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

Deliverable number (relative in WP)	**D6.2**
Deliverable name:	Best practices for GHG emission inventories
WP / WP number:	6
Delivery due date:	M24 (31/01/2020)
Actual date of submission:	M29 (30/06/2020)
Online version:	M37 (15/02/2021)
Revised after 2nd EC review:	M41 (15/06/2021)
Dissemination level:	Public
Lead beneficiary:	JRC
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Changes with respect to the DoA
This document is in line with its description in the DoA. **Due to some problems during the internal review process at CEA, the deliverable was only submitted on the EC portal early 2021, although it was finalized on time.**
Dissemination and uptake **(Who will/could use this deliverable, within the project or outside the project?)**
The project partners, both those with emission inventory compilation expertise as well as those with atmospheric modeling or measuring expertise, receive with this deliverable a common background on the historical evolution towards best practices for GHG emissions tracking.
Short Summary of results (<250 words)
This deliverable presents an overview of the evolution towards effective GHG emission tracking and best practices with regard to National GHG inventories. The report describes the international guidelines and gives then a zoom on the implementation in the European Union.
Evidence of accomplishment **(report, manuscript, web-link, other)**
Report Janssens-Maenhout, Petrescu and Solazzo (2020) available on the project website: ttp://verify.lsce.ipsl.fr/index.php/repository/public-deliverables/wp5-wp6-synthesis-and-products-policy-relevant-ghg-monitoring-and-verification-system-design ***Janssens-Maenhout, Greet, Petrescu, Ana Maria Roxana, Solazzo, Efisio, Best Practices for GHG inventories, JRC Technical report, Deliverable D6.2 of the H2020 project VERIFY, June 2020***

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Version	Date	Description	Author (Organisation)
V0	01/03/2020	Creation/Writing/Formatting	Greet Janssens-Maenhout (JRC)
V0.1	25/06/2020	Revising/Delivery	Greet Janssens-Maenhout
V1	15/09/2020	Formatting/Delivery on the Participant Portal	Philippe Peylin, Aurelie Paquirissamy
V2	15/06/2021	Revised after the scientific review of the second reporting period by EC – CINEA.C01	Greet Janssens-Maenhout

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1. Glossary

Abbreviation / Acronym	Description/meaning
AFOLU	Agriculture, Forestry and Other Land Use sector
AVR	Accreditation and Verification Regulation
BR	Biennal Reports
BUR	Biennial Update Reports
CCS	CO_2 capture and storage
CMMR	Climate Monitoring Mechanism Regulation
CO_2 MVS	CO2 emissions monitoring and verification support
CRF	Common Reporting Format
D&R	Directives and Regulations
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
ES	Effort Sharing
ESA	European Space Agency
ETS	emissions trading directive
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUTL	European Union Transaction Log
FAR	first assessment report
FMCP	facilitative multilateral considerations of progress
GCOS	Global Climate Observing System
GEIA	Global Emissions InitiAtive
GHG	Green House Gases
GPG	Good Practice Guidance
GST	global stocktake
GWP	Global Warming Potential
HTAP	hemispheric transport of air pollution
ICSU	International Council for Science
IOC	International Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IPPU	Industrial Processes and Product Use
MRV	Monitoring – Reporting – Verifying
MS	Member States
NDC	Nationally Determined Contributions
NECPs	national energy and climate plans
NGHGI	National GHG Inventories

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non-LULUCF	non-Land Use, Land-Use Change and Forestry
PA	Paris Agreement
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technological Advice
TACCC	transparency, accuracy, consistency, comparability and completeness
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WCC-2	World Climate Conference
WCP	World Climate Programme
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

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2. Executive Summary

This report describes best practices with regard to National GHG Inventories. Starting from a historical overview with climate observations (by the climate science community analyzing observations and running climate models issuing assessment reports), the report continues with the development of the IPCC guidelines for GHG emission inventory compilation and highlights the evolution and progress of the 2006 guidelines versus the 1996 guidelines (by the inventory compilation community).

In addition, the report provides an overview of the major achievements of the 2019 refinement. The two scientific/technical communities, those of the three working groups drafting the assessment reports and those of the task force on GHG emission compilation could benefit from a closer collaboration. This became apparent with the enhanced transparency framework of the Paris Agreement and the H2020 project VERIFY tried to bridge these two communities.

In addition to the general guidelines valid for all countries, the document also summarises the specific EU guidance and how the review and verification of GHG emission inventory compilation is institutionalized in the EU27 + UK.

The document is structured with an introductory section 1, describing the historical overview, section 2 with the comparison of the progress of the 2006 guidelines compared to the 1996 ones, section 3 focusing on the Katowice Rulebook and the 2019 refinement and section 4 with a description of the implementation of these GHG emission procedures in the EU27 + UK. Finally, section 5 provides some insight on the international scientific efforts to bring the emissions science further as new discipline and the report is closed with some final thoughts in the conclusion and recommendations section.

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3. Introduction and setting the scene with historical origin

The World Meteorological Organisation (WMO) has been the initiator of many climate activities. In 1979, WMO established the World Climate Programme (WCP), and in 1980 the World Climate Research Programme (WCRP) together with two co-sponsors: the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO[1].

Together with the UN Environment Programme, WMO established the first panel of climate experts, the so-called Intergovernmental Panel on Climate Change (IPCC) that shaped the agenda for the second World Climate Conference (WCC-2) in 1990 (Figure 1). The World Climate Programme decided at the WCC2 to establish the Global Climate Observing System (GCOS) (co-sponsored by WMO, IOC, UNEP and ICSU). IPCC's first assessment report (FAR) of 1990 was at the basis of the negotiations of the United Nations Framework Convention on Climate Change (UNFCCC, 1992, in force since 1994) and the establishment of the Subsidiary Body for Scientific and Technological Advice (SBSTA) in addition to the Subsidiary Body for Implementation (SBI).

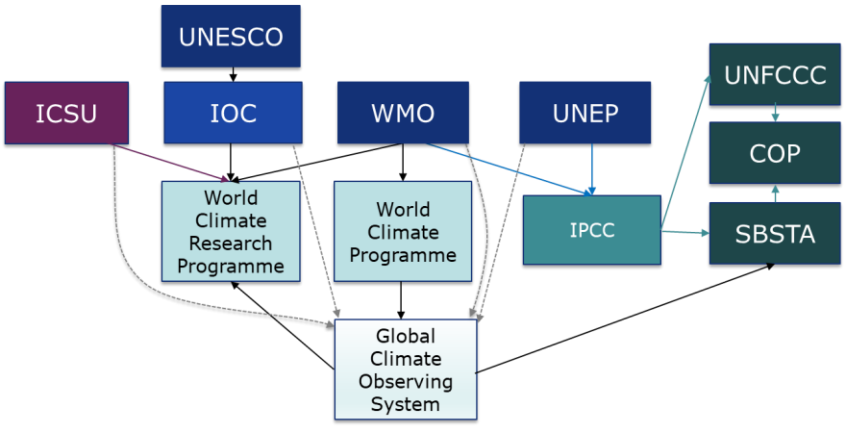

Figure 1 : Organisational structure and sponsorship arrangements for the World Climate Programme (WCP), the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC bodies (Conference of Parties and the Subsidiary Body for Scientific and Technological Advice), (Zillman, 2009).

To the IPCC's FAR followed 4 other Assessment Reports, which are the most well-known works of IPCC (AR2-AR5), and for which the IPCC received in 2007 the Nobel Peace Prize. A key component of IPCC is the Task Force on National GHG Inventories (NGHGI) (Figure 2). The task force was the responsible of the full reporting guidance for the compilation of emission inventories for 195 Member States (MS). Although the target of the UNFCCC is to limit the rise of the global atmospheric surface temperature relative to pre-industrial time below 2°C (cfr. IPCC WG1 in AR5), the climate mitigation measures are related in the first place to the reduction of anthropogenic GHG emissions, and more recently to the increase in carbon sinks.

[1] IOC-UNESCO joined as co-sponsor in 1993.

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The two scientific/technical communities represented by the three working groups (WGI-WGIII) drafting the assessment reports and by those of the task force on NGHGI compilation worked in parallel addressing issues of UNFCCC from different angles.

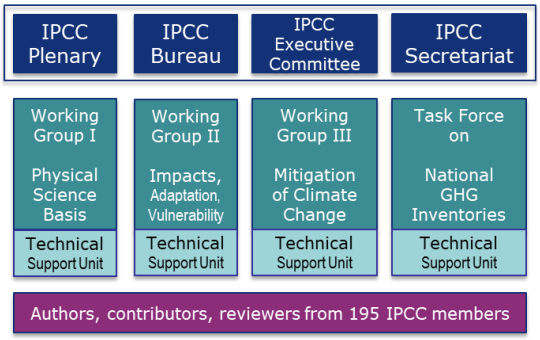

Figure 2 : Overview of the different IPCC bodies

The Paris Agreement of 2015 is a landmark agreement, because all the 195 participating countries committed to undertake climate change mitigation and adaptation actions and agreed to monitor action implementation through an enhanced transparency framework. In fact, not all 195 countries of the IPCC are on board on an equal basis in the UNFCCC. Because of the historical industrial development and responsibility for past emissions and current climate change of the developed countries (so-called Annex I countries of UNFCCC), a stronger effort of these Annex I countries is expected in 1990. At the time of the Paris Agreement, 25 years later, the contribution of developing countries (non-Annex I), in particular those with emerging economies was larger than that of the developed countries and a commitment also from developing countries is accounted for with Nationally Determined Contributions (NDC). Figure 3 gives an overview of the different groups of countries.

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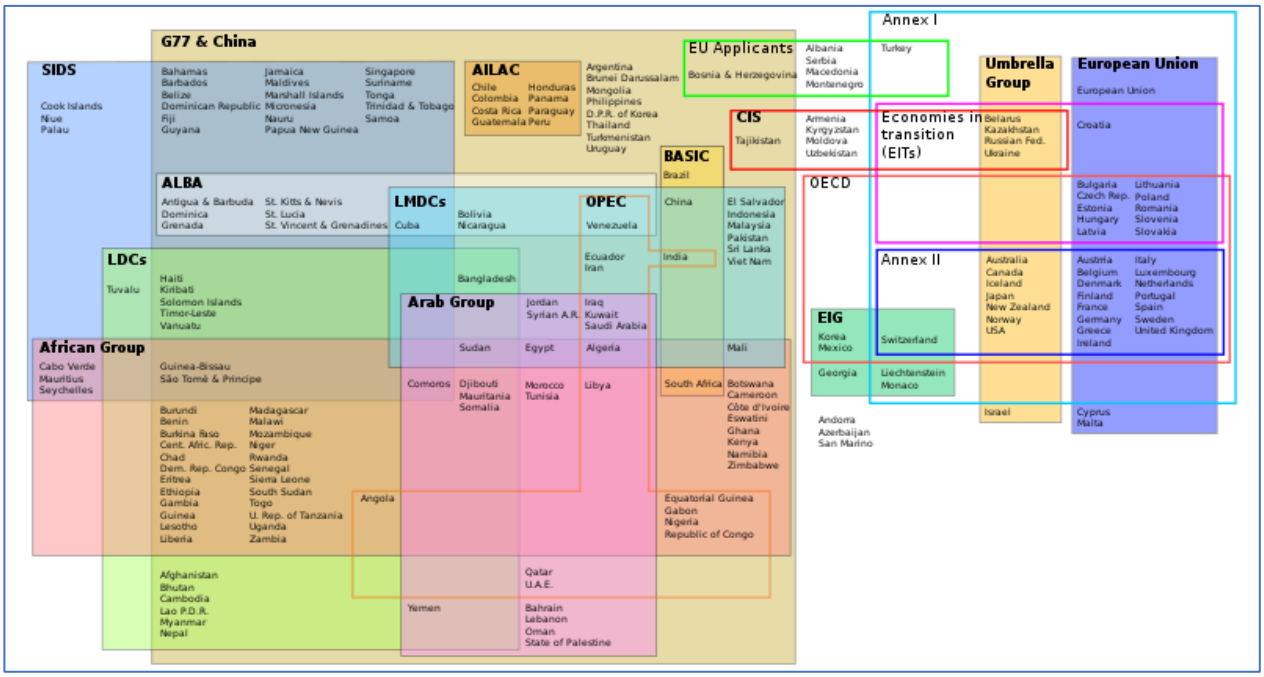

Figure 3: Overview of the developed (Annex I, including also Annex II) and developing countries (non Annex I), all contributing to the Paris Agreement through their Nationally Determined Contributions (NDCs).

While regularly updated NGHGI, referred to as *bottom-up* (BU) estimates, will form the basis in tracking progress of emission reduction efforts, atmospheric measurements are ideally designed to provide observation-based *top-down* (TD) evidence of global emission trends. To date there is no international agreement to any operational capacity to monitor anthropogenic GHG emissions (in particular CO_2) and their trends using atmospheric measurements to complement and support the national inventories.

Under the European Union's Copernicus Programme, the European Commission (EC), the European Space Agency (ESA), the European Centre for Medium-Range Weather Forecasts (ECMWF), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) supported by a pool of international experts, are joining efforts for developing such an operational capacity for anthropogenic CO2 emissions monitoring and verification support (CO_2 MVS). For a complete description we refer to Janssens-Maenhout et al. (2020).

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4. The IPCC Guidelines for National Greenhouse Gas Inventories

4.1. Starting from the Revised 1996 IPCC Guidelines

An essential component of the UN Framework Convention on Climate Change (UNFCCC, 1992) is the collection of nationally reported inventories and information on these GHG emission inventory time series. At the time the UNFCCC was drafted, the 24 members of the OECD in 1990 and 16 other European countries and Russia were considered liable of "the largest share of historical and current global emissions of GHGs" and taken up in Annex I to the UNFCCC. These Annex I countries and the European Union (EU) submit annually complete inventories of GHG emissions from the 1990 base year[2] until the latest year for which full accounting is completed and reviewed (typically with two-year time lag) and these inventories are all reviewed to ensure transparency, completeness, comparability, consistency and accuracy. Other countries are encouraged to submit their GHG inventories as part of their National Communications and Biennial Update Reports (BUR). The GHG inventories of non-Annex I countries were required to cover CO_2, CH_4 and N_2O emissions (in CO_2-equivalent) for one year (1990 or 1994), without specific documentation and only subject to a brief review.

The IPCC Guidelines were first accepted in 1994, then published in 1995 and revised by 1996. The revisions mainly consisted of efforts made by the IPCC to harmonise methods across existing inventories (e.g. used also for air quality) and resulted in a completion or an extension of the methods (Tier 1 to Tier 2) with default data for six groups of human activities. The IPCC tiers represent the level of sophistication used to estimate emissions, with Tier 1 based on default assumptions, Tier 2 similar to Tier 1 but based on country-specific parameters, and Tier 3 based on the most detailed process-level estimates (i.e., models) (Petrescu et al., 2020). Progress were made by comparing the IPCC and EMEP/CORINAIR methodologies. These changes were particularly reflected in the Energy Chapter with additions for the biomass. Table 1 summarises the major improvements (additions with methods and default data) provided with the revisions.
The third session of the Conference of Parties to the UNFCCC (COP 3) in 1997 in Kyoto (known as the Kyoto Protocol (KP)) reaffirmed that the **Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories** (IPCC GL) should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in calculation of legally-binding targets during the first commitment period 2008-2012. Unfortunately, only 40 industrialised countries (20% of the total number of parties) committed. Although these countries represented, in the mid-1990s, more than half of the global total GHG emissions, their share decreased to below half of the world global total by 2005. Developing countries did not commit to the Kyoto's agreement to reserve the privilege for (green) growth.

[2] Several countries have difference base years: parties included in Annex I with an economy in transition during the early 1990s (EIT Parties) were allowed to choose one year up to a few years before 1990 as reference because of a non-representative collapse during the breakup of the Soviet Union (e.g., Bulgaria,1988, Hungary, 1985–1987, Poland, 1988, Romania, 1989, Slovenia, 1986).

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Fearing unfair competition for the manufacturing industry by countries not part of the Kyoto Protocol also the USA withdrew from the KP.

Table 1 : Update for the 1995 guidelines, taken up under the revised 1996 guidelines.

1. Changes in the *Energy sector*	• assignment of GHG emissions from autoproducers to the sector where they were generated and not to the transformation sector (revision); • development of a Tier 1 method for estimating non- CO_2 GHGs and SO_2 emissions based on fuel consumption (new); • development of a Tier 2 method for estimating emissions from aircraft (new); • inclusion of default values for various types of traditional biomass fuels (new); • clarification of the definition of National Navigation (the definition of International Marine Bunkers remains unchanged)
2. New methods and default data for the estimation of emissions from *industrial processes*	• direct greenhouse gases (CO_2, CH_4, and N_2O) and SO_2 from: - mineral production; - chemical industries; - metal manufacture. • O_3 precursors (NOx, CO, NMVOC) from: - chemical industries - metal manufacture • halocarbons (PFCs, HFCs) and sulphur hexafluoride (SF6) from metal manufacture, use and production. - Tier 1 (a): for bulk chemicals; - Tier 1 (b): for bulk chemicals and chemicals stored in products; - Tier 2: product (containing PFCs, HFCs, SF6) lifetimes are taken into account.
3. Revised method and new default data for the estimation of *CH_4 from agriculture*	• Revised method and new default data for the estimation of CH_4 emissions from Rice Cultivation uses: - internationally-agreed definitions of rice ecosystems (revision); - default data (e.g. seasonally integrated CH_4 emission factors) (new); - scaling factors for CH_4 emissions factors relative to continuously flooded fields (without-organic amendment) (new).
4. Revisions for the estimation of *N_2O from agricultural soils and manure management*	• default method for the estimation of N_2O emissions from Manure Management and Agricultural soils (new); • revised default emission factors for the estimation of direct emissions of N_2O from soils (revision); • default data (e.g. N_2O emission factors for animal waste and for indirect emissions) (new).
5. Revisions with new default data and classification for *Land Use, Land-use Change and Forestry*	• Revised /new default data and classification are suggested for: - land-cover types (revision); - rates of forest conversion (new); - aboveground biomass for native tropical forests (revision); - rates of tropical forest regrowth (revision) • Method for the estimation of CO_2 fluxes from agricultural soils (revision) and default data (new).
6. Revision with new data and classification for *waste*	• Solid waste disposal Revised/new data and classification are listed below for: - solid waste disposal site classification: definition encompasses all sites classified in the current Guidelines (revision); - methane correction factor to account for the methane generation potential of the site (new); - wider range of default data for waste generation, composition and disposal data (revision). • Wastewater - revised approach and default data for calculating CH_4 emissions (revision). • Human sewage - method and default data for the estimation of N_2O emissions (new).

The Revised 1996 IPCC Guidelines provide assistance to the analyst in the preparation of NGHGI and are available at https://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html. They are composed of three volumes:

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- **Volume 1**: These Reporting Instructions provide step-by-step directions for assembling, documenting and transmitting completed national inventory data consistently, regardless of the method used to produce the estimates. These instructions are intended for all users of the IPCC Guidelines and provide the primary means of ensuring that all reports are consistent and comparable.
- **Volume 2**: This Workbook contains suggestions about planning and steps to build a national inventory, and is devoted to countries who do not have a national inventory available and are not experienced in producing such inventories. It also contains step-by-step instructions for calculating emissions of CO_2 and CH_4, as well as some other trace gases, from six major emission source categories. It is intended to help experts in as many countries as possible to start developing inventories.
- **Volume 3**: This Reference Manual provides a compendium of information on methods for estimation of emissions for a broader range of GHGs and a complete list of source types for each GHG. It summarises a range of possible methods for many source types. It also provides summaries of the scientific basis for the inventory methods recommended and gives extensive references to the technical literature.

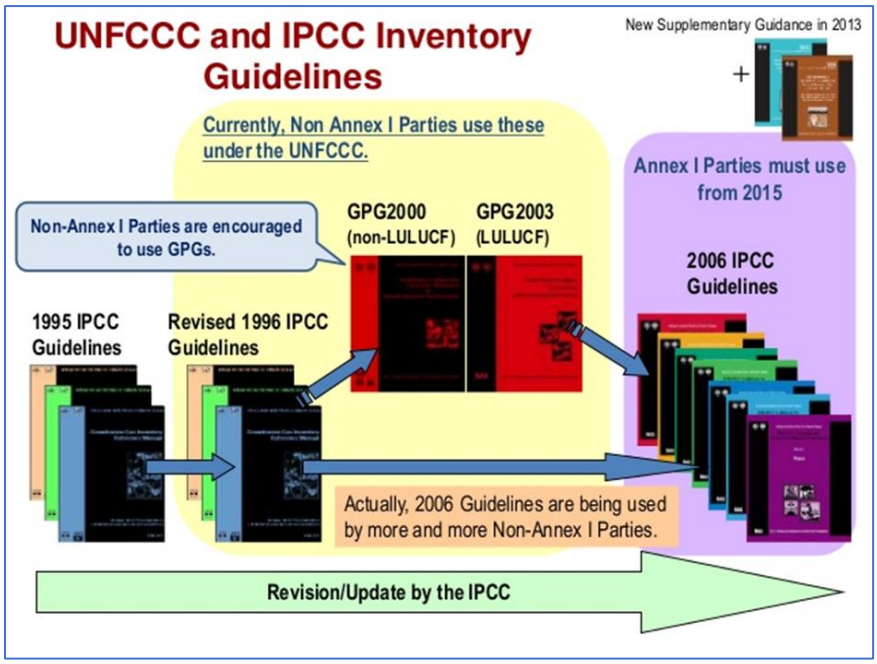

Figure 4: Historical overview of the evolution of IPCC guidelines for GHG emission inventory compilation.

As shown in Figure 4, the 1996 Guidelines were extended in 2000 with the **Good Practice Guidance on non-Land Use, Land-Use Change and Forestry (non-LULUCF) sectors** GPG2000 (IPCC, 2000). The GPG2000 provided supplementary information to the 1996 IPCC Guidelines to improve inventory transparency, documentation, consistency over time, completeness, and comparability. It also provided methods for addressing uncertainties and implementing quality control and quality assurance, with extra guidance for

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the Agriculture Sector. GPG2000 introduced a method for identifying key sources that should be given high priority because of their significance in affecting the absolute level or trend in emissions, their uncertainty, or qualitative factors such as unexpectedly high or low estimates. The goal of this method is to provide practical guidance on how to develop a national inventory with an efficient use of resources, identifying sources that are candidates for using a more detailed (higher tier) estimation method.

In 2003 the report on **Good Practice on the remaining LULUCF sector (GPG2003-LULUCF)** was published. GPG2003-LULUCF provides supplementary methods and good practice guidance for estimating, measuring, monitoring and reporting the carbon stock changes and greenhouse gas emissions from LULUCF activities for the Kyoto Protocol, including uncertainties, QA/QC. In addition, GPG-LULUCF provides guidance related to the specific features of the LULUCF sector on consistent representation of land areas, sampling for area estimates and for estimating emissions and removals, verification, and guidance on how to complement the Convention reporting for the LULUCF sector to meet the supplementary requirements under the Kyoto Protocol.

4.2. The 2006 IPCC guidelines: current basis for National GHG reports.

The IPCC Panel approved in 2003 the plans to review and update the "Revised IPCC 1996 Guidelines for National Greenhouse Gas inventories" in response to the SBSTA invitation. With the inventory reporting experience followed the implementation of the Kyoto Protocol, it was considered important to take into consideration the relevant progress on GHG inventory compilation for the Convention and the Protocol. The Terms of Reference and content for the "2006 IPCC Guidelines for National Greenhouse Gas Inventories" were developed by the IPCC Task Force on inventories on the basis of:

- the existing 1996 IPCC Guidelines,
- the two IPCC Good Practice Guidance reports (GPG2000 and GPG-LULUCF),
- the inventory related issues of the special reports on safeguarding ozone and on CO_2 capture and storage, and
- Experiences from the UNFCCC technical inventory review process.

All was merged into one document, resulting in a normal evolution (not a revolution) of the GHG inventory compilation practices. Experience and feedback in using the existing reports and from the UNFCCC inventory reviews, as well as advances in science were taken into account in the preparation.

One of the main differences was the change in numbering of categories for human activities in the "2006 IPCC Guidelines", which are each synthesized into separate volumes. While the Energy sector; Industrial Processes and Product Use (IPPU) sectors and Waste sector remained unchanged, the agriculture sector and the Land use change and forestry sector of the 1996 guidelines were merged into the Agriculture, Forestry and Other Land Use sector (AFOLU) with a structure consistent with the IPCC GPG2003-LULUCF

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report. In addition, new sources and gases (Table 2) are detailed in the 2006 IPCC Guidelines, including the Global Warming Potential coefficients (GWPs)[3].

As such, the 2006 IPCC Guidelines contain five volumes, each sector is extended with some source/sink categories that were not explicitly covered in the Revised 1996 IPCC Guidelines. It should be noted that these source/sink categories are not necessarily "new" because these emissions/removals could have been included in the "Other" categories even when using the Revised 1996 IPCC Guidelines, in particular if these were significant. In fact, any significant sources of emissions should be covered in national GHG inventories. Absence of technical inventory methodology in the IPCC Guidelines for certain sources does not mean that national inventories do not need to cover such sources. The current UNFCCC Common Reporting Format (CRF) applies the following numbering of sectors: 1. Energy, 2. IPPU, 3. Agriculture, 4. LULUCF, 5. Waste. These are also described extensively in the following five volumes:

- **Volume 1: General Guidance and Reporting** (with extended advice on data collection and improved Key Category Analysis -better integrated across emission and removal categories);
- **Volume 2: Sector 1 - Energy** (with as extra sources: Treatment of CO_2 capture and storage (CCS), CH4 from abandoned coal mines, Catalytic converters using urea, Uncontrolled combustion and burning of coal deposits).
- **Volume 3: Sector 2 - Industrial Processes and Product Use (IPPU)** (with clearer guidance on non-energy uses of fossil fuels and on the estimation of actual emissions of fluorinated compounds Other process use of carbonates and petrochemical and soot production have been reorganised and refined. Major new additions are: Caprolactam, glyoxaland glyoxylic acid production, Titanium dioxide production, Petrochemical and carbon black production, Lead production, Zinc production, Thin-film-transistor flat panel displays, photovoltaic and heat transfer fluid, Sulphur Hexafluoride and per-fluorocarbons from other product use (Military applications and accelerators);
- **Volume 4: Sectors 3 and 4 - Agriculture, Forestry and Other Land Use (AFOLU)** (with integration of agriculture and land use, land-use change and forestry, with consolidation of previously optional categories (e.g., CO_2 emissions and removals associated with terrestrial carbon stocks in settlements) and with detailed methods on harvested wood products and guidance on emissions from managed wetlands. Major new additions are: Indirect N_2O from manure management, CO_2 emissions from urea fertilization, N_2O from nitrogen mineralization associated with loss of soil organic matter resulting from change of land use or management of mineral soils);
- **Volume 5: Sector 5 - Waste** (with improved methodology for CH_4 from landfills, guidance on carbon accumulation in landfills and on biological treatment and open burning of waste. Major additions are: uncategorized waste disposal sites and Biological treatment of solid waste).

[3] GWP100 refers to the global warming potential for the 100-year time horizon. Under UNFCCC reporting and SBSTA34 (2011), GWPs are a well-defined metric based on radiative forcing that continues to be useful in a multi-gas approach. UNFCCC NGHGI (2018) submissions use the IPCC AR4 as scientific base for GWP conversion factors (CH_4 - 25 and N_2O - 298), (Petrescu et al 2020).

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Table 2: New sources and gases completing the 1996 guidelines in the 2006 guidelines. New categories are indicated in red.

Main category of emission sectors	Emission sectors of data	IPCC_1996	IPCC_2006
Energy comprises the production, handling, transmission and combustion of fossil fuels and biofuels and is calculated with energy statistics. For CO2 the short cycle C is split off from the long cycle C, because the short cycle CO2 emitted from the combustion of biofuel is assumed to neutralise the CO2 uptake during the same year the biofuel was grown. Any disequilibrium of this balance needs to be taken up under the Land-Use, Land-use change and forestry sector. As such the long cycle CO2 energy refers to fossil fuel combustion only, the short cycle CO2 energy refers to the biofuel combustion. All other substances include fossil and biofuel combustion. This includes also the fugitive emissions (under the 1B category), referring mainly to gas flaring and venting during oil and gas production, coalbed methane during underground or surface mining and CH4 distribution losses and evaporation during transmission and	Power industry	1A1a	1.A.1.a
	Combustion for manufacturing	1A2	1.A.2
	Energy for buildings	1A4	1.A.4+ 1.A.5.a+ 1.A.5.b.i+ 1.A.5.b.ii
	Aviation	1A3a	1.A.3.a
	Railways, pipelines, off-road	1A3c+ 1A3e	1.A.3.c+ 1.A.3.e
	Shipping	1A3d+ 1C2	1.A.3.d
	Road transportation	1A3b	1.A.3.b
	Coal mining and Handling	1B1a+1B1b	1.B.1.a+ 1.B.1.ai3 (Abandoned Underground Mines) +1.B.1.b (uncontrolled burning coal dumps) +1.B.1.c
	Oil and Gas exploitation (incl. Venting&flaring)	1B2a1-4 +1B2b + 1B2c	1.B.2.a.i-ii-iii(1-3)+ 1.B.2.b.i-ii-iii (1-5)
	Oil refineries and transformation industry	1A1b+ 1A1c+ 1A5b + 1B2a5-6+ 2C1b	1.A.1.b+ 1.B.2.a.iii(4-6)+ 1.A.1.c+ 1.A.5.b+ 1.B.2.b.iii.3
	Other	Incl. Elsewhere	1B3 (geothermal) +1.C (CO2 Capture&Storage)
Industrial Processes and Products Use refer to non-combustion emissions from either manufacturing of cement, lime, soda ash, carbides, ammonia, methanol, ethylene, methanol, adipic acid, nitric acid, caprolactam, glyoxal and other chemicals, or from production of metals and from the use of soda ash, limestone and dolomite, from production of ferrous and non-ferrous metals and from non-energy use of lubricants and waxes. The emission estimates use the volume of industrial product produced (and traded) from the industry statistics. This includes also the Solvents and Products use includes CO2 from solvents in paint, degreasing and dry cleaning, chemical products and other product use, as well as use of N2O as anaesthesia and in aerosol spray cans.	Mineral processes	2A1-4 (mineral, dolomite, soda)	2.A.1+2.A.2+2.A.3(+glass)+2.A.4 (+Other Process Uses of Carbonates)
	Chemical processes	2B1(NH3)-2B5(other)+2E	2.B.1(without urea-CO2) +2.B.2+2.B.3+ 2.B.4(Caprolactam, Glyoxaland GlyoxylicAcid Production) +2.B.5+ 2.B.6(TiO2) +2.B.7 (soda ash)+2.B.8(petrochem.+C-black)+ 2.B.9(fluorochem.)
	Iron and steel production	2C1a-f+ 2C2	2.C.1+ 2.C.2
	Non-ferrous metals prod.	2C3+ 2C4+ 2C5	2.C.3+ 2.C.4+ 2.C.5+ 2.C.6 (Pb) + 2.C.7 (Zn)
	Non energy use of fuels	2G+2A5-6(asfalt+road)	2.D.1 (lubricants)+ 2.D.2(parafin wax)+ 2.D.4
	Food and Paper	2D	2.H
	Solvents and products use	3A-D (paint-clean)	2.D.3+ 2E+ 2F+ 2G
Agriculture, Forestry and Other Land Use comprises agriculture with the application of urea and agricultural lime, enteric fermentation, rice cultivation, enteric fermentation, manure management, fertiliser use (synthetic and manure), agricultural waste burning (in field) and is based on agricultural statistics.	Agricultural soils, incl. Rice and N2O from agriculture	4C+ 4D, incl. 4D3	3.C.2(liming)+ 3.C.3+ 3.C.4-5(direct+indirect N2O from soil)+ 3.C.6(indirect N2O from manure)+3.C.7
	Agricultural waste burning	4F	3.C.1.b
	Enteric fermentation	4A	3.A.1
	Manure management	4B	3.A.2
This includes also large scale biomass burning (with Savannah burning, Forest fires) as well as carbon stock change (forest land remaining forest land, or converting into agriculture or other land use).	Savannah burning+other	4E+4G	3.C.1+ 3.C.8+ 3.D.1(harvested wood prod.)+ 3.D.2
	Land Use, Land-Use Change and Forestry (+Forest Fires)	5 (incl. 5F)	3.B.1-6 (forestland + cropland + grassland + wetlands + settlements + other land)
Waste comprises landfills and wastewater management, and waste incineration that is not producing energy (neither generation of electricity nor heat recovery, because these are accounted in the energy sector(non-energy). Estimates are based on a combination of population and solid and liquid waste product statistics.	Solid waste incineration	6C	4.C.1+ 4.C.2 (open burning of waste)
	Solid waste disposal/ landfills + other	6A+ 6D	4.A.1-3 (+uncategorised waste)+ 4.B(biological treatment of solid waste) + 4.E
	Waste water handling (domestic/industrial)	6B1-2	4.D.1-2
Other refers to direct emissions from fossil fuel fires (coal fires & the Kuwait oil fires), N2O usage and indirect emissions from atmospheric deposition of NOx and NH3 from non-agricultural sources.	Fossil Fuel Fires	7A	5.B
	Indirect Emissions	7C	5.A

One of the elements that contribute to the overall improvement of the inventories is that both IPCC 2006 and UNFCCC guidelines include the five principles of transparency, accuracy, consistency, comparability

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and completeness (TACCC). These should help in a more structured approach with the option for more accurate methods and data and helping to avoid double counting or omissions. These five principles TACCC are defined as follows:

- ***Transparency***: All assumptions and methodologies used for an inventory need to be explained to facilitate replication and assessment of the inventory by users of the reported information.
- ***Accuracy:*** The relative measure of the exactness of an emission or removal estimate should be given and uncertainties should be reduced as far as practicable.
- ***Consistency:*** A time series of inventories shows internal consistency amongst inventories of different years, 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:*** Estimates of emissions and removals reported by Parties in inventories are comparable among Parties, if all Parties use the methodologies and formats agreed by the COP for estimating and reporting inventories. The allocation of different source/sink categories should follow the split of the IPCC Guidelines, at the level of its summary and sectoral tables;
- ***Completeness:*** An inventory should cover all sources and sinks, as well as all gases, included in the IPCC Guidelines as well as other existing relevant source/sink categories which are specific to individual Parties. Completeness also means full geographic coverage of sources and sinks.

The Land Use remained a special focus, requiring special attention to certain issues, one of them the methodological guidance for the land-use category wetlands (Chapter 7 in volume 4 of AFOLU). In 2010 the IPCC concluded that new scientific information is available on rewetting & restoration of peatlands, ditches, waterborne carbon, constructed wetlands for waste water disposal and SBSTA invited in December the IPCC to draft a Wetlands Supplement. This report with the title “Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands - Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment” was published in 2013. It describes emissions and removals from lands with organic soils and with wet mineral soils in Wetlands and other land-use categories with these soil types that are subject to human activities (‘managed’) with special attention to: (i) drained inland organic soils, (ii) rewetted organic soils, (iii) coastal wetlands, (iv) inland wetland mineral soils, and (v) constructed wetlands for wastewater treatment.

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5. Latest improvements after COP21 in Paris Agreement

5.1. The enhanced transparency framework of the Paris Agreement

At the COP21 held in December 2015, 195 out of the 197 Parties to the UNFCCC agreed to engage with strengthened efforts in combating climate change. The Paris Agreement – PA (UNFCCC, 2015) came into force in 2016 and was already one year later ratified by 174 Parties. It is a landmark agreement, representing a paradigm change for three reasons. Firstly, it downplays the distinction between Annex I (developed) and non-Annex I (developing) parties as introduced by the UNFCCC itself and calls for the contribution of all countries having them all on-board with their own measures, the so-called Nationally Determined Contributions (NDCs). Secondly, it recognizes that the climate change is unavoidable with the burden of change falling heavily on vulnerable countries and calls for adaptation (with the same prominence as mitigation) under the NDCs (Figure 5). Last but not least, the PA establishes an enhanced transparency framework, with all information on the NDCs as well as on the anthropogenic emissions envisaged by each Party in a fully transparent way and freely accessible to any citizen.

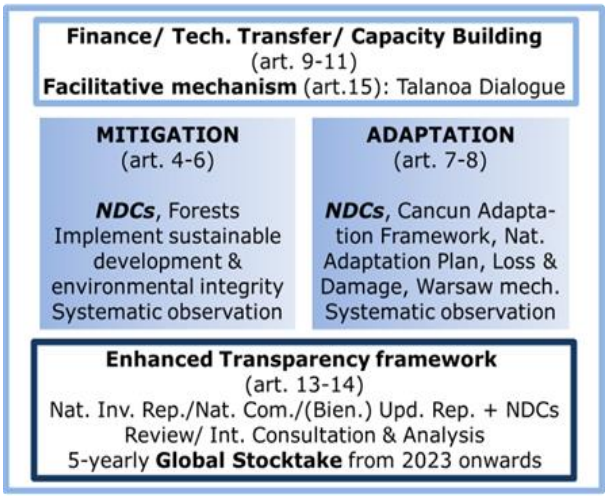

Figure 5: The pillars of the Paris Agreement (2015)

The enhanced transparency framework further builds on the Monitoring – Reporting – Verifying (MRV) framework that was established for the national GHG inventories of each Party and used under the Kyoto Protocol. The MRV framework imposes for the inventories a Measurable, Reportable and Verifiable component, following the IPCC (2006) national inventory guidelines for inventory compilers as well as reviewers. Developed (Annex I) countries, which bear the largest responsibility for the current climate change because of their large historic emission rates and because of their continued high product consumption rate, are reporting time-series of their inventory, whereas the developing (non-Annex I) countries are asked to submit Biennal Reports (BR) with a complete inventory (not per gas but in CO_2-equivalent). For the timeseries of inventories from the Annex I countries, the long established annual review process continues, whereas for the Biennial Update Reports of developing countries an

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international consultation and analysis process is introduced, as presented in Figure 6. Improvement by exchange of good practices is fostered in facilitative multilateral considerations of progress (FMCP), to which countries at least every two year will participate.

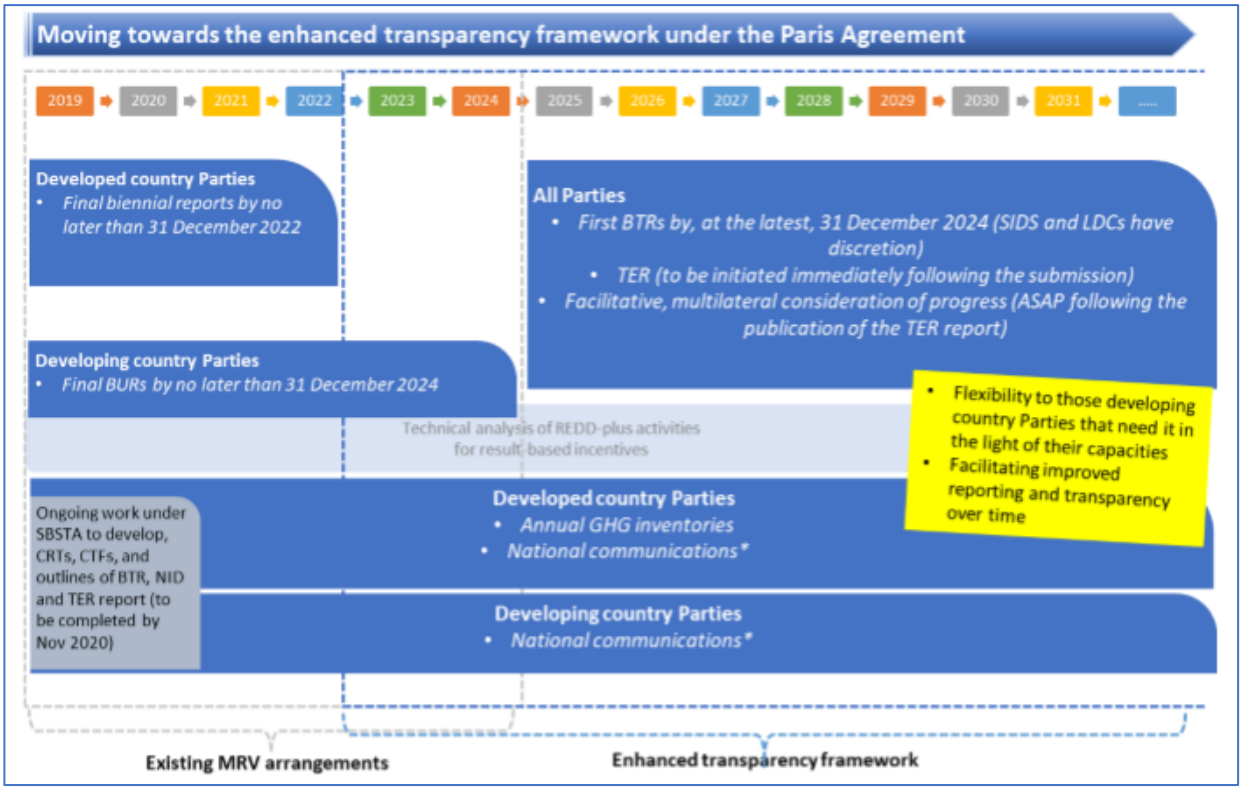

Figure 6: Time map for data entry into the enhanced transparency framework of the Paris Agreement

UNFCCC should receive, with a maximum time lag of two years, national emissions inventories from each of the 197 parties, but not all countries did provide a national inventory and non-Annex I countries (154 in total) do not provide a complete time series of inventories. In addition, many countries lack a well-developed statistical infrastructure, which is needed for a detailed BU inventory. For these countries, trend analysis can help tracking directly the trend of the growing part of the inventories (Janssens-Maenhout et al., 2019). An important role here is played by scientific BU inventories with consistent methodology to fill the knowledge gap due to linking only a few inventories of discrete years.

Both, continuity of knowledge but also observation-based evidence are important, in order to address the problem of the real level of GHG measured in the atmosphere. Since 2017, the Subsidiary Body for Scientific and Technological Advice (SBSTA) acknowledged the complementary capability offered by the GHG monitoring through in situ measurements as well as from satellite observations (UNFCCC SBSTA report No.49, November 2017). In addition, the 2019 refinement of the IPCC guidelines for national inventories (section 2.3) are reaching out to include this extra evidence with independent observations (IPCC, 2018). This is also an important step in linking the inventory information from the IPCC Task Force

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for national GHG inventories and the atmospheric knowledge from the IPCC Working Groups in charge of the Assessment Reports.

Sustained political commitments and even further policy evolution is desirable in three main ways:

1. The fostering of a strong and **sustainable statistical data infrastructure** remains essential. The statistical data summarizing human activities are directly linking to the single drivers of anthropogenic emissions and to the individual mitigation efforts. International agencies such as the IEA and the FAO are very helpful in the standardization and harmonization of reporting procedures and they provide the basis for international bottom-up emissions databases.
2. A **transboundary, multi-scale approach** for the GHG problem (from local to global) is needed. Monitoring of the atmospheric GHG concentration indicates the contributions of hot spots, such as large cities and industrial complexes, rather than the country totals. Even though no local information at subnational level needs to be reported to the UNFCCC, the NDCs will be implemented on a local scale for all practical purposes. Several local governments, such as the Covenant of Mayors, started to take climate action in parallel, going beyond the national commitments (e.g. Kona et al., 2016). Also industrial complexes, often multinationals, are climate actors and involved in the Clean Development Mechanisms and Joint Implementation Plans. Such multi-level governance asks for the monitoring of GHGs not only with national totals, but also with spatially resolved emissions.
3. A reference framework with common standard that is "verified" with **observation-based evidence** needs to be shared with all Parties, so that climate negotiations can refer to a common understanding of the GHG emission problem as a whole and over a specific region. Therefore, under the Copernicus Programme an operational system for the verification and monitoring of anthropogenic CO2 emissions using also atmospheric measurements as independent observation is under construction. This would strengthen the enhanced transparency framework of the Paris Agreement, by complementing the national inventory data with atmospheric observations and observation-based top-down knowledge. Although continued need for static inventories made with sector-specific statistics of human activities is still required to connect to the drivers of the anthropogenic emissions, also direct observations of concentrations can bring relevant information for monitoring and solving the problem. The atmospheric measurement data are now available as a fast and dynamic data flow and can compensate the two years delay in accounting of the annual balance with human activity statistics that is unavoidable.

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5.2. The Katowice Rulebook for the Global Stock Take Exercises

The Katowice Rulebook (December 2018, COP24) establishes the basic procedures and mechanisms for implementing the PA, while respecting the different socio-economic realities of all countries nevertheless raising the ambitions of climate action. The Katowice Rulebook emphasizes the importance of the inclusiveness and transparency (see shaded issues below):

- ***Mitigation with register of nationally determined contributions:*** with the progress tracking for the NDCs and the required information for the commitments. The registry portal will contain all previously submitted NDCs. Climate pledges from 2031 should cover NDCs for a common period, but it needs to be decided whether this is 5 or 10 years.
- ***Adaptation communications with register:*** with all adaptation measures (incl. needs and requirements of all Parties) and capacity building
- ***Loss and damage with financial target***: a more comprehensive picture of the challenges under climate change (and linking to Article 8 of the Paris Agreement) will be given, also to support the new common financial target for 2025 of 100 billion USD for developing countries (provided by Annex I and II countries)
- ***Indigenous peoples platform and just declaration:*** operationalisation of local communities' & indigenous peoples' platform, an unprecedented partnership, as an important tool to combat climate change. The Silesian Declaration on Solidarity and Just Transition concerns a just transition of the workforce and the creation of decent, quality jobs, in cooperation with civil society and stakeholders.
- ***Transparency:*** adoption of full transparency guidelines, with a single system for all Parties. All parties shall have submitted their first biennial report by the end of 2024, using the IPCC (2006) Guidelines. In order to increase the efficiency of activities undertaken as part of the Convention, the new transparency system will replace the existing reports (Nat.Com, BR, BUR) and the current data review systems (TER, ICA, IAR).
- ***Global review:*** a five-yearly process assessing the collective progress in efforts to curb and adapt to climate change before the Parties submit further NDCs. The global review, which will start at COP29 in 2023 consists of three phases: (i) information gathering, (ii) technical evaluation, (iii) political discussion of the results. In addition the Multilateral Facilitative Consideration of Progress helps in a dialogue between Parties of the same region to exchange good practice.
- ***Compliance committee:*** is mandated (i) to initiate procedures in agreement of the Parties in the event of serious and persistent failure to comply with the transparency guidelines, and (ii) to address systemic issues with the functioning of the Paris Agreement implementation system.
- ***Mechanisms:*** cover the areas of the Paris Agreement where agreeing on implementing regulations was not possible (in particular Article 6 of the Paris Agreement)

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5.3. The 2019 Refinement of the IPCC 2006 guidelines

The 2019 Refinement (IPCC, 2019), adopted on 12th May 2019, provides refined information contained in the 2006 IPCC Guidelines. The overall aim of the 2019 Refinement is to update with sound scientific basis the guidelines for preparing continuously improved NGHGI, in general, without being prescriptive and while keeping the concept of "Good Practice" unchanged. It does this by (i) identifying text in the 2006 Guidelines that remains unchanged, (ii) by providing new guidance and (iii) by providing revised text from the 2006 Guidelines. Users of the 2019 Refinement are expected to refer to the 2006 Guidelines (and the Wetlands Supplement) for those sections that are entirely unchanged, and the 2019 Refinement for the modified guidance. As such the 2019 Refinement is structured along the same five volumes as the 2006 IPCC Guidelines:

- **Volume 1: General Guidance and Reporting**: The 2019 Refinement helps implementing the Paris Agreement with Modalities, Procedures and Guidelines for an enhanced Transparency Framework, but is not limited to that. In principle, the 2006 IPCC Guidelines provide methods for estimating emissions and removals for each greenhouse gas in mass units, but the UNFCCC decides which metrics (e.g. for the CO_2-equivalent) need to be used. It is recognized that uncertainty is not a measure to compare the quality and efforts of different national inventories but it should be used to track increasing quality assurance and control over time. When the point estimate is very low the percentage uncertainty value may become very high and uncertainty is better expressed as the confidence interval around the point estimate. Uncertainty results depend on the national circumstances and share of sectors and categories. Moreover, for the purpose of key category analysis, there is no distinction between direct GHG emissions and indirect CO_2 inputs to the atmosphere (incl. unoxidized carbon contained in compounds (CO, NMVOCs, CH_4) emitted from human activities, forming CO_2 later in the atmosphere.
- **Volume 2: Energy:** addresses the new insights and extends the 2006 IPCC Guidelines with:
    - Additional emission sources: the oxidation (and CO_2 emissions) from coal exploration mining (calculated using the newly defined "augmentation of coal resources"), fugitive emissions from abandoned underground and surface mines (with year-specific default EF), extra methodology for surface mines, default EF for abandoned wells, transforma-tion losses for the production of biochar (in addition to the charcoal) or of syngas;
    - New technologies (evolved and diversified for distinct countries): using country-specific information from local databases (e.g. China), methods for new fuel production and transformation technologies (e.g. biomass to liquid, biomass to gas, wood pellet production) (incl. decision trees);
    - Clarifications to avoid double counting: with the increased use of biofuel, it has become very important to address the biofuel-related emissions sources, which need to be reported under the AFOLU sector. Another crosscutting issue for the fuel transformation is coordinated with the IPPU sector.
- **Volume 3: Industrial Processes and Product Use**: extends the 2006 IPCC Guidelines also with:
    - Additional emission sources: GHG hydrogen, rare earth metals, and alumina, and waterproofing of circuit boards;

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- New methods: for fluorinated treatment of textiles, carpet, leather and paper; for equipment leaks and process vents of fluorochemical production; for iron&steel metallurgical coke production (avoiding duplication with the energy sector), a new Tier 2 for CH_4, new Tier 3 (facility- or measurement-based carbon balance for CO_2; for flaring new Tier 1 for process gases and N_2O emissions; for Al production new Tier 1-2-3 methods for low and high voltage anode effects; for semiconductor manufacturing new wafer Tier 2-3 for wafer-production and new Tier 2 for microelectricalmechanical systems and new Tier 1-2 for by-products, for refrigeration and air conditioning new guidance for hydrofluorocarbon emissions;
- New technologies: dual-pressure processes for nitric acid production, new smelting technology classes for Al production, incl. new Bayer-Sinter and Nepheline processes.

- **Volume 4: Agriculture, Forestry and Other Land Use:** considerably elaborated this sector with:
  - New option to treat the interannual variability for disaggregate managed land proxy emissions and removals (incl. new definitions, disaggregated contribution of natural disturbances, good practices);
  - New Tier 3 method with guidance on parametrisation and evaluation of models (increasing transparency);
  - Methodological updates: of Tier 1-2 method for the biomass estimates from forest land, cropland and settlements (incl. dead organic matter, allometric model guidance and biomass maps); of Tier 1 soil carbon stock change for tillage management, grassland management and land-use with soil impact (incl. updated reference C stocks at global level with different soil types and climate regions); of Tier 2-3 methods for biochar amendments on soil carbon stocks in mineral soils for cropland and grassland; Tier 1 update for water management regimes before and during rice cultivation; new stock change approach, simple-decay and atmospheric-flow approach for harvested wood products;
  - Emission factor updates for livestock and manure management and soil N_2O: Tier 1 updates distinguishing high and low productivity systems, with consistent activity data (for N_2O and CH_4) from manure management, with new methane conversion factor for animal waste management system, latest available scientific data for direct and indirect N_2O from soil;
  - Additional emission source: of GHG from land converted to flooded lands and flooded land remaining flooded land (following the managed land proxy).
- **Volume 5: Waste:** 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 and provides new defaults and uncertainties for carbon content, nitrogen content and degradable organic carbon. Updates were given for:
  - New techniques and practices: treating different management conditions of solid waste disposal sites, treating different gasification and pyrolysis techniques for incineration and open burning of waste, for septic systems and centralised wastewater treatment plants (with CH_4 emission factor updates)
  - Additional source of emissions: of N_2O and CH_4 from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environment; of fossil CO_2 from wastewater treatment and discharge.

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Through these improvements the 2019 Refinement of IPCC fosters the UN Parties (and their national inventory agencies) to use more statistics and information and to apply more detailed models. In this way, the national inventories are expected to reduce the uncertainty and to improve the geocoverage and spatial representation, as shown in Figure 7.

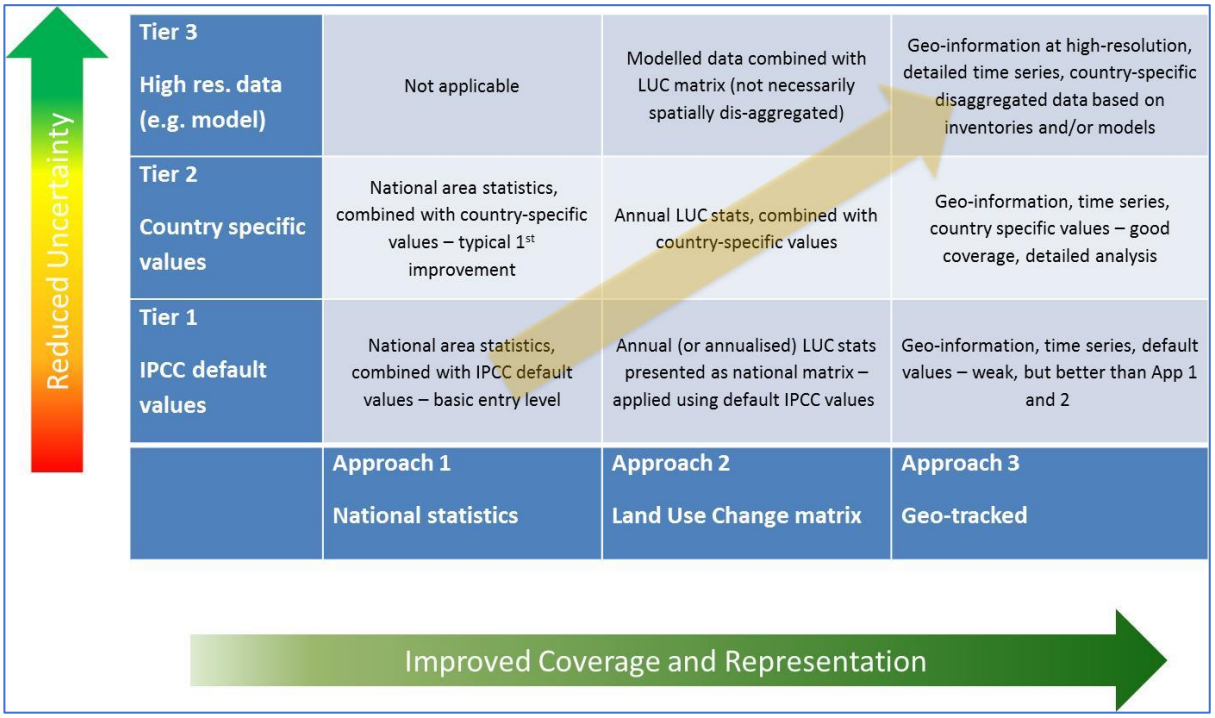

Figure 7: Moving towards higher Tier with more statistics and information and more detailed models, improving the spatial representativeness.

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6. Implementation of the guidelines in the European Union

In order to implement the UNFCCC with the Kyoto Protocol and the Paris Agreement, the European Union has adopted a series of directives and regulations in successive packages strengthening the measures towards lower emissions. These measures include the 2003 emissions trading directive (ETS), the 2014 climate and energy package and the 2018 effort sharing regulation. In addition, specific mechanisms have been added (e.g. for vehicles, for buildings) to impose effective instruments to direct investments into more energy-efficient means (Table 3). The GHG monitoring is key in the tracking of the implementation of the mitigation measures and the Climate Monitoring Mechanism Regulation (MMR) is therefore a corner stone of EU's climate policy. This has been extended with the LULUCF Regulation to account correctly also biomass use and forest growth.

Table 3: EU Directives and Regulations (D&R) on Climate change. (The reference regulation for monitoring GHGs in EU Member States is indicated in red, while the reference regulation for the carbon monitoring from the LULUCF sector is colored green.)

Directives and Regulations (D&R) on mitigation measures	D&R on adaptation/ transition
• Effort Sharing Decision (406/2009/EC) • Emission Trading System Directive (2003/87/EC) • Energy Efficiency Directive (2012/27/EU) • Energy performance of buildings Directive (2018/844/EU) • F-gas Regulation (EU) 517/2014 • Fuel Quality Directive 98/70/EC • Policy framework for climate and energy in the period from 2020 to 2030 COM(2014) 15 • Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action • Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement ('Effort Sharing Regulation') • Regulation (EU) 2019/1842 on further arrangements for the adjustments to free allocation of emission allowances due to activity level changes. • Regulations on CO2 from new passenger cars (443/2009/EC), new vans (light duty vehicles) (510/2011/EU) and new heavy-duty vehicles (2018/956/EU, 2019/1242/EU) • Renewable Energy Directive (2009/28/EC)	• EU Adaptation strategy (COM (2013) 216) • Floods Directive (2007/60/EC) • Forest strategy (COM(2013) 659) • Green Infrastructure Strategy (COM/2013/0249) • Long-term strategy 'A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' (COM(2018) 773) • Marine Strategy Framework Directive (2008/56/EC) • Thematic Strategy for Soil Protection (COM(2006) 231) • Sustainable Finance initiative • Urban agenda for the EU • Water Framework Directive (2000/60/EC)
Directives and Regulations on GHG monitoring	Generic Directives & Regulations
• Climate Monitoring Mechanism Regulation (MMR) (EU) 525/2013 and Implementing/Delegated Acts	• Copernicus Programme Regulation (377/2014/EU) • Inspire Directive

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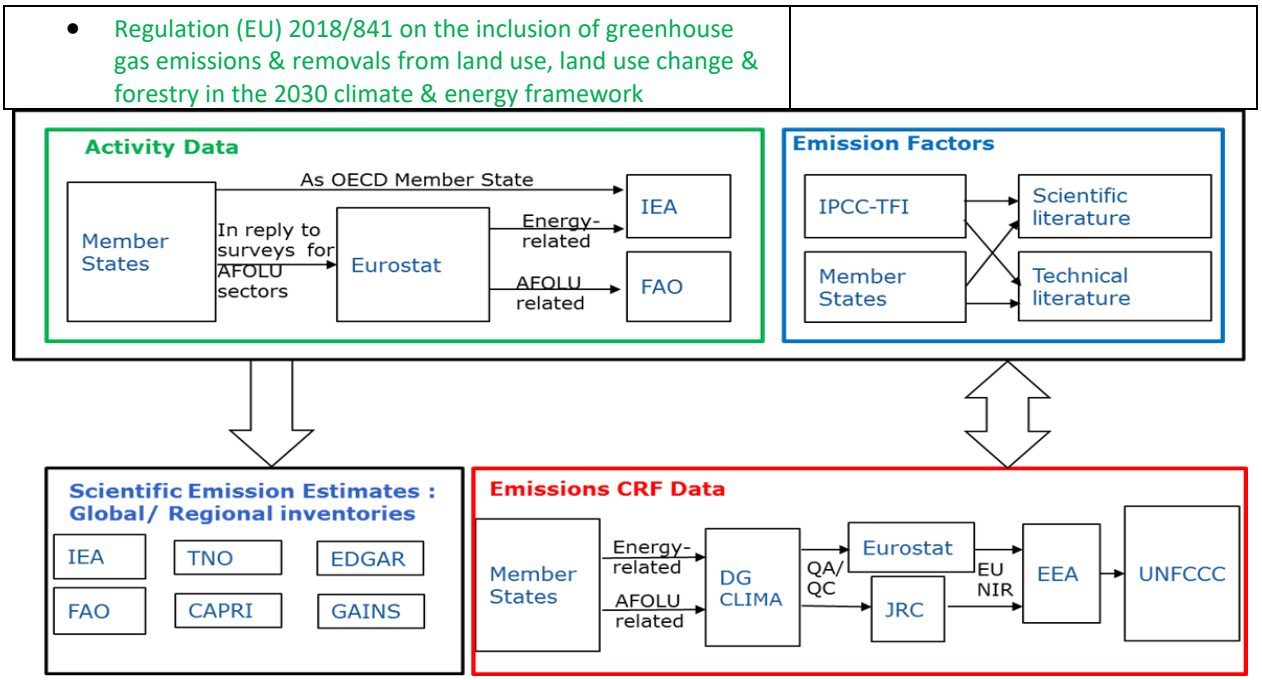

Figure 8: Data flow within EU for the GHG activity data and emissions (Petrescu et al., 2020).

In these regulations the European Environment Agency (EEA) is tasked to care of the reporting (mentioned in the regulation as "text with EEA relevance"). They provide the overview of all 39 European EEA countries and EU's GHG inventories reporting, which are needed for the UNFCCC submissions. The activity data are collected by the European Statistics Office and Figure 8 gives an overview of the data flow. This dataflow is also scheduled with strict deadlines, as shown in Figure 9.

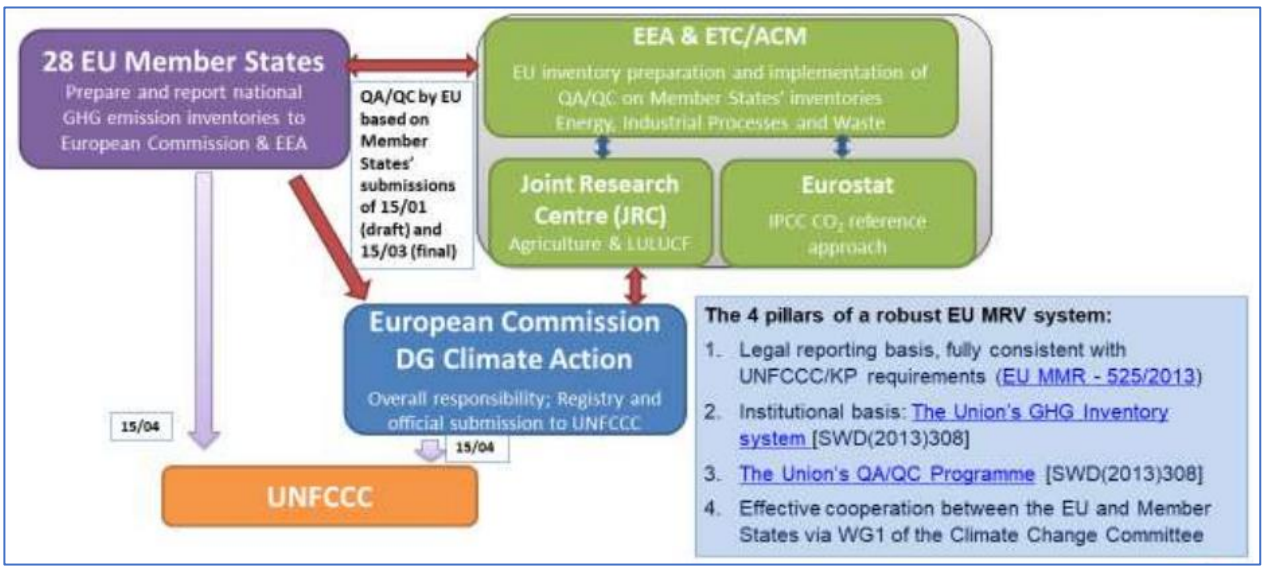

Figure 9: Overview of the organisation and scheduling of the compilation of NGHGI for EU27 and UK (UNECE, 2015)

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EEA prepares the EU Climate Action Progress Report by the end of each year, based on data submitted by Member States under the Climate Monitoring Mechanism Regulation (MMR, Regulation No 525/2013). Fig. 10 provides an overview of the targets, first set by the KP, then by the 2014 climate and energy package, which was at the basis of EU's NDCs for the PA. The EEA (2019) report describes a further decline of EU27 + UK GHG emissions by 2.1 % in 2018, reaching their lowest level since 1990. In 2018, emissions were 23.2 % below the 1990 level, which means a decrease of EU's contribution to global emissions from 15 % to 8 %. By the end May 2020, the EEA re-submits the 2020 EU GHG inventory to the UNFCCC Secretariat, which is then subject to review by the UNFCCC in November.

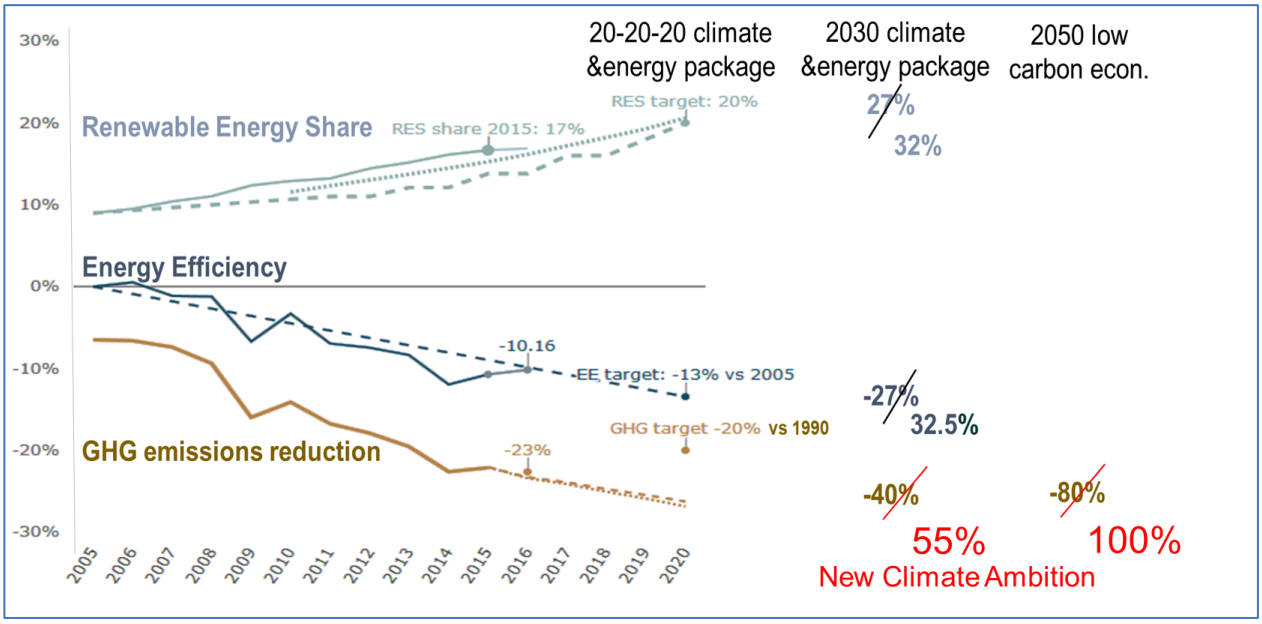

Figure 10: Overview of the targets for the EU, from the KP to the PA.

As required under article 21 of the MMR Regulation 525/2013, the European Commission prepares on an annual basis and before the COP a report (Staff Working Document) to the European Parliament and the Council on the Climate Action Progress, following a rigid structure, addressing the following chapters:

1. ***the EU ETS emissions reporting and compliance***: GHG emissions from all operators covered by the EU ETS in 2019 have to be reported by 31 March and surrendered by a corresponding number of allowances by 30 April. The verified emissions data are made available on the European Union Transaction Log (EUTL) on 1 April 2020, displaying by 1 May 2020 also the compliance data. Despite of COVID19 pandemic, all reporting was timely completed and >99 % compliant and showed overall a reduction by 8.7 % in 2019 compared to 2018 (-15 % for power generation, -2 % for manufacturing, -1 % increase for aviation). In order to prepare for phase four of the EU ETS, the Monitoring and Reporting Regulation 2018/2066 (MRR) and the Accreditation and Verification Regulation 2018/2067 (AVR), stemming from Articles 14 and 15 of the EU ETS Directive, have been reviewed. The Delegated Regulation amending the ETS Auctioning Regulation 2019/1842 on the changes to free allocation when the activity level of installations change entered into force on November 2019. It establishes rules for further changes once the 15% increase or decrease on

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activity levels set in the ETS Directive is reached to ensure continued successful auctions in phase four of the EU ETS (2021-2030). In May 2020, the Commission published the invitation to the procurement of the third common auction platform of the EU ETS, auctioning from 2021 allowances for 25 EU MS and 3 EEA-EFTA states and allowances for the Innovation Fund & the Modernisation Fund.

2. ***the emissions of the Effort Sharing (ES) Decision and Regulation***: EU27, UK, Iceland and Norway agreed to reduce GHG from non EU ETS sectors, namely the agriculture, transport, waste and building, with 40 % by 2030 compared to 1990 (Fig. 10). Review of the ES Decision inventories and exchange of good practices (incl. lessons learned from ex-post evaluations) are prepared and ongoing. The ES Regulation targets from 2021 to 2030 are calculated based on inventory data of 2005, 2016, 2017 and 2018.
3. ***the emissions from LULUCF***: For the implementation of the LULUCF Regulation (2018/841), the Commission published on June 2019 technical recommendations on the National Forestry Accounting Plans including the proposed benchmarks called Forest Reference Levels. EU GHG from LULUCF should balance by at least an accounted equivalent removal of CO_2 from the atmosphere in the period 2021–2030, the so called 'no-debit' rule. EU MS have submitted revised plans with an adjusted Forest Reference Level, which the Commission is assessing, in order to propose Forest Reference Levels for the delegated act for adoption by fall 2020.
4. ***the developing EU legislation (incl. transport and Energy Union governance)***: The Commission assessment (EC, 2019) of the Member States' draft national energy and climate plans (NECPs) under Regulation (EU) 2018/1999 includes an overall assessment and recommendations and underpinning analysis for each Member State. The Energy Council will follow this up with a focus on increasing the ambition levels for renewable energy and energy efficiency to achieve the EU level targets. The implementing act under the Governance Regulation prepared structure, format, processes and requirements on the establishment, operation and functioning of the Union greenhouse gas emission inventory system. The Commission recently adopted a Delegated Regulation with regard to values for global warming potentials and the inventory guidelines and with regard to the Union inventory system and repealing Commission Delegated Regulation (EU) No 666/2014.
5. ***climate finance:*** Provisions related to reporting on climate finance need to be in line with the Regulation on the Governance of the Energy Union and Climate Action. An e-reporting platform (ReportNet) needs to be updated so that EU MS can report all climate info by March 2021 under the Regulation.
6. ***Adaptation***: a "New EU Strategy on Adaptation to Climate Change" is under preparation (building on the 2013 strategy and the 2018 revision) and foreseen to be adopted early 2021.
7. ***participation in international climate policy***

An accompanying document to the Staff Working Document provides the technical information with country factsheets per country. An example of such country factsheet is given in Figure 11, Figure 12 and Figure 13.

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Country fact sheet: Belgium

1. Total greenhouse gas emissions

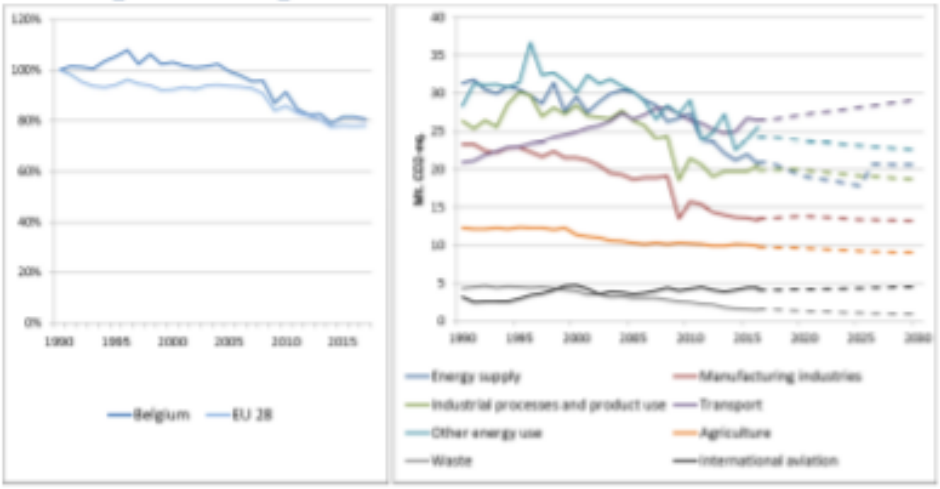

Figure 4: Left side: Total greenhouse gas emissions 1990-2017 (index 1990=100%). Right side: Total greenhouse gas emissions by sector – historical emissions 1990-2016, projections 2017-2030 (Mt. CO2-eq.).5

Figure 5: Share of emissions covered by the ETS and the ESD (2016).6

5 National total, including international aviation.
6 Excluding international aviation, CO2 from domestic aviation and NF3.

Figure 11: Factsheet example for Belgium (part 1) (EC- DG CLIMA, 2019)

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4. ETS emissions

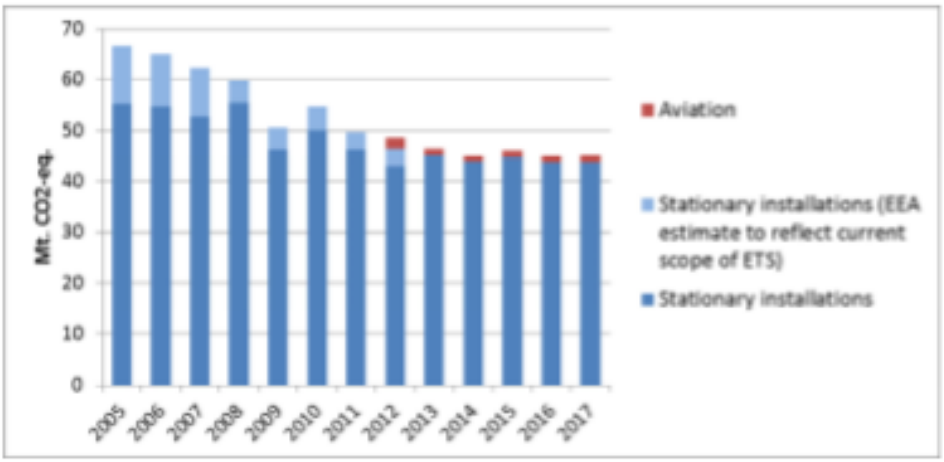

Figure 3: ETS emissions (Mt. CO2-eq.).7

3. Emissions in Effort Sharing sectors

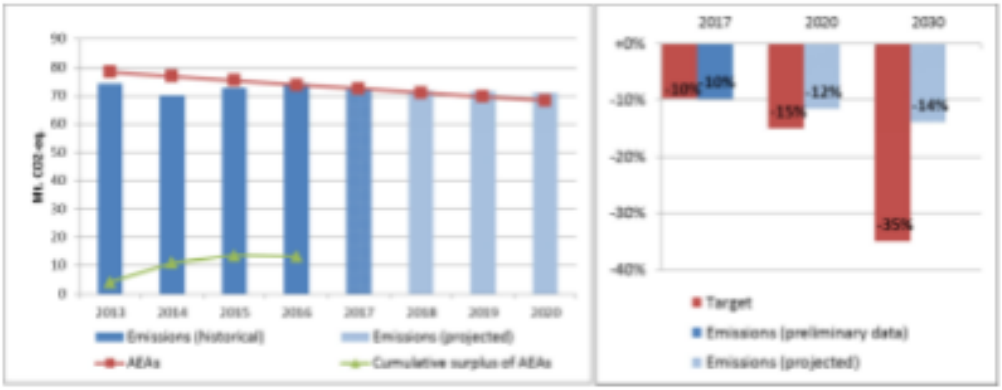

Figure 4: Left side: Emissions, annual emission allocations (AEAs) and accumulated surplus/ deficit of AEAs under the Effort Sharing Decision 2013-2020 (Mt. CO2-eq.). Right side: Emissions and targets under the Effort Sharing Decision/ Effort Sharing Regulation 2017, 2020 and 2030 as percentage change from 2005.

7 The scope of ETS was extended from 2013. To reflect the current scope of ETS, an estimate made by EEA is included in the figures from 2005 to 2012. The estimate covers only emissions from stationary installations.

Figure 12: Example factsheet for Belgium (part 2-3)

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4. Land use, land use change and forestry

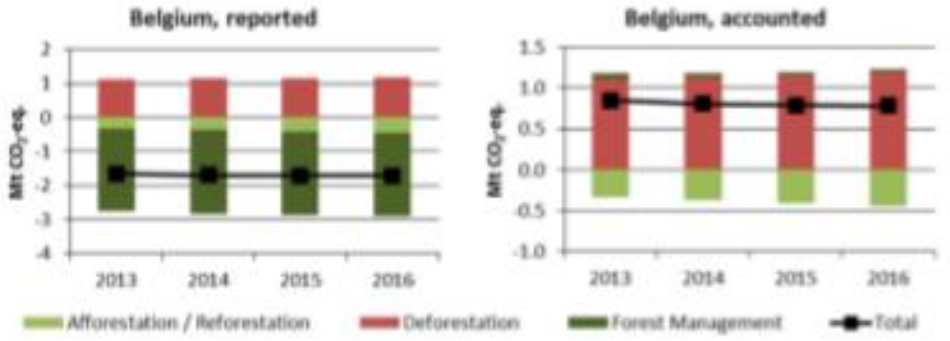

Figure 6: Reported and accounted emissions and removals from LULUCFs

Reported quantities under the Kyoto Protocol for Belgium show net removals of, on average, -1.7 Mt CO_2-eq for the period 2013 to 2016. In this regard Belgium contributes with 0.4% to the annual average sink of -384.4 Mt CO_2-eq of the EU-28. Accounting for the same period depicts net debits of, on average, 0.8 Mt CO_2-eq, which corresponds to a negative contribution of -0.7% of the EU-28 accounted sink of -115.7 Mt CO_2-eq. Belgium is one of six EU Member States which show net debits in this preliminary accounting exercise. Reported net removals show no notable trend, while accounted net debits depict slight decreases.

Data sources:

Figure 1: Annual European Union greenhouse gas inventory 1990–2016 (European Environment Agency). Approximated EU greenhouse gas inventory 2017 (European Environment Agency). Member States national projections, reviewed by the European Environment Agency.

Figure 2: ETS data viewer (abstract from European Union Transaction Log 20.07.2018). Final reviewed ESD data (...).

Figure 3: ETS data viewer (abstract from European Union Transaction Log 20.07.2018).

Figure 4: Final reviewed ESD data 2013-2016 (...). Approximated EU greenhouse gas inventory 2017 (European Environment Agency). Member States national projections, reviewed by the European Environment Agency.

Figure 5: European Commission based on data accounted and reported by Member States under the Kyoto Protocol (...).

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8 The differences between reported and accounted emissions from LULUCF under the Kyoto Protocol are described in part 1b.

Figure 13: Example Factsheet for Belgium (part 4)

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The von der Leyen Commission puts the European Green Deal (EC, 2019b) forward, with the climate neutrality ambition for 2050 as first priority. It outlines investments needed and financing tools available, covering all sectors of the economy, notably transport, energy, agriculture, buildings, and industries such as steel, cement, ICT, textiles and chemicals, and explains how to ensure a just and inclusive transition. A first European Climate Law (proposed in March 2020) enshrines the ambitious 2050 climate neutrality target into law. Two types of mitigation measures are proposed:

- An extension of the EU ETS is proposed to cover also the maritime sector, traffic and construction. The economics of such proposal need to be analysed for the industry.
- To offset a remaining part of fossil fuel emissions that cannot be cut, it is proposed that the agriculture, forestry, and other land use (AFOLU) sectors and in particular the LULUCF become a net carbon sink. The current forest sink will need to be maintained or enhanced, which is difficult given the increasing demand of forest-related products (including biofuel) and the increasing climate change pressure on forest productivity and health. Moreover, the Common Agricultural Policy will need to go greener, which requires to identify the most promising management practices that are with uncertainty delivering on mitigation.

The monitoring of the AFOLU sectors, in particular LULUCF, requires special attention, for which a certification of carbon removals and an incentive for land-based carbon sequestration is under preparation.

To enable the scaling up and wider dissemination of the removal of carbon from the atmosphere through both nature-based and technological solutions, the Green Deal's priority of ***the Circular Economy Action Plan*** of EC (2020a) proposes the initiative to certify carbon removals. This initiative explores the development of a regulatory framework for the certification of carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals. It is an important step towards providing regulatory mandates and/or incentives for the medium-term market take-up of carbon removal solutions. The Commission is starting to investigate ways to operationalize carbon removal certification.

In addition, carbon sequestration is promoted through further two Green Deal priorities. Firstly, the ***Farm to Fork Strategy*** of EC (2020b) proposes a new EU carbon farming initiative with a new business model for carbon sequestration by farmers and foresters under the Common Agricultural Policy or other public or private initiatives. Secondly, the ***Biodiversity Strategy*** (EC, 2020c) commits to planting at least 3 billion additional trees in the EU by 2030, and promotes nature-based solutions to climate change such as protecting and restoring wetlands, peatlands and coastal ecosystems, or sustainably managing marine areas, forests, grasslands and agricultural soils. All these initiatives need to be supported by robust rules to tackle land-specific challenges (e.g. the permanent or additional carbon removals), and by observations with accurate, integrated and spatially explicit datasets.

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7. Further scientific efforts & the Global Emissions Initiative

The extensive network of emissions experts covering most source types and world regions of the Global Emissions InitiAtive, GEIA (http://www.geiacenter.org/) has witnessed a crucial change in the quantification and understanding of the GHG emissions. Today's scientific capabilities, with near-real-time in-situ and remote sensing observations in combination with forward and inverse models and a better understanding of the controlling processes, contribute to this transformation and provide new approaches for compiling, verifying and analysing emissions (Tong et al., 2011; Frost et al., 2012; Bond et al., 2013). Expectations for increasing accuracy and completeness on emissions information is increasing. With the call for inclusiveness and transparency the accountability is ranked high in importance for international legislation. The quantification of emissions represents a key step in explaining observed variability and trends in atmospheric composition and accurate emission data are needed to control pollution swapping and track policy success.

Not so many regional and international datasets as common reference with regional or global coverage are available. As an example, an overview of the bottom-up AFOLU GHG databases that are most used in EU, are described in detail by Petrescu et al. (2020). However, GEIA kept improving emissions data access and analysis platforms over the past two decades, pushing for a larger outreach and users community for the regional and in particular the international datasets (e.g. the European Commissions database EDGAR (Janssens-Maenhout et al., 2019), the CDIAC and ODIAC database (Oda et al., 2017), the community data system CEDS (Hoesley et al., 2018), the GAINS model (IIASA, 2007) etc.). All these datasets are available via the GEIA platform ECCAD http://pole-ether.fr/eccad, and what is missing remains limited to a publicly available dataset with up to date energy statistics (which is so far rather a commercial product).

Communities were brought together, and a community effort built common emission datasets, such as the HTAPv2 inventory[4] for the community modelling hemispheric transport of air pollution (HTAP). To improve the interaction between databases, considerable effort was invested in interoperability (Hussar et al., 2008) and developing standards and metadata. Other plans include a virtual clearinghouse of scientific emissions and emission impact studies, the construction of inventory ensembles and the assimilation of observations for emission evaluation. These efforts are advanced by working groups on specific topics, coordinated either by GEIA or by other scientific initiatives working in concert with GEIA (e.g. IBBI- the Interdisciplinary Biomass Burning Initiative). Challenges for such working groups remain region-specific coverage, sectors with more lengthy emission-processes (e.g. agriculture), natural sources, biomass burning, co-emitted species, uncertainties, spatial and temporal profiles, to name a few of many.

[4] HTAPv2 is a global mosaic of the best available information by Janssens-Maenhout et al. (2015), an exercise that IIAS (T. Buttler) plans to update in 2020.

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8. Concluding remarks and recommendations

The emissions compilation activity considerably evolved over time: from an extension of the activities of the statistical office collecting data on human activities in the 20th century, into a fully scientific discipline elaborating emission maps with higher spatial and temporal distribution in the 21st century. Over the past three decades, the bottom-up inventory is more and more compared to top-down atmospheric measurements, a reality check completing our knowledge. National capabilities have been developed but some issues with some kind of transboundary character benefit from a transnational approach, such as the (international) shipping and aviation emissions, but also integration of spatial and temporal distribution profiles and last but not least inverse modelling to reconcile bottom-up and top-down emissions information.

Today, emissions compilation is no longer a voluntary activity in developed countries. Protocols or Agreements under International Conventions ask for the follow-up of the implementation of the measures and require the collection of national reports and communications. This is the case for the UNFCCC where the monitoring of GHG emissions ideally disposes over timeseries of the national emissions at sufficiently detailed level. With the increased emphasis on the transparency of such collective effort, the Paris Agreement rightly asks for biennial update reports (BUR) as well as the five-yearly global stocktake (GST).

To increase the exchange of best practices, the following recommendations are proposed at different scales:

- **Reviewing and improving national GHG inventories:** It is common practice in an international context with binding regulation to refer to prescriptive guidelines and good practices, where intergovernmental panels help providing methodologies and defaults. This includes the encouragement for national inventory agencies to use, where available information allows, higher Tier methods. Moreover, it insists on a full bottom-up uncertainty assessment while a top-down verification is still considered as an extra option. Technical reviews in an open dialogue are important to build up common understanding and increase the technical level of reporting. As such and as foreseen under the Katowice rulebook, biennial reviews of the biennial update reports BUR in a dialogue modus with “multilateral facilitative considerations of progress” are instrumental for a regional discussion and exchange on best practices. At that stage, top down information from inverse modeling over the region of interest might help in finding a common understanding of inconsistencies and discrepancies between the countries of the region of interest.

- **Drawing a complete and comprehensive global picture**: Where a mosaic of all inventories from all countries is fundamental to follow up on the measures globally, it remains important to assess the completeness of this global mosaic. This is an important task under the global stocktake of 2023 that the UNFCCC and the IPCC are preparing. It aims to provide also a reality check to the UN Parties negotiating the strengthening of the nationally determined measures. This reality check needs to build on observation-based evidence, making use of atmospheric measurements and

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inverse modeling. Inconsistencies and discrepancies between the mosaic of national inventories and a top down estimate are inevitable and international experts will be requested to provide explanations, making use of additional information with higher spatial and temporal disaggregation. It is evident that all efforts under the Global Carbon Project for the global CO_2 budget (Friedlingstein et al., 2019), the global CH_4 budget (Saunois et al., 2019) and the global N_2O budget (Tian et al., 2020) will provide crucial information for the Global Stocktake.

- **Linking the national and global scale by mapping and visualising important plumes:** spatially distributed inventories in a grid map brought together for the entire globe helps to identify issues (hotspots, inconsistencies, missing information, …). This was recognised in the air quality community, who moved on from the inventories required in the seventies towards grid maps today (cfr. Convention Long-Range Transport of Air Pollution). It helps highlighting where actions can be taken most effectively (as these have local effects, visible on a global grid map). In addition, the visualisation of the effect of emissions into the atmosphere, validated with atmospheric observations (in situ or space borne measurements) can inform the real problem and hotspots of GHG emissions causing of global warming. In the case of the ozone hole, the visualisation in maps was part of the solution. Let's hope we find the same for the GHGs.

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