Horizon 2020 Societal challenge 5: Climate action, environment, resource efficiency and raw materials

VERIFY

Observation-based system for monitoring and verification of greenhouse gases

GA number 776810, RIA

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1. Changes with respect to the DoA

Submission in month 18 instead of month 15 in order to fully include all the WP1 deliverables in the work.

2. Dissemination and uptake

The material presented in this deliverable is of primary interest to all partners of the VERIFY consortium and it should also be distributed outside the project, especially to stakeholders.

3. Short Summary of results (<250 words)

The User Requirement Document intends to provide an overview of framework of requirements that the inventory agencies need to fulfil and inform the subsequent working packages for a robust observation-based monitoring and verification system that will improve current country reporting. As GHG Inventories (GHGIs) have to follow a set of requirements established under the UNFCCC and the IPCC guideline and guidance (as approved by the COP), the URD initially provides an overview of current (UNFCCC) and future (Paris Agreement) reporting rules (Chapter 2). Then, to assist the scientific community to better serve the improvement of the Countries' inventory, the URD synthesize the main terminological issues identified to increase the understanding with the inventory agencies (Chapter 3), as well as providing an overview of the main inventories uncertainties that could give guidance on which sector and gas needs more focus (Chapter 4). Finally, the URD provide a list of requirements (Chapter 5), with the aim of setting the accuracy, targets, coverage and frequency of update for GHG budget product at various temporal and spatial scales.

4. Evidence of accomplishment

The content of this report represents the accomplishment of the work.

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Version	Date	Description	Author (Organisation)
V0	08/07/2019	Creation/Writing	Guido Pellis, Lucia Perugini, Antonio Bombelli, Maria Vincenza Chiriacò (CMCC); Dirk Guenter (UBA)
V1		Formatting/Delivery on the Participant Portal	Philippe Peylin (CEA)

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1 Objective

One of the main objectives of VERIFY is to integrate the efforts between the research community, national inventory compilers, operational centres in Europe and other international organizations, towards the definition of future international standards for the verification of Greenhouse Gas (GHG) emissions and removals based on independent observations. The enhancement of current observation and modelling ability for the quantification of GHG emissions and removals under the VERIFY activities is aimed at providing a prototype of an international GHG verification system that should deliver a periodic scientific synthesis of the observation-based GHG balance of EU countries. The challenge is to create a system that is compatible with the current (United Nation Framework Convention on Climate Change – UNFCCC – and Kyoto Protocol) and future (Paris Agreement) Measurement, Reporting and Verification (MRV) requirements of the Inventory authorities, which have to be compliant with defined sets of rules established by the Intergovernmental Panel on Climate Change (IPCC) Guidelines and related decisions of the Conference of Parties of the UNFCCC and Paris Agreement.

The objective of the User Requirement Document (URD) is to define the framework of requirements and provide this to the subsequent working packages of VERIFY to fulfil the MRV targets of the users, i.e. the GHG inventory agencies. The URD defines science needs for GHG inventories estimates and for an observation-based monitoring and verification system that may improve current country reporting. The URD sets the accuracy, targets, coverage and frequency of update for each GHG budget product at various temporal and spatial scales.

The URD is largely based on the results of the different deliverables produced by WP1, that are here summarized and conclusions drawn from, specifically:

D1.2 Terminology analysis: Assessment of terminologies and definitions used under UNFCCC policy and reporting processes and relevant scientific studies;
D1.3 Consolidated reporting requirement assessment: Assessment of the reporting requirements in terms of methodologies, data gaps and tools on the basis of the factsheets
D1.4 Verification requirements assessment: Analysis on tools and methods available for independent verification
D.1.5 First Networking meeting: Meeting for exchange of knowledge, take stock of progress and evaluation of results compared to the project objectives (Paris, 14 November 2018).

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2 Outline general policy framework of the overarching objective of the MRV

Reliable, transparent and comprehensive information on national and global Greenhouse Gas (GHG) emission is an important element to enable the understanding of climate change and national GHG emission mitigation policies and measures.

Article 4 of the UNFCCC (1992) requests all parties to "develop, periodically update, publish and make available to the Conference of the Parties national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, using comparable methodologies." These GHG Inventories (GHGIs) shall rely on a complete coverage of anthropogenic emissions sources, the robustness of the methodologies used and the procedures for compilation of data.

To achieve the provision of reliable and consistent GHG information, the Conference of the Parties (COP) has established a set of requirements for reporting national GHGIs[1] to be fulfilled in accordance with the IPCC guidelines[2] and guidance.

The inventories are then subjected to independent reviews, where third party experts check that UNFCCC and IPCC guidelines and guidance are duly respected. Therefore, the inventory agencies have well defined margins of manoeuvre in terms of type of data, timing of submission, methodologies and approaches that they can use in their inventories.

2.1 Current (Pre 2020) framework and requirements

The UNFCCC introduced a broad differentiation of countries essentially in developed countries parties (contained in Annex I of the Convention) and parties not contained in Annex I (mainly developing countries). Countries contained in Annex I of the convention assumed commitments under the Convention (e.g. reduce their GHG emission, provide financial support and technology transfer), whereas Non-Annex I parties did not had commitments. This differentiation is also reflected in different reporting requirements and GHGIs verification procedures (Figure 1):

- *Annex I parties* of the Convention have the obligation of transmitting annually a GHGI including a National Inventory Report (15 reports 2003-2018), to provide every 4 years a National Communication (reporting, *inter alia*, on policies and measures and support provided) and every 2 years a Biennial Report focusing mainly on the progress towards their 2020 target. National Inventory Reports (NIR) also provide information on *accounting* under the Kyoto Protocol (KP). For estimating GHG emissions

1 Report of the COP on its nineteenth session, held in Warsaw from 11 to 23 November 2013. Addendum: Decision 24/CP.19 on the Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention
2 IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (N. G. G. I. Programme, E. H.S., B. L., M. K., N. T.,& T. K Eds.). Japan: IGES.

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by sources and removals by sinks Annex I parties have to apply the 2006 IPCC Guidelines for National Greenhouse Gas Inventories on a mandatory basis. All these reports are subject to international review processes (decision 19/CP.8) coordinated by the Secretariat.

- *Developing countries* (non-Annex I) provide a National Communication every 4 years on a voluntary basis. The National Communication includes also a GHGI but not an entire time series. Decision 1/CP.16 requests Non-Annex I parties to provide a Biennial Update Report (BUR), submitted every 2 years, containing an update of national GHGIs and information on mitigation actions, consistent with the Party's capabilities or level of support provided. Verification of reports is addressed at the international level through the process of International Consultation and Analysis (ICA) of BURs. This is to identify support needed and received in order to increase the transparency of mitigation actions and their effects. Non-Annex I Parties can decide on whether to use the 2006, 2003 or 1996 Guidelines (IPCC, 2003; IPCC 1996), though they are encouraged to use the most up to date version wherever possible. Meanwhile, the majority of Non-Annex I parties which provided a BUR is using the 2006 IPCC Guidelines.

- *Least developed countries (LDCs)* Parties are given special consideration given their limited capacity to respond to climate change and associated adverse effects. Parties within this group submit their GHGI at their own discretion.

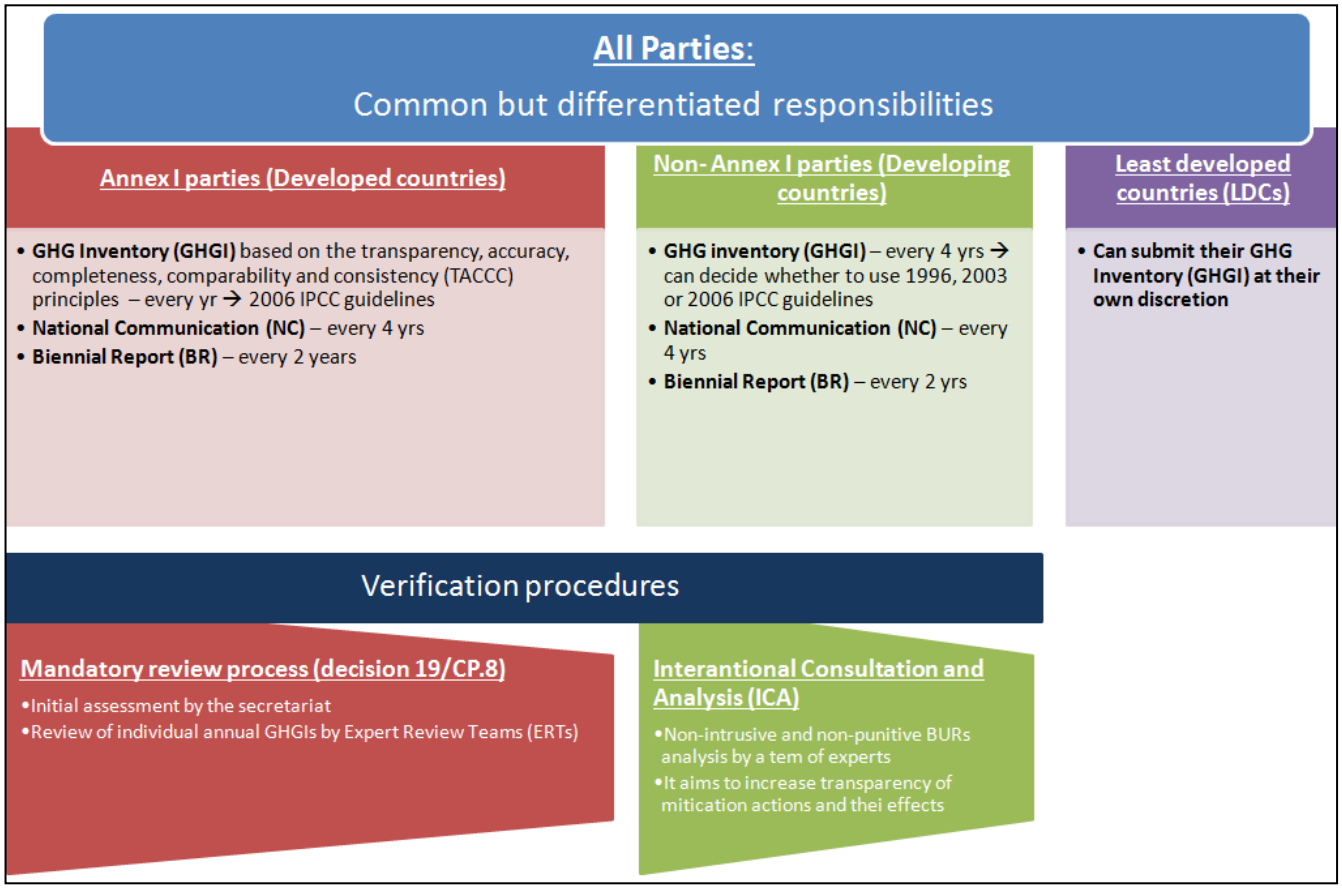

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Figure 1 – Current UNFCCC framework. In the upper part of the panel UNFCCC parties grouping with corresponding requirements are represented. In the lower part of the panel verification process are described.

2.1.1 Quality Assurance (QA) and Quality Control (QC) and verification system under UNFCCC

The Quality Assurance (QA) and Quality Control (QC) and verification system are a key aspect of the GHGI (IPCC, 2006a). The QA/QC and verification system supports the development of GHGI that can be easily assessed in terms of their quality, thereby improving inventories. Within the 2019 Refinement (IPCC, in preparation) QA, QC and verification are defined as follows:

- *Quality Control* (QC) system, is one of the routine technical activities to assess and maintain the quality of the inventory, throughout the compiling process, ensuring data integrity, correctness and, completeness as well as identifying any errors and omissions and documenting the material. Table 6.1 in IPCC, 2006 Vol. 1, Ch. 6 provides an overview of the general QC procedures.

- *Quality Assurance* (QA) system, is a review procedure managed by personnel not directly involved in the inventory development process. These are usually carried out by independent reviewers, who verify that the inventories have been compiled using the best possible estimates of emissions and removals considering the current state of scientific knowledge and data availability.

- *Verification* is the collection of activities and procedures that help to establish its reliability for use as an inventory. It refers to the methods that are completely external to the inventory process, using independent data and different methods, as well as comparing GHGI estimates made by other bodies.

The main purpose of verification activities is to provide information on how a country's GHGI may be improved. The comparison of inventory estimates with independent data may highlight significant differences, which could be associated to either or both methods used. National estimates from different independent sources using different methods can be compared to GHGI within the individual sectors. This type of comparison helps to identify major calculation errors or may highlight a key subcategory in any sector that may have been omitted or falsely allocated in calculations.

Overall, having a suitable QA/QC and verification system in place is fundamental as the inventories are subject to external expert review prior to being made publically available and used for further analysis.

VERIFY Deliverable D5.2 has introduced a few of the approaches and methods that can be used for independent comparisons, which will be referenced to where appropriate.

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2.2 Future (Post 2020) framework and requirements under the Paris Agreement

The Paris Agreement (PA) abolished the old bifurcation of the UNFCCC. No distinction is made between Annex I Parties (developed countries) and Non-Annex I Parties (developing countries) in terms of targets and reporting. Rather, the PA, in Art. 13, has established a common Enhanced Transparency Framework (ETF) for developed and developing countries.

In Katowice (2018), the Conference of Parties of the PA (CMA.1) has approved the Modalities, Procedures and Guidelines (MPG) for the ETF under the PA that will be applied starting from the first reporting under the PA (2024). Very little will change in terms of reporting obligations for developed countries under the convention, while big changes will occur for developing countries, since such requirements will be extended to all Parties, although with some flexibility related to the scope of reporting, frequency, level of details and scope of the review. In particular, under the Katowice Rulebook (decision 18/CMA.1), it was established that all parties shall use the 2006 IPCC Guidelines for the GHGI compilation.

The ETF is the backbone of the PA and aims at providing a clear understanding of climate change action tracking the progress towards the Agreements objectives of the "well-below 2°C trajectory". The main structure of the ETF is summarized in Figure 2.

The Katowice Rulebook establishes that each party should provide a ***Biennial Transparency Report (BTR),*** which has to be prepared each 2 years from 2024. According to the MPGs of Katowice Rulebook (decision 18/CMA.1) it has to include:

- a ***National inventory report of anthropogenic emissions and removals***, consisting of a national inventory document and common reporting formats regarding emission/removals from the 1990 starting date;
- ***Information to track progress of targets*** as defined in the National Determined Contributions (NDC);

In addition, developed countries need to provide information on support provided in terms of financial support, capacity building and technology transfer, while developing countries may provide information on the support needed and received. Finally, if a Party wishes, adaptation action can also be reported.

Under the PA, the second level of GHGI verification consists of a Technical Expert Review in different formats (desk review, centralized review, in-country review), that checks the consistency of the information submitted by parties with the MPGs of the ETF. It has to be performed every two years.

Nonetheless, as a key principle of the PA is the prevention of backsliding, Parties that have already submitted a GHGI with a complete time series from 1990 to the most recent year on an annual basis should continue to provide an annual GHGI. This GHGI will be reviewed in a simplified manner by the UNFCCC Secretariat.

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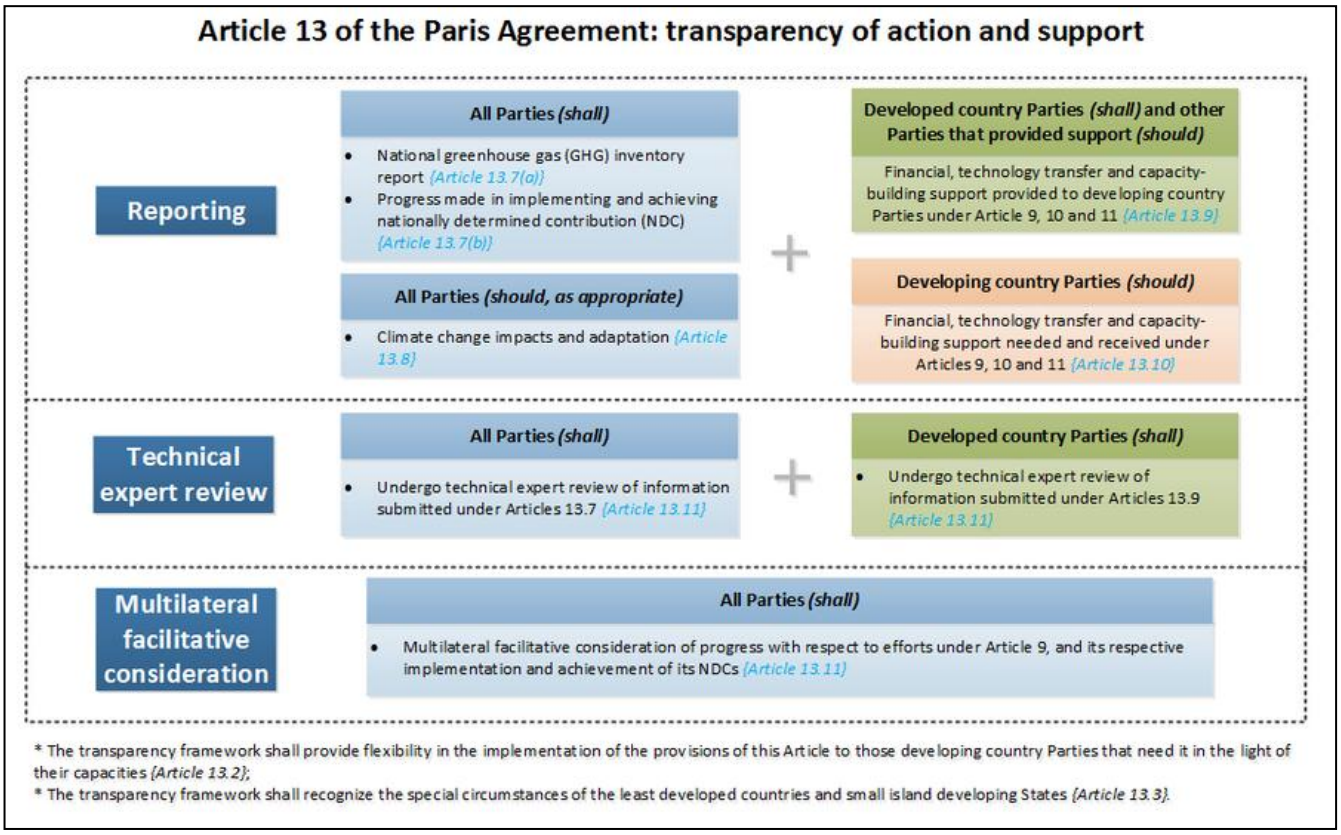


Figure 2 – Summary of the transparency process under Article 13 of the Paris Agreement (source: UNFCCC https://unfccc.int/process-and-meetings/transparency-and-reporting/the-big-picture/what-is-transparency-and-reporting).

2.2.1 Verification and periodical assessment processes under the PA

As the 2006 IPCC Guidelines and their 2019 Refinement (that can be adopted by Parties on a voluntary basis) will be applied under the ETF of the Paris Agreement, all Parties will be obliged to apply the Quality Assurance / Quality Control and Verification (QA/QC & Verification) procedures included in these guidelines, as described above (paragraph 2.1.1). However, flexibility is provided to those parties that need it in the light of their capacity.

The PA introduces also a higher level assessment process known as the *Global Stocktake* (GST).

The GST is the periodical (every five years) assessment of the *collective* progress towards achieving the purpose of the PA and its long-term goals (art.14 of the PA and Decision 19/CMA.1). The GST shall assess whether the "collective progress" resulting by the sum of the GHGIs from Parties is in line with the "well-below 2°C trajectory" as defined in the IPCC Assessment Report (AR), thus produced from atmospheric observation by the climate scientific community. In addition, GST has to provide indication to Parties on how to enhance and update their actions at national level and through cooperation. The outputs of the GST should thus provide

indication of opportunities and challenges for enhancing action and support. Therefore, climate science is playing a crucial role in the UNFCCC framework, providing data and methods for GHG estimations on the global level and, in the view of the PA implementation, also a "benchmark" for assessing the achievement of the 2°C temperature goal (Grassi et al., 2018). The first GST will start, with the initial steps, in November 2021 and has to be concluded by the end of November 2023 with the end of the third process phase (Figure 3).

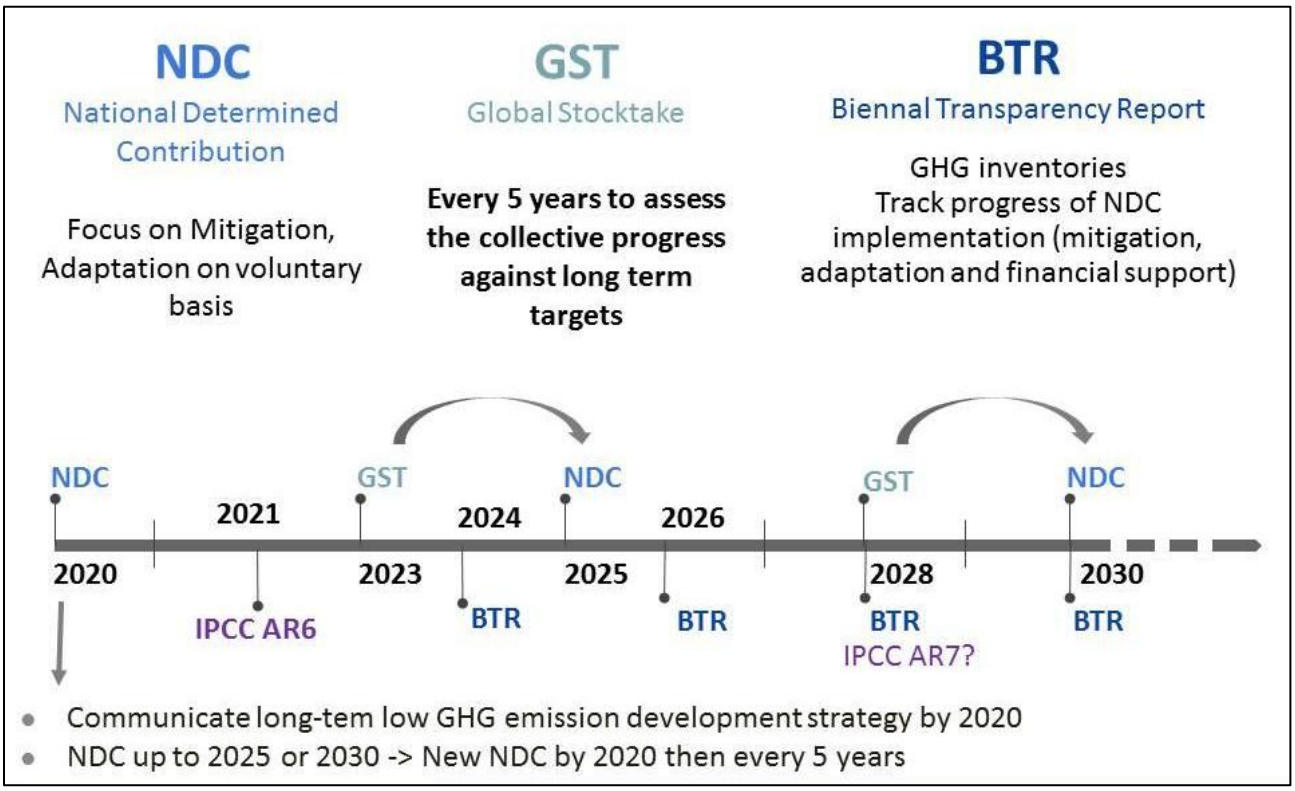
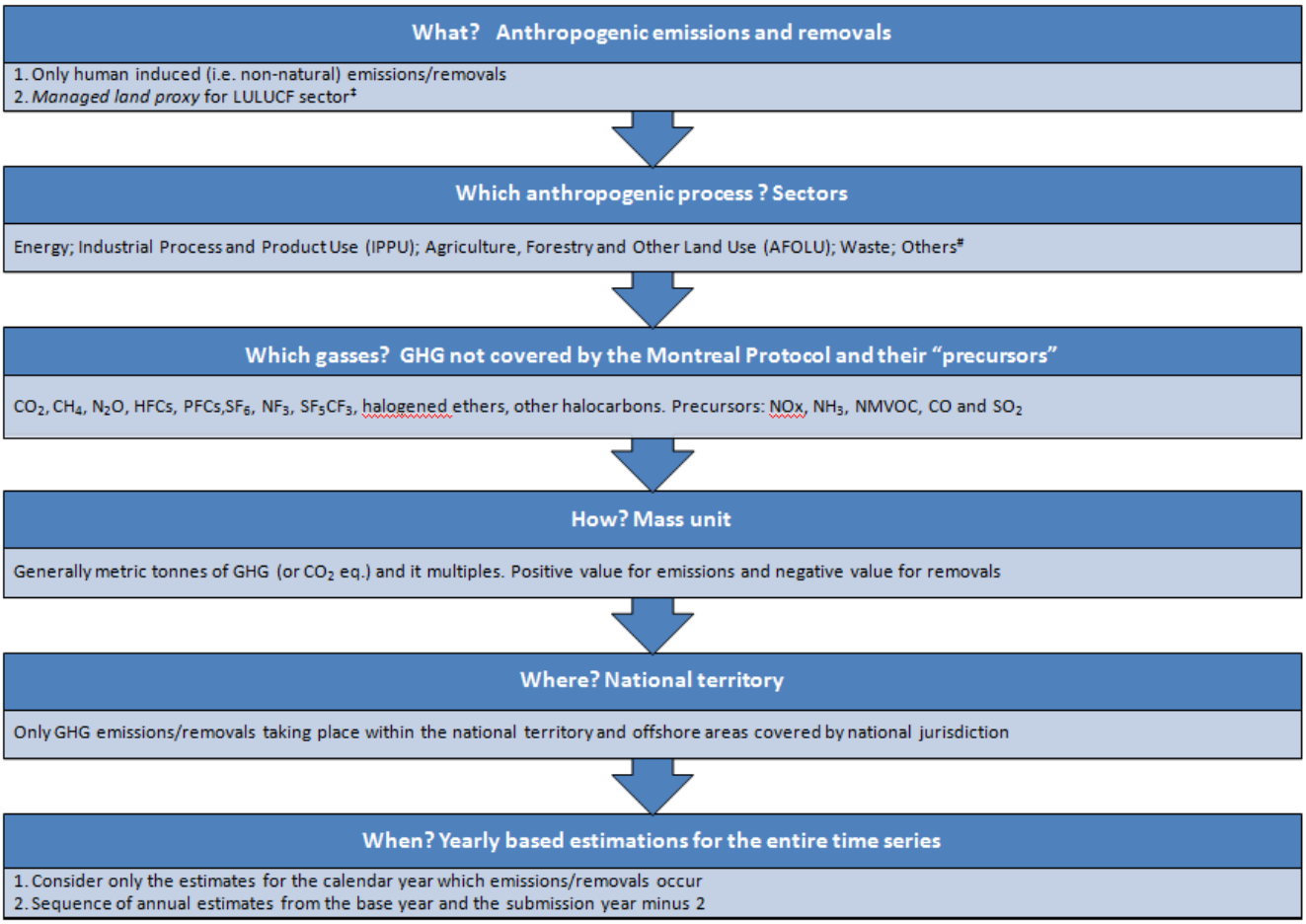


Figure 3 – Timeline of the transparency and global stocktake processes under the Paris Agreement.

2.3 Key concepts and methodological approaches used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

2006 IPCC Guidelines for National Greenhouse Gas Inventories are based on a set of concepts and definitions that are aimed to ensure comparable inventories between countries and reporting years, avoiding double counting or omissions, and containing time series which reflect actual changes in emissions. Figure 4 summarizes the main key concepts used for the GHGIs compilation according to the 2006 IPCC Guidelines (IPCC, 2006a).



‡ A discussion on the *Managed land proxy* definition is reported in the following chapters of this User Requirement Document.
# Each sector can be subdivided In categories and subcategories. Broad sector subdivision is summarised in table 1.

Figure 4 – Main logical structure of the key concepts used for a GHG Inventory organisation based n the 2006 IPCC Guidelines. More details are included in the following text and next chapters.

As a general overall requirement, the UNFCCC reporting guidelines (decision 24/CP.19) stipulate that reporting under the Convention and the Kyoto Protocol must follow the *five key principles of transparency, accuracy, completeness, consistency and comparability (TACCC)* which are described in Box 1. *The reporting under UNFCCC shall meet the TACCC principles*.

BOX 1: The inventories TACCC principles

- Transparency: Data sources, assumptions and methodologies used for inventories should be clearly explained for facilitating replications, reviews and assessments of the inventories by users.
- Accuracy: Emission and removal estimates should be systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable.
- Completeness: An annual GHG inventory covers at least all sources and sinks, as well as all gases, for which methodologies are provided in the 2006 IPCC Guidelines (or supplementary methodologies). The full geographical coverage of the sources and sinks of a Party should be considered too.
- Consistency: All the GHG inventory elements across sectors, categories and gasses should be consistently reported for all the year of the time-series. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks.
- Comparability: Emission and removal estimates reported by [Annex I] Parties in their inventories should be comparable among the other [Annex I] Parties. Therefore, these Parties should use the methodologies and formats agreed by the COP for making estimations and reporting their inventories (e.g. common reporting tables – CRF – provided in the decision 24/CP.19, Annex II).

Definitions are based on the Decision 24/CP.19, Ch. I.B, Annex I

Basic methodological approach: IPCC Guidelines emission estimates are based on the most simple methodological approach, which combine the information on the extent to which a human activity takes place (i.e. activity data - AD) with coefficients which quantify the emissions or removals per unit of AD (i.e. emission factors - EF):

$$\text{Emissions} = \text{AD} \cdot \text{EF}$$

However, more complex modelling approaches are also allowed and regularly needed, especially at the higher tier complexity level.

GHG gases to be reported – Annex I parties have to consider in Inventory reports six gases or groups of gases: carbon dioxide, (CO_2); methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Each party should also provide information on the following precursor gases: carbon monoxide (CO), nitrogen oxides and non-methane volatile organic compounds (NMVOCs), as well as sulfur oxides, and on a voluntary basis also the indirect CO_2 from the atmospheric oxidation of CH_4, CO and NMVOCs, presented as aggregated and separated category with the national totals. However, *developing countries* have the flexibility to limit their reporting to the most important gases (CO_2, CH_4 and N_2O).

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Sectors to be reported: According to 2006 IPCC Guidelines countries shall report emissions and removals strictly based on the source of origin or removal. The IPCC defined five major sectors of emissions to be followed in the GHGIs: Energy; Industrial Processes and Product Use; Agriculture, Forestry and Other Land Use (AFOLU) and Waste / Waste water. Each of these sectors is subdivided into categories and sub-categories (see Table 1). However, decision 24/CP.19 divided the AFOLU into two sectors: Agriculture and Land use, Land use change and forestry (LULUCF). While Annex I parties are requested to use the sectors of the UNFCCC reporting guidelines, developing country parties use the sectors of the IPCC guidelines. To report emissions, the UNFCCC reporting guidelines provide Common Reporting Format (CRF) tables which have to be used by Annex I parties, while developing countries are not commit these tables but use the reporting tables of the IPCC. In June 2019 the UNFCCC Subsidiary Body for Scientific and Technology Advice (SBSTA) started to develop common reporting tables for reporting under the PA for all parties based on the CRF tables.

Land categories and carbon pools*:* For the inventory purpose, the land area can be categorised into six land uses (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land) and, subsequently into, in land management systems. In addition, each land use category can be subdivided into land remaining in that category and land converted from one category to another. For each land use and all the possible transitions, three aggregate carbon pools have to be considered in addition to (whenever necessary) harvested wood products (HWP):

- Biomass (living): above and belowground;
- Dead organic matter: litter and deadwood;
- Soil organic carbon: in mineral and organic soils.

Global warming potential*:* According to the Decision 24/CP.19, to express the aggregated emissions and removals in CO_2 equivalent (CO_2eq.), the 100-years time horizon global warming potentials (GWPs) that have to be used up to 2020 are those from the forth Assessment Report (AR4) (IPCC, 2007)**.** For the Post 2020 under the PA the Katowice Rule book established that the GWPs 100 to be used are those from the fifth Assessment Report (AR5) (IPCC, 2013).

Time series*:* Annex I parties are requested to report emission/removal estimations from 1990 up to two years before the due date of the reporting. Under the PA all parties are obliged to report entire time series. However, developing countries are warranted some flexibility on the starting date of reporting.

Tiers: 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 most demanding in terms of complexity and data requirements (mostly plant specific data or modelling). Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate.

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Default data: Tier 1 methods for all categories are designed to use readily available national or international statistics in combination with the provided default emission factors and additional parameters that are provided, and therefore should be feasible for all countries.

Key Categories: the concept of key category is used to identify the categories that have a significant influence on a country's total inventory of GHGs in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals. Key Categories should be the priority for countries during inventory resource allocation for data collection, compilation, quality assurance/quality control and reporting. According to the 2006 IPCC Guidelines the threshold for key categories is defined by 95 percent of the national total emissions. The PA granted flexibility to developing countries by using a 85 percentage threshold.

Uncertainty analysis: The 2006 IPCC Guidelines defines uncertainties as "the lack of knowledge of the true value of a variable that can be described as a probability density function (PDF) characterising the range and likelihood of possible values". Uncertainty depends on the analyst's state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods. The quantitative uncertainty analysis is performed by estimating the 95 percent confidence interval of the GHG emissions/removals for the individual process, category, sectors, and for the total inventory as well. The 2006 IPCC Guidelines (Vol. 1, Ch. 3) suggests two methods for the error propagation. The Approach 1 method combines, in a simple way, the uncertainties in activity data and emission factors, for each category and greenhouse gas, and then aggregates these uncertainties, for all categories and greenhouse gas components, to obtain the total uncertainty for the inventory. The Approach 2 method for uncertainties determination is the same, in principle, but it also considers the distribution function for uncertainties and carries out aggregation using Monte Carlo simulation. In the Tier 2 method, the process also necessarily includes the determination of the PDF for both.

Clear documentation: 2006 IPCC Guidelines provide guidance on ensuring quality on all the steps of the inventory compilation defining in Vol. 1, Ch. 1 the principles of Transparency, Accuracy, Completeness, Consistency and Comparability (TACCC). For the purpose of the VERIFY project, it is particularly relevant that the 2006 IPCC Guidelines stress the necessity to use, for the reporting compilation, only clear documented input data. This measure is necessary to both respect the Quality Assurance/Quality Control and Verification system (QA/QC and Verification – Vol. 1, Ch. 6) and to have the possibility for continuous GHGIs improvement.

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Table 1 – Main subdivision of inventory sectors. Each sector is characterised by a code and can be disaggregated into categories and sub-categories.

Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
1	**ENERGY**	**1.A**	**Fuel Combustion Activity**	1.A.1	Energy Industries
				1.A.2	Manufacturing industries and construction
				1.A.3	Transport
				1.A.4	Other Sectors
				1.A.5	Other - Military
		1.B	**Fugitive Emission from Fuels**	1.B.1	Solid Fuels
				1.B.2	Oil and Natural Gas
		1.C	**Carbon Dioxide Transport and Storage**	1.C.1	Transport of CO_2
				1.C.2	Injection and Storage
				1.C.3	Other
		1.D	**International transport**		
2	**INDUSTRIAL PROCESS AND PRODUCT USE (IPPU)**	**2.A**	**Mineral Industry**	2.A.1	Cement production
				2.A.2	Lime Production
				2.A.3	Glass Production
				2.A.4	Other Process Uses of Carbonates
				2.A.5	Other
		2.B	**Chemical Industry**	2.B.1	Ammonia Production
				2.B.2	Nitric Acid Production
				2.B.3	Adipic Acid Production
				2.B.4	Caprolactam, Glyoxal and Glyoxylic Acid Production
				2.B.5	Carbide Production

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Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
				2.B.6	Titanium Dioxide Production
				2.B.7	Soda Ash Production
				2.B.8	Petrochemical and Carbon Black Production
				2.B.9	Fluorochemical Production
				2.B.10	Other (Dodecandioic acid and fertilizer)
		2.C	**Metal Industry**	2.C.1	Iron and Steel Production
				2.C.2	Ferroalloys Production
				2.C.3	Aluminium Production
				2.C.4	Magnesium Production
				2.C.5	Lead Production
				2.C.6	Zinc Production
				2.C.7	Other (Copper)
		2.D	**Non-Energy Products from Fuels and Solvent Use**	2.D.1	Lubricant Use
				2.D.2	Paraffin Wax Use
				2.D.3	Other
		2.E	**Electronics Industry**	2.E.1	Integrated Circuit or Semiconductor
				2.E.2	TFT Flat Panel Display
				2.E.3	Photovoltaics
				2.E.4	Heat Transfer Fluid
				2.E.5	Other

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Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
		2.F	**Product Uses as Substitutes for Ozone Depleting Substances**	2.F.1	Refrigeration and Air Conditioning
				2.F.2	Foam Blowing Agents
				2.F.3	Fire Protection
				2.F.4	Aerosols
				2.F.5	Solvents
				2.F.6	Other Applications
		2.G	**Other product manufacture and use**	2.G.1	Electrical Equipment
				2.G.2	SF_6 and PFCs from Other Product Uses
				2.G.3	Medical application and N_2O from Product Uses
				2.G.4	Other
		2.H	**Other**	2.H.1	Pulp and Paper Industry
				2.H.2	Food and Beverages Industry
				2.H.3	Other
3	**AGRICULTURE**	**3.A**	**Enteric fermentation**	3.A.1	Cattle
				3.A.2	Sheep
				3.A.3	Swine
				3.A.4	Other livestock
		3.B	**Manure management**	3.B.1	Cattle
				3.B.2	Sheep
				3.B.3	Swine
				3.B.4	Other livestock
		3.C	**Rice cultivation**	3.C.1	Irrigated
				3.C.2	Rainfed

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Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
				3.C.3	Deep water
				3.C.4	Other
		3.D	**Agricultural soils**	3.D (a)	Direct N_2O emissions from managed soils
				3.D (b)	Indirect N_2O Emissions from managed soils
		3.E	**Prescribed burning of savannas**		
		3.F	**Field burning of agricultural residues**	3 F 1	Cereals
				3 F 2	Pulses
				3 F 3	Tubers and roots
				3 F 4	Sugar cane
				3 F 5	Other
		3.G	**Liming**		
		3.H	**Urea application**		
		3.I	**Other carbon containing fertilizers**		
		3.J	**Other**		
4	**LULUCF**	**4.I**	**Direct N_2O emissions from nitrogen inputs to managed soil**		
		4.II	**Emissions and removals from drainage and rewetting and other management of organic and mineral soils**		
		4.III	**Direct N_2O emissions from nitrogen mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils**		
		4.IV	**Indirect nitrous oxide (N_2O) emissions from managed soils**		
		4.V	**Biomass Burning**		

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Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
		4.A	**Forest Land**	4.A (a)	Soil, Litter, Dead organic matter
				4.A (b)	Above & below ground biomass
		4.B	**Cropland**		
		4.C	**Grassland**		
		4.D	**Wetlands**		
		4.E	**Settlements**		
		4.F	**Other Land**		
		4.G	**Harvested Wood Products**		
		4.H	**Other**		
5	**WASTE**	**5.A**	**Solid Waste Disposal**	5.A.1	Managed Waste Disposal Sites
				5.A.2	Unmanaged Waste Disposal Sites
				5.A.3	Uncategorised Waste Disposal Sites
		5.B	**Biological Treatment of Solid Waste**	5.B.1	Composting
				5.B.2	Anaerobic digestion at biogas facilities
		5.C	**Incineration and Open Burning of Waste**	5.C.1	Waste Incineration
				5.C.2	Open Burning of Waste
		5.D	**Wastewater Treatment and Discharge**	5.D.1	Domestic Wastewater Treatment and Discharge
				5.D.2	Industrial Wastewater Treatment and Discharge
				5.D.3	Other

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Sector code	Sector name	Category code	Category name	Sub-category code	Sub-category name
		5.E	**Other (please specify)**		

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3 Current terminological issues between UNFCCC reporting and scientific communities

On the basis of the current regulation, the scientific community's role is fundamental for improved, reliable and accurate GHG budget estimations. The new regulation indicates that, from 2020, the scientific community's contribution will be more important than before. This is mainly due to the fundamental role of climate science research in the observation-based monitoring and verification system for the periodical (every five years) assessment of the collective progress towards achieving the purpose of the PA and its long-term goals (i.e. the Global Stocktake). In particular, the GST will be based on data provided by the scientific communities on the estimations of the surface air temperature trajectory. This trajectory depends not only on the effect of anthropogenic GHGs emissions/removals, but also on non-anthropogenic (i.e. natural) ones, which have not to be estimated and considered in the GHG inventories. However, as previously described in section 2.2.1, the GST shall also assess whether the "collective progress" resulting by the sum of the GHGIs from Parties is in line with the "well-below 2°C trajectory" because only these inventories can be used for the definition of national and global GHG emission mitigation policies and measures. Therefore, it is becoming more and more evident that world's reporting and climate science community needs to communicate with each other better than ever before.

For this reason, we investigated and report the main discrepancies and issues still present between climate science and UNFCCC reporting framework (see D 1.2 for more detailed information). These issues can be grouped into the four main categories.

3.1 Emission attribution problems

As summarized in the previous chapter, the 2006 IPCC Guidelines and the UNFCCC Reporting Guidelines adopted for GHGIs preparation generally require estimated emissions and removals for each specific sector and category. However, in some cases (especially for IPPU and Energy sectors), such a distinction may not be possible in climate science research projects. For example, it may be difficult to estimate emissions derived from energy and non-energy use of fuels/feedstock (e.g. in the chemical or iron and steel industry).

3.2 Methodological differences

Methodological differences can be considered as issues strictly dependent on the structural scheme of scientific analyses and the general GHGIs reporting framework. These typically consist of:

- The wide use of emission factors in the GHGIs (in lower and higher tier level), while this concept is generally not useful in climate science research. This issue can have a significant effect on both mean value and uncertainty estimations.

- Direct and indirect emissions as well as GHG precursors are reported separately in the GHGI, while these are not separated in the climate science research (i.e. the inversion approaches) or, when considered separately, their distinction may be arbitrary. For example, considering IPPU sector, the use of solvents

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and other products results in emissions of non-methane volatile organic compounds (NMVOC), a CO_2 precursor. These, are reported in GHG inventories, while these amounts of CO_2 may not be captured by satellite and in-situ monitoring of emissions.

- The consideration of emissions/removals from sources that are considered as significant may change from climate science approaches and the GHGIs.

- The definition of anthropogenic and biogenic emissions may differ between GHGIs and climate science research. While in GHGIs anthropogenic is used for emissions course by human-activities and biogenic as emissions within the natural carbon-cycle, climate science often use anthropogenic more narrow for emissions related to the energy and non-energy usage for fossil fuels. Emissions from biological processes, e.g. from agriculture and land use, are defined as biogenic emissions.

3.3 System boundary differences

These are differences related to both spatial and temporal scale of GHGIs and climate science research. In particular:

- Regarding the **spatial scale**, GHGIs have to be arranged at the country level, while top-down approaches of climate research are generally based on continental or global level, which can have a **varying** refined spatial resolution. Other climate study types are generally based at the local scale projects.

- Regarding the **temporal scale**, GHGIs are based on yearly reports while top-down approaches are based on a variable temporal scale but generally more refined (a few hours in some cases to monthly scales) than that of the GHGIs. In these cases, the finer temporal scale of scientific research with respect to that of the GHGIs leads to difficulties in both the use of scientific results in future inventory reports and their application for GHGIs verification procedures.

3.4 Terminology

A terminological issue between GHGIs and the climate scientific communities is linked to discrepancies in the interpretation of specific terms and their definition. According to the D 1.2, this issue affects mainly the AFOLU sector and in particular the Land Use, Land-Use Change and Forestry (LULUCF) one. However, according to recent papers (see for example Grassi et al., 2017; and Federici et al., 2017), these issues can significantly affect the difference between the GHG reporting and climate science estimations. The most relevant terminological issues, related to the LULUCF sector, are:

- **Anthropogenic effect**. The IPCC AR5 consider emissions/removals derived only from direct human-induced activities (i.e. changes in vegetation distribution), while, according to the 2006 IPCC Guidelines “managed land proxy”, the GHGIs consider all the effects derived by lands where human interventions and practices have been applied to perform production, ecological or social functions (IPCC 2006c).

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- **Managed land**. A specific comparison among managed land emission from different countries is negatively affected by the fact that its definition, according to the IPCC 2006 Guidelines, is not prescriptive.

- **Land Use/Land Cover**. In the preparation of GHGIs, it is requested to consider a land use classification based on human use and management practices. Whereas, scientific studies generally focus land interpretation based on remote sensing data and, therefore, they are able to detect land cover types (different biophysical characteristics). Remote sensing products still have higher uncertainties associated with the differentiation between grassland and cropland classes than with forest, urban or water. Cropland and grassland have either lower biomass than forests with signal of bare soil in the background (means lower normalized difference vegetation index – NDVI – signal) or lower blue fraction in the red, green and blue (RGB) compared to water and urban. Moreover, IPCC 2006 Guidelines give the possibility to each country to adopt a specific land use categories definition. This issue causes problems with both the comparability and external verification of GHGIs results. In addition, it can also be subdivided on the base of the different international definitions of specific land use categories like forest land and grassland. The forest land definition under UNFCCC is based on specific parameters thresholds such as tree height at maturity, crown coverage and minimum area of land covered by trees, which can vary between countries. Whereas, the grassland definition is less prescriptive and can include all surfaces (wooded and herbaceous) not included in forest, cropland, or in the other main land use categories (settlements and wetlands).

- **Carbon pools.** Firstly, main definition issues arise because the 2006 IPCC Guidelines carbon pool definitions allow for specific modifications based on national circumstances. Secondly, other issues are related to the general difficulties in the correct estimation of the soil organic carbon pool because of the adoption of different stock estimation approaches which can be based on equivalent soil depth or equivalent soil mass method. Thirdly, other issues are related to the soil portion considered for the SOC stock estimations. 2006 IPCC Guidelines request to consider, at least, the upper 30 cm of soil and the past scientific literature focused only on this topsoil portion. Nowadays, many more scientific studies indicate the relevant role of the upper 1 m soil portion for SOC stock estimations and their changes. Additionally, current land surface models tend to simulate the entire soil organic carbon stocks.

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4 Inventory uncertainties

According to the 2006 IPCC Guidelines, uncertainty assessment for all sectors is a fundamental aspect for a complete inventory submission. The estimations of uncertainties can be considered an important result to incite Parties to the precision of GHGIs and in selecting more precise methodologies in order to obtain more accurate GHG emission/removal estimations.

In order to obtain total uncertainties per sector or a final one for the total inventory, it is necessary to propagate the uncertainties of the input data (i.e. activity data and emission factors) used for emission/removal estimations. Main propagation techniques focus on uncertainty combinations (for Tier 1 level) and on Monte Carlo simulations (for Tier 2 level).

Differences in the uncertainty levels among inventories and among different sectors can be substantial. Generally, rather low uncertainty levels can be seen when the emissions are estimated using country and sector specific methodologies, while rather high uncertainty levels occur when emissions/removals are estimated using IPCC default values. In addition, it has to be considered that some uncertainties can originate in the basis of input data uncertainties based on expert judgments, which are more subjective than objective, and therefore difficult to use for an objective uncertainty comparison (Gillenwater et al., 2007; Winiwarter, 2007). In addition, other differences among Party's inventories can be due to differences in the industrialization levels or to high/low uncertainty levels linked to input data (Rypdal & Winiwater, 2001).

Deliverable 1.3 gives an overview of 26 EU Member States (MS) (all EU MS with the exception of Sweden and Czech Republic) uncertainties considering both sector and main GHGs subdivision. Deliverable results indicate that the reported uncertainty level in the total emissions of greenhouse gas inventories for 2016 ranges between 3% and 49.9%. The reported trend uncertainty in the total emissions of greenhouse gas inventories for 2016 ranges between 1.4 – 34%. The countries with the lowest uncertainties are the Netherlands (level uncertainty) and Spain (trend uncertainty), and the countries with the highest uncertainties are Lithuania (level uncertainty) and Finland (trend uncertainty). In addition, the uncertainty analysis shows a clear trend on uncertainties among different sectors. This trend appears in almost all EU MS equally (see D 1.3, Annex).

Deliverable 1.3 suggests that **Energy** (CRF 1) is the most relevant sector in terms of emissions in all countries (except for Iceland) and that, overall, it is responsible for 78% of the total emissions. However, its uncertainty level is lower with respect to that of the other sectors because of the generally solid data based on national energy statistics. Overall, the lowest uncertainty level refers to the CO_2 emissions estimation, while those referring to N_2O and CH_4 are higher with respect to the previous one because several MS have adopted IPCC defaults factors for these gasses. *Fuel combustion* (1 A) is characterised by the lowest estimation uncertainties (0.9%). On the other opposite, the highest uncertainties have been estimated for N_2O and CH_4 (18.4% UNFCCC, 2018) in the *Fugitive emissions from fuels* (subsector 1 B) subsector.

Generally, **IPPU** (CRF 2) is the second or third sector for GHG emissions. Its uncertainties are quite small because emission estimations are usually based on plant-specific data and country-specific methods. CO_2 estimations are more accurate than those of N_2O and CH_4.

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In contrast to Energy and IPPU, the other sectors (Agriculture, LULUCF and Waste) are characterised by very high uncertainty percentages (45.5, 32.6 and 51.4%, respectively). A main common reason is that these sectors are characterised by GHG emission/removal estimations based on a number of variable factors and parameters, which make it harder to measure them accurately and because these sectors (with the exception of LULUCF) are characterised by mainly non-CO_2 GHGs emission.

Considering **Agriculture sector**, the main emitting sources for CH_4 are the different subcategories of enteric fermentation (3 A) and for N_2O the different subcategories of both manure management (3 B) and agricultural soils (3 D). Generally, lower uncertainty is associated to the CH_4 emissions from enteric fermentation from cattle, because almost all MS calculate corresponding emission with very sophisticated methods.

Considering **LULUCF sector**, the key categories for CO_2 emission and removals estimation are Forest Land, Cropland, Grassland, Wetlands, Settlements and Harvested Wood Products. Different MS adopt different methods for their emission/removal estimations. These methods can be country specific (low uncertainties) or based on IPCC default factors (high uncertainties). According to Rypdal & Winiwarter (2001), there is an incomplete understanding of GHG dynamics from soil (which represents the largest contribution to national uncertainty assessments). This represents the main reason for overall highly uncertainty estimations in addition to the extension of the land use and management change.

Regarding **Waste sector**, almost all MS report CH_4 emissions from solid waste disposal on managed and unmanaged landfills using a Tier 2 methodology. In all other source categories in the waste sector, the share of MS using a higher Tier method is much lower than in the previous case. Important contributions to the overall uncertainty are generally high uncertainties about the amount of solid waste (organic material that decomposes to produce CH_4) that is deposited.

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5 Requirements for data provision

Based on the current and future regulation and on the main terminological and methodological issues which emerged as results of the previous chapters, hereafter we list and briefly discuss the main requirements for the scientific community. We do not want to consider in detail basic information that have to be present in a well-structured and potentially reproducible scientific research project, for example, explicit measurement units, uncertainty estimations, geographical coordinates (if special data are included) and complete methodological descriptions. However, closely respecting the following requests could make the researchers' data and results much easier to use by the reporting community.

Anthropogenic emissions and managed land: GHGIs must include only human induced (anthropogenic) emissions and removals. Main issues in the identification of such GHG fluxes can be referred to agricultural and LULUCF sectors where, according to the 2006 IPCC Guidelines, all the emissions/removals derived by *a land where human interventions and practices have been applied to perform production, ecological or social functions* (IPCC 2006c) have to be considered (IPCC *managed land proxy*). According to this definition, all direct human-induced, indirect human-induced and natural emissions/removals from/to managed land have to be reported. According to Gasser and Ciais (2013), Pongratz et al. (2014) and Federici et al. (2017), at present, the most promising solution to solve anthropogenic effects, managed land and land use terminological differences among studies is *the careful choice and declaration of the component fluxes included in the research, or to be included in future works. By defining better the considered system boundaries, these expedients both increase the understanding of the components included in the estimates and facilitate the aggregation/disaggregation for study*.

Sectors and categories reference: GHGs estimations need to be assigned to a specific source/sink category or sector (see Table 1). For estimates that can group together emissions/removals from/to different sources/sinks it is advisable to try to disaggregate the emission/removal estimates on the basis of other data or information, as, for example, proxy variables. *When this is not possible, the declaration of possible categories that are covered by the measurement is advisable to increase the understanding of the components included. In any case it is strongly advisable that attribution of categories is performed in consultation with the relevant experts form the inventory agencies related to the geographic area/sector of interest.*

Gas considered and final results: there are six GHGs that parties have to consider in their inventory reports: carbon dioxide, (CO_2); methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Each party should also provide information on the following precursor gases: carbon monoxide (CO), nitrogen oxides, non-methane volatile organic compounds (NMVOCs), and sulfur oxides. It is highly recommended to report data for each GHG separately. If gases are reported in CO_2 equivalent (CO_2 eq), then the GWP used should be reported, considering that AR4 (IPCC, 2007) 100-years time horizon GWPs are currently in use, while AR5 (IPCC, 2013) will be the one used from 2020.

Mass unit: For the inventory purposes, all the GHG have to be reported in a mass unit which is generally metric tonnes or its multiples, or Giga grams.

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Spatial and temporal: According to 2006 IPCC Guidelines, emissions/removals must be reported on a national basis (within the national territory) and shall refer to a specific calendar year. However, according to Leip et al. (2018), the future fluxes estimation for specific gases (like CH_4 and N_2O) at a finer spatial and temporal resolution by a top-down approach seems extremely relevant when these fluxes are affected by a high spatial and temporal variability, for example, for those released by microbial activities or those depending on the operating times and load of installations (for IPPU sector). *Therefore, it is strongly recommended for the scientific community to provide the results expressed in a format that can, at least, be aggregated on both national and yearly scales*.

Terminology: Considering terminological issues, it is advisable to use a clear and transparent definition of the terminology used in the manuscripts and detailed information on the adopted methodologies, taking into consideration as far as possible the glossary of terms defined by IPCC. Considering the LULUCF sectors in particular, it seems particularly important to clearly define the parameters adopted for Land Use/Land Cover classification and their thresholds (e.g definition of forest adopted by different Countries). Similar solutions can be generally adaptable to other terminological issues as, for example, those related to the methodological approach adopted for the soil organic carbon stock estimations and those related to the soil depth considered.

Uncertainty level: 2006 IPCC Guidelines do not define uncertainty threshold for the inclusion of any emission/removal estimation. However, the uncertainty level reduction is an important issue to be considered for future GHGIs improvements. Table 2 shows a list of the most important GHG emission/removal sources (or categories or sub-categories) characterized by the highest level uncertainty according to the 2016 Annual European Union GHGI (EEA, 2018). As previously described, the high level uncertainty for these GHG sources can be due to:

- the lack of country or sector specific methodologies and data (and a consequent Tier 1 level application);
- the high level of input data uncertainty (i.e. AD and EF);
- the error propagation for the final EU key categories emission/removal estimations which are based on MS GHGIs.

An entire list of EU GHG key categories is included in the Annex I. Data included in this list suggest that the GHGs characterised by the highest level uncertainties (even higher than 100%) are N_2O and CH_4. As previously described in chapter 4, this is mainly due to the usual application of IPCC default factors by a high MS number for their emission estimations (see Deliverable 1.3 for more detail) because of the lack of more accurate methodologies at national level (i.e. national emission factors or models). Therefore, we encourage the scientific community to put more efforts on improving emission estimations related to these GHGs.

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Table 2 – Summary of the main key categories (sub-categories and sources) and GHGs characterised by the highest uncertainty level according to the EU-28 plus Iceland 2018 GHG Inventory (which refers to the 1990-2016 time-series). The records are selected on the basis of a percentage of the total emission (excluded LULUCF emissions/removals) value of 1% or more, for the year 2016. The records are listed on the basis of decreasing level uncertainty values in this year. The total emissions (without LULUCF) are 5653747 Gg CO_2 eq (year 1990), 4300059 Gg CO_2 eq (year 2016), 4324868 Gg CO_2 eq (year 2017).Data source: Annual European Union greenhouse gas inventory (EEA 2018, 2019) The complete list of all EU-28 plus Iceland key categories estimations is included in Annex I.

Category, sub-category or source of emission/removal		Gas	1990		2016			2017		
Code	Name		Mean (Gg CO_2 eq)†	Percentage of the total emissions (excluded LULICF)	Mean (Gg CO_2 eq)	Percentage of the total emissions (excluded LULICF)	Level uncertainty	Mean (Gg CO_2 eq)	Percentage of the total emissions (excluded LULICF)	Level uncertainty
3.D	Agricultural Soils	N_2O	196797	3%	158007	4%	121.6%	164376	4%	124.3%
3.B	Manure Management	N_2O	30120	1%	23679	1%	81.4%	22230	1%	68.0%
4.E	Settlements	CO_2	36436	1%	41993	1%	50.1%	43662	1%	31.9%
4.B	Cropland	CO_2	74546	1%	61143	1%	47.5%	59561	1%	49.9%
1.B.1	Solid Fuels	CH_4	102763	2%	25683	1%	46.8%	30379	1%	72.9%
2.F	Product uses as substitutes for ODS	HFC	1734	0%	97291	2%	42.6%	84207	2%	48.6%
4.G	Harvested wood products	CO_2	-32017	-1%	-27879	-1%	42.4%	-38897	-1%	40.6%
1.B.2	Oil and Natural Gas and other emissions from energy production	CH_4	64.41	0%	27733	1%	32.9%	22940	1%	29.5%
5.A	Solid Waste Disposal	CH_4	188845	3%	99669	2%	27.3%	100523	2%	28.2%
4.A	Forest Land	CO_2	-360336	-6%	-405577	-9%	19.6%	-357492	-8%	20.2%
3.B	Manure Management	CH_4	52818	1%	41485	1%	18.9%	42126	1%	20.3%
3.A	Enteric Fermentation	CH_4	251238	4%	190100	4%	12.0%	194987	5%	10.7%
1.A.4.b	Residential	CO_2	186666	3%	131244	3%	6.5%	131282	3%	6.5%
1.A.4.a	Commercial/Institutional	CO_2	82082	1%	53517	1%	6.2%	54537	1%	6.2%
1.A.2.a	Iron and Steel	CO_2	51557	1%	40904	1%	5.4%	42268	1%	5.7%
2.B	Chemical industry	CO_2	61613	1%	53223	1%	4.8%	54178	1%	5.0%
1.A.1.b	Petroleum refining	CO_2	53513	1%	50348	1%	4.3%	50307	1%	4.2%
1.A.2.g	Other	CO_2	170229	3%	82052	2%	3.4%	87980	2%	3.3%
2.C	Metal industry	CO_2	118090	2%	67622	2%	3.3%	71263	2%	3.2%
2.A	Mineral industry	CO_2	148362	3%	105477	2%	3.2%	110062	3%	3.1%
1.A.3.b	Road transport	CO_2	479024	8%	571702	13%	3.0%	593536	14%	2.9%
1.A.1.a	Public electricity and heat production	CO_2	587349	10%	473151	11%	2.9%	456966	11%	2.6%

Note: Emissions are in Gg CO_2 equivalents; positive value correspond to emissions, negative ones to removals.

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† 1990 values are based on 2019 calculations (EEA, 2019).

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UNFCCC [United Nation Framework Convention on Climate Change] (2019) Decision 19 CMA.1 - Matters relating to Article 14 of the Paris Agreement and paragraphs 99–101 of decision 1/CP.21

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Annex I

Table 3 –List of all the key categories and corresponding GHG emission/removal estimations and uncertainties based on the 2016 and 2017 Annual European Union GHGI (EEA, 2018; EEA, 2019). Data are reported according to category, sub-category and sector codes (see section 2.3 and Table 1).

† The 1990 values are referred to the last (2019) European Union GHGI. There values can change over time because of recalculations.

Note: Emissions are in Gg CO_2 equivalents; the sum of the source category emissions may not be the total sector emissions because uncertainty estimates are not available for all source categories

Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
1.A	**Fuel combustion activities**	**All**	**4300321**	**3263413**	**0.9%**	**3280935**	**0.9%**
1.A	**Fuel combustion activities (where no subsector data were submitted)**	**All**	**607779**	**452733**	**1.3%**	**365139**	**1.4%**
1.A.1	**Energy industries**	**all**	**1399837**	**970256**	**1.6%**	**1016802**	**1.4%**
1.A.1	**Energy industries (where no subsector data were submitted)**	**all**	**680451**	**424055**	**1.5%**	**484083**	**1.4%**
1.A.1.a	Public electricity and heat production	CO_2	587349	473151	2.9%	456966	2.6%
1.A.1.a	Public electricity and heat production	CH_4	245	2988	67.1%	2961	68.4%
1.A.1.a	Public electricity and heat production	N_2O	2842	2844	32.2%	2795	32.1%
1.A.1.b	Petroleum refining	CO_2	53513	50348	4.3%	50307	4.2%
1.A.1.b	Petroleum refining	CH_4	19	16	17.6%	17	18.3%
1.A.1.b	Petroleum refining	N_2O	230	130	30.4%	142	30.9%
1.A.1.c	Manufacture of solid fuels and other energy industries	CO_2	74414	16388	4.9%	19184	4.6%
1.A.1.c	Manufacture of solid fuels and other energy industries	CH_4	102	185	137.7%	189	135.8%
1.A.1.c	Manufacture of solid fuels and other energy industries	N_2O	670	151	23.0%	158	22.8%
1.A.2	**Manufacturing industries and construction**	**all**	**742512**	**390445**	**1.5%**	**423817**	**1.4%**
1.A.2	**Manufacturing industries and construction (where no subsector data were submitted)**	**all**	**447145**	**231247**	**1.9%**	**255594**	**1.9%**
1.A.2.a	Iron and Steel	CO_2	51557	40904	5.4%	42268	5.7%
1.A.2.a	Iron and Steel	CH_4	73	61	26.6%	61	26.5%
1.A.2.a	Iron and Steel	N_2O	228	111	34.2%	115	34.6%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
1.A.2.b	Non-ferrous Metals	CO_2	2615	2142	8.7%	2414	7.9%
1.A.2.b	Non-ferrous Metals	CH_4	3	2	64.7%	3	58.5%
1.A.2.b	Non-ferrous Metals	N_2O	20	9	94.5%	11	70.6%
1.A.2.c	Chemicals	CO_2	29660	605	2.3%	5647	1.8%
1.A.2.c	Chemicals	CH_4	19	16	69.6%	16	70.8%
1.A.2.c	Chemicals	N_2O	31	27	402.2%	27	403.4%
1.A.2.d	Pulp, Paper and Print	CO_2	3010	1542	4.0%	1652	3.8%
1.A.2.d	Pulp, Paper and Print	CH_4	15	19	37.0%	20	37.3%
1.A.2.d	Pulp, Paper and Print	N_2O	77	99	70.0%	99	71.4%
1.A.2.e	Food Processing, Beverages and Tobacco	CO_2	7766	3977	1.6%	3931	1.6%
1.A.2.e	Food Processing, Beverages and Tobacco	CH_4	11	10	66.8%	12	66.8%
1.A.2.e	Food Processing, Beverages and Tobacco	N_2O	40	11	226.0%	13	209.2%
1.A.2.f	Non-metallic minerals	CO_2	28352	21074	2.7%	22701	2.6%
1.A.2.f	Non-metallic minerals	CH_4	67	37	31.8%	38	30.6%
1.A.2.f	Non-metallic minerals	N_2O	237	177	58.2%	196	51.2%
1.A.2.g	Other	CO_2	170229	82052	3.4%	87980	3.3%
1.A.2.g	Other	CH_4	194	231	30.2%	251	29.0%
1.A.2.g	Other	N_2O	1164	644	30.4%	768	31.5%
1.A.3	**Transport**	**all**	**781303**	**914701**	**2.1%**	**929360**	**2.1%**
1.A.3	**Transport (where no subsector data were submitted)**	**all**	**251352**	**292932**	**2.9%**	**300214**	**3.0%**
1.A.3.a	Domestic aviation	CO_2	7871	8482	12.0%	8534	12.5%
1.A.3.a	Domestic aviation	CH_4	11	5	72.2%	4	69.6%
1.A.3.a	Domestic aviation	N_2O	72	65	147.8%	63	151.6%
1.A.3.b	Road transport	CO_2	479024	571702	3.0%	593536	2.9%
1.A.3.b	Road transport	CH_4	4004	4103	8.0%	841	32.9%
1.A.3.b	Road transport	N_2O	4098	17322	12.2%	5095	41.9%
1.A.3.c	Railways	CO_2	7855	3079	4.3%	3227	4.7%
1.A.3.c	Railways	CH_4	10	293	5.0%	4	76.9%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
1.A.3.c	Railways	N_2O	503	200	121.3%	203	122.0%
1.A.3.d	Domestic navigation	CO_2	21907	12835	16.0%	14015	19.9%
1.A.3.d	Domestic navigation	CH_4	24	239	10.5%	22	88.1%
1.A.3.d	Domestic navigation	N_2O	309	207	218.5%	215	216.9%
1.A.3.e	Other transportation	CO_2	4234	3044	1.9%	3365	2.1%
1.A.3.e	Other transportation	CH_4	7	13	41.8%	7	61.8%
1.A.3.e	Other transportation	N_2O	23	181	14.6%	16	70.0%
1.A.4	**Other sectors**	**all**	**744690**	**530928**	**2.6%**	**541504**	**2.5%**
1.A.4	**Other sectors (where no subsector data were submitted)**	**all**	**432539**	**316633**	**3.1%**	**327360**	**2.9%**
1.A.4.a	Commercial/Institutional	CO_2	82082	53517	6.2%	54537	6.2%
1.A.4.a	Commercial/Institutional	CH_4	1575	834	16.8%	164	54.5%
1.A.4.a	Commercial/Institutional	N_2O	272	448	76.6%	134	130.7%
1.A.4.b	Residential	CO_2	186666	131244	6.5%	131282	6.5%
1.A.4.b	Residential	CH_4	4017	3422	58.5%	2826	68.9%
1.A.4.b	Residential	N_2O	1018	517	139.7%	672	118.7%
1.A.4.c	Agriculture/forestry/fishing	CO_2	35400	21139	6.2%	22619	5.9%
1.A.4.c	Agriculture/forestry/fishing	CH_4	456	2779	21.4%	1573	40.5%
1.A.4.c	Agriculture/forestry/fishing	N_2O	664	394	100.0%	337	127.2%
1.A.5	**Other**	**all**	**24200**	**4350**	**4.6%**	**4314**	**4.9%**
1.A.5	Other	CO_2	23715	4239	19.0%	4222	18.3%
1.A.5	Other	CH_4	301	50	186.6%	41	138.1%
1.A.5	Other	N_2O	184	61	258.6%	51	389.2%
1.B	**Fugitive emissions from fuels**	**all**	**207967**	**86009**	**18.4%**	**84604**	**27.9%**
1.B	**Fugitive emissions from fuels (where no subsector data were submitted)**	**all**	**14008**	**7931**	**48.2%**	**7917**	**52.0%**
1.B.1	Solid Fuels	CO_2	8276	3505	8.2%	4155	11.8%
1.B.1	Solid Fuels	CH_4	102763	25683	46.8%	30379	72.9%
1.B.1	Solid Fuels	N_2O	0.1	579.6	5.0%	0	107.5%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
1.B.2	Oil and Natural Gas and other emissions form energy production	CO_2	18378	20046	12.6%	19110	12.5%
1.B.2	Oil and Natural Gas and other emissions form energy production	CH_4	64.41	27733	32.9%	22940	29.5%
1.B.2	Oil and Natural Gas and other emissions form energy production	N_2O	131	531	95.7%	140	448.3%
2	**IPPU**	**all**	**534187**	**356624**	**11.8%**	**350274**	**11.8%**
2	**IPPU (where no subsector data were submitted)**	**all**	**0**	**0**	**0.0%**	**0**	
2.A	Mineral industry	CO_2	148362	105477	3.2%	110062	3.1%
2.A	Mineral industry	CH_4	31	6	100.0%	6	100.0%
2.A	Mineral industry	N_2O	0	0	0.0%	0	
2.B	Chemical industry	CO_2	61613	53223	4.8%	54178	5.0%
2.B	Chemical industry	CH_4	1157	1240	33.1%	1142	29.7%
2.B	Chemical industry	N_2O	116745	6318	8.5%	6744	7.4%
2.B	Chemical industry	HFC	35144	475	14.9%	432	13.9%
2.B	Chemical industry	PFC	4428	2358	46.5%	1545	46.9%
2.B	Chemical industry	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	
2.B	Chemical industry	SF_6	1891	88	3.0%	79	3.0%
2.B	Chemical industry	NF_3	0	0	0.0%	0	
2.C	Metal industry	CO_2	118090	67622	3.3%	71263	3.2%
2.C	Metal industry	CH_4	284	342	10.1%	139	14.8%
2.C	Metal industry	N_2O	44	22	79.4%	22	79.2%
2.C	Metal industry	HFC	4446	79	29.6%	44	32.3%
2.C	Metal industry	PFC	15931	524	10.2%	485	10.1%
2.C	Metal industry	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	
2.C	Metal industry	SF_6	1655	182	20.5%	289	19.6%
2.C	Metal industry	NF_3	0	0	0.0%	0	
2.D	Non-energy products from fuels and solvent use	CO_2	13975	9848	39.2%	9352	44.2%
2.D	Non-energy products from fuels and solvent use	CH_4	5	2	88.1%	2	88.4%
2.D	Non-energy products from fuels and solvent use	N_2O	5	5	77.2%	5	73.8%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
2.E	Electronics industry	CO_2	0	0	0.0%	0	
2.E	Electronics industry	CH_4	0	0	0.0%	0	
2.E	Electronics industry	N_2O	0	0	0.0%	0	
2.E	Electronics industry	HFC	42	1299	23.0%	1271	23.2%
2.E	Electronics industry	PFC	262	545	21.5%	332	26.4%
2.E	Electronics industry	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	0.0%
2.E	Electronics industry	SF_6	200	121	14.4%	139	16.6%
2.E	Electronics industry	NF_3	94	55	16.2%	44	17.2%
2.F	Product uses as substitutes for ODS	CO_2	0	1400	51.0%	1815	51.0%
2.F	Product uses as substitutes for ODS	CH_4	0	0	0.0%	0	
2.F	Product uses as substitutes for ODS	N_2O	0	0	0.0%	0	
2.F	Product uses as substitutes for ODS	HFC	1734	97291	42.6%	84207	48.6%
2.F	Product uses as substitutes for ODS	PFC	21	93	101.3%	53	154.6%
2.F	Product uses as substitutes for ODS	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	
2.F	Product uses as substitutes for ODS	SF_6	0	0	0.0%	0	
2.F	Product uses as substitutes for ODS	NF_3	0	0	0.0%	0	
2.G	Other product manufacture and use	CO_2	805	613	13.8%	600	11.3%
2.G	Other product manufacture and use	CH_4	57	76	30.6%	79	30.4%
2.G	Other product manufacture and use	N_2O	3326	3022	46.2%	2790	48.4%
2.G	Other product manufacture and use	HFC	46	114	99.8%	143	91.3%
2.G	Other product manufacture and use	PFC	401	664	30.6%	773	29.9%
2.G	Other product manufacture and use	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	
2.G	Other product manufacture and use	SF_6	3215	2178	24.9%	2042	26.1%
2.G	Other product manufacture and use	NF_3	0	0	0.0%	0	
2.H	Other	CO_2	98	129	19.9%	62	26.1%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
2.H	Other	CH_4	6	9	6.0%	8	21.0%
2.H	Other	N_2O	64	1161	20.6%	84	20.8%
2.H	Other	HFC	0	3	17.0%	2	30.0%
2.H	Other	PFC	0	4	48.4%	5	48.2%
2.H	Other	Unspecified mix of HFCs and PFCs	0	0	0.0%	0	
2.H	Other	SF_6	7	37	52.4%	38	63.6%
2.H	Other	NF_3	0	0	0.0%	0	
3	**Agriculture**	**all**	**550243**	**428892**	**45.4%**	**438304**	**47.00%**
3	**Agriculture (where no subsector data were submitted)**	**all**	**0**	**752**	**0.0%**	**0**	**0.00%**
3.A	Enteric Fermentation	CO_2	0	0	0.0%	0	0.00%
3.A	Enteric Fermentation	CH_4	251238	190100	12.0%	194987	10.70%
3.A	Enteric Fermentation	N_2O	0	5	55.9%	0	0.00%
3.B	Manure Management	CO_2	0	3	70.7%	0	0.00%
3.B	Manure Management	CH_4	52818	41485	18.9%	42126	20.30%
3.B	Manure Management	N_2O	30120	23679	81.4%	22230	68.00%
3.C	Rice Cultivation	CO_2	0	0	0.0%	0	0.00%
3.C	Rice Cultivation	CH_4	2715	2201	17.9%	2202	30.90%
3.C	Rice Cultivation	N_2O	0	26	39.2%	0	0.00%
3.D	Agricultural Soils	CO_2	0	0	0.0%	0	0.00%
3.D	Agricultural Soils	CH_4	0	0	0.0%	0	0.00%
3.D	Agricultural Soils	N_2O	196797	158007	121.6%	164376	124.30%
3.E	Prescribed Burning of savannas	CO_2	0	0	0.0%	0	0.00%
3.E	Prescribed Burning of savannas	CH_4	0	0	0.0%	0	0.00%
3.E	Prescribed Burning of savannas	N_2O	0	0	0.0%	0	0.00%
3.F	Field Burning of Agriculture Residues	CO_2	0	0	0.0%	0	0.00%
3.F	Field Burning of Agriculture Residues	CH_4	1534	631	52.3%	513	52.60%
3.F	Field Burning of Agriculture Residues	N_2O	361184	229	54.5%	184	54.20%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
3.G	Liming	CO_2	10212	5769	25.9%	5499	24.20%
3.G	Liming	CH_4	0	0	0.0%	0	0.00%
3.G	Liming	N_2O	0	0	0.0%	0	0.00%
3.H	Urea application	CO_2	3450	4059	17.7%	3947	16.80%
3.H	Urea application	CH_4	0	0	0.0%	0	0.00%
3.H	Urea application	N_2O	0	0	0.0%	0	0.00%
3.I	Other carbon-containing fertilizers	CO_2	590316	309	9.8%	316	10.20%
3.I	Other carbon-containing fertilizers	CH_4	0	0	0.0%	0	0.00%
3.I	Other carbon-containing fertilizers	N_2O	0	0	0.0%	0	0.00%
3.J	Other	CO_2	0	0	0.0%	0	0.00%
3.J	Other	CH_4	277	1360	41.2%	1564	45.10%
3.J	Other	N_2O	132	267	97.6%	360	90.60%
4	**LULUCF**	**all**	**-214591**	**-279966**	**32.6%**	**-243019**	**34.30%**
4	**LULUCF (where no subsector data were submitted)**	**all**	**302**	**650**	**55.9%**	**-176**	**197.30%**
4.A	Forest Land	CO_2	-360336	-405577	19.6%	-357492	20.20%
4.A	Forest Land	CH_4	2072	1856	69.0%	3194	55.60%
4.A	Forest Land	N_2O	2848	2477	84.8%	2503	99.10%
4.B	Cropland	CO_2	74546	61143	47.5%	59561	49.90%
4.B	Cropland	CH_4	729	498	126.9%	747	111.10%
4.B	Cropland	N_2O	3752	3187	116.1%	5411	68.10%
4.C	Grassland	CO_2	23477	5475	373.6%	7926	232.60%
4.C	Grassland	CH_4	1679	939	148.5%	1073	132.80%
4.C	Grassland	N_2O	702	344	117.7%	431	99.90%
4.D	Wetlands	CO_2	10313	15698	57.1%	12348	56.20%
4.D	Wetlands	CH_4	3405	1552	59.1%	3330	53.50%
4.D	Wetlands	N_2O	4367	1923	42.9%	364	56.30%
4.E	Settlements	CO_2	36436	41993	50.1%	43662	31.90%

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
4.E	Settlements	CH_4	77	113	96.4%	115	97.90%
4.E	Settlements	N_2O	2315	4912	67.4%	3705	82.30%
4.F	Other Land	CO_2	3044	460	721.0%	404	114.30%
4.F	Other Land	CH_4	141	212	29.3%	399	29.70%
4.F	Other Land	N_2O	535	1.246	31.4%	1162	32.10%
4.G	Harvested wood products	CO_2	-32017	-27879	42.4%	-38897	40.60%
4.G	Harvested wood products	CH_4	0	0	0.0%	0	0.00%
4.G	Harvested wood products	N_2O	0	0	0.0%	0	0.00%
4.H	Other	CO_2	0	69	30.4%	60	30.40%
4.H	Other	CH_4	0	220	100.0%	219	100.00%
4.H	Other	N_2O	493	516	93.4%	490	93.60%
4.I		CO_2	0	0	0.0%	0	0.00%
4.I		CH_4	0	0	0.0%	0	0.00%
4.I		N_2O	21	17	206.7%	29	198.70%
4.II		CO_2	1970	1679	74.6%	1689	57.20%
4.II		CH_4	1731	979	139.5%	1118	110.60%
4.II		N_2O	2147	1277	140.8%	2105	113.00%
4.III		CO_2	0	0	0.0%	0	0.00%
4.III		CH_4	0	0	0.0%	0	0.00%
4.III		N_2O	132	273	733.0%	136	812.00%
4.IV		CO_2	0	0	0.0%	0	0.00%
4.IV		CH_4	0	0	0.0%	0	0.00%
4.IV		N_2O	441	3746	44.4%	302	138.50%
4.V		CO_2	61	68	38.4%	908	94.40%
4.V		CH_4	15	10	38.5%	91	71.00%
4.V		N_2O	10	7	37.6%	63	72.30%
5	**Waste**	**all**	**240327**	**137837**	**51.4%**	**138497**	**51.50%**

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Sector, sub-sector or source of emission/removal		Gas	1990	2016		2017	
Code	Name		Mean (Gg CO_2 eq)†	Mean (Gg CO_2 eq)	Level uncertainty	Mean (Gg CO_2 eq)	Level uncertainty
5.A	Solid Waste Disposal	CO_2	0	0	0.0%	0	0.00%
5.A	Solid Waste Disposal	CH_4	188845	99669	27.3%	100523	28.20%
5.A	Solid Waste Disposal	N_2O	0	0	0.0%	0	0.00%
5.B	Waste Water Handling	CO_2	0	0	0.0%	0	0.00%
5.B	Waste Water Handling	CH_4	390	4437	86.2%	4511	85.00%
5.B	Waste Water Handling	N_2O	344	2951	88.7%	2936	87.70%
5.C	Waste Incineration	CO_2	5185	3474	14.0%	3155	30.20%
5.C	Waste Incineration	CH_4	215	124	28.1%	92	27.90%
5.C	Waste Incineration	N_2O	203	179	100.5%	200	95.60%
5.D	Wastewater treatment and discharge	CO_2	0	0	0.0%	0	0.00%
5.D	Wastewater treatment and discharge	CH_4	36390	19813	47.4%	19808	50.20%
5.D	Wastewater treatment and discharge	N_2O	8733	7072	913.5%	7181	899.30%
5.E	Other	CO_2	20	17	300.2%	16	300.20%
5.E	Other	CH_4	2	27	43.1%	6	154.00%
5.E	Other	N_2O	0	73	59.2%	69	60.00%

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