2019 REFINEMENT TO THE 2006 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES

OVERVIEW

Final Draft for IPCC-49

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1 INTRODUCTION

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*) which were published in 2006 provide methodologies for estimating national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. This IPCC Methodology Report titled the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2019 Refinement*) was published in 2019 to refine the *2006 IPCC Guidelines* with the aim to provide an updated and sound scientific basis for supporting the preparation and continuous improvement of national greenhouse gas inventories.

In order to achieve this overall aim, the *2019 Refinement*:

- Provides supplementary methodologies for sources and sinks of greenhouse gases only where currently there are gaps or where new technologies and production processes have emerged requiring elaborated methodologies or for sources and sinks that were not well covered by the *2006 IPCC Guidelines*;
- Provides updated default values of emission factors and other parameters based on the latest available scientific information only where significant differences from the default values presented in the *2006 IPCC Guidelines* are identified;
- Provides additional or alternative up-to-date information and guidance, where possible, as clarification or elaboration of existing guidance in the *2006 IPCC Guidelines*.

The *2019 Refinement* does not revise the *2006 IPCC Guidelines*, but updates, supplements and/or elaborates the *2006 IPCC Guidelines* where gaps or out-of-date science have been identified. It does not replace the *2006 IPCC Guidelines*, but should be used in conjunction with the *2006 IPCC Guidelines* and, where indicated, with the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (*Wetlands Supplement*).

2 BACKGROUND

The Bureau of IPCC Task Force on National Greenhouse Gas Inventories (TFB), at its 26th meeting held in Ottawa, Canada in August 2014, concluded that:

- The *2006 IPCC Guidelines* provide a technically sound methodological basis of national greenhouse gas inventories, and therefore fundamental revision was unnecessary.
- To maintain the scientific validity of the *2006 IPCC Guidelines*, certain refinements might be required, taking into account scientific and other technical advances that had matured sufficiently since 2006.

Following these conclusions by the TFB and also in accordance with the approval by the IPCC at its 40th Session held in Berlin, Germany in April 2014, the Task Force on National Greenhouse Gas Inventories (TFI) started a technical assessment of IPCC inventory guidelines through an on-line questionnaire survey and four expert meetings in 2015 and 20161,2,3,4.

The technical assessment revealed that there had been new scientific and empirical knowledge related to sources and sinks of greenhouse gases as well as inventory management published since 2006 that the IPCC should take into account, particularly with respect to data for emission factor development for some categories and gases. Consequently, the TFB recognized the necessity and usefulness of refining the 2006 IPCC Guidelines, and concluded that the refinement should be made as early as possible so as to help all the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) use good practice inventory methodologies based on up-to-date scientific knowledge.

The IPCC, at its 43rd Session in Nairobi, Kenya in April 2016, approved the proposal made by the Co-Chairs of TFI on "Refinement of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, including production of a Methodology Report(s)"5. At the same session, the IPCC decided to consider the outline of the new Methodology Report(s) at the 44th Session of the IPCC in October 2016 and to consider the draft Methodology Report(s) at a Plenary session of the IPCC in May 20196. Following this decision, a scoping meeting for a Methodology Report(s) to refine the *2006 IPCC Guidelines* was held in Minsk, Belarus in August 2016. The outcome of the scoping meeting was approved by the TFB at its 28th meeting which was held immediately after the scoping meeting, and submitted to the IPCC for consideration. Finally the IPCC, at its 44th Session in Bangkok, Thailand in October 2016, decided to prepare the *2019 Refinement* and adopted its scope and outline[7].

[1] Expert Meeting for Technical Assessment of IPCC Inventory Guidelines (Energy, IPPU, Waste Sectors), 29 June - 1 July 2015, Geneva, Switzerland

[2] Expert Meeting for Technical Assessment of IPCC Inventory Guidelines (AFOLU Sector), 13-16 July 2015, São Paulo, Brazil

[3] Expert meeting for Technical Assessment of IPCC Inventory Guidelines: follow-up on specified issues from the 2015 expert meetings, 25-26 April 2016, Wollongong, Australia

[4] Expert meeting for Technical Assessment of IPCC Inventory Guidelines (Cross-sectoral issues), 27-29 April 2016, Wollongong, Australia

[5] Decision IPCC/XLIII-8 "Update of methodologies on National Greenhouse Gas Inventories"

[6] Decision IPCC/XLIII-7 "Sixth Assessment Report (AR6) Products. Strategic Planning"

[7] Decision IPCC/XLIV-5 "Sixth Assessment Report (AR6) Products, Outline of the Methodology Report(s) to refine the 2006 Guidelines for National Greenhouse Gas Inventories"

3 KEY CONCEPTS UNCHANGED FROM THE 2006 IPCC GUIDELINES

The following key concepts should be noted when using the *2019 Refinement*. These are consistent with the *2006 IPCC Guidelines*.

- Guidance is provided for greenhouse gas inventory arrangements and management, data gathering, compilation, and reporting. Reporting refers to the presentation of emission inventory estimates in tables or other formats used to communicate inventory information. The guidance is relevant but not prescriptive with respect to the reporting of national inventories under international agreements, and the use of reported information under these agreements.
- Reporting tables are provided in Volume 1 as part of general guidance for reporting. They are not intended to prescribe specific reporting formats under the UNFCCC that should be developed and agreed by the Parties to the UNFCCC.
- Methods are provided for estimating emissions (and removals as appropriate) for each gas in mass units. It does not recommend any specific metrics (e.g., GWP values) to calculate emission estimates in CO_2 equivalent units. Some guidance (e.g., key category analysis) suggests calculation of emission estimates in CO_2 equivalent, for which inventory compilers may use any metrics that are designed to convert greenhouse gas emissions into CO_2 equivalent.
- A *tier* represents a level of methodological complexity. Usually three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 the most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as *higher tier* methods and are generally considered to be more accurate on condition that adequate data are available to develop, evaluate and apply a higher tier method.
- This guidance assists countries in compiling complete, national inventories of greenhouse gases. The guidance has been structured so that any country, regardless of experience or resources, should be able to produce reliable estimates of their emissions and removals of these gases. It uses the overarching framework and the concepts consistent with the *2006 IPCC Guidelines*. National greenhouse gas inventories rely on a few key concepts for which there is a common understanding (see Chapter 1, Volume 1). This helps ensure that inventories are comparable between countries, do not contain double counting or omissions, and that the time series reflect actual changes in emissions.
- Some technical material is presented in appendices, where emissions or removals are poorly understood and where there is insufficient information available to develop reliable, globally applicable, default methods for a particular source or sink. Countries may use appendices as a basis for further methodological development, but a national inventory can be considered complete without the inclusion of estimates for these sources.

4 COVERAGE OF THE 2019 REFINEMENT

The *2019 Refinement* covers all IPCC inventory sectors but refinements are included for only those categories where the science was considered to have sufficiently advanced since 2006 or where new or additional guidance was required. The specific categories that have been refined through this process were selected through a technical assessment carried out in 2015 and 2016 and a subsequent scoping meeting held in August 2016 using the significance and prioritization criteria shown in Box 1[8].

BOX 1
SIGNIFICANCE AND PRIORITIZATION CRITERIA

- Significance of the source/sink and the gas within the sector on a global scale. Sources significant only for a limited number of particular countries, currently or in the foreseeable future, may not meet this criterion. The adequacy of the existing guidance for a particular category should be considered, as should the likelihood that new information would lead to a definite improvement in the IPCC Guidelines.
- Availability of relevant new scientific results.
- Sufficient data availability and maturity of scientific advances since 2006 to provide a basis for methodological development or refinement, including (1) ability to develop new or updated default emission/removal factors; and (2) feasibility of obtaining the necessary data to implement the methods.
- Emergence of new sources or gases meeting these criteria.

The outline of the *2019 Refinement* adopted by the IPCC was developed on the basis of the categories selected through the process mentioned above. However, the IPCC also agreed on the following principles when the outline was adopted.

- Authors should develop modifications even for those chapters/sections/subsections where "No refinement" is indicated in the approved table of contents, if deemed necessary to ensure consistency with the refinements made in the other chapters/sections/subsections.
- Authors may conclude no refinement should be made even for the chapters/sections/subsections where refinement is expected in this approved table of contents, after comprehensive review of available literature.

In addition to the greenhouse gases included in the *2006 IPCC Guidelines*, the *2019 Refinement* includes gases for which global warming potential (GWP) values are given in one of the subsequent IPCC Assessment Reports, unless the gases are covered by Annexes A through E of the Montreal Protocol. (Annex F of the Montreal Protocol lists hydrofluorocarbons, which are included in the 2019 Refinement.) The 2019 Refinement also provides estimation methods for halogenated greenhouse gases for which GWP values were not available from IPCC Assessment Reports at the time the 2019 Refinement was developed. (See Volume 1, Chapter 8 and Volume 3, Chapters 6, 7, and 8 for examples of both sets of gases.)

The 2006 IPCC Guidelines contain links to information on methods used under other agreements and conventions, for the estimation of emissions of tropospheric precursors which may be used to supplement the reporting of emissions and removals of greenhouse gases. The 2019 Refinement follows this approach, and does not provide methods for the estimation of emissions of tropospheric precursors (see Chapter 7, Volume 1).

The structure of the 2019 Refinement is the same as that of the *2006 IPCC Guidelines* so as to make it easier for inventory compilers to use the *2019 Refinement* with the *2006 IPCC Guidelines*. It comprises an Overview Chapter (this chapter) and the following five volumes.

- Volume 1: General Guidance and Reporting
- Volume 2: Energy

[8] There are potential issues for future revision or refinement that are not addressed in the *2019 Refinement*, including those identified during the Technical Assessment in 2015-2016 but considered too early to work on, as well as those identified after the approval of table of contents of the *2019 Refinement* by the IPCC at its 44th Session in Bangkok, Thailand in October 2016.

- Volume 3: Industrial Processes and Product Use (IPPU)
- Volume 4: Agriculture, Forestry and Other Land Use (AFOLU)
- Volume 5: Waste

Across all the volumes, some additional sections have been included. The guidance focuses on inventory methodologies rather than on scientific discussions of the background material, for which references are provided.

5 RELATIONSHIP WITH THE 2006 IPCC GUIDELINES

As stated in Section 1 above, the *2019 Refinement* does not revise the *2006 IPCC Guidelines*, but updates, supplements and/or elaborates the *2006 IPCC Guidelines* where gaps or out-of-date science have been identified. It does not replace the *2006 IPCC Guidelines*, but should be used in conjunction with the *2006 IPCC Guidelines* and, where indicated, with the *Wetlands Supplement*.[9]

In line with this principle, the *2019 Refinement* was developed by:

- updating existing guidance in the *2006 IPCC Guidelines* to address the needs explained in the first or second bullet in Section 1 (Introduction) of this chapter. When updating a section or an entire chapter, in some cases these sections or chapters have been entirely rewritten with new structure.
- elaborating existing guidance in the *2006 IPCC Guidelines* to address the needs explained in the first or third bullet of Section 1 (Introduction) of this chapter.
- adding completely new guidance on issues for which there is essentially no guidance in the *2006 IPCC Guidelines* to address the needs explained in the first bullet in Section 1 (Introduction) of this chapter.

With a view to helping inventory compilers understand the relationship between the *2019 Refinement* and the *2006 IPCC Guidelines*, each volume has an annex titled "Mapping tables" to relate the *2019 Refinement* to the *2006 IPCC Guidelines*. This annex in each volume provides a road map for relating sections, equations, tables, figures and boxes in the *2019 Refinement* to the *2006 IPCC Guidelines*. In these annexes, types of refinement (update, new guidance, no refinement or removed) are clarified for chapters/sections/subsections from inventory compilers' perspective in order to help them understand how they should use the *2019 Refinement*. The types of refinement used there are explained in Table 1 below.

TABLE 1
TYPES OF REFINEMENT FROM INVENTORY COMPLIERS' PERSPECTIVE

Type of refinement	Explanation
Update	Inventory compilers should use the chapter/section/subsection in the *2019 Refinement* instead of the corresponding chapter/section/subsection in the *2006 IPCC Guidelines*.
New Guidance	Recognizing that there is no guidance in the *2006 IPCC Guidelines*, inventory compilers should use the chapter/section/subsection in the *2019 Refinement.*
No Refinement	Inventory compliers should use the corresponding chapter/section/subsection in the *2006 IPCC Guidelines*, because no refinement has been made in that chapter/section/subsection.
Removed	There were few cases where guidance/sections were removed because they were no longer relevant.

Every chapter/section/subsection in the *2019 Refinement* which is explained as "Update" or "New Guidance" contains all necessary paragraphs, tables, figures, etc. including those unchanged from the *2006 IPCC Guidelines*, so that inventory compilers do not have to look back to the *2006 IPCC Guidelines*.

In addition, with a view to ensure consistency with the *2006 IPCC Guidelines* to the extent possible, efforts were made to keep the numbering of tables, figures, boxes, equations the same as in the *2006 IPCC Guidelines*. As a consequence, the numbering of new/updated tables, figures, boxes, equations in the *2019 Refinement* is not necessarily in sequence.

[9] The IPCC decided to produce the *2019 Refinement* as a separate Methodology Report which should be used in conjunction with the *2006 IPCC Guidelines*. Consolidating all methodological guidance into a single Methodology Report would require a new decision by the IPCC.

BOX 2
EXAMPLE OF MAPPING TABLE TO RELATE THE 2019 REFINEMENT TO THE 2006 IPCC GUIDELINES (VOL.4)

Section Title	Type of Refinement	2006 Guidelines Section Number	2019 Refinement Section Number
Introduction	NR	2.1	2.1
Inventory Framework	U	2.2	2.2
Overview of carbon stock change estimation	NR	2.2.1	2.2.1
Overview of non-CO2 emission estimation	NR	2.2.2	2.2.2
Conversion of C stock changes to CO_2 emissions	NR	2.2.3	2.2.3
Generic methods for CO_2 emissions and removals	NR	2.3	2.3
Change in biomass carbon stocks (above-ground biomass and below-ground biomass)	NR	2.3.1	2.3.1
Land remaining in a land-use category	NR	2.3.1.1	2.3.1.1
Land converted to a new land-use category	NR	2.3.1.2	2.3.1.2
Additional generic guidance for tier 2 methods	NG	-	2.3.1.3
Change in dead organic matter	NR	2.3.2	2.3.2
Land remaining in a land-use category	U	2.3.2.1	2.3.2.1
Land converted to a new land-use category	U	2.3.2.2	2.3.2.2
[illegible]	NR	2.3.3	2.3.3

U = Update, NG = New Guidance, NR = No Refinement

"*Good practice*" is a key concept for inventory compilers to follow in preparing national greenhouse gas inventories. The key concept does not change in the *2019 Refinement*. The term "*good practice*" has been defined, since 2000 when this concept was introduced[10], as "*a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that uncertainties are reduced so far as practicable*". This definition has gained general acceptance amongst countries as the basis for inventory development and its centrality has been retained for the *2019 Refinement*. Certain terms in the definition have been updated based on feedback from the statistics community, such that this definition can be also understood as "*a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that they are precise so far as practicable*" in the context of refinement of Chapter 3 of Volume 1[11].

These requirements are intended to ensure that estimates of anthropogenic emissions by sources and removals by sinks, even if uncertain, are *bona fide* estimates, in the sense of not containing any biases that could have been identified and eliminated, and that random errors have been reduced as far as practicable, given national circumstances. Estimates of this type are presumably the best attainable, given current scientific knowledge and available resources. The *2019 Refinement* also recognises the principles of transparency, accuracy, completeness, consistency and comparability defined in the *2006 IPCC Guidelines*.

[10] The definition was originally introduced with the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* published in 2000.

[11] In the *2006 IPCC Guidelines*, the term "uncertainty" was used with two meanings – a general one which is associated with both accuracy and precision, and a specific one only as the inverse of precision. This definition text of "*good practice*" which uses the term "precise" instead of "uncertainties" overcomes inconsistencies with general IPCC definition for uncertainty, without changing the original concept of "*good practice*".

6 SPECIFIC DEVELOPMENTS IN THE 2019 REFINEMENT

The *2019 Refinement* contains the following specific developments, among others, since the *2006 IPCC Guidelines*:

Volume 1 (*General Guidance and Reporting*)

- *National greenhouse gas inventory arrangements and management tools*: The *2019 Refinement* elaborates guidance on establishing greenhouse gas inventory arrangements to support the development, improvement and maintenance of national greenhouse gas inventories. This guidance is not designed to be prescriptive given that the shape and form of greenhouse gas inventory arrangements depend on national circumstances. Instead, the guidance provides approaches and examples of national greenhouse gas inventory arrangements that could be useful in establishing greenhouse gas inventory arrangements. In addition, institutional arrangements include the interactions between institutions/organisations that are involved with the greenhouse gas inventory inputs, compilation processes, and outputs. The *2019 Refinement* provides new guidance on generic inventory management tools such as workplans, improvement plans, data management systems, quality systems, training and capacity building and documentation procedures. As it is the case for the provided guidance on national greenhouse gas inventory arrangements, the management tools presented in this new guidance should not be considered prescriptive. However, they provide some suggested approaches and examples demonstrated to be useful when developing greenhouse gas inventory systems. (Chapter 1)

- *Data collection strategy*: General guidance for collecting existing national/international data and new data is elaborated. The material can be used both by countries establishing a data collection strategy for the first time and by countries with established data collection procedures. It is also to be applicable to emission factor, activity, and uncertainty data collection. (Chapter 2)

- *Use of facility-level data in inventories*: Detailed industrial facility-level data that are increasingly collected for various goals such as tracking the progress of emission trading programmes or climate change policies have the potential to be utilized in national greenhouse gas inventories. The challenge for inventory compilers is assessing how best to integrate facility reported data to achieve improvements, especially if there are some outstanding coverage and completeness issues. The *2019 Refinement* includes new guidance on how best to use facility-level data that are not originally designed for national greenhouse gas inventory compilation. A new decision tree for selecting facility-level data is provided as well as *good practice* reporting considerations associated with facility-level data used in the national greenhouse gas inventory. (Chapter 2)

- *Uncertainty analysis*: The *2019 Refinement* provides an update on uncertainties associated with activity data. It also incorporates guidance on how to derive uncertainty estimates from activity data generated based on random samples. This elaborated guidance has useful applications particularly in the AFOLU sector in dealing with uncertainty estimates from land use surveys or forest cover surveys. The updated guidance also includes key requirements for use of Approach 1 uncertainty assessment with examples. A practical step-by-step example demonstrating the use of Approach 2 uncertainty assessment (Monte-Carlo analysis) is also provided to guide inventory compilers. (Chapter 3)

- *Key category analysis*: No major modifications with respect to the *2006 IPCC Guidelines* have occurred but a simplification of the equation to perform *key category analysis* using trend assessment (Approach 1) has been implemented in the *2019 Refinement*. General principles and guidance have been updated and an updated trend approach is described. Priorities for maintenance and improvement of the inventory are addressed, and new guidance in determining the appropriate level of disaggregation of greenhouse gas estimates to identify key categories is provided. (Chapter 4)

- *Non-linear interpolation*: A new methodology for non-linear interpolation analysis has been added in the *2019 Refinement*, along with an example. This is relevant in cases where time series consistency is best represented by multiplicative (exponential) rather than additive (linear) relationships. (Chapter 5)

- *Comparison of greenhouse gas emission estimates with atmospheric measurements*: Guidance on comparison of greenhouse gas emission estimates with atmospheric measurement has been updated and elaborated to reflect the state of science for atmospheric measurements and their application to improving national greenhouse gas inventories. These approaches can be used to provide additional scientific verification of inputs and results for particular categories and gases, and therefore help countries to target areas of uncertainty. The most notable advances were achieved in the application of inverse models of atmospheric transport for emission estimates at the national scale. Thus, atmospheric measurements are being used to provide useful quality assurance of the national greenhouse gas emission estimates. The guidance highlights key components and steps that can be applied when using atmospheric measurements and inverse models for comparison with

inventory emission estimates as part of a country's overall QA/QC and verification system as described in Chapter 6 of Volume 1. (Chapter 6)

- *Use and reporting of models*: The *2019 Refinement* provides new guidance on the use and reporting of models. This new guidance applies to complex models, generally Tier 3 approaches. A step-by-step approach to report on the use of models in emission inventories is presented along with a checklist for ensuring *good practice* in the use of complex, higher tier models in national greenhouse gas inventories. (Chapter 6)

- *Indirect greenhouse gas emissions*: The *2019 Refinement* includes a series of updates ranging from improvements in the explanation of the methodology for indirect nitrous oxide (N_2O) emissions from the atmospheric deposition of nitrogen in nitrogen oxides (NO_x) and ammonia (NH_3), detailed methodological guidance on treatment of carbon dioxide (CO_2) inputs to the atmosphere from emissions of carbon-containing compounds, that are not already reported in GHG inventories an update on the background science on precursors and indirect emissions[12]. The *2019 Refinement* also incorporates new guidance on non-biogenic sources of CO_2 from the atmospheric oxidation of methane (CH_4), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs), examples of NMVOCs from the different source categories as well as guidance on carbon content of various materials and total solvent NMVOC emissions (Chapter 7).

- *National GHG inventory coverage*: The *2019 Refinement* provides updated guidance on specific issues to be taken into account in national GHG inventories. The guidance now includes reporting of non-CO_2 emissions from the biochar production and CO_2 and CH_4 emissions from flooded land. Additionally, existing guidance on reporting of captured biogenic CO_2 was further clarified. (Chapter 8).

Volume 2 (Energy)

- All methodological updates made in the *2019 Refinement* are in the fugitive emissions categories. No methodological updates were made for stationary combustion, mobile combustion, or other sources other than fugitives.

- *Fugitive CH_4 and CO_2 emissions from mining, processing, storage and transportation of coal*: The *2019 Refinement* includes guidance on fugitive CO_2 emissions from underground and surface mines including CO_2 from methane utilization or flaring from underground coal mines. The *2019 Refinement* adds year-specific default input values for fugitive CH_4 emissions from abandoned underground mines for 2017 through 2050 (previously the series of default values ended at 2016). A section on a basis for future methodological development is presented in the Appendix for fugitive emissions from abandoned surface mines and from coal exploration. (Chapter 4)

- *Fugitive emissions from oil and natural gas systems*: The *2019 Refinement* includes updates to emission factors to reflect the range of technologies and practices in use, including for unconventional oil and gas exploration. Additional detail on the appropriate selection of factors considering technologies and practices in place is provided. The *2019 Refinement* includes methods and emission factors for abandoned wells. An annex provides guidance on converting activity data inputs to the standard conditions applicable to the emission factors presented. Another annex provides data that allow compilers to disaggregate factors into venting, leak, and flaring sources. As terminologies for technologies and practices can vary, an annex is provided with definitions for key terms. (Chapter 4)

- *Fugitive emissions from fuel transformation*: The *2019 Refinement* includes a new section on fugitive emissions from fuel transformation, including methods for fugitive emissions from charcoal production, biochar production, coke production, (including flaring), gasification transformation processes (coal to liquids, and gas to liquids), and methods in Appendix (biomass to liquids, biomass to gas, and wood pellet production). These have been appropriately cross-referenced with Volume 3 (IPPU) and Volume 4 (AFOLU). (Chapter 4)

[12] Chapter 7 of Volume 1 refers to "inputs of CO_2 to the atmosphere" to represent the unoxidized carbon contained in compounds (e.g., CO, NMVOCs, CH_4) that are emitted from some anthropogenic activities. The CO_2 is formed at a later time in the atmosphere and not released directly from these activities

Volume 3 (Industrial Processes and Product Use)

- *New categories and new gases*: The *2019 Refinement* expands the scope of the *2006 IPCC Guidelines* to include more manufacturing sectors identified as sources of greenhouse gases. These include production of hydrogen, rare earth metals, and alumina, and waterproofing of circuit boards. In addition, a basis for future methodological development is provided for fluorinated treatment of textiles, carpet, leather and paper. Additional greenhouse gases identified in the IPCC Fourth and Fifth Assessment Reports, as well as other references, are also included where anthropogenic sources have been identified. Greenhouse gases identified in the IPCC Fourth and Fifth Assessment Reports include, for example, additional hydrofluorocarbons, perfluorocarbons, and halogenated ethers, such as PFPMIE (a perfluoropolyether widely used as a heat transfer fluid in electronics manufacturing). (Chapters 3, 4, 6, 8)

- *Updates*: The guidance for several source categories has been updated. This includes the guidance for production of nitric acid, fluorochemicals, iron and steel, aluminium, and electronics, and for the production and use of refrigeration and air-conditioning equipment. (Chapters 3, 4, 6, 7) Important updates include:

  - ✓ For nitric acid, updates to the production process categories (e.g., to include dual-pressure processes) and corresponding updates to the default emission factors for the Tier 2 method.

  - ✓ For fluorochemical production, updates to clarify the full range of emissions and their sources at fluorochemical production plants, updated default emission factors for the Tier 1 method, and updates to the Tier 3 method to include emissions from equipment leaks and to provide more detail for estimating emissions from process vents.

  - ✓ For iron and steel, updates to the guidance for metallurgical coke production to align it with the new methods presented in the Energy Volume for fugitive emissions, and to present new methods such as a Tier 1b simplified carbon balance method; updates to the methodological guidance for iron and steel production to include improved decision-trees, a new Tier 2 method for methane emissions, new Tier 3a (plant-specific carbon balance) and Tier 3b (based on emission measurements) methods for carbon dioxide emissions, a new Tier 1 method for carbon dioxide emissions from flaring of process gases, and new methods to estimate nitrous oxide emissions including a Tier 1 method for emissions from flaring of process gases. Default emission factors have been extensively updated, and the Tier 2 material-specific carbon contents list has been extended and updated.

  - ✓ For aluminium, several updates to the guidance for estimating PFC emissions, including an update to the smelting technology classes, updated default emission factors for the Tier 1 method, new guidance for estimating emissions from low-voltage anode effects, updated default emission factors for the existing Tier 2 and Tier 3 (now Tier 2a and Tier 3a) methods for estimating emissions from high-voltage anode effects (termed "anode effects" in the *2006 IPCC Guidelines*), new Tier 2b and Tier 3b methods for estimating emissions from high-voltage anode effects that better account for the impact of anode effect duration, and a new Tier 3DM method for facility-specific direct measurement of total PFC emissions. New guidance has also been added for estimating emissions from the production of alumina through the Bayer-Sinter and Nepheline processes.

  - ✓ For electronics, new guidance on tracking gas consumption and on apportioning use to different process types, updated and new Tier 2 methods that account for the size of manufactured wafers in semiconductor manufacturing, a new Tier 3b method for estimating emissions by developing facility-specific emission factors at the stack level, new guidance on adapting Tier 2 methods to account for technological changes, new guidance for the sub-sector microelectricalmechanical systems (MEMS), and updates to the default emission factors for Tier 1 and Tier 2 methods, including an expanded list of input gases, by-products, and fluorinated liquids.

  - ✓ For refrigeration and air conditioning, new "cook-book" style guidance on building an HFC emissions inventory (including guidance on data sources and on establishing the existing bank of HFCs), and new and updated tables regarding the identity and distribution of ODS substitutes by application and by substance for both developing and developed countries.

- *Updates to Figure 1.1 (Industrial Processes and Product Use categories):* Figure 1.1 has been updated to reflect the changes described above by (1) adding subcategories for Hydrogen Production (2B10), Rare Earths Production (2C7), Microelectricalmechanical Systems (2E4), and Waterproofing of Electronic Circuits (2G2c) to reflect the addition of new guidance for these subcategories; (2) adding several subcategories under Fluorochemical Production to reflect the broad range of fluorochemical products, (3) updating the name of the Electronics subcategory previously called "TFT Flat Panel Display" to the more comprehensive "Display," and (4) removing the subcategory "Heat Transfer Fluid" from the Electronics category, because the fluorinated liquids previously covered by this subcategory may be used in any of the Electronics sub-sectors (Semiconductors, Displays, Photovoltaics, or MEMS), may be used for applications other than heat transfer (including for testing, soldering, and cleaning), and are identifiable through their chemical contents. (Chapter 1)

Volume 4 (*Agriculture, Forestry and Other Land Use*)

- *Tier 3 model:* Section on Tier 3 model has been refined to expand the guidance on how to parameterize and evaluate models, the integration of data to models, and means to increase its transparency. Case studies have been included to demonstrate how different countries have developed and worked with Tier 3 methods. (Chapter 2)

- *Interannual variability (IAV)*: A new section has been introduced to provide an option that may be used to disaggregate Managed Land Proxy (MLP) emissions and removals into those that are considered to result from human effects and those that are considered to result from natural disturbances. This section may be of interest to countries with AFOLU sector emissions that have high IAV due to natural disturbances. The section first addresses definitional issues, followed by a description of whether or not different methodological approaches used to estimate carbon stock changes quantify the interannual variability of emissions and removals. A generic approach to report the disaggregated contribution of natural disturbances to the emissions and removals on managed lands is then provided, along with country-specific examples. For those countries that choose to implement this disaggregation, it is *good practice* to report the total MLP emissions and removals as well as the disaggregated components (Chapter 2).

- *Biomass estimates*: Biomass Tier 1 factors have been updated for Forest Land, Cropland and Settlements. Guidance on Tier 1 methods for Cropland and Settlements has been refined and clarified. Guidance for time series consistency for Forest Land has also been updated. Factors for dead organic matter have been updated, and new sections on Tier 2 guidance for the use of allometric models and biomass maps have been introduced. (Chapters 2, 4, 5, 8)

- *Soil carbon:* Tier 1 carbon stock change factors have been updated for tillage management, grassland management and land use based on evolving understanding of management impacts on soils. Many of the updated factors reflect a smaller impact of anthropogenic activity on soil carbon than default factors provided in the *2006 IPCC Guidelines*. Reference C stocks have also been updated based on an analysis of a global dataset that produces more representative reference stocks for different soil types by climate regions. The Tier 2 and Tier 3 methods have also been refined to estimate the impact of biochar amendments on soil carbon stocks in mineral soils for cropland and grassland. More guidance is provided for developing Tier 2 stock change factors and Tier 3 methods. In addition, an alternative Tier 2 approach, i.e., steady-state method, been provided in the *Cropland Remaining Cropland* section of the report. (Chapters 2, 4, 5, 6, 7, 8)

- *Rice cultivation*: Tier 1 factors have been updated for the baseline emission factors, scaling factors for water management regimes before and during cultivation periods, and conversion factors for organic amendments. Default cultivation periods have also been added for estimating annual emission factors. (Chapter 5)

- *Flooded Lands*: New guidance is provided for CO_2 and non-CO_2 emissions from *Land Converted to Flooded Lands* and *Flooded Land Remaining Flooded Land*. Methods for future development associated with these sources were included in Appendix 2 and Appendix 3 of Volume 4 of the *2006 IPCC Guidelines*. The science has matured over the past decade and these sources are now included in the main guidance (instead of appendices) of Chapter 7, Volume 4 of the *2019 Refinement* for a more complete inventory of greenhouse gas emissions from managed lands. The methods include estimation of total emissions following the Managed Land Proxy and an optional method to develop indicative estimates of the anthropogenic component of total emissions[13]. (Chapter 7)

[13] In the outline of the *2019 Refinement* approved by the IPCC at its 44th Session in Bangkok, Thailand in October 2016, refinement was requested to update CO_2 emission factors for land converted to flooded land (Wetlands) and to develop, on the basis of comprehensive review of available literature, consistent methodologies that take into account factoring out of emissions and removals that would otherwise occur in the absence of the flooded area for estimating CO_2 and CH_4 emissions from flooded lands (both land converted to flooded land and flooded land remaining flooded land). Methods have been developed to comply with the direction from the 44th Session of the IPCC. These methods provide transparency in terms of

- *Livestock and manure management*: Tier 1 emission factors have been updated considering current productivity data and integrating differential emission factors and for high and low productivity systems. Further, for major animal categories, Tier 1 parameters such as enteric fermentation EFs, volatile solids and nitrogen excretion are derived based on consistent data sources. The Tier 1 method to estimate CH_4 emissions from manure management has been updated for consistency with N_2O emissions. Certain Tier 2 parameters have been refined. The methane conversion rate (Y_m) for cattle and buffalo, varies based on animal diet and level of productivity. The methane conversion factor (MCF) for animal waste management systems are presented based on climatic regions, as opposed to annual temperatures and a simple calculation model for deriving the MCF based on monthly temperature regimes has been presented. Finally, improved guidance has been developed for the treatment of nitrogen transfers among livestock emission source categories and transfers to agricultural soils. (Chapter 10)

- *Soil N_2O*: Tier 1 estimates have been updated based on the latest science for direct and indirect emission factors. A key development is the disaggregation of emission factors by climate region. (Chapter 11)

- *Harvested wood products (HWPs)*: The methods and equations in the *2006 IPCC Guidelines* have been updated. The updated methods and equations better help inventory compilers to include the HWP pool estimates in greenhouse gas inventories using any of the approaches: 'stock-change' approach, 'production' approach, ´simple-decay´ and 'atmospheric-flow' approach. (Chapter 12)

Volume 5 (Waste)

- *Waste generation, composition and management*: The *2019 Refinement* updates key parameters used in the first order decay (FOD) method including waste generation rate and waste composition by countries and region using UN classification. The *2019 Refinement* also provides default values and uncertainty of carbon content, nitrogen content and degradable organic carbon (DOC) of domestic and industrial sludge. (Chapter 2)

- *Estimation of CH_4 emission from landfill*: Guidance on the use of methane correction factor (MCF) in different management conditions of solid waste disposal sites (SWDS) has been updated. New default values for the MCF to estimate CH_4 emissions from active aeration landfill have been provided by level of landfill management (poorly and well managed). The IPCC Waste Model has been updated according to the refinement. Default values for the fraction of degradable organic carbon which decomposes (DOC_f) for different waste components and their uncertainties have been updated, and relevant guidance has been added. (Chapter 3)

- *Incineration and open burning of waste*: Guidance on emission estimation from new technologies including gasification and pyrolysis has been elaborated with provision of CH_4 and N_2O emission factors to ensure a more complete coverage of sources. Oxidation factor of municipal solid waste (MSW) open burning has been updated. (Chapter 5)

- *CH_4 emissions from wastewater treatment*: Updated guidance is provided for the estimation of CH_4 from wastewater treatment, and updated emission factors for septic systems and centralised wastewater treatment plants are provided. Updated emission factors are also provided for CH_4 emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments. (Chapter 6)

- *N_2O emissions from wastewater treatment*: New guidance and emission factors are provided for N_2O emissions from domestic and industrial wastewater treatment plants, and updated emission factors are provided for N_2O emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments. (Chapter 6)

- *Non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge*: A discussion of non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge, where fossil organic carbon is present in wastewater or treatment sludge, is presented as an appendix as a basis for future methodological development. (Chapter 6)

- *Discharge into aquatic environments*: An alternate set of emission factors is provided for CH_4 and N_2O emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments when the country has activity data to differentiate the conditions of the waterbody receiving the discharge. (Chapter 6)

the total emissions from Flooded Land following the Managed Land Proxy, which is consistent with other methodologies for the AFOLU sector, and an optional method to develop indicative estimates of the anthropogenic component of total emissions for both *Flooded Land Remaining Flooded Land* and *Land Converted to Flooded Land*.