calculations and reporting should be done under Section 11.2, *Chapter 11* 'N_2O emissions from managed soils'.

For more detail about coordination with reporting on N_2O emissions from managed soils see Section 10.5.4, *Chapter 10*.

- Refinement: Yes.

3C RICE CULTIVATION

- Category description

This category includes CH_4 emissions produced by anaerobic decomposition of organic material in flooded rice fields. The annual amount of CH_4 emitted from a given area of rice fields is a function of the number and duration of crops grown, water regimes before and during cultivation

period, and organic and inorganic soil amendments. Soil type, temperature, and rice cultivar also affect CH_4 emissions.

For more detail about CH_4 emissions from rice cultivation see Section 5.5, *Chapter 5*.

- Methodological approaches to emission estimation

There are three tier approaches to estimate emissions.

Tier 1 applies to countries in which either CH_4 emissions from rice cultivation are not a key category or country-specific emission factors do not exist.

Tier 2 method for estimating emissions applies the same methodological approach as Tier 1, but country-specific emission factors and/or scaling factors should be used.

Tier 3 includes models and monitoring networks tailored to address national circumstances of rice cultivation.

For more detail about each of these methods see Section 5.5.1, *Chapter 5*.

- Activity data

CH_4 emissions from rice cultivation are estimated using national data on harvested areas and additional information on cultivation period of rice and agricultural management. For more detail about the required input data see Section 5.5.3, *Chapter 5*.

- Estimation parameters

With a Tier 1 method, emissions are estimated using a default emission factor for fields with no preseason flooding for less than 180 days prior to rice cultivation and continuously flooded fields without organic amendments (EFc). The default for EFc is 1.30 kg CH4/ha * day, Table 5.11, Section 5.5.2, *Chapter 5*.

Scaling factors are used to adjust the EFc to account for the various conditions; these scaling factors are provided in Tables 5.12 through 5.14, Section 5.5.2, *Chapter 5*.

For more detail about selecting emission factors and estimating methane emissions using Tier 2 or 3 methodology see Section 5.5.2, *Chapter 5*.

- Quality control procedures; uncertainties

For a detailed description of quality control procedures and of estimating CH_4 emissions from rice cultivation see Section 5.5.5, *Chapter 5*.

The general principles of uncertainty assessment relevant for national emission inventories should be used.

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: No.

3D N2O EMISSIONS FROM MANAGED SOILS

- Category description

Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2). Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere. One of the main controlling factors in this reaction is the availability of inorganic nitrogen in the soil.

The emissions of N_2O that result from anthropogenic nitrogen inputs or nitrogen mineralisation occur through both a direct pathway (i.e., directly from the soils to which the nitrogen is added/released), and through two indirect pathways: 1. following volatilisation of NH_3 and NOx from managed soils and from fossil fuel combustion and biomass burning, and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; 2. after leaching and runoff of nitrogen, mainly as NO_3^-, from managed soils.

Direct emissions are estimated separately from indirect emissions, though using a common set of activity data.

For a more detailed category description see Section 11.2, *Chapter 11.*

3D1 Direct N_2O emissions from managed soils

- Category description

This category includes direct N_2O emissions from managed soils, i.e. direct emissions from soils to which nitrogen is added or supplied from the following sources:

- synthetic nitrogen fertilizers (F_{SN});
- organic nitrogen applied as fertiliser (e.g., animal manure, compost, sewage sludge, rendering waste) (F_{ON});
- urine and dung nitrogen deposited on pasture, range and paddock by grazing animals, (F_{PRP});
- nitrogen in crop residues (above-ground and below-ground), including from nitrogen-fixing crops and from forages during pasture renewal (F_{CR});
- nitrogen mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils (F_{SOM});
- drainage/management of organic soils (i.e., Histosols) (F_{OS}).

For a description of direct N_2O emissions from managed soils see Section 11.2.1, *Chapter 11.*

- Methodological approaches to emission estimation

There are three tier approaches to estimate emissions. For more detail about the approaches see Section 11.2.1.1, *Chapter 11.*

- Activity data

Direct N_2O emissions from managed soils are estimated using official national statistics on the amount of applied synthetic (mineral nitrogen) fertilizers, organic nitrogen fertilizers, official national statistics on crop yield, total annual harvested crop area, and livestock population by species, similar to the 3A category. For a detailed description of selecting activity data see Section 11.2.1.3, *Chapter 11.*

- Estimation parameters

Three default emission factors are used under Tier 1 methodology to estimate direct N_2O emissions from managed soils:

EF_1 – this emission factor refers to the amount of N_2O emitted from the various synthetic and organic nitrogen applications to soils, including crop residue and mineralisation of soil organic carbon in mineral soils due to land-use change or management.

EF_2 – this emission factor refers to the amount of N_2O emitted from an area of drained/managed organic soils.

EF_{3PRP} – this emission factor estimates the amount of N_2O emitted from urine and dung nitrogen deposited by grazing animals on pasture, range and paddock.

For more detail about default emission factors see Table 11.1, Section 11.2.1.2, *Chapter 11.*

Where a country has more detailed information about: 1) environmental factors (climate, soil organic carbon content, soil texture, drainage and soil pH); and (2) management-related factors (nitrogen application rate per fertilizer type, type of crop, with differences between legumes, non-leguminous arable crops, and grass), then it may choose to use disaggregated emission factors with the Tier 2 approach.

For more detail about selecting emission factors see Section 11.2.1.2, *Chapter 11.*

- Cross-cutting issues

The Agricultural Sector includes N_2O emissions from organogenic soils of cropland converted to hay land and pasture. CO_2 and CH_4 emissions from these soils are reported under the LULUCF Sector (4C 'Continuous Pasture and Hay-Land') (*Chapter 6, 'Grassland').*

- Quality control procedures; uncertainties

Complete coverage of the direct N_2O emissions from managed land requires estimation of emissions for all of the anthropogenic inputs and activities, if they occur. For a detailed description of the quality control procedures see Section 11.2.3, *Chapter 11.*

Uncertainties in estimates of direct N_2O emissions from managed soils are caused by uncertainties related to the emission factors, natural variability, partitioning fractions, activity data,

lack of coverage of measurements, spatial aggregation, and lack of information on specific on-farm practices. For a detailed description of uncertainties estimation see Section 11.2.1.4, *Chapter 11.*

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: Yes.

3D2 Indirect emissions from managed soils

- Category description

This category includes indirect N_2O emissions produced by:

- the volatilisation of nitrogen as NH_3 and oxides of nitrogen (NOx), and the deposition of these gases and their products NH_4^+ and NO_3^- onto soils;
- the leaching and runoff from land of nitrogen from synthetic and organic fertiliser additions, crop residues, mineralisation of nitrogen associated with loss of soil carbon in mineral and drained/managed organic soils through land-use change or management practices, and urine and dung deposition from grazing animals.

Key sources of nitrogen for indirect N_2O emissions from managed soils include:

- synthetic nitrogen fertilisers (F_{SN});
- organic nitrogen applied as fertiliser (e.g., applied animal manure, compost, sewage sludge, rendering waste and other organic amendments) (F_{ON});
- urine and dung nitrogen deposited on pasture, range and paddock by grazing animals (F_{PRP});
- nitrogen in crop residues (above- and below-ground), including nitrogen-fixing crops and forage/pasture renewal returned to soils (F_{CR});
- nitrogen mineralisation associated with loss of soil organic matter resulting from change of land use or management on mineral soils (F_{SOM}).

For more detail about indirect N_2O emissions from managed soils see Section 11.2.2, *Chapter 11.*

- Methodological approaches to emission estimation

There are three tier approaches to estimate indirect N_2O emissions from managed soils. For more detail about the approaches see Section 11.2.2.1, *Chapter 11.*

- Activity data

Input data to estimate indirect N_2O emissions are similar to those for the 3D1 category for relevant sources: applied synthetic fertilizers, organic fertilizers, crop yield, total annual harvested crop area, and livestock population by species similar to the 3A category. For more detail on the selection of activity data see Section 11.2.2.3, *Chapter 11.*

- Estimation parameters

Two emission factors are used for the estimation of indirect N_2O emissions:

– one associated with volatilised and re-deposited nitrogen (EF_4);

– the other associated with nitrogen lost through leaching/runoff (EF_5).

The method also requires values for the fractions of nitrogen that are lost through volatilisation (FracGASF and FracGASM) or leaching/runoff (FracLEACH-(H)).

The default values of all these factors are presented in Table 11.3, Section 11.2.2.3, *Chapter 11.*

For more detail about the selection of emission factors for volatilisation and leaching see Section 11.2.2.2, *Chapter 11.*

- Cross-cutting issues

The sources of NH_3 and NOx are not confined to agricultural fertilisers and manures, but also include fossil fuel combustion, biomass burning, and various processes in the chemical industry, *Volume 3, 'Industrial processes and product use'*.

- Quality control procedures; uncertainties

Complete coverage of the indirect N_2O emissions from managed land requires estimation of emissions for all of the anthropogenic inputs and activities, if they occur. For a detailed description of the quality control procedures see Section 11.2.3, *Chapter 11.*

Uncertainties in estimates of indirect N_2O emissions from managed soils are caused by uncertainties related to the natural variability; emission, volatilisation, and leaching factors; activity data; and lack of coverage of measurements. For a detailed description of uncertainties estimation see Section 11.2.2.4, *Chapter 11.*

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: Yes.

3F FIELD BURNING OF AGRICULTURAL RESIDUES

- Category description

This category includes emissions that are associated with burning of agricultural residues, which vary by country, crop, and management system. CH_4, CO, NOx and N_2O emissions are reported for biomass burning. CO_2 emissions from biomass burning are not reported for this category. The percentage of the agricultural crop residues burnt on-site, which is the mass of fuel available for burning, should be estimated taking into account the fractions removed before burning due to animal consumption, decay in the field, and use in other sectors. This is important to eliminate the possibility of double counting.

For more detail about estimation of non-CO_2 emissions from biomass burning see Section 2.4, *Chapter 2.*

- Methodological approaches to emission estimation

There are three tier approaches to emission estimation. For more detail about each of the approaches see Section 2.4, *Chapter 2.*

- Activity data

Input data include estimates of land areas under the crop types for which agricultural residues are normally burnt. For more detail about the activity data description for each Tier of emission estimation see Section 2.4, *Chapter 2.*

- Estimation parameters

Emission estimation using a Tier 1 method is based on default emission factors as provided in Table 2.5, Section 2.4, *Chapter 2,* for each greenhouse gas of interest. Using a Tier 2 method includes the use of country-specific combustion factors.

For more detail about the emission factors see Section 2.4, *Chapter 2.*

- Cross-cutting issues

Methods for estimating greenhouse gas emissions from fire on cropland and grassland and from savanna burning are described in relevant sections of the LULUCF Sector; for more detail see *Chapter 5 'Cropland'* and *Chapter 6 'Grassland'.*

- Quality control procedures; uncertainties

Complete coverage of non-CO_2 emissions from burning of agricultural residues requires estimation of emissions for all of the anthropogenic inputs and activities, if they occur.

Uncertainties in estimates are caused by natural variability of emission factors and activity data.

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: No.

3G EMISSIONS FROM LIMING

- Category description

This category includes CO_2 emissions from adding carbonates (for example, calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) to soils to reduce soil acidity and improve plant growth in agricultural lands. For more detail about CO_2 emissions from liming see Section 11.3, *Chapter 11.*

- Methodological approaches to emission estimation

There are three tier approaches to estimate emissions. For more detail about the approaches see Section 11.3.1, *Chapter 11.*

- Activity data

National usage statistics for carbonate lime should be used as input data under Tier 1 method of estimating CO_2 emissions from liming.

In addition to the data that are described for Tier 1, a Tier 2 methodology may incorporate information on the purity of carbonate limes as well as site-level and hydrological characteristics to estimate the proportion of carbonate-C in lime applications that is emitted to the atmosphere.

For more detail about selecting the activity data see Section 11.3.3, *Chapter 11.*

- Estimation parameters

When estimating CO_2 emissions under Tier 1 methodology, default emission factors are 0.12 for limestone and 0.13 for dolomite.

When a Tier 2 method is used, derivation of emission factors could entail differentiation of sources with variable compositions of lime.

For more detail about emission factors see Section 11.3.2, *Chapter 11.*

- Quality control procedures; uncertainties

Two sources of uncertainty exist for CO_2 emissions from liming: uncertainties in the amount of carbonate lime applied to soils; and uncertainties in the net amount of carbonate-C from liming applications that is emitted as CO_2. For more detail about uncertainty estimations see Section 11.3.4, *Chapter 11.*

Quality control procedures for emission estimation should ensure that activity data have been processed to estimate lime application to soils and that emission factors have been identified. For more detail about quality control description see Section 11.3.5, *Chapter 11.*

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: No.

3H EMISSIONS FROM UREA APPLICATION

- Category description

This category includes CO_2 emissions produced by adding urea ($CO(NH_2)_2$) to soils during fertilization. For a more detailed description of CO_2 emissions from liming see Section 11.4, *Chapter 11.*

- Methodological approaches to emission estimation

There are three tier approaches to estimate emissions. For more detail about the approaches see Section 11.4.1, *Chapter 11.*

- Activity data

Under Tier 1 method, domestic production records and import/export data on urea can be used to obtain an approximate estimate of the amount of urea applied to soils on an annual basis.

In addition to the data described for Tier 1, a Tier 2 method may incorporate information on site-level and hydrological characteristics that were used to estimate the proportion of carbon in urea that is emitted to the atmosphere.

For more detail about the activity data see Section 11.4.3, *Chapter 11*.

- Estimation parameters

When estimating CO_2 emissions under Tier 1 methodology, default emission factor is 0.20 for carbon emissions from urea application.

A Tier 2 method requires derivation of country-specific emission factors based on the available additional information.

For more detail about emission factors selection see Section 11.4.2, *Chapter 11*.

- Cross-cutting issues

The CO_2 removal from the atmosphere during urea manufacturing and products use is estimated for the IPPU Sector, *Volume 3 'Industrial processes and product use'*.

- Quality control procedures; uncertainties

Quality control procedures are similar to those for the 3A category.

Two sources of uncertainty exist for CO_2 emissions from urea: uncertainties in the amount of urea applied to soils; and uncertainties in the net amount of urea-C that is emitted as CO_2. Activity data uncertainties depend on the accuracy of production, sales, import/export, and/or usage data. For more detail about estimating the uncertainties see Section 11.4.4, *Chapter 11*.

Quality control procedures for emission estimation should ensure that activity data have been processed to estimate urea application to soils and that emission factors have been identified. For more detail about quality control description see Section 11.3.5, *Chapter 11*.

- Filling out Reporting Tables

There is no fundamental difference between filling out Reporting Tables and Worksheets.

- Refinement: No.

LAND USE, LAND USE CHANGE, AND FORESTRY (LULUCF)

The LULUCF sector has some unique characteristics with respect to developing inventory methods. There are many processes leading to emissions and removals of greenhouse gases, which may be widely dispersed in space and highly variable in time. The factors governing emissions and removals can be both natural and anthropogenic (direct and indirect) and it can be difficult to clearly distinguish between the causal factors. While recognizing this complexity, inventory methods need to be practical and operational. The *2006 IPCC Guidelines* were designed to assist in estimating and reporting national inventories of anthropogenic greenhouse gas emissions and removals.

Methodological guidance on the estimation of emissions and removals in the LULUCF Sector are provided in *Volume 4. Agriculture, Forestry, and Other Land Use, 2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

Chapter 1 Introduction

Chapter 2 Generic Methodologies Applicable to Multiple Land-Use Categories

Chapter 3 Consistent Representation of Lands

Chapter 4 Forest Land

Chapter 5 Cropland

Chapter 6 Grassland

Chapter 7 Wetlands

Chapter 8 Settlements

Chapter 9 Other Land

Chapter 10 Emissions from Livestock and Manure Management

Chapter 11 N2O Emissions from Managed Soils and CO2 Emissions from Lime and Urea Application

Chapter 12 Harvested Wood Products

For the LULUCF Sector, anthropogenic emissions and removals of greenhouse gases are defined as all those occurring on 'managed lands.' 'Managed lands' are land where human interventions and practices have been applied to perform production, ecological or social functions.

Information, in terms of classification, area data, and sampling, that represents various land-use categories, is needed to estimate the carbon stocks and the emissions and removals of greenhouse gases associated with the activities in the LULUCF Sector.

Countries use various methods to obtain input data, including annual census, periodic surveys and remote sensing. Each of these methods of data collection will yield different types of information (e.g., maps or tabulations) at different reporting frequencies, and with different attributes. Based on the availability of data on land use and land use change one of the three generic approaches should be chosen:

Approach 1 identifies the total area for each individual land-use category within a country, but does not provide detailed information on the nature of conversions between land uses.

Approach 2 introduces tracking of conversions between land-use categories.

Approach 3 extends the information available in Approach 2 by allowing land-use conversions to be tracked on a spatially explicit basis. Countries may use a mix of Approaches for different regions over time.

For more detail about the approaches and methods of data collection see Section 3.1, *Chapter 3, 2006 IPCC Guidelines.*

The 2006 IPCC Guidelines specify six major land-use categories:

I. Forest Land;
II. Cropland;
III. Grassland;
IV. Wetlands;
V. Settlements;
VI. Other Land.

These categories are:

- robust as a basis for emissions and removals estimation;
- implementable; and
- complete, in that all land areas in a country may be classified by these categories without duplication.

For more detail about land-use categories see Section 3.2, *Chapter 3, 2006 IPCC Guidelines.*

Emissions and removals of greenhouse gases within the LULUCF sector are generally estimated for four key carbon reservoirs (pools), the change in which may be followed by greenhouse gas emissions or removals:

a. biomass:
   i. above-ground;
   ii. below-ground;
b. dead organic matter:
   i. dead wood;
   ii. litter;
c. soil organic matter:
   i. mineral soil;
   ii. organic soil;
d. harvested wood products.

Estimating changes in carbon pools and fluxes depends on data and model availability, as well as resources and capacity to collect and analyze additional information. General methods applicable to various land-use categories and more detail about carbon pools can be found in *Sections 2.3 and 2.4, Chapter 2, 2006 IPCC Guidelines.*

METHODOLOGICAL RECOMMENDATIONS FOR CATEGORIES

3B1 Forest Land

3B1a – Forest Land Remaining Forest Land

- Category description

This category involves greenhouse gas emissions and removals induced by changes in biomass (above-ground and below-ground), dead organic matter, and soil organic matter in managed forests that have been under Forest Land for over 20 years (default), or for over a country-specific transition period. For a more detailed category description see Section 4.2, *Chapter 4, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

The Forest Land Remaining Forest Land category includes five carbon pools for which estimation of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Two methods are proposed to estimate changes in biomass carbon stock, namely, Gain-Loss Method and Stock-Difference Method (for more detail see Section 4.2.1, *Chapter 4, Volume 4, 2006 IPCC Guidelines)*. Carbon stock changes in the dead organic matter (DOM) pool can be described by estimating carbon stock changes in the dead wood and litter pools. Tier 1 methods assume that the net carbon stock changes in DOM pools are zero. Countries that want to quantify DOM dynamics need to develop Tier 2 or 3 methodologies. For a general description of methods for estimating carbon stock changes in dead organic matter pools see *Chapter 2, Volume 4, 2006 IPCC Guidelines*. Changes in carbon stock are estimated for two types of forest soil: mineral soils and organic soil. This pool does not include litter, which is included in the dead organic matter pool. For more detail about the methodological approaches see Section 2.3.3, *Chapter 2, Volume 4, 2006 IPCC Guidelines.* Estimates of contributions from non-CO2 greenhouse gases should include emissions from fires on forest lands (see Section 2.4, *Chapter 2, Volume 4, 2006 IPCC Guidelines)*. Tier 1, 2, and 3 methods are provided for all pools.

- Activity data

Activity data inputs for all tiers include information on areas of managed Forest Land according to different forest types, climate, management systems, and regions, as well as data on wood removals (including fuel wood removals) and biomass loss due to fires and other causes of stands destruction (for more detail see Section 4.2, *Chapter 4, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from forest agencies) to be used for Tier 1 estimations, or from national forest inventories to be used for Tier 2 or 3 estimates. For more detail about input data see Section 4.2, *Chapter 4, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission factors provided by the 2006 IPCC Guidelines (Tables 4.4-4.14, *Chapter 4, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Cross-cutting issues

The LULUCF Sector is closely related to the Agricultural Sector. While changes in carbon stock in agricultural soils are always reported for the LULUCF Sector, some non-CO2 emissions / removals, albeit involving changes in carbon stock, are reported for the Agricultural Sector (for

example, N_2O emissions from cultivation of organic soils and those resulting from the mineralization / immobilization as a result of soil organic matter loss / increase in the mineral soils of Cropland Remaining Cropland). Besides, CH4 and N2O emissions from agricultural residue burning and from savanna burning are reported for the Agricultural Sector, whereas CO_2 emissions from woody biomass on cropland and grassland are reported for the LULUCF Sector.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require cross-checks with the sub-sectors of the Agricultural Sector. Standard quality assurance and quality control measures include checks for data entry and for the consistency of total forest land area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in Section 4.2, *Chapter 4, Volume 4, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulties in emissions estimation for this category include potential omissions and double counting of input data with those for the Agricultural Sector and Harvested Wood Products.

- Refinement

There are changes regarding the methodologies and the use of tiers for estimating emissions by pools for Forest Land Remaining Forest Land. The changes are described in *Chapter 4.2, Volume 4, 2019 Refinement*

3B1b – Land Converted to Forest Land

- Category description

This category includes emissions and removals of greenhouse gases in biomass (above-ground and below-ground), dead organic matter, and organic carbon, which occur on lands converted to Forest Land from different land-uses, including cropland, grassland, wetlands, settlements, and other and abandoned lands, through afforestation and reforestation, either by natural or artificial regeneration (including plantations). For a more detailed category description see Section 4.3, *Chapter 4, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

The Land Converted to Forest Land category includes five carbon pools, for which estimation of changes in annual carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Methods for evaluating annual carbon stock changes in biomass are provided in Section 2.3.1.2, *Chapter 2, Volume 4, 2006 IPCC Guidelines*. Carbon stock changes in the dead organic matter (DOM) pool can be described by estimating carbon stock changes in the dead wood and litter pools. Tier 1 methods assume that the net carbon stock changes in DOM pools are zero. Countries with high rates of conversion of unmanaged to managed forests should use Tier 2 or 3 methods to estimate annual changes in DOM carbon stocks. For a general description of methods for estimating carbon stock changes in dead organic matter pools see Section 2.3.2, *Chapter 2, Volume 4, 2006 IPCC Guidelines*. Changes in carbon stock are estimated for two types of forest soil: mineral soils and organic soils. For more detail about the methodological approaches see Section 2.3.3, *Chapter 2, Volume 4, 2006 IPCC Guidelines*. Estimates of contributions from non-CO2 greenhouse gases should include emissions from fires and biomass burning on Land Converted to Forest Land (see Section 2.4, *Chapter 2, Volume 4, 2006 IPCC Guidelines*). Guidance for estimating N_2O emissions from forest soils is provided in *Chapter 11, 2006 IPCC Guidance*. Tier 1, 2, and 3 methods are provided for all pools.

- Activity data

All Tiers require information on areas converted to Forest Land within 20 years of inventory for the purpose of estimating annual carbon stock changes in biomass, dead organic matter, and soils, as well as of estimating non-CO2 greenhouse gas emissions (for more detail see Section 4.3, *Chapter 4, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from forest agencies) to be used for Tier 1 estimates, or from national forest inventories to be used for Tier 2 or 3 estimates. For more detail about input data see Section 4.3, *Chapter 4, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission factors provided by the 2006 IPCC Guidelines *(Tables 4.4-4.14, Chapter 4, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Cross-cutting issues

Logging areas with subsequent reforestation or forest regeneration should be counted in the Forest Land Remaining Forest Land category, as no land-use change occurs in this case. For omissions / double counting with other sectors see Section 3B1a Forest Land Remaining Forest Land.

- Quality control measures; uncertainties

Coordinated reporting and timely monitoring of changes in various land-use areas and monitoring of afforestation and reforestation activities are key for quality control in this category. Land Converted to Forest Land area, as used in the estimations, should be the same for different pools. For a more detailed description of quality control measures see Section 4.4.3, *Chapter 4, Volume 4, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes potential omissions and double counting of converted land on the whole time series.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions in soil carbon pools. For more detail about the changes see *Chapter 4.3.3, Volume 4 Refinements 2019.*

3B2 Cropland

3B2a – Cropland Remaining Cropland

- Category description

This category involves greenhouse gas emissions and removals induced by changes in biomass (above-ground and below-ground), dead organic matter, and soil organic matter in cropland that have been under Cropland for over 20 years (default). For a more detailed category description see Section 5.2, *Chapter 5, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

The Cropland Remaining Cropland category includes four carbon pools for which estimations of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter, and soil organic matter. Tier 1, 2, and 3 methods are proposed for all the pools. For a more detailed description of the methodological approaches see Section 5.2, *Chapter 5, Volume 4, 2006 IPCC Guidelines*.

- Activity data

Input activity data for all tiers include information on areas of Cropland according to different cropland types, climate, management systems, and regions, as well as data on biomass loss due to fires (for more detail see Section 5.2, *Chapter 5, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimates, or from national

agricultural inventories to be used for Tier 2 or 3 estimates. For more detail about input data see Section 5.2, *Chapter 5, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission factors provided by the 2006 IPCC Guidelines (Tables 5.1-5.6, *Chapter 5, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Cross-cutting issues

The LULUCF Sector is closely related to the Agricultural Sector. While changes in carbon stock in agricultural soils are always reported for the LULUCF Sector, some non-CO2 emissions / removals, albeit involving changes in carbon stock, are reported for the Agricultural Sector (for example, N_2O emissions from the cultivation of organic soils and those resulting from the mineralization / immobilization as a result of soil organic matter loss / increase in the mineral soils of Cropland Remaining Cropland). Besides, CH4 and N2O emissions from agricultural residue burning and from savanna burning are reported for the Agriculture, whereas CO_2 emissions from woody biomass on cropland and grassland are reported for the LULUCF Sector.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require cross-checks with the sub-sectors of the Agricultural Sector. Standard quality assurance and quality control measures include checks for data entry and total cropland area consistency, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes potential omissions and double counting of input data with those for the Agricultural Sector.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 5.2, *Chapter 5, Volume 4 Refinements 2019.*

3B2b – Land Converted to Cropland

- Category description

This category involves greenhouse gas emissions and removals induced by changes in biomass (above-ground and below-ground), dead organic matter, and soil organic matter in Land Converted to Cropland. For a more detailed category description see Section 5.3, *Chapter 5, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

The Land Converted to Cropland category includes five carbon pools for which estimations of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Tier 1, 2, and 3 methods are proposed for all the pools. For a more detailed description of the methodological approaches see Section 5.3, *Chapter 5, Volume 4, 2006 IPCC Guidelines*.

- Activity data

Input activity data for all tiers include information on areas of Land Converted to Cropland with an indication of the previous land use, types of crops, climate, management systems, and regions, as well as data on fire-induced biomass loss (for more detail see Section 5.3, *Chapter 5, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimations. For more detail about input data see Section 5.3, *Chapter 5, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission factors provided by the 2006 IPCC Guidelines (Tables 5.8-5.10, *Chapter 5, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Land Converted to Cropland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes potential omissions and double counting of input data with those for the Agricultural Sector.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 5.3, *Chapter 5, Volume 4 Refinements 2019.*

3B3 Grassland

3B3a – Grassland Remaining Grassland

- Category description

Grassland Remaining Grassland includes managed pastures which have always been under grassland vegetation and pasture use or other land categories converted to grassland more than 20 years ago. Constructing a greenhouse gas inventory for the Grassland Remaining Grassland category involves estimation of changes in carbon stock for five carbon pools (i.e. above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO2 gases. The principal sources of emissions and removals of greenhouse gases in this category are associated with grassland management and changes in management. For a more detailed category description see Section 6.2, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

The Grassland Remaining Grassland category includes five carbon pools for which estimations of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Tier 1, 2, and 3 methods are proposed for all the pools. For a more detailed description of the methodological approaches see Section 6.2, *Chapter 6, Volume 4, 2006 IPCC Guidelines*.

- Activity data

Input activity data for all tiers include information on areas of Grassland Remaining Grassland by types of vegetation, climate, management systems, and regions, as well as data on fire-induced biomass loss (for more detail see Section 6.2, *Chapter 6, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimations. For more detail about input data see Section 6.2, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Tier 1 is to be chosen when there are no significant emissions or removals in Grassland Remaining Grassland. A Tier 1 approach assumes no change in biomass in all Grassland Remaining Grassland. Countries experiencing significant changes in grassland management or disturbance are encouraged to develop domestic data to estimate this impact, and report it under a Tier 2 or 3 methodology.

- Cross-cutting issues

The LULUCF Sector is closely related to the Agricultural Sector. While changes in carbon stock in agricultural soils are always reported for the LULUCF Sector, some non-CO2 emissions / removals, albeit involving changes in carbon stock, are reported for the Agricultural Sector (for example, N_2O emissions from cultivation of organic soils and those resulting from the mineralization / immobilization as a result of soil organic matter loss / increase in the mineral soils of Cropland Remaining Cropland). Besides, CH4 and N2O emissions from agricultural residue burning and from savanna burning are reported for the Agricultural Sector, whereas CO_2 emissions from woody biomass on Cropland and Grassland are reported for the LULUCF Sector.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require cross-checks with the sub-sectors of the Agricultural Sector. Standard quality assurance and quality control measures include checks for data entry and for the consistency of total grassland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes potential omissions and double counting of input data with those for the Agricultural Sector.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 6.2, *Chapter 6, Volume 4 Refinements 2019.*

3B3b – Land Converted to Grassland

- Category description

Land Converted to Grassland includes forest land or other land-use categories which were converted to grassland within the last 20 years. Greenhouse gas inventory for the Land Converted to Grassland (LG) category involves estimation of changes in carbon stock for five carbon pools (i.e. above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO2 gases. The principal sources of emissions and removals of greenhouse gases in this category are associated with land use change and management. For a more detailed category description see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

The Land Converted to Grassland category includes five carbon pools for which estimations of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Tier 1, 2, and 3 methods are proposed for all the pools. For a more detailed description of the methodological approaches see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines*.

- Activity data

Input activity data for all tiers include information on areas of Land Converted to Grassland with an indication of the previous land use, types of vegetation, climate, management systems, and regions, as well as data on fire-induced biomass loss (for more detail see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimates. For more detail about input data see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Tier 1 methods require estimates of the biomass of the land use before and after conversion. It is assumed that all biomass is cleared when preparing a site for grassland use, thus, the default for biomass immediately after conversion is 0 tonne/ha. Default values for biomass can be found at:

- Forest land prior to clearing;
- Cropland containing woody perennial crops: see Chapter 5 (Cropland);

- Cropland containing annual crops: use default of 4.7 tonnes of carbon per ha, or 10 tonnes of dry matter per ha; the error range associated with this default is +75%. Default values for Grassland biomass following conversion from other land uses are shown in Table 6.4, Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

When using Tier 2 or 3 methods it is possible to use country-specific emission factors that account for specific national circumstances.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Land Converted to Grassland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes input data collection, identification of the previous land use and carbon stock.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 6.3, *Chapter 6, Volume 4 Refinements 2019.*

3B4 Wetlands

3B4a – Wetlands Remaining Wetlands

- Category description

This category includes Peatlands Remaining Peatlands and Flooded Land Remaining Flooded Land. For more detail about the category description see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

Estimating CO2 emissions from lands undergoing peat extraction has two basic elements: on-site emissions from peat deposits during the extraction phase and off-site emissions from the horticultural (non-energy) use of peat. Peat extraction starts with vegetation clearing, which

prevents further carbon sequestration, so only CO2 emissions are considered. No methodologies are provided for Flooded Land Remaining Flooded Land. Default methodologies for Land Converted to Flooded Land contain guidance on the estimation of CO2 emissions associated with flooding. For more detail about the category description see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines.*

- Activity data

All tiers require data on areas of peatlands managed for peat extraction and peat production data by weight or volume of air-dry peat. Countries can obtain data on their flooded land area from a drainage basin cover analysis, from a national dam database, from the International Commission on Large Dams (ICOLD, 1998) or from the World Commission on Dams report (WCD, 2000). (For more detail see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines*).

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimations. For more detail about input data see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines.*

Default emission factors provided by the 2006 IPCC Guidelines (Tables 7.4-7.6*, Chapter 7, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Cross-cutting issues

Emissions from the energy use of peat for the Wetlands Remaining Wetlands category should be reported for the Energy Sector.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require cross-checks with the sub-sectors of the Energy Sector. Standard quality assurance and quality control measures include checks for data entry and for the consistency of total grassland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are made using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes (if any)

The main difficulty in emissions estimation for this category includes potential omissions and double counting of input data with those for the Energy Sector.

- Refinement

There are many changes in methodologies and the use of tiers to estimate greenhouse gas emissions for the Wetlands Remaining Wetlands category. For more detail about the changes see *Sections 7.2 and 7.3, Chapter 7, Volume 4 Refinements 2019.*

3B4b – Land Converted to Wetlands

- Category description

This category includes peatlands being drained and converted for peat extraction and lands converted to flooded land. For more detail about the category description see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

Under a Tier 1 approach, activity data do not distinguish between peatlands under peat extraction (Peatlands Remaining Peatlands) and those being converted for peat extraction. For Land Converted to Flooded Land guidance is provided only for the estimation of CO2 emissions. The IPCC Guidelines provide Tier 1, 2, and 3 methodologies. For a more detailed description of the methodological approaches see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines*.

- Activity data

All Tiers require data on areas of peatlands managed for peat extraction and peat production data by weight or volume of air-dry peat. Countries can obtain data on their flooded land area from a drainage basin cover analysis or national dam database, from the International Commission on Large Dams (ICOLD, 1998) or from the World Commission on Dams report (WCD, 2000). (For more detail see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines*).

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimations. For more detail about input data see *Sections 7.2 and 7.3, Chapter 7, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission factors provided by the 2006 IPCC Guidelines (Tables 7.4-7.6*, Chapter 7, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific emission factors derived from country-specific national circumstances.

- Cross-cutting issues

Emissions from the energy use of peat for the Wetlands Remaining Wetlands category should be reported for the Energy Sector.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Land Converted to Grassland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulty in emissions estimation for this category includes potential omissions and double counting of input data with those for the Energy Sector.

- Refinement

There are many changes in methodologies and the use of tiers to estimate greenhouse gas emissions for the Wetlands Remaining Wetlands category. For more detail about the changes see Section 7.2, *Chapter 7, Volume 4 Refinements 2019.*

3B5 Settlements

3B5a – Settlements Remaining Settlements

- Category description

This category refers to all classes of urban formations that have been in use as settlements (e.g., areas that are functionally or administratively associated with public or private land in cities, villages, or other settlement types), since the last time data were collected. For a more detailed category description see Section 8.2, *Chapter 8, Volume 4, 2006 IPCC Guidelines.*

- Methodological approaches to emission estimation

In the Settlements Remaining Settlements category, emissions and removals are estimated by the subcategories of changes in carbon stocks in biomass (both woody and perennial non-woody components), in dead organic matter, and in soils. For all carbon pools Tier 1, 2, and 3 methodologies are provided. For a more detailed description of methodological approaches see Section 8.2, *Chapter 8, Volume 4, 2006 IPCC Guidelines*.

- Activity data

For Tier 1 estimations no activity data are required. The activity data needed to implement a Tier 2 method are either area of crown cover for each class within a perennial type, or number of individual plants in each class within a perennial type. Crown cover is defined as the percent of ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage. For Tier 2a, crown cover area data can be obtained from aerial photographs of urban areas, provided expertise in photo interpretation, image sampling, and area measurement are available. Values in percent crown cover (crown density) should be converted to total crown cover area. Under Tier 3, the type of activity data to be collected depends on the methodological approaches used. If the stock-difference method is used, then it is necessary to disaggregate and estimate area under different vegetation types (parks, rural or urban settlements, avenues, playgrounds, etc.) using remote sensing techniques and different climate or economic development indicators. The higher the tier to be used, the more disaggregated the activity data, and the more precise the estimation methods. (For more detail see Section 8.2, *Chapter 8, Volume 4, 2006 IPCC Guidelines).*

Activity data can be obtained from national statistical reporting (for example, from national statistics obtained from municipalities) to be used for Tier 1 estimations, or from national inventories or national statistical agencies to be used for Tier 2 or 3 estimations. For more detail about input data see Section 8.2, *Chapter 8, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Tier 1 assumes no change in carbon stocks in live biomass in Settlements Remaining Settlements, in other words, that the growth and loss terms balance. If the category Settlements Remaining Settlements is determined to be a key category, then a country should collect appropriate activity data and/or develop emission factors appropriate to the region and adopt Tier 2 or 3. For more detail see Section 8.2, *Chapter 8, Volume 4, 2006 IPCC Guidelines*.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require cross-checks with the sub-sectors of the Agricultural Sector. Standard quality assurance and quality control measures include checks for data entry and for the consistency of total grassland area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are made using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 8.2, *Chapter 8, Volume 4 Refinements 2019.*

3B5b – Land Converted to Settlements

- Category description

Conversion of forest land, cropland, grassland, etc. to Settlements induces greenhouse gas emissions and removals. For a more detailed category description see Section 8.3, *Chapter 8, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

The Land Converted to Grassland category includes five carbon pools for which estimations of changes in carbon stock are required: biomass (above-ground and below-ground), dead organic matter (dead wood and litter), and soil organic matter. Tier 1, 2, and 3 methods are proposed for all the pools. For a more detailed description of the methodological approaches see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines*.

- Activity data

The amount of land converted to Settlements, stratified by climate region and soil type, is required to estimate the appropriate stocks at the Tier 1 level. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. (For more detail see Section 8.3, *Chapter 8, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from agricultural agencies) to be used for Tier 1 estimations, or from national inventories to be used for Tier 2 or 3 estimations. For more detail about input data see Section 6.3, *Chapter 6, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default emission and removal factors are provided in Table 8.4, Section 6.3, Chapter 6, Volume 4, 2006 IPCC Guidelines.

Tier 2 and 3 estimates allow for the use of country-specific factors derived from country-specific national circumstances.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Land Converted to Settlements area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Recommendations for verification: problems related to calculations and common mistakes

The main difficulties in emissions estimation for this category include input data collection, identification of the previous land use and carbon stock.

- Refinement

There are some changes in methodologies and the use of tiers to estimate emissions by carbon pools for the Cropland Remaining Cropland category. For more detail about the changes see Section 8.3, *Chapter 8, Volume 4 Refinements 2019.*

3B6 Other Land

3B6a – Other Land Remaining Other Land

- Category description

Other Land is defined as to include bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories. For a more detailed category description see Section 9.2, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

In the Other Land Remaining Other Land category, emissions are estimated by the subcategories of changes in carbon stocks in biomass (both woody and perennial non-woody components), in dead organic matter, and in soils. For all carbon pools Tier 1, 2, and 3 methodologies are provided. For a more detailed description of methodological approaches see Section 9.2, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Activity data

All tiers require estimates of the area of land converted to Other Land over a time period that is consistent with land-use surveys and the period used for conversions in the land-use change matrix. (For more detail see Section 9.2, *Chapter 9, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from municipalities) to be used for Tier 1 estimation, or from national inventories or national statistical agencies to be used for Tier 2 or 3 estimation. For more detail about input data see Section 9.2, *Chapter 9, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default parameters are provided for biomass stocks before conversion to enable countries with limited data resources to estimate emissions and removals from this source. The method requires the estimation of carbon stocks before conversion for the initial land use and assumes that the carbon stock after conversion is zero. Tables provided in Chapters 4, 5, 6, 7 and 8 of this report for average carbon stock in carbon pools can be used to estimate carbon stocks before conversion. Estimation of changes in carbon stock using Tier 2 or 3 methods requires country-specific information, which may be obtained, for example, through systematic studies of biomass carbon stocks in the various land-use categories. For more detail about emission factors see Section 9.2, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Other Land area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Refinement: No.

3B6b – Land Converted to Other Land

- Category description

Other Land is defined as to include bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories. For a more detailed category description see Section 9.3, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

In the Land Converted to Other Land category, emissions are estimated by the subcategories of changes in carbon stocks in biomass (both woody and perennial non-woody components), in dead organic matter, and in soils. For all carbon pools Tier 1, 2, and 3 methodologies are provided.

For a more detailed description of methodological approaches see Section 9.3, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Activity data

All tiers require estimates of the area of land converted to Other Land over a time period that is consistent with land-use surveys and the period used for conversions in the land-use change matrix. (For more detail see Section 9.3, *Chapter 9, Volume 4, 2006 IPCC Guidelines).*

Input data can be obtained from national statistical reporting (for example, from national statistics obtained from municipalities) to be used for Tier 1 estimations, or from national inventories or national statistical agencies to be used for Tier 2 or 3 estimations. For more detail about input data see Section 9.3, *Chapter 9, Volume 4, 2006 IPCC Guidelines.*

- Estimation parameters

Default parameters are provided for biomass stocks before conversion to enable countries with limited data resources to estimate emissions and removals from this source. The method requires the estimation of carbon stocks before conversion for the initial land use and assumes that the carbon stock after conversion is zero. Tables provided in Chapters 4, 5, 6, 7 and 8 of this report for average carbon stock in carbon pools can be used to estimate carbon stocks before conversion. Estimation of changes in carbon stock using Tier 2 or 3 methods requires country-specific information, which may be obtained, for example, through systematic studies of biomass carbon stocks in the various land-use categories. For more detail about emission factors see Section 9.3, *Chapter 9, Volume 4, 2006 IPCC Guidelines*.

- Quality control measures; uncertainties

Standard quality assurance and quality control measures include checks for data entry and for the consistency of total Land Converted to Other Land area, activity data trends and greenhouse gas emission trends.

Uncertainty estimates are made using the information about activity data and emission factors uncertainties as described in the methodology presented in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

General reporting and documentation requirements are described in *Chapter 8, Volume 1, 2006 IPCC Guidelines.*

- Refinement: No.

3D1 – Harvested Wood Products (HWP)

- Category description

Harvested wood products pool includes all wood material (including bark) that leaves harvest sites, cropland, and other land uses. Part of HWP can be deposited in solid waste disposal sites (SWDS). Slash and other material left at harvest sites should be regarded as dead organic matter in the associated land-use category (see Chapters 4, 5, 6, 7, 8, and 9 of the 2006 IPCC Guidelines). For a more detailed category description see *Chapter 12, Volume 4, 2006 IPCC Guidelines*.

- Methodological approaches to emission estimation

Either the stocks in the country, or the annual change in carbon in HWP stocks originating from wood harvested in the country (including exported HWP) may be considered. The HWP Contribution can be reported as zero, if the inventory compiler judges that the annual change in carbon in HWP stocks is insignificant. Chapter 12, Volume 4, the IPCC Guidelines, provides four approaches to estimating emissions in this category: the stock-change approach; the atmospheric flow approach; the production approach; and the simple decay approach. Tier 1, 2, or 3 methods may be applied to any of the four approaches depending on the data availability. For more detail about the methodological approaches see Section 12.1, *Chapter 12, Volume 4, 2006 IPCC Guidelines.*

- Input data

Activity data include wood and paper products production, imports and exports in the reporting country. Description of product types is provided in Table 12.5, *Chapter 12, Volume 4, 2006 IPCC Guidelines.* In order to account for current year carbon release from HWP placed in use decades ago, estimates are needed for HWP data prior to 1961. In order to obtain the data prior to 1961, they are extrapolated backward to 1900 using Equation 12.6 *(Chapter 12, Volume 4, 2006 IPCC Guidelines).* Input data may be obtained from the national or international (FAO) statistical reports.

- Estimation parameters

Recalculation factors and default emission factors provided by the 2006 IPCC Guidelines *(*Section 12.2.2, Tables 12.2-12.3*, Chapter 12, Volume 4)* are used for Tier 1 estimates. Tier 2 and 3 estimates allow for the use of country-specific factors derived from country-specific national circumstances.

Cross-cutting issues

CO2 released from wood burnt for energy is not included in the Energy Sector totals (although CO2 emissions from biofuels are reported as a memo item for Quality Assessment / Quality Control purposes). CH4 and other gases from HWP used for energy are included in the Energy Sector. CO2 released from HWP in solid waste disposal sites (SWDS) is not included in the

Waste Sector totals, although CH4 emissions from HWP are included. In accordance with the Waste Sector Guidelines, methane emissions from wood in SWDS are reported for the Waste Sector by the country where the SWDS is located, regardless of which country the waste comes from (*see Section 3, Chapter 3, Volume 5, 2006 IPCC Guidelines*).

CO2 emissions from woody biomass burning are reported for the LULUCF Sector. However, these CO2 emissions can be estimated as an implicit component of change in carbon stock for forests and other wood-producing land categories or as part of change in carbon stock in the HWP pool. The details depend on the approach used for estimating CO2 emissions and removals from the use of HWP. CO2 emissions from burnt woody biomass are not reported either for the Energy Sector (combustion for energy use) or for the Waste Sector (burning or loss without energy recuperation). This is done to avoid potential double counting of these emissions.

- Quality control measures; uncertainties

Quality control measures in this category are specific in that they require checks for national or FAO database data entry and wood production, exports and imports consistency. It is also recommended to review wood and paper products densities from the IPCC emission factors database and to use national data, where the latter are available. It is important to ensure that estimates of HWP deposited in SWDS, which build on the number of SWDS, correlate with SWDS deposits according to the estimations for the Waste Sector.

Uncertainty estimates are obtained using the information about activity data and emission factors uncertainties as described in the methodology presented in Section 12.3, *Chapter 12, Volume 4, 2006 IPCC Guidelines.*

- Filling out the Reporting Tables

The approach used for estimating the HWP contribution should be specified in the Reporting Tables. It is required that information on HWP production, exports and imports be reported, even if the HWP contribution is taken equal to zero. If the Simple Decay approach is used for estimations, it should be indicated in the Documentation Box of Background Table which of the following options is used: 1a) CO2 equivalent of carbon in annual harvest of HWP is retained with (deducted from) the net emission / removals estimate reported separately for each land area (-44/12 * H), and 1b) HWP contribution equals the CO2 release from harvest in the country (44/12* $\uparrow C_{HWP\ DH}$); or 2) HWP contribution equals [-44/12* (H -$\uparrow C_{HWP\ DH}$)].

- Refinement

There are some changes in emission factors and approaches. For more detail about the changes see *Chapter 12, Volume 4, Refinements 2019.*

WASTE SECTOR

STRUCTURE OF THE WASTE SECTOR AND SOURCES OF GHG EMISSIONS

Volume 5, 'Waste', 2006 IPCC Guidelines, gives methodological guidance for the estimation of CO_2, CH_4, and N_2O emissions from waste and wastewater treatment, including the following sources:

5A Solid Waste Disposal;

5B Biological Treatment of Solid Waste;

5C Incineration and Open Burning of Waste;

5D Wastewater Treatment and Discharge.

Estimation of long-term carbon storage related to solid waste disposal is provided as additional information for this sector (5.F Memo Items. Long-term C Storage).

Waste and wastewater treatment (5.A, 5.B, and 5.D categories) may involve application of biogas combusting technologies. GHG emissions from this process are considered insignificant, but they are also included in the sections of Volume 5, 'Waste' that cover the relevant emission sources.

Typically, CH_4 emissions from solid waste disposal sites (SWDS) are the largest GHG source. It is good practice to ensure that all of the sources are fully taken into account by GHG inventory compilers.

In practice, the above sources can be split into two groups:

- GHG sources in waste treatment; and
- GHG sources in wastewater treatment.

Some of the waste and wastewater categories, the so-called liquid waste (liquid household waste, waste petroleum products and oils, etc.), may raise questions about their classification; where this is the case, one should go by the treatment technologies.

Within each of these categories, GHG emissions from various waste and wastewater treatment technologies are considered. The technologies may substantially differ by types of GHG, estimation methodologies, activity data, factors and parameters, therefore, in Volume 5, 'Waste', they are broken down by separate sources and described in the relevant chapters, each having its own set of approaches, formulas, and tables:

Chapter 3, Solid Waste Disposal and Long-Term Carbon Storage;

Chapter 4, Biological Treatment of Solid Waste;

Chapter 5, Incineration and Open Burning of Waste;

Chapter 6, Wastewater Treatment and Discharge.

Based on various parameters and available activity data, these source categories may be broken down by more detailed subcategories, some of which may also have their own methodological approaches, factors, and parameters. In addition, where there are emissions of several GHG from one source, the same individual approach can be used for each of them.

Since Chapters 3 to 5 describe GHG emissions from waste management, and the activity data required to estimate these emissions are interconnected, a special *Chapter 2, 'Waste Generation, Composition, and Management'* was included in . The approaches and activity data discussed therein can be further used to estimate emissions from sources 5.A to 5.C and 5.F, and in some instances from source 5.D.

REPORTED GHG AND POSSIBLE DOUBLE COUNTING WITH OTHER EMISSION SOURCES

The methodology provides guidance for the estimation of direct CO_2, CH_4, and N_2O emissions. In addition, it allows for the estimation of indirect N_2O emissions (see Chapter 7, Volume 1, 2006 IPCC Guidelines). Emissions of non-methane volatile organic compounds (NMVOCs), NOx, CO, and NH_3 can also be produced from waste and wastewater treatment, yet specific methodologies for the estimation of emissions for these gases are not included in the *2006 IPCC Guidelines.* If desired to produce such estimates, the readers are guided to refer to other guidelines (for example, .

GHG inventory compilers should pay attention to the fact that CO_2 emissions from biogenic material (animal and plant residues, wastewater from their treatment and domestic wastewater, as well as methane generated by this waste) are not reported in the Waste Sector (see Section 1.2, *Chapter 1, Volume 1, 'General Guidance and Reporting'*).

All emissions from the use of heat (including for electricity generation) produced by waste incineration (and of methane generated from waste and wastewater treatment) are reported for the Energy Sector (Volume 2, 'Energy'). In this case CO_2 emissions containing biogenic carbon are reported separately as an information item. Other, more specific, cases of reporting GHG emissions for other sectors (including double counting) are described below in explanations for relevant sources.

Emissions from waste-to-energy, where waste and wastewater are used as fuel or raw materials should be reported in the Energy Sector or Industrial Processes and Product Use (*Volume 2, 'Energy', and Volume 3, 'Industrial Processes and Product Use'*) and are not included in the Waste Sector. Emissions that are not generated by waste and wastewater *per se*, but rather by waste management activities (for example, the use of fuel for waste transportation and treatment), are also described in other volumes of *2006 IPCC Guidelines.*

METHODOLOGICAL ISSUES OF WASTE TREATMENT DATA SELECTION

When collecting activity data to estimate GHG emissions from waste disposal, biological treatment, and incineration and open burning, the basic purpose is to determine:

- the composition of waste subject to such treatment;
- the amount of waste by types/material that can produce GHG in these instances;
- organic and fossil carbon content in this waste.

A detailed description of methodological approaches to the collection and selection of these activity data (including based on the 'Waste Stream Analysis' method) and parameters, as well as their default values for the estimation of GHG emissions from waste, are provided in *Chapter 2, Volume 5, 'Waste'*. Emissions from waste produced by operations other than disposal, incineration and open burning, and biological treatment are considered insignificant and are not included in the GHG emissions estimation methodology.

Various types of waste are often grouped into mixed groups based on their origin and accounting specificity. The methodology specifies the following mixed waste groups: municipal solid waste (MSW) (which some countries may also classify as domestic solid waste or municipal waste); industrial waste; sludge (in some countries can be included either in MSW or in industrial waste, based on the origin); agricultural waste (may be included in the industrial waste), and some others. It is good practice to account for all these types of waste in the GHG inventory, and it is

important to avoid both underestimation and double counting of waste between the different categories. Types of waste from individual sources not included in the estimates of GHG emissions are specified in the descriptions of these sources. *2006 IPCC Guidelines* mainly focus on estimating GHG emissions from MSW treatment.

Activity data for estimations can be obtained from national statistics (obtained annually or periodically) on waste generation, composition, and management (with an account of exports and imports). Such data can be obtained from national statistical waste treatment reports; surveys (including those made by various national agencies and companies responsible for waste collection and disposal, industrial plants and waste treatment associations); national waste management regulations (standards, sanitation and cleaning plans, etc.); reports by individual companies and international organizations (*FAOstat http://www.fao.org/, WorldBank https://data.worldbank.org/,* etc.). Where national data are not available, some information from the neighboring countries with similar demographic and economic circumstances can be used.

Based on the data availability, one of the two approaches to estimating the amount and composition of disposed, treated, or incinerated waste can be used: using direct data on such waste types; or using data on the waste generated in a country and estimating the fractions that are treated or disposed of by various methods. If need be, waste amount data should be converted from bulk to mass (using the density data) and from wet to dry weight (using waste moisture data). The data required to calculate GHG emissions from waste disposal are the most difficult to obtain, because the methodology requires the use of historical data on waste disposal that are collected for at least 50 years.

MSW generation and management data. Analyses of MSW generation and management data can be based both on individual types of waste included in this category and the category as a whole. Where direct national data on MSW generation are not available, information on per capita MSW generation may be used (based on current coverage of the urban and rural population with waste collection services). Data on the population can be obtained from national or international demographic statistics (for example, *FAOstat http://www.fao.org/*). Default data on MSW generation rates and management practices are provided in *Sections 2.2.1 and 2.3.1, as well as in Annex 2A.1, Chapter 2, Volume 5, 'Waste',* only for a limited number of regions and countries. Recommended values for MSW components by regions and for water and organic/fossil carbon content are provided in Section 2.3.1, *Chapter 2, Volume 5, 'Waste'*. Liquid household waste (if separated out by a country into a special group) is discussed in *Chapter 6, Volume 5, 'Waste',* among GHG sources in wastewater treatment and discharge.

Sewage sludge generation and management data. Sewage sludge management may be referred to as waste management (categories 5.A-5.C) or wastewater treatment (category 5.D). Sludge management in wastewater and sludge treatment systems and related GHG emissions are discussed in *Chapter 6, Volume 5, 'Waste',* as emissions from wastewater treatment facilities. Biological treatment of sludge and other solid waste at facilities other than wastewater treatment facilities is viewed as solid waste treatment (category 5.B). Disposal and incineration of sludge are viewed as disposal and incineration of solid waste (categories 5.A and 5.C). Where a methodology that allows it to report GHG emissions from wastewater and sludge together is used (see Section 6.2, *Chapter 6, Volume 5, 'Waste'),* all emissions from sludge are viewed as emissions from wastewater and are attributed to category 5.D, whether or not other management technologies are available. The sludge that is generated and managed in these circumstances should not be used to estimate GHG emissions. Sludge that is applied on agricultural land should be considered in the Agricultural Sector **(**Section 11.2, *Chapter 11, Volume 4 'Agriculture, Forestry, and Other Land Use'***).** The methodology does not provide default values for sludge generation and management. Where relevant national data are not available, it is required to use the method of joint accounting of sludge and wastewater emissions, which allows not to use data on sludge. Default values for water content and organic / fossil carbon content in domestic and industrial sludge (same for all industries) are provided in Section 2.3.2, *Chapter 2, Volume 5, 'Waste'.*

Industrial waste generation and management data. In some countries, certain types of industrial waste may be included in MSW or defined as separate categories. If this is the case, it is important to ensure the avoidance of double counting of emissions. Industrial waste can be classified and accounted either by types of waste or by types of industry. It is good practice to use country-specific data on industrial waste disposal, incineration, and biological treatment for estimations. Default values for 2000 industrial waste generation by industries for some countries are provided in Section 2.2.3, *Chapter 2, Volume 5, 'Waste'.* No management data are available for this type of waste. Default values for water content and organic/fossil carbon content in industrial wastes from different industries, as well as for industrial waste in general, are provided in Section 2.3.3, *Chapter 2, Volume 5, 'Waste'.*

Agricultural waste generation and management data. Manure management, as well as burning of agricultural residues and related emissions are treated in the Agricultural Sector *(Volume 4, 'Agriculture, Forestry, and Other Land Use').* Where manure is treated with other wastes, it may be reported for the Waste Sector; if this is the case, double counting of emissions should be avoided.

Liquid waste. Only category 5.C 'Incineration of waste' is considered for liquid waste management technologies. Since only CO_2 emissions of fossil origin are reported for the Waste Sector, liquid waste of biogenic origin (such as waste oil from the food industry) does not need to be accounted for, unless biogenic and fossil oils are mixed, and the latter are predominant. Therefore, the management of fossil liquid waste and related products may imply incineration and open burning, which are treated under 5.C category 'Incineration of waste', or purification together with wastewater, which is treated under 5.D category 'Wastewater treatment and discharge'. Where liquid waste is placed in special facilities, GHG emissions do not need to be estimated. The IPCC does not provide any default values for liquid waste generation or management. Water content and fossil carbon content defaults are provided in Section 5.4.1, *Volume 5, 'Waste',* only for fossil liquid waste.

5A SOLID WASTE DISPOSAL

- Category description

This category includes CH_4 emissions from anaerobic biological degradation of organic solid waste which is deposited on landfills (hereinafter referred to as SWDS). The use of waste as fertilizer in the agricultural sector is not to be treated as waste disposal. A fraction of methane in biogas that is generated at SWDS can be recovered and combusted in order to minimize methane emissions to the atmosphere. Good practice does not require the estimation of GHG emissions from biogas flaring, as CH_4 and N_2O emissions are very small and CO_2 emissions are of biogenic origin. However, if it is wished to do so, GHG emissions from methane use for energy or heat should be reported under the Energy Sector, and where methane combustion is without energy use, under relevant subcategories based on its origin. The emission estimation method is discussed in *Chapter 4.2, Volume 2, 'Energy'*.

Based on the availability and level of detail of information on country-specific technologies used by SWDS, this category may be broken down by the following subcategories:

- 5A1 Managed Waste Disposal Sites
  - 5A1a Anaerobic Managed Waste Disposal Sites
  - 5A1b Semi-aerobic Managed Waste Disposal Sites
- 5A2 Unmanaged Waste Disposal Sites
- 5A3 Uncategorized Waste Disposal Sites

Category 5A1 'Managed Waste Disposal Sites' includes two separate categories (5A1a and 5A1b) which are combined for reporting purposes.

Methodological approaches to estimating CH_4 emissions for all these categories are alike. The critical factor for referring wastes and the emissions they produce to a certain subcategory is a set of technologies and measures used by the SWDS where these wastes are deposited. Where it is impossible to breakdown these categories by subcategories, all of the emissions should be treated as '5.A.3. Uncategorized Waste Disposal Sites'. For more detail about the categories description see Section 3.2.3, *Chapter 3, Volume 5, 'Waste'*.

- Methodological approaches to emission estimation

Methodological approach to estimating emissions under this category is based on the assessment of the amount of carbon in deposited waste and on the rate and efficiency of biological decomposition of carbon-containing organic substances. This method suggests that only organic material which contains carbon of biogenic origin is subject to such decomposition (i.e., all types of plastics, synthetic materials and other substances that contain organic material with fossil carbon are treated as non-degradable).

First Order Decay (hereinafter referred to as FOD) method should be used for estimations; it assumes slow decay of organic components in waste, during which CH_4 is formed for several decades, including in closed SWDS. The FOD model is built on an exponential function that describes the fraction of degradable material in waste deposited in different years, which each year is degraded into CH_4 and CO_2. This means that the amount of CH_4 generated each year is irrelevant to the amount of waste disposed of in that year, but it is the total of degradable organic matter remaining in the SWDS that matters. The model also takes account of oxidation of generated CH_4 in the cover of the SWDS and a potential for its recovery for energy or heat or for flaring. For a more detailed mathematical description of the FOD model and its possibilities see *Annex 3A.1, Chapter 3, Volume 5, 'Waste'*.

There are three tier approaches; for more detail see Section 3.2.1, *Chapter 3, Volume 5, 'Waste'*. The same method of estimating GHG emissions is used for all the tiers, the only difference relates to the possibility of using country-specific activity data, emission factors, and parameters.

A step-by-step calculation, including several formulas with different activity data and parameters, is proposed to estimate CH_4 emissions from SWDS. Estimation of annual CH_4 emissions from individual subcategories builds on carrying out and summing up calculations based on the disposal of various groups of mixed waste / waste types at the SWDS of selected type.

The methodology provides two options for the estimation of the emissions from MSW depending on the available activity data. The first option is based on waste composition data then the amounts of each type of degradable waste material (food, paper, wood, etc.) in MSW are calculated separately. The second option is based on MSW as bulk waste.

Calculations are made not only for all the years included in the GHG emissions reporting, but also for those previous years, which made a significant contribution to these emissions due to the slow waste decay at SWDS (GHG emissions estimation period). Simple FOD Spreadsheet Model (tables in the Excel format) was developed to help countries in using the FOD method to estimate methane emissions from SWDS. For more detail about the Model and its possibilities see Section 3.2.1.1, *Chapter 3, Volume 5, 'Waste'*; the Model per se can be downloaded from the IPCC website *(https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/IPCC_Waste_Model.xls)*. A compact table approach to emission estimation can be used for independent calculations by making a simple calculation table; for more detail see *Section 3A1.4, Annex 3A1 to Chapter 3, Volume 5, 'Waste'*.

Where measurement-derived country-specific data on methane generation at SWDS are available, see Section 3.3, *Chapter 3, Volume 5, 'Waste',* for a detailed description of how to use them for GHG emission reporting purposes.

- Activity data

The amount of waste disposed into SWDS (W) is the amount of wet waste by degradable solid waste types (subject to waste component data availability) disposed of in SWDS in a certain year. Data on SWDS disposal in a country for the recent several decades or more (see the IPCC recommended half-life time default, Section 3.2.3, *Chapter 3, Volume 5, 'Waste'*) and waste composition should be used. It is good practice to estimate the amount of such waste by SWDS types. IPCC-recommended key types of waste are specified in Section 2.2, *Chapter 2, Volume 5, 'Waste';* waste composition (including MSW and industrial waste, which is critical for GHG emission estimation) is provided in Section 2.3, *Chapter 2, Volume 5, 'Waste'.* For a detailed description of activity data approaches and for default values to estimate MSW and other waste disposal see *Chapter 2, Volume 5, 'Waste', and* Section 3.2.2, *Chapter 3, Volume 5, 'Waste'*. Importantly, only bulk waste / waste types that may contain carbon of biogenic origin (DOC) should be included in the GHG emission estimation (certain components of bulk waste may not contain DOC). Waste components not included in this category are specified in Section 2.2, *Chapter 2, Volume 5, 'Waste'*.

Where information on incineration (including accidental fires) of waste on SWDS is available, this waste should be excluded from the total degradable waste. The recommended approach to estimating these values is provided in Section 5.3.2, *Chapter 5, Volume 5, 'Waste'*.

- Estimation parameters

Degradable organic carbon (DOC) is the carbon of biogenic origin in waste that is accessible to biochemical decomposition of organic material under anaerobic conditions in SWDS. Section

2.3, *Chapter 2, and* Section 3.2.2, *Chapter 3, Volume 5, 'Waste',* describe approaches to selecting these data and provide DOC default values for individual MSW components, industrial waste by industry, clinical waste, and sewage sludge. If estimates are made for bulk waste (for example, MSW), the DOC can be calculated as a weighted average based on the composition of waste, DOC content in these components, and their fractions in the bulk waste. It should be noted, that the inert part of the waste (glass, plastics, metal, etc.) is important when estimating the total amount of DOC in deposited bulk waste.

Fraction of degradable organic carbon that decomposes (DOC_f) is an estimate of the fraction of carbon that will ultimately degrade in SWDS. Section 3.2.3, *Chapter 3, Volume 5, 'Waste',* provides a single recommended default value for DOC_f for all waste components.

CH_4 correction factor (MCF) is the completeness of the organic material decomposition in SWDS based on whether the process is aerobic or anaerobic. Section 3.2.3, *Chapter 3, Volume 5, 'Waste',* provides recommended values for MCF for 4 types of SWDS – 2 managed (varying by SWDS deposition technology) and 2 unmanaged (varying by the depth of waste deposits or water table). It should be noted, that a region's SWDS classification into managed or unmanaged sites may change over a number of years, as waste management practices change. If countries cannot categorize their SWDS, the default MCF for 'uncategorized SWDS' can be used. When making the calculations it is important to note that where SWDS are classified into managed and unmanaged sites with different MCF values, GHG emissions from these SWDS types should be estimated separately.

CH_4 fraction in the generated landfill gas (F) is the content of CH_4 in the landfill gas (biogas) formed in SWDS. Section 3.2.3, *Chapter 3, Volume 5, 'Waste',* provides the default value for F, that is recommended for the estimation of emissions from all SWDS types and waste components. It should be noted that where country-specific values for F are used, the CH_4 fraction measured in the biogas emitted from the SWDS may be substantially different from the CH_4 fraction in the biogas within the SWDS.

Oxidation factor (OX) is the share of methane generated at the SWDS, which is consumed by methanotrophic micro-organisms in cover soils or other waste cover material. Section 3.2.3, *Chapter 3, Volume 5, 'Waste',* recommends that this process be ignored (i.e. the OX value for all SWDS is zero), yet a recommended OX value is provided for the specific type of managed SWDS covered with soil or compost.

Reaction rate constant (k) determines the rate of decay of organic material in waste to half of its initial mass. There are two alternative approaches to select the *k* value for the calculations:

- calculate (select from the recommended values) a weighted average for *k* for mixed waste (for example, MSW), preferably taking account of the change in waste components by years. This approach is also used where sufficient data on the waste components are not available;
- divide the waste stream into categories of waste according to their degradation speed.

The selected *k* value determines the half-life which, in its turn, determines the number of years to be used for calculating GHG emissions from waste deposition.

Section 3.2.3, *Chapter 3, Volume 5, 'Waste',* provides recommended values for k and corresponding half-lives for a variety of waste components (including MSW as a whole) based on the temperature and moisture conditions in different regions.

Methane recovery (R) is the amount of CH_4 recovered at the SWDS as a fraction of biogas combusted in a flare or energy/heat device. Where data on biogas collection are not available, it is recommended that this process be ignored (CH_4 recovery assumed to be zero). If these data are available, they should be split for methane recovery for energy and heat and for flaring. In either case, it should be noted that methane, not biogas, recovery is to be accounted for in emissions estimations.

- Cross-cutting issues

Emissions from animal and poultry manure deposition are reported in the Agricultural Sector (*Section 10.4, Chapter 10, Volume 4, 'Agriculture, Forestry, and Other Land Use'*). CH_4 emissions from SWDS with heat and energy recovery should be reported for the Energy Sector **(**Volume 2, 'Energy'**)**. Emissions from open burning of waste at SWDS are reported in the '5.C. Incineration and Open Burning of Waste' category under the Waste Sector; the amount of burned waste should be subtracted from the total waste disposal. In order to avoid double counting, it is important to check with emissions from sewage sludge, and if these are reported under the '5.D Wastewater Treatment and Discharge' category, the amount of sludge should be subtracted from the total waste deposited on SWDS.

- Quality control procedures; uncertainties

The most effective way of activity data quality control is by using the 'waste stream analysis' method described in Section 2.2, *Chapter 2, Volume 5, 'Waste'*. Standard quality control procedures should be implemented as recommended in *Chapter 6, Volume 1, 'General Guidance and Reporting'*, 2006 IPCC Guidelines.

Recommended uncertainties for activity data, emission factors and parameters are provided in Section 3.7, *Chapter 3, Volume 5, 'Waste'*. Standard uncertainty evaluation procedures are provided in *Chapter 3, Volume 1, 'General Guidance and Reporting'*.

The data used for population, per capita waste generation and waste composition should be consistent with the data reported for categories *5.B 'Biological Treatment of Solid Waste'; 5.C 'Incineration and Open Burning of Waste'; 5.D 'Wastewater Treatment and Discharge'*.

- Filling out Reporting Tables

Four separate tables are typically used for different sub-categories. Categories 5.A.1.a and 5.A.1.b are automatically integrated into category 5.A.1 'Managed Waste Disposal Sites' in a separate table. Data from categories 5.A.1, 5.A.2, and 5.A.3 are automatically integrated in a separate table 'Category 5.A. Solid Waste Disposal'. When completing CH_4 emissions data, only information from the base year (typically, 1990) onward should be used, despite the fact that estimations have been made for 50 (approximately) years. In addition to GHG emissions, the reporting tables include 'annual waste deposition in SWDS', which includes the amount of waste of all types deposited in this SWDS type (wet weight basis).

CO_2 emissions from SWDS and methane combusting are considered biogenic and are not included in standard reporting. CH4 emissions include both emissions from SWDS (minus the amount of methane recovered) and from biogas burning (where this process is accounted for). The parameter 'Amount of CH4 flared' is the amount of methane combusted in a flare. The parameter 'Amount of CH4 for energy recovery' is the amount of methane combusted for energy and heat generation (or processed into fuel).

The data from Form 5.A 'Solid Waste Disposal' are summed up with the data from other same-level GHG emission sources and translated into Form 5 'Waste', the data in which are integrated across the sector.

- Recommendations for verification: problems related to calculations and common mistakes

When selecting the activity data, it is important to take account of waste density and water content and to use the factors and parameters recommended for wet/dry weight of waste. When using direct activity data from SWDS, it is important to remember that estimations may also include waste from closed SWDS. When using the recommended IPCC defaults, it is important to distinguish between the values given as fractions and percent. Formulas use fractions; therefore, the recommended values in percent need to be re-calculated. When using the recommended values for k, these should not be mixed with half-lives.

- Refinement: Yes.

5B BIOLOGICAL TREATMENT OF SOLID WASTE

This category includes CH_4 and N_2O emissions from biological decomposition of organic solid waste in aerobic (composting) and anaerobic (digestion at special facilities) conditions. A fraction of CH_4 obtained from biogas through biological treatment can be recovered and combusted in order to minimize methane emissions to the atmosphere. Good practice does not require the estimation of GHG emissions from biogas combusting, as CH4 and N2O emissions are very small and CO_2 emissions are of biogenic origin. However, if it is wished to do so, GHG emissions from methane use for energy or heat generation should be reported under the Energy Sector, and where methane combustion is without energy use, under relevant subcategories based on its origin.

The critical factor for referring wastes to a certain category is the biological treatment technology applied to the selected wastes. Based on the availability and level of detail of information on treated waste composition, this category may be broken down by the following subcategories:

- 5B1 Composting
  - 5B1a Composting of Municipal Solid Waste
  - 5B1b Composting of Other Waste
- 5B2 Anaerobic Digestion at Biogas Facilities
  - 5B2a Anaerobic Digestion of Municipal Solid Waste
  - 5B2b Anaerobic Digestion of Other Waste

In the course of further work on the inventory categories 5B1a and 5B1b can be integrated into 5B1 'Composting', and categories 5B2.a and 5B2b into 5B2 'Anaerobic digestion'. The type of waste treated is the factor that determines the category under which emissions should be reported. Where waste cannot be treated as MSW (if the composition of waste is unknown), and also where other types of waste are composted/digested, emissions should be reported under category 5B1b or 5B2b.

Estimations of GHG emissions take account of all types of solid organic waste, except manure, which is treated in the Agricultural Sector (*Volume 4 'Agriculture, Forestry, and Other Land Use')*, and sludge, which is treated directly at the water treatment facilities (reported under category 5.D 'Wastewater treatment and discharge' and treated in *Chapter 6, Volume 5, 'Waste'*). A fraction of methane in biogas that is generated by biological treatment of waste (mostly by anaerobic digestion) can be recovered and combusted in order to minimize methane emissions to the atmosphere.

For more detail about the categories description see Section 4.2.3, *Chapter 4, Volume 5, 'Waste'.*

- Methodological approaches to emission estimation

Methodological approaches to estimating GHG emissions for all these subcategories for the same gases are alike.

2006 IPCC Guidelines provide two different approaches to estimating emissions from solid waste composting and digestion: CH_4 and N_2O. Methodological approach to estimating CH_4 emissions builds on the amount of degradable organic carbon in processed waste and the effectiveness of CH_4 generation in aerobic and anaerobic conditions with an account of flaring of part of the methane. Methodological approach to estimating N_2O emissions builds on the evaluation of the amount of nitrogen in processed waste and the effectiveness of N_2O generation in composting/digestion processes. There are three-tier approaches for these two gases, which are described in detail in Section 4.1, *Chapter 4, Volume 5, 'Waste'*. The same method of estimating GHG emissions is used at all the tiers, the only difference relates to the possibility of using country-specific activity data, factors, and parameters applicable to specific facilities.

- Activity data

Amount of composted/digested waste (M) is the total amount of biologically degradable wet/dry waste treated by biological treatment in the inventory year. Data separation by waste types/material may be required for Tier 2 or 3 estimations. For more detail about the approaches to collecting activity data and for their recommended values see *Chapter 2, Volume 5, 'Waste', and* Section 4.1.2, *Chapter 4, Volume 5, 'Waste'*. Activity data can be obtained from national statistics, to be used in Tier 1 estimations, or from companies' reporting, to be used for Tier 1, 2, or 3 estimations. Wastes that are not reported under this category are specified in Section 2.2, *Chapter 2, Volume 5, 'Waste'*.

Amount of recovered methane (R) is the amount of CH_4 recovered from composting/digestion facilities as fraction of biogas combusted in a flare or energy and/or heat generation. Where information on biogas collection is not available, it is recommended that this process not be accounted for (CH_4 recovery assumed to be zero). Where it is wished to account for this process, data should be collected separately for methane recovery for flaring and for energy use. For anaerobic digestion, Section 4.1, *Chapter 4, Volume 5, 'Waste',* provides recommended values for R where additional information on CH_4 emissions from unintentional leakages or other unexpected events in the work of biogas plants is unavailable.

- Estimation parameters

Emission factors for methane ($EF(CH_4)$) are the ratio of CH_4 to the amount of composted/digested waste. Section 4.1.3, *Chapter 4, Volume 5, 'Waste',* provides recommended default $EF(CH_4)$ values for all waste types/material on a dry/wet weight basis.

Emission factors for nitrous oxide ($EF(N_2O)$) are the ratio of N_2O emissions and the amount of composted/digested waste. Section 4.1.3, *Chapter 4, Volume 5, 'Waste',* provides recommended default $EF(N_2O)$ values for all waste types/material on a dry/wet weight basis.

Where actual water content and DOC and N content in waste is substantially different from the values in recommended defaults, the emission factors should be verified.

- Cross-cutting issues

Emissions from manure composting and digestion are reported under the Agricultural Sector *(Volume 4, 'Agriculture, Forestry, and Other Land Use')*, yet where manure is treated together with other solid waste, GHG emissions can be reported under this sector; it is important that double counting be avoided in this case. Double counting should also be avoided by checking with emissions from wastewater sludge, and where they are reported together with wastewater for the '5.D Wastewater treatment and discharge' category, it is important that their amount be subtracted from the total composted or digested waste. Emissions from CH_4 combustion should be reported for the Energy Sector (*Volume 2, 'Energy'*), if methane is recovered for energy or heat use; otherwise they should be reported in this category (Waste).

- Quality control procedures; uncertainties

The most effective way of activity data quality control is by using the 'waste stream analysis' method described in *Chapter 3, Volume 5, 'Waste'*. Standard quality control procedures should be implemented as recommended in *Chapter 6, Volume 1, '2006 IPCC Guidelines*.

The data used for population, per capita waste generation and waste composition should be consistent with the data reported for categories 5A 'Solid Waste Disposal'; 5B 'Biological Treatment of Solid Waste'; 5C 'Incineration and Open Burning of Waste'; 5D 'Wastewater Treatment and Discharge'.

Recommended uncertainties for activity data, emission factors and parameters are provided in Section 4.4, *Chapter 3, Volume 5, 'Waste'*. Standard uncertainty evaluation procedures are provided in *Chapter 3, Volume 1, 'General Guidance and Reporting'*.

- Filling out Reporting Tables

Four forms should be completed for different subcategories (2 for composting and 2 for digestion). Data from categories 5B1a and 5B1b are automatically integrated into category 5B1 'Composting' in a separate form. In addition to GHG emissions, the reporting tables include 'amount of annually composted waste' on a wet weight basis. CH_4 emissions include emissions already taking into account CH_4 recovery and combustion (if applicable). The parameter 'Amount of CH_4 flared' is the amount of methane combusted in a flare. Forms 5B2.a and 5B2b should be completed in a similar way, with the integration of parameter 'Amount of CH_4 for energy recovery',

which is the amount of methane burned for energy and heat generation (or processed into fuel). These data are integrated into form 5B2 'Anaerobic Digestion at Biogas Facilities'.

Where waste cannot be treated as MSW, or where other types of waste are composted/digested, the data should be input in tables 5B1b or 5B2b.

The data from Form 5B1 'Composting' are automatically summed up with the data from Form 5B2 'Anaerobic Digestion at Biogas Facilities' and translated into Form 5B 'Biological Treatment of Solid Waste'.

The data from Form 5B 'Biological Treatment of Solid Waste' are automatically summed up with the data from other same-level GHG emission sources and translated into Form 5. 'Waste', the data in which are integrated across the sector.

- Recommendations for verification: problems related to calculations and common mistakes

When selecting the activity data, it is important to take account of waste density and water content and to use the factors and parameters recommended for wet/dry weight of waste.

- Refinement: No.

5.C INCINERATION AND OPEN BURNING OF WASTE

This category includes CH_4 and N_2O emissions from waste incineration in special facilities and from open burning without energy and/or heat recovery, and breaks down by the following subcategories:

- 5C1 Waste Incineration
- 5C2 Open Burning of Waste

The combustion technology applied determines to which subcategory the emissions should be assigned. If such data are not available, no breakdown by subcategories should be made.

VOCs, CO, NO_x, and SO_x emissions can also be produced by incineration, but they should be estimated using other methodologies; for more detail about relevant approaches see Section 5.1, *Chapter 5, Volume 5, 'Waste'*.

All GHG emissions from waste incineration with energy and heat recovery are reported in the Energy Sector (Volume 2, 'Energy').

Indirect N_2O emissions from nitrogen deposition to soils and NO_x emissions from waste incineration can be estimated as directed by *Chapter 7 'Precursors and Indirect Emissions', Volume 1, 'General Guidance and Reporting'*. For more detail see Section 5.4.3, *Chapter 5, Volume 5, 'Waste'*.

General information on the estimation of indirect N_2O emissions from the conversion of nitrogen deposited to soils and of NOx emissions from incineration and open burning is provided in Chapter 7, Volume 1, 'General Guidance and Reporting'.

Similar approaches to estimating the same set of GHG for these categories are used. However, approaches to selecting activity data and parameters for incineration and open burning somewhat differ, therefore these two categories are considered separately hereinafter.

5C1 Waste Incineration

This category includes CH_4 and N_2O emissions from the combustion of solid and liquid waste in controlled incineration facilities.

All emissions from waste incineration with energy or heat recovery are reported in the Energy Sector (Volume 2, 'Energy'). It includes both fossil and biogenic CO_2 emissions, albeit the latter should be reported only as an information item. Emissions from gas, oil, or other fuels used for waste incineration should not be reported in this category, but under the Energy Sector (Volume 2, 'Energy').

Based on the availability and detail of information on the activity data related to the composition of incinerated waste, this category may be broken down as follows:

- 5C11 Incineration of Biogenic Waste
  - 5C11a Incineration of Biogenic Municipal Solid Waste
  - 5C11b Incineration of Other Biogenic Waste
- 5C12 Incineration of Non-biogenic Waste
  - 5C12a Incineration of Non-biogenic Municipal Solid Waste
  - 5C12b Incineration of Other Non-biogenic Waste

In the course of further work on the inventory categories 5C11a and 5C11b are integrated in category 5C11 'Incineration of Biogenic Waste', and categories 5C12a and 5C12b into category 5C12 'Incineration of Non-biogenic Waste'.

The methodological approaches to estimating GHG emissions under these categories are alike. Emissions are assigned to subcategories mostly based on the waste types and whether the carbon is fossil or biogenic. Where waste cannot be treated as MSW, or where other waste types are burned, emissions should be assigned to categories 5C11b and/or 5C12b.

- Methodology for estimating GHG emissions from waste incineration

2006 IPCC Guidelines describe somewhat different approaches to estimating CO_2, CH_4 and N_2O emissions from waste incineration. The overall approach to estimating GHG emissions is based on the amount and composition of incinerated waste and on the combustion completeness.

The *good practice* is to differentiate between the waste types/material and to estimate emissions from each type of waste separately.

More detail about the incinerated waste composition is required to estimate CO_2 emissions; moreover, the methodology provides modifications of the formula to estimate emissions from the incineration of liquid waste and of MSW with known composition.

For all GHG, there are three-tier approaches. For more detail about the approaches see Section 5.2.1, *5.2.2, and 5.2.3, Chapter 5, Volume 5, 'Waste'*.

Methodologies for estimating CO_2 and CH_4 emissions are similar for all the tiers, the only difference relates to the possibility of using country-specific activity data and plant-specific emission factors and parameters, including from individual companies. Tier 1 and 2 methodologies for estimating N_2O emissions are alike, the only difference relates to the possibility of using country-specific activity data, emission factors and parameters. Tier 3 estimations use a special formula and require flue gas measurements by individual companies.

Annual GHG emissions from waste incineration should be estimated by summing up individual assessments based on the incineration of various waste types at one-level incineration plants.

- Activity data for the estimation of CH4 emissions

Amount of waste incinerated (IW) is the amount of incinerated wet waste by waste types/material (based on the waste composition data availability) in the inventory year. For a description of approaches to activity data collection see *Chapter 2, Volume 5, 'Waste'* and Section 5.3, *Chapter 5, Volume 5, 'Waste'*.

Fossil liquid waste is a special waste category (see *Chapter 2, Volume 5, 'Waste'*). If the amount of such waste is in terms of volume, this should be converted into mass using density.

Dry matter content (dm) is the amount of dry matter in the incinerated waste (wet weight). For mixed waste of identified composition (for example, MSW) incinerated together estimation of dry matter content is provided using data on component fractions (by waste types) and dry matter content in each component. Recommended values for dm by waste types/material (and by MSW components) are given in *Chapter 2, Volume 5, 'Waste'*.

- Estimation parameters for CH4 emissions

Total carbon content in incinerated waste (CF) is the fraction of carbon in incinerated wet waste by types/material. For mixed waste of identified composition (for example, MSW) incinerated together estimation of average weighted carbon content is provided using data on component fractions (by waste types) and carbon content in each component.

Fossil carbon fraction in total carbon (FCF) is the content of fossil carbon in total carbon in incinerated waste by types/material. Where relevant data are available, inventories should account

for incinerated waste composition by type and by element. If such data are not available, inventory compilers should use recommended values provided in Section 2.3, *Chapter 2, Volume 5, 'Waste'*.

The parameters of total carbon content in percent of dry weight and fossil carbon fraction could be combined to the parameter: fossil carbon content in percent of dry weight. Estimation of total carbon content in MSW and other mixed waste of identified composition is based on the estimation of its average weighted value.

This methodology requires, that estimation of biogenic CO_2 emissions in the Energy Sector be based on the fraction of biogenic carbon obtained from known data on the total carbon content and the fossil carbon content (or on direct data about the biogenic carbon content, see the DOC factor description in Section 3.2.3, *Chapter 3, Volume 5, 'Waste')*.

Oxidation factor (OF) shows the completeness of waste incineration, i.e. of carbon conversion into CO_2. Section 5.4.1.3, *Chapter 5, Volume 5, 'Waste'* provides a single recommended value for OF for all waste types (MSW, industrial waste, clinical waste, sewage sludge, and fossil liquid waste).

Conversion factor from C to CO_2 is the ratio of the molecular weight of carbon dioxide to that of carbon; the recommended value is provided in Section 5.2.1, *Chapter 5, Volume 5, 'Waste'*.

- Estimation parameters for N2O and CH4 emissions

Emission factors for nitrous oxide ($EF(N_2O)$) are the ratio of N_2O emissions to the amount of incinerated waste. N_2O emission factors relate the flue gas purification technology and vary by plants and composition of incinerated waste. If need be, N_2O emission factors can be obtained through measurements using the method described in the methodology. Section 5.4, *Chapter 5, Volume 5, 'Waste',* provides recommended values for $EF(N_2O)$ by MSW incineration technologies and single values for all incineration technologies for industrial waste, industrial residues, and sewage sludge.

Emission factors for methane ($EF(CH_4)$) are the ratio of CH_4 emissions to the amount of incinerated waste. Section 5.4, *Chapter 5, Volume 5, 'Waste',* provides the single recommended $EF(CH_4)$ value for all types of waste on the wet/dry weight basis.

- Cross-cutting issues

When estimating emissions from sludge combined with wastewater, all emissions from sludge should be considered and reported under category 5D 'Wastewater treatment and discharge' (*Chapter 6, Volume 5, 'Waste'*).

GHG emissions from waste incineration with energy and heat recovery are reported in the Energy Sector (*Volume 2, 'Energy'*).

Emissions from agricultural residue burning are treated in the Agricultural Sector, Section 2.4, Chapter 2, and Section 11.2, Chapter 11, Volume 4, 'Agriculture, Forestry, and Other Land Use'.

- Quality control; uncertainties

Double counting with the Energy Sector should be avoided where waste is used as a fuel.

Where activity data are used to estimate CO_2 emissions, the amount and composition of waste should be consistent with the activity data used for estimating N_2O emissions, except for liquid waste.

The most effective way of activity data quality control is by using the 'waste stream analysis' method described in *Chapter 2, Volume 5, 'Waste'*. The data used for waste composition should be consistent with the data reported for categories 5A 'Solid Waste Disposal'; 5B 'Biological Treatment of Solid Waste'; 5D 'Wastewater Treatment and Discharge'. Standard quality control procedures should be implemented as recommended in *Chapter 6, Volume 1, '2006 IPCC Guidelines.*

Recommended uncertainties for activity data, emission factors and parameters are provided in Section 5.7.1, *Chapter 5, Volume 5, 'Waste'*. Standard uncertainty evaluation procedures are provided in *Chapter 3, Volume 1, 2006 IPCC Guidelines.*

- Filling out Reporting Tables

Four separate tables are used for different sub-categories. The data from categories 5C11a and 5C11b are automatically integrated into category 5C11 'Incineration of Biogenic Waste' in a separate table. In addition to GHG emissions, the reporting tables include 'amount of annually incinerated waste' on a wet weight basis. Forms 5C12.a and 5C12b are completed in a similar way and integrated into category 5C12 'Incineration of Non-biogenic Waste'. Where waste cannot be treated as MSW, or where other types of waste are incinerated, emissions should be reported under category 5C11b and/or 5C12b. When completing relevant forms 5C11b and 5C12b 'Other waste', types of incinerated waste (or lack of relevant information) should be indicated.

The data from the category 5C11 'Incineration of Biogenic Waste' and 5C12 'Incineration of Non-biogenic Waste' are automatically summed up in the category 5.C.1 'Waste Incineration'.

The data from the category 5B 'Biological Treatment of Solid Waste' are automatically summed up with the data from other same-level GHG emission sources and translated into Form 5. 'Waste', the data in which are integrated across the sector.

The data from the category 5C1 are automatically summed up with the data from the category 5C2 and translated into Form 5C 'Incineration and Open Burning of Waste'. If GHG emissions are estimated without differentiation by incineration/open burning (including for liquid waste), the data should be input directly in the Form 5C 'Incineration and Open Burning of Waste'.

The data from Form 5C 'Incineration and Open Burning of Waste' are summed up with the data from other same-level GHG emission sources and translated into Form 5. 'Waste', the data in which are integrated across the sector.

- Recommendations for verification: problems related to calculations and common mistakes

When selecting the activity data, it is important to take account of waste density and water content and to use the factors and parameters recommended for wet/dry weight of waste. When using the recommended IPCC defaults, it is important to distinguish between the values given as fractions and percent. The formulas use fractions; therefore, the recommended values given in percent need to be re-calculated.

Importantly, despite special fields in the reporting tables, CO_2 emissions from biogenic waste are not reported under the Waste Sector, not even as an information item.

The methodology described in *2006 IPCC Guidelines* does not require the differentiation of CH_4 and N_2O emissions by biogenic and non-biogenic waste, types of waste, or mixed waste (containing both fossil carbon and DOC, for example, MSW), whereas in the CRF tables these are assigned to different categories. Where incinerated waste cannot be differentiated by types with fossil carbon content and biogenic carbon content, and where CH_4 and N_2O emissions cannot be estimated separately for these waste types, a factor (which is the ratio of fossil to biogenic carbon content) can be used to verify total estimates of emissions from mixed waste, and then can be assigned to relevant categories. In any case, double counting of such emissions should be avoided.

- Refinement: Yes.

5C2 Open Burning of Waste

This category includes CH_4 and N_2O emissions from open-air burning (or using devices that do not control the combustion air and do not ensure complete combustion) and from accidental fires on SWDS. Based on the availability and detail of information of the activity data on the composition of burned waste this category can be broken down by a number of subcategories:

- 5C21 Open Burning of Biogenic Waste
  - 5C21a Open Burning of Biogenic Municipal Solid Waste
  - 5C21b Open Burning of Other Biogenic Waste
- 5C22 Open Burning of Non-Biogenic Waste
  - 5C22a Open Burning of Non-Biogenic Municipal Solid Waste
  - 5C22b Open Burning of Other Non-Biogenic Waste

For the reporting purposes categories 5C21a and 5C21b can be integrated into the category 5C21 'Open Burning of Biogenic Waste', and categories 5C22a and 5C22b into the category 5C22 'Open Burning of Non-Biogenic Waste'.

The methodological approaches to estimating GHG emissions under these categories are alike. Organic and/or non-organic carbon content in the burned waste is the factor determining to which subcategory the emissions are assigned. If the waste cannot be assigned to a certain type, or if waste types other than MSW are burned, the emissions should be assigned to categories 5C11b and/or 5C12b.

- GHG emission estimation methodology

2006 IPCC Guidelines describe a variety of approaches to estimating CO_2, CH_4 and N_2O emissions from open burning. The overall approach to estimating GHG emissions is based on the amount and composition of burned waste and on the combustion efficiency. The *good practice* is to differentiate between the waste types/material and to estimate emissions from each type of waste separately.

- Activity data

The amount of waste open-burned (WB) is the amount of wet waste of a certain type that was open-burned. Where waste statistics are not available, the amount of waste open-burned can be estimated using data from period surveys or research projects. It is recommended that total amount of MSW open-burned (MSW_B) be estimated using the fraction of population burning waste and per capita MSW waste generation based on the following data:

Population (P) is the number of people living in a country in the inventory year. The data can be obtained from the demographic statistics, national or international (for example, *FAOstat http://www.fao.org/*).

Fraction of population burning waste (Pfrac) is an estimate of the fraction of a country's population who regularly (i.e., for them it is the only practice used to eliminate waste) or sporadically burn their waste. It is recommended that research findings related to the use of the open burning of waste be used. Where such direct data are not available, the methodology suggests the Pfrac identification approach for developed and developing countries.

Per capita MSW generation (MSW_P) is the amount of wet MSW generated by one person. If national waste generation statistics provide data per day, these should be recalculated for a year (365 days).

Fraction of the waste amount that is open burned (Bfrac) is the estimated fraction of the total waste amount that is actually burned. Where there is no evidence that the population use open

burning regularly or that all of the waste is burned, Bfrac should be estimated using the data available or expert judgment. There are no IPCC recommended values.

- Cross-cutting issues

When estimating emissions from sludge combined with wastewater, all emissions from sludge should be considered and reported under category 5.D 'Wastewater treatment and discharge' (*Chapter 6, Volume 5, 'Waste'*).

GHG emissions from waste incineration with energy and heat recovery are reported in the Energy Sector (*Volume 2, 'Energy'*).

Emissions from agricultural residue burning are considered in the Agricultural Sector, Section 2.4, *Chapter 2, and* Section 11.2, *Chapter 11, Volume 4, 'Agriculture, Forestry, and Other Land Use'.*

- Quality control procedures; uncertainties

Where activity data are used to estimate CO_2 emissions, the amount and composition of waste should be consistent with the activity data used for estimating N_2O emissions, except for liquid waste.

The most effective way of activity data quality control is by using the 'waste stream analysis' method described in *Chapter 2, Volume 5, 'Waste'*. Standard quality control procedures should be implemented as recommended in *Chapter 6, Volume 1, '2006 IPCC Guidelines*.

Recommended uncertainties for activity data, emission factors and parameters are provided in Section 5.7.1, *Chapter 5, Volume 5, 'Waste'*. Standard uncertainty evaluation procedures are provided in *Chapter 3, Volume 1, 'General Guidance and Reporting'.*

The data used for population, per capita waste generation and waste composition should be consistent with the data reported for categories 5A 'Solid Waste Disposal'; 5B 'Biological Treatment of Solid Waste'; 5D 'Wastewater Treatment and Discharge'.

- Filling out Reporting Tables

Four separate tables are used for different sub-categories. The data from categories 5C21a and 5C21b are automatically integrated into category 5C21 'Open Burning of Biogenic Waste' in a separate table. In addition to GHG emissions, the reporting tables include the 'amount of annually incinerated waste' on a wet weight basis. Forms 5C22a and 5C22b are completed in a similar way and integrated into category 5C22 'Open Burning of Non-biogenic Waste'. Where waste cannot be treated as MSW, or where other types of waste are incinerated, emissions should be reported under category 5C21b and/or 5C22b 'Other waste'. When completing forms 5C11b and 5C12b, types of incinerated waste (or lack of relevant information) should be indicated.

The data from Forms 5C21 ‘Open Burning of Biogenic Waste’ and 5C22 ‘Open Burning of Non-Biogenic Waste’ are automatically summed up in Form 5C2 ‘Waste Incineration’.

The data from Form 5C1 are automatically summed up with the data from Form 5C2 and translated into Form C ‘Incineration and Open Burning of Waste’. Where no distinction can be made between GHG emissions from waste incineration and open burning (including liquid waste), data should be completed directly into Form 5C ‘Incineration and Open Burning of Waste’.

The data from Form 5C ‘Incineration and Open Burning of Waste’ are summed up with the data from other same-level GHG emission sources and translated into Form 5 ‘Waste’, the data in which are integrated across the sector.

- Recommendations for verification: problems related to calculations and common mistakes

When selecting the activity data, it is important to take account of waste density and water content and to use the factors and parameters recommended for wet/dry weight of waste. When using the recommended IPCC defaults, it is important to distinguish between the values given as fractions and percent. The formulas use fractions; therefore, the recommended values given in percent need to be re-calculated.

Importantly, despite special fields in the reporting tables, CO_2 emissions from biogenic waste are not reported under the Waste Sector, not even as an information item.

The methodology described in *2006 IPCC Guidelines* does not require the differentiation of CH_4 and N_2O emissions by biogenic and non-biogenic waste, types of waste, or mixed waste (containing both fossil carbon and DOC, for example, MSW), whereas in the CRF tables these are assigned to different categories. Where combusted waste cannot be differentiated by types with fossil carbon content and biogenic carbon content, and where CH_4 and N_2O emissions cannot be estimated separately for these waste types, a factor (which is the ratio of fossil to biogenic carbon content) can be used to verify total estimates of emissions from mixed waste, and then these can be assigned to relevant categories. In any case, double counting of such emissions should be avoided.

- Refinement: Yes.

5D WASTEWATER TREATMENT AND DISCHARGE

This category includes CH_4 and N_2O emissions from biological treatment of wastewater at special treatment facilities or from their discharge into water bodies. Wastewater includes effluents from household people activities (domestic wastewater) and from industrial practices (industrial wastewater).

Based on the wastewater type this source can be broken down by the following subcategories:

- 5D1 Domestic Wastewater

- 5D2 Industrial Wastewater
- 5D3 Other Wastewater

Where no distinction is possible between domestic and industrial wastewater, it can be assigned to category 5D3.

Wastewater with degradable organic material, as well as its sludge components, can produce CH_4 if it degrades in anaerobic conditions. CH_4 generated at wastewater treatment facilities as a fraction of biogas can be recovered and combusted in a flare or energy device to reduce CH_4 total emission. N_2O emissions are associated with the degradation of nitrogen compounds, such as urea, nitrate and protein, in wastewater. Direct N_2O emissions can be produced at wastewater treatment facilities with biogenic elements removal, while indirect N_2O emissions are produced at water bodies, where effluent is discharged. CO_2 emissions from wastewater are not reported in the Waste Sector, for they are of biogenic origin.

Good practice does not require taking account of GHG emissions from the burning of recovered biogas, as the CH_4 and N_2O emissions are very small, and the CO_2 emissions are of biogenic origin. However, if it is wished to do so, GHG emissions from methane combustion with energy and heat recovery should be reported in the Energy Sector, and flaring without energy and heat recovery in the relevant subcategory 5D1 or 5D2, based on its origin. The estimation methodology is provided in *Chapter 4.2, Volume 2, 'Energy'*.

GHG emissions from sewage sediment removed from water treatment facilities should be treated in *categories 5.A-5.C* in the Waste Sector, based on the treatment or utilization technology (except when used as fertilizer on agricultural land), except when sludge and wastewater emissions are estimated together. In this latter case emissions from sludge should be reported under category 5D1 or 5D2, based on its origin.

N_2O emissions from the irrigation of agricultural land with wastewater or from the use of sludge as fertilizer are discussed in Section 11.2, *Chapter 11, Volume 4, 'Agriculture, Forestry, and Other Land Use'* (N_2O emissions from managed soils and CO_2 emissions from lime and urea application).

5D1 Domestic Wastewater

This category includes CH_4 and N_2O emissions from domestic wastewater treatment at water treatment facilities and/or from discharge into water bodies. Domestic wastewater includes household wastewater and industrial wastewater discharged into domestic sewer systems.

- Methodology for estimating GHG emissions from domestic wastewater

2006 IPCC Guidelines describe a variety of approaches to estimating CH_4 and N_2O emissions from wastewater treatment and discharge.

A number of formulas with a variety of activity data and parameters are provided for a step-by-step estimation of CH_4 emissions from domestic wastewater. Three-tier approaches are used to estimate CH_4 emissions based on data availability; for more detail about the tiers see Section 6.2.2.1, *Chapter 6, Volume 5, 'Waste'*. Tier 1 and 2 methods for estimating CH_4 emissions are alike, the only difference relates to the possibility of using country-specific activity data, emission factors and parameters. Tier 3 estimations use country-specific methods and field measurements at individual treatment systems/pathways.

CH_4 emissions from this category primarily depend on the amount of organically degradable carbon in wastewater and parameters of treatment systems and discharge pathways. Therefore, estimation of annual methane emissions builds on the estimation of average-weighted country-specific emission factors that are obtained by summing up the fractions of all country-specific domestic wastewater treatment/discharge systems and their relevant emission factors. A recommended list of such systems is provided in Table 6.3, Section 6.2.2.2, *Chapter 6, Volume 5, 'Waste'*.

It is good practice to distinguish between wastewater treatment/discharge pathways and take account of country-specific conditions. To determine the use of each type of treatment or discharge system it is recommended to refer to national statistics on water use and sewage and to water supply/wastewater associations or, where the data are not available, to international associations or organizations (for example, *WHO, www.who.int.)*. More data can be obtained from the national statistics on demography and the residential sector amenities; reports by utilities responsible for wastewater treatment; regional authorities responsible for water resource management; research projects; and international organizations.

The method for estimating N_2O emissions has only one tier of estimation, which includes step-by-step use of a variety of formulas. It also addresses indirect N_2O emissions from wastewater treatment effluent discharged into aquatic environments (taking no account of their preliminary denitrification). For countries that have predominantly centralized wastewater treatment plants with the use of denitrification technologies *2006 IPCC Guidelines* recommend that emissions be estimated for each such plant. For more detail about this methodology see *Block 6.1,* Section 6.3.1.3, *Chapter 6, Volume 5, 'Waste'*.

Industrial wastewater discharged into domestic sewer systems is also included in this category.

- Activity data to estimate CH4 emissions

Total organically degradable carbon in wastewater (TOW) is the total amount of organically degradable material in the wastewater in the inventory year. This parameter is a function of a country's population and the amount of organic wastewater they produce.

Population (P) is a country's population in the inventory year. Data can be obtained from the national demographic statistics or from international organizations (for example, *FAOstat* *http://www.fao.org/*).

Biochemical oxygen demand per 1 person (BOD) is the amount of organically degradable carbon in wastewater expressed in BOD5 produced by 1 person. Where the activity data are available per day, the value should be recalculated for a year (365 days). Where the activity data are available in other BOD values, they should be recalculated for BOD5. If need be, COD values may be used, but then the value for Bo should also be expressed in COD. If country-specific data are not available, recommended values for BOD5 for individual regions and countries are–provided in Section 6.2.2.3, *Chapter 6, Volume 5, 'Waste'*.

Correction factor for additional industrial BOD discharge into sewers (I) is the correction factor that takes account of the BOD from industries and establishments (for example, grocery stores) that is co-discharged with domestic wastewater. Where country-specific data are not available, recommended values for I are used (separately for collected and uncollected wastewater) as provided in Section 6.2.2.3, *Chapter 6, Volume 5, 'Waste'.*

Amount of CH_4 recovered (R) is the amount of methane collected as a fraction of biogas at wastewater treatment facilities (which are mostly metatanks) and combusted in a flare or used for energy and heat. Where information on CH_4 recovery is not available, it is not accounted for (the default is zero). Where information on CH_4 recovery is available, a distinction should be made between flaring and methane recovery for energy and heat generation. In all cases, recovered methane, not biogas, should be taken into account when estimating emissions.

Amount of organic component removed as sludge (S) is the amount of organic material (BOD) in sludge, which is removed to be disposed of at MSW sites, incinerated or composted, or for other purposes. CH_4 emissions from this sludge are not then reported for 5D 'Wastewater treatment and discharge'. Where information on sludge removal is not available and/or if recommended values for MCF are used, CH_4 emissions from sludge treatment at wastewater treatment facilities and from wastewater should be estimated together. In other words, the amount of sludge removed is taken equal to zero. No recommended values for BOD contents in the sludge are provided.

- Activity data for N2O emission estimation

Total annual amount of nitrogen in the wastewater effluent ($N_{EFFLUENT}$) is the amount of nitrogen in domestic wastewater in the inventory year. It is estimated based on a country's population and nitrogen from domestic and industrial wastewater discharged in the sewer systems.

Population (P) is a country's population in the inventory year; similar to the activity data needed to estimate CH_4 emissions from domestic wastewater.

Per capita protein generation (Protein) is per capita protein consumption in the inventory year (kg/person/yr). This information is available from national statistics on food consumption or from international organizations (for example, *FAOstat* http://www.fao.org).

Nitrogen removed with sludge (N_{SLUDGE}) is the amount of nitrogen removed with wastewater sludge in the inventory year. It is good practice not to account for nitrogen removal with sludge (it is taken equal to zero). However, if it is wished to do so, the amount of removed sludge and the nitrogen content therein may be used. If a country wants to report N_2O emissions from wastewater facilities, the amount of nitrogen removed should also be subtracted from $N_{EFFLUENT}$.

Fraction of nitrogen in protein (F_{NPR}) is the amount of nitrogen in protein.

Factor for non-consumed protein ($F_{NON-CON}$) is the factor that accounts for the amount of protein, which was not consumed by population and added to the wastewater.

Factor for industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$) is the factor that accounts for protein from industrial and commercial sources discharged into the sewer system.

Section 6.3.1.3, *Chapter 6, Volume 5, 'Waste'* provides recommended values for F_{NPR}, $F_{NON-COM}$ (separately for countries using and not using non-consumed protein discharge to wastewater pathways) and $F_{IND-COM}$.

- Estimation parameters for CH4 emissions

CH_4 emission factors for selected wastewater treatment/discharge systems ($EF(CH_4)$) are the ratio of methane emissions from each type of wastewater treatment/discharge systems and the amount of organically degradable waste discharged into the sewer. They are a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF) for each of them.

Maximum CH_4 producing capacity (Bo) is the maximum amount of CH_4 that can be produced from the organics in domestic wastewater; depends on the organics composition. Good practice is to use country-specific data for Bo for the most important wastewater treatment/discharge systems. If country-specific data are not available, Section 6.2.2.2, *Chapter 6, Volume 5, 'Waste',* provides a single recommended value for Bo. If need be, a COD-based value of Bo can be converted into a BOD5-based value by multiplying with the factor provided in the above section.

Methane correction factor (MCF) is a factor indicating the extent to which the CH_4 producing capacity (Bo) is realized in each type of wastewater treatment / discharge system, i.e. it is an indication of the degree to which the system is anaerobic. Section 6.2.2.2, *Chapter 6, Volume 5, 'Waste',* provides recommended values for MCF for certain types of wastewater treatment/discharge systems, including untreated and treated systems/pathways (including centralized/individual aerobic and anaerobic treatment plants based on the climate specifics). If these recommended values for MCF are used, emissions from wastewater and sludge should be estimated together, and the information about organic component removed as sludge (S) is not used.

Estimation of the total share of organics in each wastewater treatment system/pathway is based on the fraction of population using this wastewater treatment system/pathway. Two parameters are used to this end: the degree of urbanization and the degree to which wastewater treatment/discharge systems are used by each urbanization group. Since types of domestic wastewater treatment/discharge systems depend on the amount and degree of pollution of treated waste, as well as on the financial and technical capacities of communities, the degree to which these types of wastewater treatment/discharge systems are used in a country can be estimated using a variety of methods. Section 6.2.2.1 describes recommended effective practice of distinguishing between population groups based on the degree of urbanization and income levels that determine their use of various pathways for domestic wastewater treatment/discharge.

Degree of urbanization (U) is an estimate of the fraction of a country's population that use specific type of domestic wastewater treatment/discharge system and are separated out based on their degree of urbanization and income level.

Degree of utilization of treatment/discharge pathway or system for each income group fraction (T) is the share of rural/urban population with a specific level of income that use one type of treatment system of those selected for the estimation.

Country-specific data on the urbanization and the breakdown of population by levels of income can be obtained from the national statistics or from international organizations (for example, *WHO* www.who.int). Section 6.2.2.3, *Chapter 6, Volume 5, 'Waste'* provides recommended values for U and T for different regions and countries.

- Estimation parameters for N2O emissions

Emission factors for nitrous oxide ($EF(N_2O)$) are the ratio of N_2O emissions to the amount of nitrous compounds in wastewater treatment effluent that is discharged into the water bodies. Section 6.3.1.2, *Chapter 6, Volume 5, 'Waste',* provides recommended values for $EF(N_2O)$ and the recalculation factor for N_2O-N conversion to N_2O.

- Cross-cutting issues

If biogas from wastewater treatment facilities is recovered and combusted for energy or heat generation, relevant GHG emissions should be reported in the Energy Sector **(**Volume 2, 'Energy'**)**.

If information about the removal of organic sludge, that is disposed of at MSW sites, incinerated or composted, is taken into account, CH_4 emissions from this sludge are then reported under relevant categories 5A-5C in the Waste Sector. GHG emissions from this sludge used as fertilizer are reported in the Agricultural Sector **(**Section 11.2, Chapter 11, Volume *4, 'Agriculture, Forestry, and Other Land Use'*).

GHG emissions from industrial wastewater that is released into domestic sewer systems are included in this category.

- Quality control procedures; uncertainties

When estimating the activity data it should be noted, that while characterizing all wastewater according to the percentages flowing to different treatment systems and the percentage of untreated wastewater, the wastewater flows should sum up to 1 (or 100 % of all the wastewater generated in the region). Data on sludge (including sludge amount and the fraction of organics), if used for this estimation and to estimate emissions from categories 5A-5C, should be checked for consistency. It is important to avoid double counting of GHG emissions from industrial wastewater under 5D1 and 5D2 categories, where this wastewater is treated together.

One method to control the quality of the activity data is by making a carbon balance check in the wastewater inflow and outflow and in biogas (Section 6.2.2.6, *Chapter 6, Volume 5, 'Waste').*

Estimations should be based on either BOD5 or COD units.

The data used for population should be consistent with the data reported for category 5.A 'Solid Waste Disposal'.

- Filling out Reporting Tables

The data should be input into the form on emissions from domestic wastewater (5D1) and into the overall form (5D). In addition to direct CH_4 and N_2O emissions, 5D1 form includes 'total organics in wastewater' and 'the amount of sludge removed' in thousand tons BOD5, and 'nitrogen in effluent' in thousand tons.

CH_4 emissions include emissions from biogas combusting (if it was taken into account). The parameter 'Amount of CH4 flared' indicates the amount of methane recovered and combusted in a flare. The parameter 'Amount of CH4 for energy recovery' indicates the amount of methane recovered and combusted for energy and heat.

The data from form 5D1 are summed up with the data from forms 5D2 and 5D3 and translated into the overall form 5D 'Wastewater Treatment and Discharge'.

Activity data and parameters that were used to estimate N_2O emissions should be input in the overall form 5D. They include population (thousand people); protein generation (kg/person/yr); fraction of nitrogen in protein; factor for non-consumed protein; factor for industrial protein; and degree of utilization of modern, centralized wastewater treatment plants (with nitrogen compounds removal).

The data from form 5D are summed up with the data from other sources and translated into form 5.Waste, which is integrated across the sector. This form 5.Waste also provides values for indirect N_2O emissions.

- Recommendations for verification: problems related to calculations and common mistakes

It should be noted that when N_2O emissions are estimated using the formulas provided in this section, the results are obtained in kg and must be converted into thousand tons.

The reporting tables incorrectly present columns for N_2O emissions from domestic wastewater. All the activity data and parameters used to estimate N_2O emissions from domestic wastewater should be input in the overall form 5D, while only form 5.Waste, which is integrated across the section, has a column for indirect N_2O emissions.

The methodology does not clearly specify, how the amount of nitrogen (and of N_2O it produces) that is removed from agricultural land through fertigation should be taken into account, or how sludge used as fertilizer should be considered; yet in any case, double counting of N_2O emissions should be avoided.

- Refinement: Yes.

5D2 Industrial Wastewater

This category includes CH_4 emissions from industrial wastewater treated at on-site plants and/or discharged into bodies of water. Emissions from industrial wastewater discharged into domestic sewers are included in the domestic wastewater emissions (category 5D1).

While the methodology mentions that N_2O emissions can be produced by industrial wastewater effluent, it does not offer any estimation method, nor recommends that such estimation be made.

- Methodology for estimating GHG emissions from industrial wastewater

2006 IPCC Guidelines offer a variety of approaches to the estimation of CH_4 emissions from industrial wastewater treatment and discharge.

A number of formulas with a variety of activity data and parameters are provided for a step-by-step estimation of CH_4 emissions from industrial wastewater. Three-tier approaches are used to estimate CH_4 emissions based on data availability; for more detail about the tiers see Section 6.2.3.1, *Chapter 6, Volume 5, 'Waste'*.

Tier 1 and 2 methods for estimating CH_4 emissions are alike, the only difference relates to the possibility of using country-specific activity data, emission factors and parameters. Tier 3 estimations use country-specific methods and field measurements at individual treatment systems/pathways at industrial plants.

The CH_4 emissions estimation method for industrial wastewater is similar to that for domestic wastewater. CH_4 emissions from this category primarily depend on the amount of organically degradable carbon in wastewater and parameters of treatment systems and discharge pathways. Therefore, estimation of total methane emissions from industrial wastewater builds on carrying out and summing up calculations for each typical wastewater treatment/discharge system across each country-specific industrial sector. The estimation should only account for industrial wastewater sources with large methane producing potential.

A recommended list of industrial sectors is provided in Table 6.9, Section 6.2.3.3, and the list of such systems is provided in Table 6.8, Section 6.2.3.2, *Chapter 6, Volume 5, 'Waste'*.

The methodology does not include N_2O emissions from industrial sources, except for industrial wastewater that is co-discharged with domestic wastewater into the sewer system. The N_2O emissions from industrial sources are believed to be insignificant compared to emissions from domestic wastewater.

- Activity data to estimate CH4 emissions

Total organically degradable carbon in wastewater (TOW) is the total amount of organically degradable material in the industrial wastewater from each specified industry in the inventory year. This parameter is a function of industrial output, wastewater generation, and degradable organics concentration in the wastewater.

Total industrial product for industrial sector (P) is the total amount of products in a specified industrial sector in the inventory year. The data can be obtained from the national industrial statistics, industrial associations, individual plants or relevant international organizations.

Wastewater generation (W) is the estimated volume of wastewater collected per 1 unit of product in a specified industrial sector in the inventory year (tons). The data can be obtained from the national industrial statistics, industrial associations, individual plants or relevant international organizations.

Degradable organics concentration in wastewater (COD) is the concentration of organically degradable carbon in industrial wastewater expressed in Chemical Oxygen Demand (COD) and produced in a select industrial sector.

Amount of CH4 recovered (R) is the amount of methane collected as a fraction of biogas at wastewater treatment facilities (which are mostly metatanks) and combusted in a flare for energy and heat use. Where information on CH_4 recovery is not available, it is not accounted for (the

default is zero). Where information on CH_4 recovery is available, a distinction should be made between methane flaring and recovery for energy and heat generation. In all cases, recovered methane, not biogas, should be taken into account when estimating emissions.

Amount of organic component removed as sludge (S) is the amount of organic material (BOD) in sludge, which is removed to be disposed of at MSW sites, incinerated or composted, or for other purposes. CH_4 emissions from this sludge are not then reported for 'Wastewater treatment and discharge'. Where information on sludge removal is not available and/or if recommended values for MCF are used to estimate emission factors, CH_4 emissions from sludge treatment at wastewater treatment facilities and from wastewater should be estimated together. In other words, the amount of sludge removed is taken equal to zero. No recommended values for the amount of sludge or BOD contents therein are provided.

- Estimation parameters for CH4 emissions

CH_4 emission factors for selected industrial wastewater treatment/discharge systems ($EF(CH_4)$) are the ratio of methane emissions from each type of industrial wastewater treatment/discharge systems to the amount of organically degradable waste discharged into the sewer. They are a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF) for each of them.

Maximum CH_4 producing capacity (Bo) is the maximum amount of CH_4 that can be produced from the organics in wastewater from the specified industry. Good practice is to use country-specific data for Bo for the most important wastewater treatment/discharge systems. If country-specific data are not available, Section 6.2.3.2, *Chapter 6, Volume 5, 'Waste',* provides a single recommended value for Bo for all industries.

Methane correction factor (MCF) is a factor indicating the extent to which the CH_4 producing capacity (Bo) is realized in each type of wastewater treatment / discharge system, i.e. it is an indication of the degree to which the system is anaerobic. Section 6.2.3.2, *Chapter 6, Volume 5, 'Waste',* provides recommended values for MCF for certain types of industrial wastewater treatment / discharge systems, including untreated and treated systems/pathways (including aerobic and anaerobic treatment plants). If these recommended values for MCF are used, emissions from wastewater and sludge should be estimated together, and the information about organic component removed as sludge (S) is not used.

- Cross-cutting issues

If biogas from wastewater treatment facilities is recovered and flared for energy or heat generation, GHG emissions should be reported in the Energy Sector **(**Volume 2, 'Energy'**).**

If information about the removal of organic sludge that is disposed of at MSW sites, incinerated or composted is taken into account, CH_4 emissions from this sludge are then treated and reported under relevant categories 5A-5C in the Waste Sector. GHG emissions from this sludge used as fertilizer are reported in the Agricultural Sector **(**Section 11.2, Chapter 11, Volume *4, 'Agriculture, Forestry, and Other Land Use'***).**

If industrial wastewater is released into domestic sewer systems, the emissions are to be included with the domestic wastewater emissions.

- Quality control procedures; uncertainties

Data on sludge (including sludge amount and the fraction of organics), if used for this estimation and to estimate emissions from categories 5A-5C, should be checked for consistency. It is important to avoid double counting of GHG emissions from industrial wastewater under 5D1 and 5D2 categories, where this wastewater is treated together.

Estimations should be based on either BOD5 or COD units.

- Filling out Reporting Tables

The data on GHG emissions from industrial wastewater should be input into form 5.D.2 'Industrial Wastewater'. In addition to GHG emissions, form 5.D.2 includes 'total organics in wastewater' and 'the amount of sludge removed' in thousand tons COD. CH_4 emissions include flaring (if it was taken into account). The parameter 'Amount of CH_4 flared' indicates the amount of methane recovered and combusted in a flare. The parameter 'Amount of CH_4 for energy recovery' indicates the amount of methane recovered for energy and heat. The data from form 5.D.2 are summed up with the data from forms 5D1 and 5D3 and translated into the overall form 5D 'Wastewater Treatment and Discharge'.

The data from form 5D are summed up with the data from other sources and translated into the overall form 5.'Waste', which is integrated across the sector.

- Recommendations for verification: problems related to calculations and common mistakes

It should be noted that the above methodology (where no additional data are used) implied that CH4 emissions from on-site industrial wastewater treatment and with release into domestic sewer systems (if such collection and treatment pathway is available) be counted together.

- Refinement: Yes.

5F CARBON STORAGE WITH WASTE DISPOSAL (ADDITIONAL INFORMATION)

This category breaks down by the following subcategories:

- 5F1 Long-term Storage of C in Waste Disposal Sites
- 5F2 Annual Change in Total Long-term C Storage

- 5F3 Annual Change in Total Long-term C Storage in HWP Waste.

The FOD model described in Section 3.2.1.1, *Chapter 3, Volume 5, 'Waste',* provides these estimates as a by-product. Long-term Storage of C in Waste Disposal Sites (category 5F1) and Annual Change in Total Long-term C Storage (category 5F2) are fixed as information units only in the Waste Sector. Annual Change in Total Long-term C Storage in HWP Waste is also reported in the Forestry Sector (Chapter 12 'Harvested Wood Products', Volume *4, 'Agriculture, Forestry, and Other Land Use'*).

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REPORTING UNDER PARIS AGREEMENT

GENERAL PRINCIPLES FOR PROVIDING INFORMATION

The issues of providing information on emissions and removals of greenhouse gases (GHG) are governed by Article 13 of the Paris Agreement (PA), which sets **Enhanced Transparency Framework for action and support**[23] with built-in flexibility which takes into account Parties' different capacities and builds upon collective experience (Paris Agreement, 2015).

Figure 4 illustrates the role and place of the **Enhanced Transparency Framework** in the overall implementation of the Paris Agreement.

[23] Enhanced Transparency Framework.

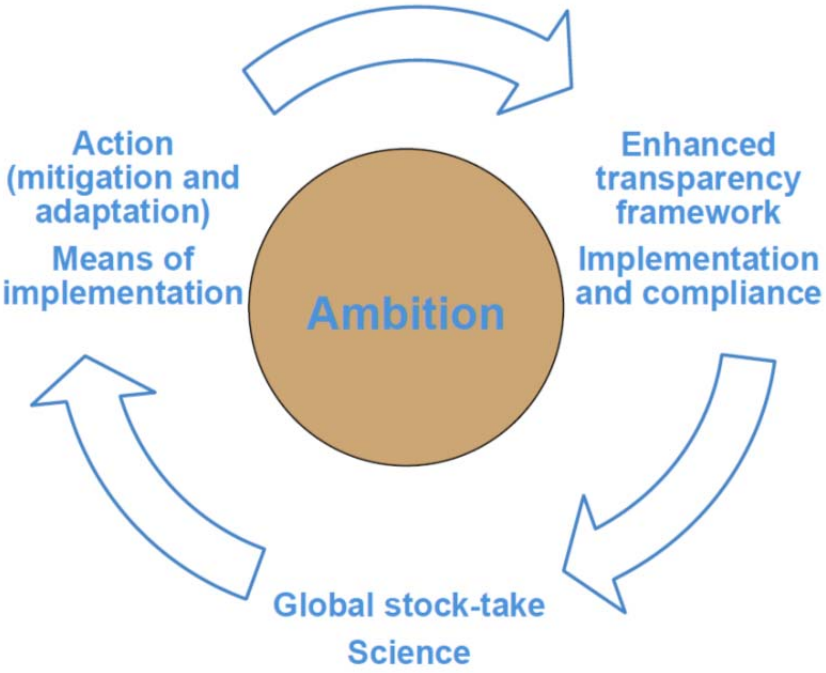

Figure 4. Enhanced Transparency Framework for action and support as a driving force for the implementation of the Paris Agreement (*Source: UNFCCC Secretariat*)

Article 13 of the PA stipulates a number of key principles for how the information on anthropogenic emissions and removals should be submitted and reviewed.

- The transparency framework shall build on and enhance the transparency arrangements under the Convention… and shall be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and avoid placing undue burden on Parties;
- The purpose of the framework for transparency… is to provide a clear understanding of climate change action in the light of the objective of the Convention... including clarity and tracking of progress towards achieving **Parties' individual nationally determined contributions (INDC)**[24];
- Each Party to the PA shall regularly provide the following information:
    - A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the IPCC and agreed upon by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;
    - Information necessary to track progress towards the implementation and achievement of its nationally determined contribution;

[24] Article 4, Paragraph 2 of the Paris Agreement stipulates, that "each Party shall prepare, communicate and maintain successive nationally determined contributions that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions".

- Information submitted by each Party shall undergo **a technical expert review**. For those developing country Parties that need it in the light of their capacities, the review process shall include assistance in identifying capacity-building needs.
- The technical expert review:
    - shall include a review of the consistency of the information with the modalities, procedures and guidelines, taking into account the flexibility accorded to the Party;
    - shall identify areas of improvement for the Party;
    - shall pay particular attention to the respective national capabilities and circumstances of developing country Parties;
- In addition, each Party shall participate in **a facilitative, multilateral consideration of progress** with respect to its respective implementation and achievement of its INDC;
- Support shall be provided to developing countries for the implementation of Article 13 of the PA;
- Support shall also be provided for the building of transparency-related capacity of developing country Parties on a continuous basis.

The first session of the Conference of the Parties to the Paris Agreement held in Catowice (Poland) in 2018 adopted the **modalities, procedures, and guidelines** for the transparency framework for action and support.[25]

MPG includes the following key provisions:

- Building on and enhancing the transparency arrangements under the Convention, recognizing the special circumstances of the least developed countries and small island developing states, and implementing the ETF in a facilitative, non-intrusive, and non-punitive manner, respecting national sovereignty and avoiding placing undue burden on Parties;
- Facilitating improved reporting and transparency over time;
- Providing **flexibility to those developing country Parties** that need it in the light of their capacities;
- Promoting transparency, accuracy, completeness, consistency and comparability;
- Avoiding duplication of work and undue burden on Parties and the secretariat;
- Ensuring that double counting is avoided;
- Ensuring environmental integrity.

[25] The following abbreviations will be used hereinafter for the readers' convenience: ETF for enhanced transparency framework for action and support, and MPG for modalities, procedures, and guidelines.

- In addition to the information on emissions and removals of greenhouse gases, ETF and MPG set out rules for providing by the Parties to the PA of the following:[26]
- information necessary to track progress in implementing and achieving the NDC;
- information on climate change impacts and adaptation under Article 7 of the PA;
- information on financial, technology transfer and capacity-building support provided, needed, and received by the Parties under Articles 9–11 of the PA.

In compliance with the MPG requirements, each Party to the PA should implement and maintain national inventory arrangements, including institutional, legal and procedural arrangements for the continued estimation, compilation and timely submission of national inventory reports. National inventory arrangements can vary by Party depending on their national circumstances and preferences, and change over time.

Each Party shall report on the following functions related to inventory planning, preparation and management:

- Its national entity or national focal point with overall responsibility for the national inventory;
- Its inventory preparation process, including division of specific responsibilities of institutions participating in the inventory preparation to ensure that sufficient activity data collection, choice and development of methods, emission factors and other parameters are in accordance with the IPCC Guidelines and the MPG;
- Its archiving of all information for the reported time series, including all disaggregated emission factors and activity data, all documentation about generating and aggregating data, including quality assurance/quality control (QA/QC), review results and planned inventory improvements;
- Its processes for the official consideration and approval of the inventory.

The issue of flexibility provided by the MPG to those developing country Parties that need it in the light of their capacities, shall be treated by the reporting Party on its own. A developing country Party shall clearly indicate the provision to which flexibility is applied, concisely clarify capacity constraints, noting that some constraints may be relevant to more than one MPG provision, and provide self-determined estimated time frames for improvements in relation to those capacity constraints. When a developing country Party applies flexibility provided for in the MPG, the technical expert review teams shall not review the Party's determination to apply such flexibility or whether the Party possesses the capacity to implement that specific provision without flexibility.

[26] The issues of providing these data are not described in this Methodological guidance; the list is provided for reference only.

Facilitating improved reporting

Each Party should, to the extent possible, identify, regularly update and include as part of its biennial transparency report information on areas of improvement in relation to its reporting, including GHG emissions and removals. Such information includes:

- Areas of improvement identified by the Party and the technical expert review team in relation to the Party's implementation of Article 13 of the PA;
- How the Party is addressing or intends to address these areas of improvement, as appropriate;
- Identification of reporting-related capacity-building support needs and any progress made.

Those developing country Parties that need flexibility in the light of their capacities are encouraged to highlight the areas of improvement that are related to the flexibility provisions used.

Methodological issues

The methodologies for estimating emissions and removals in the Paris Agreement have not changed compared to the methodologies used for national inventories submitted under the UNFCCC commitments.[27]

Those developing countries that need flexibility in the light of their capacities have a right to:

- Identify key categories using a threshold no lower than 85 per cent in place of the 95 per cent threshold defined in the IPCC Guidelines, allowing a focus on improving fewer categories and prioritizing resources;
- Provide a qualitative, rather than a quantitative, discussion of uncertainty for key categories, using the IPCC Guidelines, where quantitative input data are not available to estimate the uncertainties;
- Apply higher thresholds to insignificant (not reported) GHG emissions in specific categories, if the likely level of emissions is below 0.1 per cent of the national total GHG emissions, excluding LULUCF, or 1,000 kt CO2eq, whichever is lower. The total national aggregate of estimated emissions for all gases from categories considered insignificant, in this case, shall remain below 0.2 per cent of the national total GHG emissions, excluding LULUCF;
- Elaborate a quality assurance/quality control (QA/QC) plan and provide information on general QC procedures in accordance with the IPCC Guidelines on a voluntary, rather than mandatory, basis.

[27] These methodologies are discussed in the 'General principles for emissions estimation' section of this Methodology guidance.

Metrics (to report emissions expressed in CO2eq)

Each Party shall use the 100-year time-horizon global warming potential values from the IPCC Fifth Assessment Report, or from a subsequent IPCC assessment report, to report aggregate emissions and removals of GHGs, expressed in carbon dioxide equivalent.[28] [29] [30] Each Party may also use other metrics (e.g. global temperature potential) to report supplemental information on aggregate emissions and removals of GHGs, expressed in CO2eq. In such cases, the Party shall provide in the national inventory document information on the values of the metrics used and the IPCC assessment report they were sourced from.

Reporting format and the contents of inventory report

Each Party shall provide a national inventory report of anthropogenic emissions by sources and removals by sinks of GHGs, in accordance with its biennial transparency report. The national inventory report may be submitted as a component of a biennial transparency report or as a stand-alone document.

The national inventory report consists of a national inventory document and the common reporting tables.[31]

Each Party that submits a stand-alone national inventory report shall provide a summary of its GHG emissions and removals as part of its biennial report. The summary shall be provided for the reporting years that correspond to the Party's most recent national inventory report, in a tabular format.

Each Party shall transmit its biennial transparency report (and national inventory report, if submitted as a stand-alone document), via an online portal maintained by the UNFCCC secretariat. The secretariat shall post the reports on the UNFCCC website.

The reports shall be submitted in one of the six official languages of the United Nations.

Each Party shall report seven gases (carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3)). Those developing country Parties that need flexibility in the light of their capacities with respect to this provision may instead report at least three gases (CO2, CH4 and

[28] The use of global warming potential values from subsequent (after the Fifth AR) IPCC assessment reports is only possible after these reports are approved by the decision of the Conference of the Parties to the PA.
[29] At the time of preparing this Methodology guidance the Fifth Assessment Report was the latest IPCC report.
[30] Prior to the transition to reporting under the Paris Agreement, global warming potential values, as provided in the IPCC Fourth Assessment Report, will be used to report aggregate emissions.
[31] At the time of preparing this Methodology guidance the format of common reporting tables was not finalized yet; it is expected that it will be largely similar to the common reporting format tables that are being currently used by Annex I Parties to the UNFCCC in their national inventory reports of emissions and removals of GHG.

N2O) as well as any of the additional four gases (HFCs, PFCs, SF6 and NF3) that are included in the Party's NDC, are covered by an activity under Article 6 of the PA, or have been previously reported.

Each Party shall report a consistent annual time series starting from 1990; those developing country Parties that need flexibility in the light of their capacities with respect to this provision may instead report data covering, at a minimum, the reference year/period for its NDC and, in addition, a consistent annual time series from at least 2020 onwards.

Other requirements for the contents of national inventory reports are similar to those for national inventories currently submitted by the Annex I Parties to the UNFCCC.[32]

Technical expert review

In accordance with Article 13, paragraph 3, of the Paris Agreement, the technical expert review will be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and will avoid placing undue burden on Parties.

Technical expert review teams shall not:

- make political judgments;
- review the adequacy or appropriateness of a Party's NDC;
- review the adequacy of a Party's domestic actions;
- review the adequacy of a Party's support provided.

A technical expert review may be conducted as a centralized review, in-country review, desk review or simplified review.

Technical expert review reports shall be made publicly available on the UNFCCC website.

Facilitative, multilateral consideration of progress

Information to be considered in a facilitative, multilateral consideration of progress includes:

- information submitted by the Party in its reports;
- the Party's technical expert review report;
- any additional information provided by the Party for the purpose of the facilitative, multilateral consideration of progress.

A facilitative, multilateral consideration of progress shall include two phases. At the first phase, the Party concerned will respond to the questions received. The questions can be submitted by any other Party to the PA. Such questions shall be submitted through an online platform that opens three months prior to the working group session. The Party concerned shall make best efforts to respond to the questions no later than one month prior to the working group session through the

[32] These requirements are discussed in the "Basic Reporting Rules" of this Methodology guidance.

online platform. Those developing country Parties that need flexibility in the light of their capacities with respect to this provision may instead submit written responses up to two weeks prior to the working group session. The Party may indicate in its response if it considers the written question to be outside the scope of a facilitative, multilateral consideration of progress. The secretariat shall compile the questions and answers and publish them on the UNFCCC website prior to the working group session phase.

The second phase of the facilitative, multilateral consideration of progress – working group session phase – shall take place during sessions of the SBI[33] and consist of the following steps:

- a presentation by the Party;
- a discussion session:
    - All Parties may participate in the discussion session and raise questions to the Party concerned.
    - Working group sessions shall be open to registered observers and shall be made publicly accessible through an online live recording;
- a Party may provide additional written responses to questions raised during the discussion session through the online platform within 30 days following the session.

Within one month of the working group session, the secretariat shall prepare and publish on the UNFCCC website a record of the facilitative, multilateral consideration of progress for the Party concerned, which will include:

- questions submitted and responses provided;
- a copy of the Party's presentation;
- a recording of the working group session;
- a procedural summary of the Party's facilitative, multilateral consideration of progress;
- any additional information generated through the online platform, as available.

[33] SBI – Subsidiary body for implementation, UNFCCC.

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AUTHORS

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This Handbook builds on the most recent versions of the current regulations guiding the preparation of GHG emissions and removals inventories and on the UNFCCC's national reporting guidelines. The information is structured by sections, and references are provided to the original data sources to facilitate the analysis and mastery by professionals who wish to go into national GHG inventory reporting. The text is supplemented with additional materials describing the change expected in the coming years in relation to the implementation of the Paris Agreement and outlining new methodology approaches of the International Panel on Climate Change.

The Handbook is intended for experts from the Central Asian countries and other developing countries, which are non-Annex I parties under the UNFCCC.