Manual on the Basic Set of Environment Statistics of the FDES

GHG Statistics

(Sub-component 1.3 Environmental Quality: 1.3.1.b Global atmospheric concentrations of greenhouse gases and
Sub-component 3.1 Emissions to Air
of the Basic Set of Environment Statistics of the FDES 2013)

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Methodology sheet of the Basic Set of Environment Statistics of the FDES

Acknowledgement

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[1] New title for topic 3.1.1 is proposed: **'GHG emissions by sources and removals by sinks'**. This will require changing also the title of the sub-component in a future BSES update.

[2] It is suggested to reorder potential disaggregation categories in a future BSES update as follows: National, Sub-national, By IPCC source categories, By ISIC economic activity; also, to delete 'By tourists'.

[3] Nitrogen trifluoride (NF_3) is a new mandatory gas to be reported by Annex I Parties. To add NF_3 and Carbon Monoxide (indirect).

[4] '2019 IPCC refinement to the 2006 IPCC guidelines for National GHG inventories' added as suggested (https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html)

[5] It is suggested to substitute 'Other' by 'Carbon monoxide'.

[6] It is suggested to rename Sulphur dioxide (SO_2) to (SO_x).

Component 1: Environmental Conditions and Quality

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Statistics and related information		Category of measurement	Potential aggregations and scales	Methodological guidance
b.	Global atmospheric concentrations of greenhouse gases		• Global	• World Meteorological Organization (WMO)
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2. Introduction / Relevance

Climate change remains one of the most important challenges facing humanity. It affects every country and disrupts national economies and affects lives, costing people, communities and countries significantly today and in the future. Yet there is a significant inequity between countries' emissions and impacts, meaning that those who contribute to climate change the least, suffer from it the most.[7] People are experiencing the significant impacts of climate change, which include changing weather patterns, rising sea level, and more extreme weather events. As stressed by the Climate Change 2014 Synthesis Report[8] of the Intergovernmental Panel on Climate Change (IPCC), the impacts of climate change on sustainable development are observed through both slow onset events (e.g., sea level rise, increasing temperatures, ocean acidification, glacial retreat and related impacts, salinization, land and forest degradation, loss of biodiversity and desertification) and extreme weather events. Climate change impacts are already disrupting livelihoods in many parts of the world, particularly those that are dependent on predictable temperature and rainfall, clean water availability, and arable land. Sea level rise will also increasingly affect coastal communities by exacerbating erosion and leading to loss of land and coastal industries.
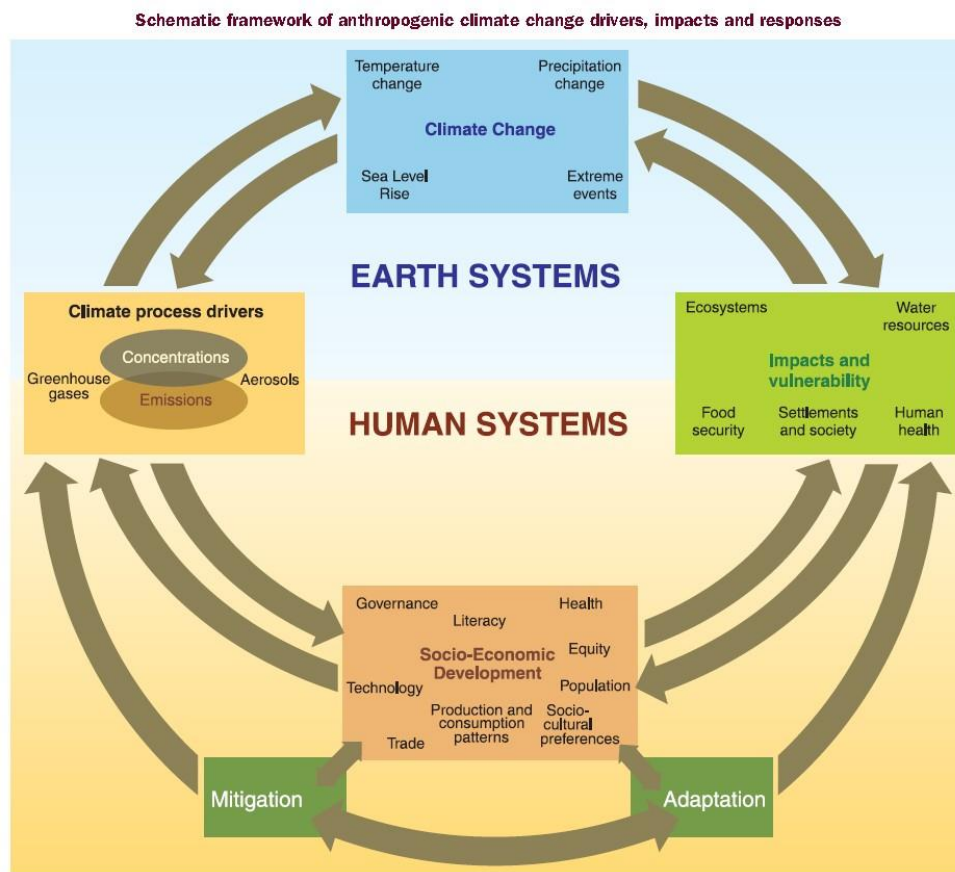
Figure 1 - Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages, source IPCC (2007)[9]

[7] Althor, G., et al. (2016). "Global mismatch between greenhouse gas emissions and the burden of climate change." Scientific Reports 6: 20281.
[8] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp: https://archive.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf (accessed 10 September 2020)
[9] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva,

It is now accepted unequivocally that climate change takes place and is caused by the greenhouse gas (GHG) emissions released to the atmosphere as a result of human activities. These emissions are changing the chemical composition of the atmosphere with increased concentration of three main gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). According to the last IPCC report on the Physical Science Basis[10] (part of the Fifth Assessment Reports, AR5[11]) which covers the period 2000-2010, the atmospheric concentrations of CO_2 have increased by 40% and of CH_4 by 150% since pre-industrial times. These amounts have further increased since then.

The greenhouse gas effect which leads to global warming, is the result of long-wave (infrared) energy capture by the GHGs in the atmosphere and its downward re-emitting which causes warming at the lower atmosphere and land/ocean surface. CO_2 is the main GHG emitted through human activities, and CH_4 and N_2O follow. Together the three gases cause 80% of the total radiative forcing of well-mixed GHGs. Figure 2 illustrates the details on the global carbon cycle from the AR5 on the physical science mentioned above. The key figures globally are: (1) total annual CO_2 emissions averaged for 2000-2009 (because of fossil fuels and land use change) amount to 8.9 (PgC yr^{-1}); (2) Net land flux (or land sink) is 2.6 (PgC yr^{-1}); and (3) Net ocean flux (or ocean sink) of 2.3 (PgC yr^{-1}), which leaves 4 (PgC yr^{-1}) or 45%, as the annual increase in the atmosphere. In comparison, CH_4 has much lower emissions with an average annual increase of 0.017 (PgCH$_4$ yr^{-1}), which is also more uncertain. The annual emissions because of human activities are in the range of 0.272 – 0.329 (PgCH$_4$ yr^{-1}).
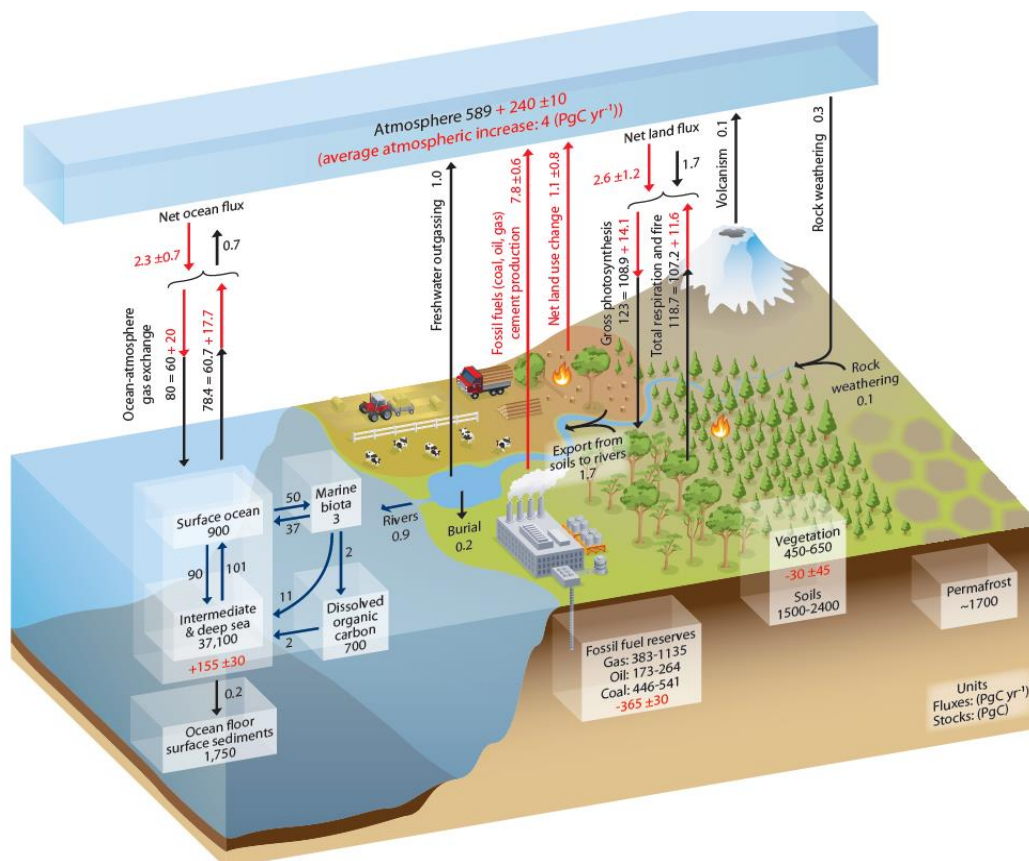
Figure 2: Global carbon cycle, source IPCC (2013)[12]

Switzerland, 104 pp: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf (pg. 26, accessed 10 September 2020)

[10] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf (accessed 10 September 2020)

[11] IPCC Fifth Assessment Reports: https://www.ipcc.ch/assessment-report/ar5/ (accessed 10 September 2020)

[12] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y.

Accurate statistics on GHG are of critical importance to support global environmental policies, foremost on climate change and ocean acidification abatement. Likewise, for regional and locally relevant ones e.g., for European Emissions Trading; carbon sequestration enhancement policies (REDD+)[13]; urban air quality improvement, etc. While generic guidelines are abundant (with key sources introduced in this document) there are many issues facing statistical data quality such as accuracy, completeness, consistency, and uncertainties of nationally reported GHG figures (about 10 – 20% according to Prinn et al., 2011)[14], which ultimately bring persistent quantitative misunderstandings[15] on climate change causes and effects. The role of the national statistical office (NSO) has been long discussed and advanced in a number of countries, such as Finland[16] and Norway[17] considering the measurement, reporting and verification (MRV) requirements of the Kyoto Protocol, but remains limited in most other countries. Besides data quality at the national level, the need for disaggregated and spatially explicit figures has been underlined.[18]

The purpose of this methodology sheet is to advance further the definitions, classifications and methods for official GHG statistics and the role of NSOs in their production. It provides references to the existing guidance sources and examples, as well as suggestions for further work. The methodology sheet addresses two components of the FDES:

- Global atmospheric concentrations of CO_2 and CH_4 (Topic 1.3.1.b, part of the component on Environmental quality) are briefly introduced in Section 3C. These are not a subject of national statistics production, and
- Detailed statistics of GHG emissions by sources and removals by sinks under topic 3.1.1 (part of the component on Residuals) are presented in the remainder of the document since these are within the scope of national GHG reporting.

Building on the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, Parties reached a new universal agreement in Paris[19], in 2015, to reduce emissions, keep global warming to below 2°C above pre-industrial levels (i.e. about 1850) and mobilize resources to finance adaptation, as societies move towards a low-carbon economy base. The session and its outcome, the Paris Agreement, were of critical importance, given that it was the first time that all countries have agreed to GHG reductions in their national economies, not only those listed in Annex I Parties of the UNFCCC. The landmark Paris Agreement sets the path to enable humanity to combat climate change and boost the transition towards resilient, low-carbon societies and economies around the globe. The agreement includes provisions on mitigation, adaptation and capacity-building that directly relate to the information going forward and addresses the capacity-building needs of developing countries, least developed countries and small island developing States. It will set new stringent emission reduction requirements based on nationally determined contributions (NDCs), proposed by parties and will need to be sustainable to enable long-term change.[20]

Another important document, "Transforming our world: the 2030 Agenda for Sustainable Development" addresses climate change in Goal 13 "Take urgent action to combat climate change and its impacts" of the SDGs. Goal 13 contains six targets which are monitored through indicators that require statistical strengthening for many countries. Climate change issues and related indicators also appear in several other SDG targets.[21] Target 13.2 'Integrate climate change

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Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf (pg. 474, accessed 10 September 2020)

[13] Reducing emissions from deforestation and forest degradation (REDD): https://www.un-redd.org/ (accessed 10 September 2020)

[14] Prinn, R. G., et al. (2011). A strategy for a global observing system for verification of national greenhouse gas emissions, MIT Joint Program on the Science and Policy of Global Change.

[15] Althor, G., et al. (2016). "Global mismatch between greenhouse gas emissions and the burden of climate change." Scientific Reports 6: 20281.

[16] Monni, S., et al. (2007). "Uncertainty of forest carbon stock changes–implications to the total uncertainty of GHG inventory of Finland." Climatic Change 81(3-4): 391-413.

[17] Flugsrud, K. and B. Hoem (2011). "Uncertainties in the Norwegian greenhouse gas emission inventory.": https://ssb.brage.unit.no/ssb-xmlui/bitstream/handle/11250/181161/rapp_201135_en.pdf?sequence=1 (accessed 10 September 2020)

[18] Report of a Conference (in 2008) organized by the United Nations Statistics Division in collaboration with the Statistical Office of the European Communities (Eurostat) and the World Bank on Climate Change and Official Statistics: https://unstats.un.org/unsd/climate_change/docs/Climate%20Change%20and%20Official%20Statistics_Report.pdf (accessed 10 September 2020)

[19] United Nations (2015) Paris Agreement: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (accessed 10 September 2020)

[20] Available from http://www.cop21paris.org (accessed 10 September 2020).

[21] United Nations. Sustainable Development Goals, IAEG-SDG, http://unstats.un.org/sdgs/iaeg-sdgs/ (accessed 10 September 2020)

measures into policy and planning' is specifically focused on GHG emissions. Goal 14 aims to 'Conserve and sustainably use the oceans, seas and marine resources' with target 14.3 specifically aiming to 'Reduce ocean acidification'.[22]

Climate change is a cross-cutting issue involving complex dynamics that include economic, social and environmental factors that affect each other and pose a considerable challenge with regard to statistical measurement at both the country and agency levels. The statistical community around the world will undoubtedly face increasing data demands from diverse stakeholders. It is important to produce statistics to inform about climate change in terms of drivers, impacts, vulnerability, mitigation and adaptation, so that policy making can be more robust and evidence-based.[23] Addressing these information needs, and based on the *Conference of European Statisticians (CES) Recommendations on Climate Change-related Statistics*, a CES Task Force has identified a set of 44 core climate change-related indicators which paint the picture of the most relevant climate change-related issues and respond to the most relevant climate change-related policy questions in the region. The initial set of indicators was approved by the CES in June 2017 and the final set, after some refinement, in June 2020. The list of indicators (before final editing) is available online.[24]

At the 47th Session of the United Nations Statistical Commission, the Commission requested UNSD to review and consider the ECE list as a basis for developing a global set of climate change statistics and indicators, applicable to countries at various stages of development.[25] The global set is under development, its overall objective is to provide a framework with suitable indicators to serve as guidance for countries to prepare their own sets, especially for those with less developed statistical systems. The global set aims to meet the needs of all countries, and to contain a comprehensive list of indicators accompanied by metadata (including, *inter alia*, definitions, aggregations, measurement categories and data references).[26]

There are internationally accepted generic methodological guidelines developed by the IPCC for countries to nationally prepare GHG inventories to be submitted to the UNFCCC. Various methodological guidelines exist but are possibly insufficient or not optimally used. While several international agencies estimate GHG statistics for all countries at IPCC default levels,[27] the official statistics from national GHG inventories reported to UNFCCC are often incomplete, especially for developing countries (non-Annex I Parties to the Convention). The available guidance and data sources are presented and referenced in this document. Guidance on compiling GHG accounts in relation to economic activities can be consulted in the SEEA Central Framework, and additional guidance on CO_2 removals (carbon sequestration and carbon stocks) in SEEA EEA.[28] UNECE developed specific guidance on the subject of NSOs' involvement in GHG reporting, with a focus on Annex I countries.[29] The Paris Agreement[30] and its work programme adopted in 2018 in Katowice, Poland have provided requirements for all Parties to report information on their inventory preparation process as recommended in the Enhanced Transparency Framework (ETF).[31] This includes specific responsibilities of institutions (such as NSOs) participating in the GHG inventory preparation.

While IPCC guidance addresses exclusively GHG emissions and removals resulting from anthropogenic activities, for statistical production purposes the scope may be widened, where relevant to address also 'natural' sources and sinks.

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[22] SDG Tracker, Target 14.3: https://sdg-tracker.org/oceans#targets (accessed 10 September 2020)

[23] UNSD website on climate change statistics: https://unstats.un.org/unsd/envstats/climatechange.cshtml

[24] UNECE, Updated set of core climate change-related indicators and statistics and its implementation guidelines: https://www.unece.org/index.php?id=53381 (document number 4, accessed 10 September 2020).

[25] Report on the forty-seventh session of the United Nations Statistical Commission (2016): https://unstats.un.org/unsd/statcom/47th-session/documents/Report-on-the-47th-session-of-the-statistical-commission-E.pdf (pg. 20, accessed 10 September 2020)

[26] UNSD website on Global Set of Climate Change Statistics and Indicators: https://unstats.un.org/unsd/envstats/ClimateChange_StatAndInd_global.cshtml (accessed 10 September 2020)

[27] See examples from IEA (CO2 emissions statistics: https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics), FAO (Emission shares: http://www.fao.org/faostat/en/#data/EM/), Joint Research Centre of the European Commission (Emissions Database for Global Atmospheric Research – EDGAR: https://www.eea.europa.eu/themes/air/links/data-sources/emission-database-for-global-atmospheric)

[28] EC, OECD, UN and WB (2014). System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting, pg. 30, https://seea.un.org/sites/seea.un.org/files/seea_eea_final_en_1.pdf (accessed 10 September 2020)

[29] UNECE: https://www.unece.org/fileadmin/DAM/stats/documents/ece/ces/ge.33/2018/mtg7/What_NSOs_need_to_know_about_inventories_FORUM_Rfinal.pdf (accessed 10 September 2020)

[30] United Nations (2015) Paris Agreement: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (accessed 10 September 2020)

[31] UNFCCC, Enhanced Transparency Framework: https://unfccc.int/enhanced-transparency-framework#eq-1; see also the report from the session in Katowice: https://unfccc.int/sites/default/files/resource/cma2018_3_add2_new_advance.pdf (accessed 10 September 2020)

In particular, removals resulting from carbon sequestration on land not subject to any management activities are not included in the national GHG inventory and those removals associated with the indirect effect of environmental changes (e.g. CO_2 fertilization, N deposition) may not be captured by inventory methodologies. While for reporting purposes the consistency for UNFCCC needs to be adhered to, for analytical and quality assessment such wider considerations are recommendable. In addition, the indirect effects may become of particular policy relevance in the future because of possible changes in the global carbon cycle, for example large-scale loss of forests' sink functions.

3. Definitions and description of statistics

Definition of Greenhouse gas (GHG): The Fourth Assessment Report of the IPCC[32] provides the following definition: 'Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere'. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).' Nitrogen trifluoride (NF_3) is a new mandatory gas to be reported by Annex I Parties.

Global Warming Potential (GWP): The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a GHG to that from the emission of one kilogram of CO_2 over a period of time (usually 100 years). Under the Paris Agreement, GWP values from the Fifth Assessment Reports (AR5)[33] will be applied.

CO_2 equivalent: is the representation of GHG in terms of CO_2.[34]
The methodological guidance in this sheet if based on the production-based perspective, which is distinct from consumption-based ones, e.g., carbon footprint.[35]

3A. Total emissions by sources and removals by sinks of direct greenhouse gases (GHGs), by gas (Topic 3.1.1.a)

Emissions are the release of GHGs and/or their precursors into the atmosphere over a specified area and period of time.[36] Removals conversely are the absorption of atmospheric GHGs by a sink. CO_2 is the only gas for which removals are estimated in the national GHG inventory.

Direct GHG emissions are those directly emitted into the atmosphere by a source. GHG inventories under the UNFCCC cover estimation and reporting of anthropogenic GHG emissions and removals occurring on 'managed land'. Emissions resulting from fires in unmanaged forests would be considered as 'anthropogenic' if after burning the land use is changed, for example to pasture, and the land is accordingly re-categorized as 'managed'.

In sections 3A and 3B, all emissions are measured and reported in terms of mass (while in 3C in terms of concentration).

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[32] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf (pg. 82, accessed 10 September 2020)

[33] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf (pg. 731, accessed 10 September 2020)

[34] To get the CO_2 equivalent one needs to multiply the mass of gas by GWP.

[35] Encyclopedia Britannica: https://www.britannica.com/science/carbon-footprint (accessed 10 September 2020)

[36] United Nations (1992) United Nations Framework Convention on Climate Change: https://unfccc.int/resource/docs/convkp/conveng.pdf (Article 1.4, pg. 3, accessed 10 September 2020)

Carbon dioxide (CO$_2$) (FDES 3.1.1.a.1)

A naturally occurring colourless and odourless gas, it is one input of photosynthesis, which stores it into plant material as carbon compounds. It is thus released back to the atmosphere with the burning of fossil fuels (which are derived from plant material fixed millions of years back) and existing biomass, as well as from land-use changes and other industrial processes. It is the principal human caused GHG that affects the Earth's radiative balance. It is the reference gas against which other GHG are measured and therefore has a Global Warming Potential (GWP) of 1. Although CO$_2$ does not directly impair human health, it is a GHG that traps infrared radiation thus naturally warming the planet. Its increase in the atmosphere causes global warming.

Methane (CH$_4$) (FDES 3.1.1.a.2)

A hydrocarbon that is a GHG with a global warming potential estimated at 28 according to the IPCC AR5. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion.

Nitrous oxide (N$_2$O) (FDES 3.1.1.a.3)

A powerful GHG with global warming potential evaluated at 265. Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Perfluorocarbons (PFCs) (FDES 3.1.1.a.4)

Synthetically produced halocarbons containing only carbon and fluorine atoms. They are characterized by extreme stability, non-flammability, low toxicity, zero ozone depleting potential, and high global warming potential.

Hydrofluorocarbons (HFCs) (FDES 3.1.1.a.5)

Hydrofluorocarbons contain only hydrogen, fluorine and carbon atoms. Because HFCs contain no chlorine, bromine, or iodine, they do not deplete the ozone layer and were thus introduced as alternatives to ozone depleting substances (ODSs) in serving many industrial, commercial, and personal needs. Like other halocarbons, they are potent GHGs.

Sulphur hexafluoride (SF$_6$) (FDES 3.1.1.a.6)

A colourless gas soluble in alcohol and ether, slightly soluble in water. A very powerful GHG used primarily in electrical transmission and distribution systems and as a dielectric in electronics. The global warming potential of SF$_6$ is 23,500.

Nitrogen trifluoride (NF$_3$) (not included in FDES)

A colourless, odourless, non-flammable gas. A very powerful GHG used primarily in microelectronics. The global warming potential of NF$_3$ is 16,100.

3B. Total emissions of indirect greenhouse gases (GHGs), by gas (Topic 3.1.1.b)

Indirect GHG or GHG precursors are compounds which by themselves are not significant as GHGs, but which nevertheless have an effect on the concentration of GHGs in the atmosphere, as they take part in physical or chemical processes regulating the production or destruction rates of GHGs.[37] The most important indirect GHGs are those generated by chemical decomposition of precursor gases such as sulphur oxides (SO$_X$) and nitrogen oxides (NOx) (linked to both industrial production and soil applications of nitrogen fertilizers) and non-methane volatile organic compounds (NMVOCs). There are also indirect GHG emissions resulting from chemical transformation of other GHGs, e.g., CO$_2$ released from CH$_4$ oxidation.

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[37] UNFCCC Handbook 2006, http://unfccc.int/resource/docs/publications/handbook.pdf (accessed 10 September 2020)

Sulphur oxides (SOₓ) (FDES 3.1.1.b.1)

Sulphur oxides emitted into the atmosphere through natural and anthropogenic processes are changed in a complex series of chemical reactions in the atmosphere to sulphate aerosols. These aerosols are believed to result in negative radiative forcing (i.e., tending to cool the Earth's surface) and do result in acid deposition (e.g., acid rain).[38]

Nitrogen oxides (NOx) (FDES 3.1.1.b.2)

Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced, for example, by the combustion of fossil fuels in vehicles and electric power plants. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), impair visibility, and have health consequences; they are considered pollutants.

Non-methane volatile organic compounds (NMVOCs) (FDES 3.1.1.b.3)

A class of emissions which includes a wide range of specific organic chemical substances. Non-methane volatile organic compounds (NMVOCs) play a major role in the formation of ozone in the troposphere (lower atmosphere). Ozone in the troposphere is a GHG. It is also a major local and regional air pollutant, causing significant health and environmental damage. Because they contribute to ozone formation, NMVOCs are considered "precursor" greenhouse gases. NMVOCs, once oxidized in the atmosphere, produce CO_2.[39]

Carbon monoxide (CO) (not included in FDES)
Carbon monoxide (CO) is a very weak direct GHG but has important indirect effects on global warming. More than half of CO emissions are human-made. The highest concentrations tend to occur close to areas of high human population.[40]

3C. Global atmospheric concentrations of greenhouse gases (FDES 1.3.1.b)

The GHGs which are the focus of anthropogenic climate change are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O); the first two were introduced as tier 2 statistics in the FDES. This section is relevant at the global level but may be still of interest in national inventories.

Global atmospheric concentration level of carbon dioxide (CO_2) (FDES 1.3.b.1)

As of June 2020, CO_2 atmospheric concentration level was about 412 ppm[41], or about 40% higher than the 278 ppm concentration in pre-industrial times. According to the Fifth Assessment Report of IPCC, CO_2 contributed to 78% of the total GHG emission increase from 1970 to 2010.[42]

Global atmospheric concentration level of methane (CH_4) (FDES 1.3.b.2)

As mentioned above, methane is a hydrocarbon, which is a potent GHG with the second highest concentration in the atmosphere. According to the IPCC report on physical science (IPCC, 2013), its concentration was 1,803 ppb in 2011.[43] In February 2020 the level was 1,873.7 ppb.[44]

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[38] UNFCCC. Glossary. Non Annex I Training Package (CD ROM), http://unfccc.int/resource/cd_roms/na1/ghg_inventories/english/8_glossary/Glossary.htm#S (accessed 10 September 2020)
[39] IPCC. Glossary. In: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (accessed 10 September 2020)
[40] Other Indirect Greenhouse Gases - Carbon monoxide: http://www.ghgonline.org/otherco.htm (accessed 10 September 2020)
[41] NOAA, Recent Global CO_2 Trend: https://www.esrl.noaa.gov/gmd/ccgg/trends/gl_trend.html (accessed 10 September 2020)
[42] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.: https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf (accessed 10 September 2020)
[43] IPCC (2013) Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf (accessed 10 September 2020)
[44] NOAA, Global CH_4 Monthly Means: https://esrl.noaa.gov/gmd/ccgg/trends_ch4/ (accessed 10 September 2020)

4. International sources and recommendations

4A. Classifications and groupings

The 2006 IPCC Guidelines[45] for National Greenhouse Gas Inventories divides the GHG estimates into five main sectors, which are groupings of related processes, sources and sinks, described below:

• Energy: fuel combustion activities (includes energy industries, manufacturing and construction, transport and other

sectors), fugitive emissions from fuels, CO_2 transport and storage.

• Industrial Processes and Product Use (IPPU): mineral industry, chemical industry, metal industry, non-energy products from fuels and solvent use, electronics industry, product uses as substitutes for ODS, other product manufacture and use.

• Agriculture, Forestry and Other Land Use (AFOLU): 2006 IPCC Guidelines for National Greenhouse Gas Inventories uses six land-use categories to report emissions and removals from land use and land-use conversions – forest land, cropland, grassland, wetlands, settlements, and other land. Also includes emissions from livestock and manure management, emissions from managed soils, and emissions from liming and urea application. Methods to estimate annual harvested wood product (HWP) variables are also covered in this category.

• Waste: solid waste disposal, biological treatment or solid waste, incineration and open burning of waste, wastewater treatment and discharge (domestic and industrial) and release of GHGs from other waste handling activities.

Other minor sources (e.g., indirect emissions from nitrogen deposition from non-agriculture sources).

The 2006 IPCC Guidelines (including their 2019 Refinement) contain 5 volumes, one for general guidance (volume 1) and the other for each sector: volume 2 – energy; volume 3 – industrial processes and product use (IPPU); volume 4 – agriculture, forestry and other land use (AFOLU); volume 5 – waste. Table 8.2, chapter 8, volume I (General Guidance and Reporting) introduces the classification and definition of categories and subcategories of emissions and removals.[46]

While some countries are moving towards using the 2006 IPCC Guidelines[47], most countries decide to report emissions and removals from agriculture and for land use, land use change and forestry (LULUCF) separately, which is consistent with the IPCC 2000 good practice guidance and the 2003 good practice guidance for LULUCF.[48] This approach is also agreed for reporting GHG emission inventories under the UNFCCC.[49]

Classifications of more detailed land-cover/land-use/vegetation or ecosystem types may be relevant for estimating emissions and removals in the context of SEEA (in Central Framework, p. 178)[50] and REDD+.

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[45] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan: https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed 10 September 2020)

[46] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 1, chapter 8, https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_8_Ch8_Reporting_Guidance.pdf (pg. 10, accessed 10 September 2020)

[47] Some developing countries are still using the Revised 1996 IPCC Guidelines: https://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html (accessed 10 September 2020)

[48] Available from http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html and http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html (accessed 10 September 2020)

[49] Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories (Annex to Decision 24/CP.19 (FCCC/CP/2013/10/Add.3))

[50] United Nations, European Commission, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank (2014) System of Environmental-Economic Accounting 2012: Central Framework. Studies in Methods, Series F, No. 109. Sales No. 12.XVII.12, https://seea.un.org/sites/seea.un.org/files/seea_cf_final_en.pdf (accessed 10 September 2020)

4B. Reference to international recommendations, frameworks and standards

In line with recommendations by IPCC, emissions are usually estimated by applying technical coefficients to the level of output or other indication of the relevant economic activities, so that countries with good economic production statistics can produce the estimation of GHG emissions. National emissions of CO_2 and other GHGs to the atmosphere statistics can be found in countries reporting (through their national communications and national GHG inventories) to the UNFCCC. Regional and global level statistics and indicators based on the previously described statistics and also from estimation and modelling can be found in specific international databases, including by the UN system, such as FAO for agriculture and land use, land use change and forestry (LULUCF, in terms of IPCC terminology) and IEA for energy emissions. Both databases are referred to in IPCC guidelines as references that can and should be used in the absence of available national data. The latter datasets provide complete time series of emissions for the respective sectors, by all countries, at IPCC Tier 1 level. In the UNFCCC database, GHG emission statistics are provided at different tiers, depending on countries capabilities and choices, and generally available for Annex 1 parties (industrialized countries), but rather incomplete for non-Annex I parties (developing countries).

The 2006 IPCC Guidelines for National GHG Inventories recommend three tiered approaches, whereby a tier represents a level of methodological complexity, as follows:

Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided. Country-specific activity data are needed but for Tier 1 there are often globally available sources of activity data estimates, although these data are usually spatially coarse.

Tier 2 can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data. Country-defined emission factors are more appropriate for sources and sinks in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized processes.

At Tier 3, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers.

Several international organizations have produced guidance documents and have set standards for the collection of GHG emissions.

Technical Guidelines for the Development of Greenhouse Gas Inventories

- **The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* are the official -methodological reference** intended for use by countries to estimate GHG inventories to report to the UNFCCC. As mentioned above, the volumes 2-5 provide issues to sector specific data collection (e.g., on energy, industrial processes, agriculture, LULUCF and waste, whereby appropriate activity data for a particular category of emissions apply). They also provide worksheets to assist with the transparent application of the most basic estimation methodology, or Tier 1 (http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html). The 2006 Guidelines have been recently refined [51] taking into account updates and scientific advances (https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories). The new guidelines however do not substitute the 2006 ones but are to be applied in conjunction.

- **UNFCCC Guidelines**: Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention (decision 24/CP.19).

- **Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amount**: is a reference tool to assist Parties included in Annex I to the UNFCCC (Annex I Parties) in the implementation of their commitments related to the accounting of emissions and assigned amount under the Kyoto Protocol. It synthesizes the requirements with respect to national systems for the preparation of inventories, national registries for tracking holdings of and transactions of Kyoto units, reporting, review and compliance procedures related to the reporting of GHG emission inventories and

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[51] By the Task Force on National Greenhouse Gas Inventories (TFI) as requested by a decision taken at the 44th Session of IPCC in Bangkok, Thailand, in October 2016.

accounting of assigned amount, accounting for LULUCF activities, participation in the Kyoto mechanisms and the procedures for establishing, maintaining and suspending eligibility to participate, and transactions of Kyoto units (http://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf).

• **2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol** (https://www.ipcc-nggip.iges.or.jp/public/kpsg/index.html).

• **Modalities, procedures and guidelines for the enhanced transparency framework (ETF)** for action and support referred to in Article 13 of the Paris Agreement (decision 18/CMA.1) (https://unfccc.int/sites/default/files/resource/cp24_auv_transparency.pdf).

• **Reference Manual for the Enhanced Transparency Framework under the Paris Agreement** serves as a tool for technical expert reviewers, to understand the requirements related to reporting and review of information contained in the BTRs, and how this information is relevant for a Party's overall implementation of the Paris Agreement (https://unfccc.int/documents/209929).

• **Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF)**: this report is the response to the invitation by the UNFCCC to the IPCC to develop good practice guidance for LULUCF. *GPG-LULUCF* provides methods and good practice guidance for estimating, measuring, monitoring and reporting on carbon stock changes and GHG emissions from LULUCF activities under Article 3, paragraphs 3 and 4, and Articles 6 and 12 of the Kyoto Protocol. This guide assists countries in developing inventories for the land use, land-use change and forestry sector that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and quality procedures, and efficient in the use of resources. It is consistent with the existing good practice guidance for the other sector within the context of the IPCC Guidelines. This report was accepted by the IPCC Plenary in 2003 (http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html).

• **2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories**: **Wetlands** (*Wetlands Supplement*): it provides updated information in relation to 2006 IPCC Guidelines. It includes inland organic soils and wetlands on mineral soils, coastal wetlands and constructed wetlands for wastewater treatment (www.ipcc-nggip.iges.or.jp/public/wetlands).

Software Tools and Modelling Framework

• **IPCC Inventory Software**: this software implements the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and its 2013 Wetlands Supplement (http://www.ipcc-nggip.iges.or.jp/software/index.html).

• **Open Foris**: is an FAO-led initiative to develop, share and support specialized software tools required by countries and institutions to implement multi-purpose forest inventories. It is a set of free and open-source software tools that facilitates efficient data collection, analysis and reporting. The initiative was created under the FAO-Finland Forestry Programme in collaboration with FAO's support to National Forest Monitoring and Assessment (NFMA) and the UN-REDD Programme to address the growing need for accurate and timely information on the state of forest resources and their use and users (http://www.fao.org/forestry/fma/openforis/en). Efforts include methods to estimate tree allometry from basic statistics, needed for carbon stock change computations (http://www.globallometree.org/about).

• **Global Livestock Environmental Accounting Model (GLEAM)**: a modelling framework that simulates the interaction of activities and processes involved in livestock production and the environment. GLEAM differentiates key stages along livestock supply chains and captures their impacts, such as GHG emissions, land use and land degradation, nutrient and water use and interaction with biodiversity. In relation to the estimation of GHG emissions, the model covers emissions of methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). Use of Tier 2 methodology in animal derived emissions from enteric fermentation and manure management that provides more accurate information on how animal feeding and manure management options can help in mitigation (http://www.fao.org/gleam/en).

References to assist countries in producing data related to climate change

- **World Programme for the Census of Agriculture 2020. Volume 1 – Programme, Concepts and Definitions. Annex II: Greenhouse Gas Emissions:** this publication is intended to provide guidance on agricultural censuses carried out by countries in the period between 2016 and 2025. The WCA 2020 will ensure that data collected are comparable at the international level while also addressing the main emerging information needs of the 21st century. The annex provides guidance to countries on which variables are relevant to estimating GHG and should be included in National Census programmes (www.fao.org/3/a-i4913e.pdf).

- **Estimating Greenhouse Gas Emissions in Agriculture, A Manual to Address Data Requirements for Developing Countries (FAO, 2014):** this manual helps to identify, build and access the minimum set of activity data necessary for GHG estimation. Users are provided with step-by-step guidance on how to use this minimum set to build a default, yet complete national GHG emission dataset for agriculture and land use, which follows the default, Tier 1 approach of the IPCC Guidelines on National GHG Inventories (http://www.fao.org/climatechange/41521-0373071b6020a176718f15891d3387559.pdf).

- **Conference of European Statisticians Recommendations on Climate Change-Related Statistics (UNECE, 2014)**: this publication presents recommendations for improving the statistics related to climate change collected by national statistical systems and enhancing their utility for the compilation of GHG inventories. These recommendations were endorsed at the plenary session of the Conference above-mentioned in April 2014. They were developed by the Task Force on Climate Change-Related Statistics at the request of heads of national statistical offices of the member states of the UNECE – United Nations Economic Commission for Europe and other countries (http://www.unece.org/fileadmin/DAM/stats/publications/2014/CES_CC_Recommendations.pdf).

- **Report of the Australian Bureau of Statistics on Climate Change and Official Statistics to the 40th session of the Statistical Commission in 2009:** this report makes recommendations to mainstream climate change in official statistics both at the national and international level (http://unstats.un.org/unsd/statcom/doc09/2009-2-ProReview-E.pdf).

- **United Nations Framework Convention on Climate Change Handbook:** this document focuses on the institutional framework of the Convention (2006) and the actions taken by the Conference of the Parties to the Convention (COP). The handbook has two parts: 1 - describes the institutions, Parties, observers and procedures of the Convention; 2 - provides information on the thematic work within the Convention (mitigating climate change, adapting to it, providing financial resources, developing and transferring technology, building capacity and communicating information about implementation). It serves as a reference for those interested in and working on the issues around climate change (http://unfccc.int/resource/docs/publications/handbook.pdf).

- **Emerging Activities to Combat Climate Change – Use of FAO Data and IPCC GHG Inventory Guidelines for Agriculture and Land Use:** The FAO-IPCC-IFAD report summarizes the findings of a joint workshop held at FAO Headquarters on 13-14 November 2014. It provides information on access and use of FAO data and analysis tools for AFOLU, in support of national reporting processes under the UNFCCC, including GHG inventories, Biennial Update Reports, and national mitigation planning. Furthermore, the report usefully highlights country needs for new data and guidance for monitoring, reporting and verification of emerging activities in agriculture, forestry and land use, aimed at combating climate change in coming decades (http://sdg.iisd.org/events/emerging-activities-to-combat-climate-change-use-of-fao-data-and-ipcc-ghg-inventory-guidelines-for-agriculture-and-land-use/).

- **Report of the Secretary-General on Climate Change Statistics to the 47th session of the Statistical Commission in 2016** (http://unstats.un.org/unsd/statcom/47th-session/documents/2016-15-Climate-change-statistics-E.pdf) and **Report of the Statistical Commission** (https://unstats.un.org/unsd/statcom/47th-session/documents/Report-on-the-47th-session-of-the-statistical-commission-E.pdf).

- **Report of the Secretary-General on Climate Change Statistics to the 49th session of the Statistical Commission in 2018** (https://unstats.un.org/unsd/statcom/49th-session/documents/2018-14-ClimateChange-E.pdf) and **Report of the Statistical Commission** (https://unstats.un.org/unsd/statcom/49th-session/documents/Report-on-the-49th-session-E.pdf).

- **System of Environmental and Economic Accounting Central Framework (SEEA-CF): Manual for air emission accounts** (2015), published by EUROSTAT (https://ec.europa.eu/eurostat/documents/3859598/7077248/KS-GQ-15-

009-EN-N.pdf/ce75a7d2-4f3a-4f04-a4b1-747a6614eeb3).   Air emission accounts include the main GHGs recorded according countries' economies (residence principle) and broken down by emitting economic activity.

- **System of Environmental and Economic Accounting for Agriculture, Forestry and Fisheries: Chapter 4.4, Physical Flow Account for Greenhouse Gas Emissions** (https://seea.un.org/content/system-environmental-economic-accounting-agriculture-forestry-and-fisheries): FAO has led the development of the SEEA Agriculture, including specific tables and combined presentations on GHG emissions, based on the IPCC guidelines but providing linkages to ISIC classifications as well as allowing analysis of GHG emissions from an agronomic perspective in addition to those possible using national GHG inventories. The concept of progressive Tiers of complexity is addressed following IPCC and FAO efforts on data and capacity development, including on land cover classification systems (http://www.fao.org/docrep/008/y7220e/y7220e02.htm#bm02).

4C. Sources of global and regional environment statistics and indicators series

Databases on global emissions and concentrations

- The standard global measurement of CO_2 concentrations in the atmosphere can be consulted in real time, online. It is available at https://www.esrl.noaa.gov/gmd/ccgg/trends/. This CO_2 observatory is the first instrument that detected an increase in CO_2 due to anthropogenic factors. It is still the most common global reference level of CO_2.

- **UNFCCC GHG database**: website of the United Nations Framework Convention on Climate Change that provides access to most recent data on national GHG emissions and removals (http://unfccc.int/ghg_data/items/3800.php).

- **FAOSTAT:** the FAOSTAT Emissions database provides a complete time series of GHG emissions for all countries, over a period 1961-present for agriculture, and 1990-present for land use, land use change and forestry. The database provides emissions categories that are fully aligned with IPCC guidelines, estimating emissions at Tier 1 2006 IPCC Guidelines. It represents a reference dataset, that countries can use in support on their own national efforts, from data gap filling to QA/QC functions. Specific geospatial datasets are also available for download alongside the FAOSTAT Emissions estimates, including information of organic soils and their degradation, burnt areas. Metadata explain the approaches for calculations and their data sources. The FAOSTAT Agri-Environmental Indicators section contains data on emissions by sectors and emissions intensities. The 'emissions by sectors' contains data on emissions of GHG by gas, economic sector, country and year. It also displays the shares of each sector in the total emissions of each gas and the shares of each gas in the emissions from each sector. The 'emissions intensities' contains data on intensities of GHG emissions by production unit for a selection of agricultural commodities (http://www.fao.org/faostat/en/#data).

- **EDGAR 4.2 FT2010 data:** Emission Database for Global Atmospheric Research (EDGAR) has been developed jointly by the European Commission's Joint Research Centre (JRC) and the Netherlands Environmental Assessment Agency. EDGAR is providing global anthropogenic emissions of GHG (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) and of precursor gases and air pollutants (CO, NOx, NMVOC, SO_2) and the aerosols (black carbon/organic carbon), per source category, both at country/region levels (http://edgar.jrc.ec.europa.eu). Emissions are calculated per source, taking into account country-specific activity data, human activity for each sector and country-specific emission factors.

- **International Energy Agency (IEA**): supports a comprehensive database on CO_2 emissions from fuel combustion, including the data on CO_2–related indicator (http://www.iea.org/statistics/topics/CO2emissions). This website includes a comprehensive list of CO_2 emissions and related indicators for 140 countries and regional aggregates. Emissions are calculated using IEA energy databases using the methods in 2006 guidelines for National Greenhouse Gas Inventories (IPCC).

- **World Data Centre for Greenhouse Gases (WDCGG)/Japan Meteorological Agency:** it provides data on GHG (CO_2, CH_4, CFCs, N_2O, surface ozone, etc.) and related gases (CO, NOx, SO_2, VOC, etc.) in the atmosphere and ocean, as observed under Global Atmosphere Watch Programme - GAW Programme of WMO – World Meteorological Organization. It also provides WDCGG publications (https://gaw.kishou.go.jp/). The GAW Programme "coordinates global atmospheric chemistry observations, analysis and scientific assessments related to the changing composition of the Earth's atmosphere and its effects on weather, climate, water and the environment. GAW is the lead programme for implementing recommendations of the Global Climate Observing System (GCOS) on the essential climate variables (GHG, ozone and aerosols). It is a major contributor to the Global Earth Observation System of Systems (GEOSS)

coordinating integrated global atmospheric chemistry observations and research for GHG, ozone, aerosols, reactive gases and precipitation chemistry" (http://www.wmo.int/gaw).

- **United Nations Statistics Division (UNSD) Environmental Indicators** disseminate global environment statistics on ten indicator themes compiled from a wide range of data sources (Air and Climate), (http://unstats.un.org/unsd/environment/qindicators.htm).

- **The World Bank Group**: data cover GHG emissions, climate systems, exposure to climate impacts, resilience, energy use (http://data.worldbank.org/topic/climate-change).

- **Little Data Book on Climate Change/World Bank**: includes data of GHG emissions and other topics related to climate (current and projected climate conditions, exposure to climate impacts, resilience, climate finance, and current national and international efforts to take action), (http://data.worldbank.org/products/data-books/little-data-book-on-climate-change).

- **Environmental Data Explorer/UNEP – United Nations Environment Programme:** it is online dataset used by UNEP and its partners in the Global Environment Outlook (GEO) report and other integrated environment assessments. It has more than 500 different variables, as national, subregional, regional and global statistics or as geospatial data sets (maps), covering themes like Freshwater, Population, Forests, Emissions, Climate, Disasters, Health and GDP (http://geodata.grid.unep.ch).

- **Carbon Dioxide Information and Analysis Center (CDIAC)**: CDIAC has data of CO_2 emissions from fossil-fuel consumption and land-use changes (estimates); records of atmospheric concentrations of CO_2 and other radiatively active trace gases; carbon cycle and terrestrial carbon management datasets and analyses; and global/regional climate data and time series. It is located in the United States of America, at DOE's Oak Ridge National Laboratory (ORNL) and includes the World Data Center (WDC) for Atmospheric Trace Gases. Website of CDIAC: http://cdiac.ornl.gov/trends/trends.htm. ORNL can be consulted at https://www.ornl.gov. WDC can be consulted at http://cdiac.ornl.gov/wdca/wdcinfo.html.

- **CAIT (Climate Analysis Indicators Tool)/WRI – World Resources Institute:** it provides comparable GHG emissions data sets and other climate-relevant indicators, to enable analysis on a wide range of climate-related data questions (http://cait.wri.org).

Regional databases

- **Eurostat**: https://ec.europa.eu/eurostat/web/climate-change/data/database

Databases with national information

- **National Inventory Submissions:** this website consists of the national inventory report (NIR) and common reporting format (CRF) of all Parties included in Annex I to the Convention. The NIRs contain detailed descriptive and numerical information and the CRF tables contain all GHG emissions and removals, implied emission factors and activity data. Available on website of UNFCCC - United Nations Framework Convention on Climate Change: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9492.php.

- **National Reports** (Annex 1 and Non-Annex I): this webpage has links with submitted national communications, submitted biennial reports, submitted Annex I GHG inventories, and so on (http://unfccc.int/national_reports/items/1408.php).

5. Data collection and sources of data

This section introduces key points on scope, units, data collection (sources/institutions), aggregation and validation of GHG statistics.

Scope of the statistics

The suggested scope covers all GHG emissions and removals for national and global reporting purposes. However, the overall scope can be partitioned for consistency with the following reporting mechanisms:

- Emissions and removals as defined by UNFCCC, according to the IPCC guidelines, considering the sources linked to anthropogenic activities/managed land within a country (territorial principle[52])
- Emissions from international transport (aviation and maritime)
- Emissions from national economy (residence principle)
- Emissions and removals from natural sources, either existing or expected (e.g., from melt of permafrost soils in sub-Arctic areas, peatlands, burning of natural forests etc.) which may not be currently reported

Statistical unit

The following units apply in accordance with the above scoping divisions:

- National territory and other administrative units, and regions within the national territory
- Resident economic sectors and activities (by ISIC)
- Ecosystem/land use/land cover types
- The globe

Measurement units

For national reporting purposes from anthropogenic sources [tCO_2 yr^{-1} -equivalent], or [tCO_2 ha yr^{-1} -equivalent] for 'natural' emissions and removals. These units allow for possibilities to convert between the mass of different gases and different temporal and spatial units.

Sources and institutions

For national-level reporting of GHG emissions to the UNFCCC, IPCC guidelines (IPCC, 1997; 2000; 2003; 2006) provide a range of methodological approaches from simple bottom up methods (i.e., Tier 1) to more complex procedures often involving process modelling and rules for scaling-up in time and space (Tier 2 and Tier 3). Tier 1 approaches provide for simple estimations, based on generalized emission factors and other parameter values that are specified either globally or regionally. Tier 2 approaches use country or region-specific data. Tier 3 approaches involve models and/or inventory measurement systems.

Once appropriate institutional arrangements have been put in place ensuring coordination and coherence across relevant national agencies, data collection is the first practical step of producing a GHG inventory. IPCC guidelines provide advice on both institutional and data processes. Official activity data are necessary and adapted to countries' national characteristics. Data collection includes the following procedures: to find and process existing data, to generate new data (surveys and measurement campaigns), to maintain data flows, to improve estimates, to generate estimates and replace existing data sources when those currently used are no longer available.[53]

Examples of possible data sources (according to the 2006 IPCC Guidelines[54]) are:

- National Statistical Agencies (Ex. Surveys, Census information)
- National regulatory authorities responsible for permitting of industrial and other processes subject to pollution emission legislation
- Ministries, in particular on Energy, Industry, Environment, Agriculture and Forestry
- National and international experts

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[52] IPCC 2006, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*: Volume 1, Chapter 1, p. 1.4: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_1_Ch1_Introduction.pdf (accessed 10 September 2020)

[53] IPCC 2006, *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

[54] IPCC 2006, IPCC Guidelines for National Greenhouse Gas Inventories: Volume 1, Chapter 2, p. 2.6: Approaches to data collection: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_2_Ch2_DataCollection.pdf

- Universities and reference libraries
- Scientific and technical articles in environmental books, journals and reports
- National Inventory Reports from Parties to the UNFCCC
- International organizations that publish statistics: UNSD, US Geological Survey (USGS), OECD, IPCC Emission Factor Database, FAO and so on.
- International organizations that have funding for implementing obligations under the UNFCCC.

Data collection

Emissions can be determined directly through measurements (emission monitoring systems) or calculated by emission factors found in technical literature as in the IPCC Guidelines.[55] The IPCC Emission Factor Database (EFDB), for example, provides emission factors and other parameters with documentation or technical references that can be used for estimating GHG emissions and removals.[56] It is important to note that factors can assume a range of values in accordance with regional characteristics.

Many countries do have institutional arrangements in place for the preparation of national GHG inventories. This is done mostly in the context of their commitments to prepare and submit national GHG inventories under the UNFCCC. As such, it is likely that these statistics exist in the country.

According to the 2006 IPCC Guidelines, the first step for the data compilation is screening of available data sources and seeing details to make a judgement about the usefulness of a data set for the production of GHG emissions (Inventories). After that, it is necessary to refine data requirements, developing a formal specification and data request. Chapter 2 (Approaches to Data Collection) and Chapter 6 (QA/QC and Verification), volume 1 of the 2006 IPCC Guidelines have information about it.[57] Some examples of specification are definition of the data set, of the format and structure, description of national coverage, sectors included, representative year, emission factors, uncertainty parameters, identification of the routines and timescales for data collection activities, and so on.

Sometimes it may be necessary to generate new data by measurements (e.g., to quantify GHG emissions directly). In this situation, it is important to use and document quality management standards that have been used (e.g., ISO standards, European Standards, national standards, etc.) and to take into account the data requirements of the uncertainty analysis (see Chapter 3, volume 1 of 2006 IPCC Guidelines).

As noted above, for UNFCCC reporting purposes, national statistics on GHG emissions and removals are routinely estimated from activity data and emission factors, according to the following formula:

Emissions/removals = AD (extent of human activity) x EF (emission or removals per unit activity)

Where:

- **EF = emission factor**

Emission factor is a coefficient that quantifies the emissions or removals of a gas per unit activity data. They are often based on samples of measurements, averaged at various levels of detail depending upon the Tier methodology used. IPCC provides default emission factors for estimating anthropogenic GHG emissions at national level, which have been agreed upon by all participating countries. To see more details please consult chapter 6, volume 1 of '2006 IPCC Guidelines'.

- **AD = activity data**

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[55] IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed 10 September 2020)

[56] IPCC. *Emission Factor Database*, www.ipcc-nggip.iges.or.jp/EFDB/main.php (accessed 10 September 2020)

[57] IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. General Guidance and Reporting*, http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html (accessed 10 September 2020)

Activity data statistics identify, describe and quantify the magnitude of a human activity resulting in emission or removals of GHG over a specified area in a given period of time. In the energy sector, for example, the annual activity data for fuel combustion sources are the total amounts of fuel burned.

Statistics on GHG removals on managed lands are also routinely produced on the bases of factors but are generally more uncertain. Quantification of removals in the LULUCF sector by stock-changes methods is recommended in the guidance[58] and is routinely applied in many countries. These methods are still further developed in the context of forest inventories for REDD+ monitoring purposes.[59]

Novel measurement and mapping methods are explored in the context of ecosystem accounting (SEEA-EEA), including both natural and managed lands, which address the processes of sequestration (or removals) clearly linked to biological processes. Therefore, additional measurement/estimation methods may need to be explored where relevant to address other physical/geological process of carbon/GHG removals, for example dissolution in the oceans.

Aggregation
Temporal aspect – annual and quarterly
Spatial aspect – globally, nationally, by ISIC activity, by ecosystem/land-use/land cover types, by regions.

Quality control, uncertainties and validation
Estimates of anthropogenic emissions and removals of GHG presented in inventories are subject to uncertainty due to several causes, from the lack of precision of basic data to incomplete knowledge of the processes that cause emissions or removals of GHG. The 2006 IPCC Guidelines recognize that the uncertainty of estimates cannot be completely eliminated and that the main objective should be to produce accurate estimates, which means that are consistently neither underestimated nor overestimated, while seeking to improve estimate precision. This precision depends on each sector's characteristics, available data and resources that are invested for determining more fitting emission factors for national circumstances. The data on emissions/removals on GHGs, especially for reporting the GHG inventories to UNFCCC are subject to the principles of TACCC (Transparency, Accuracy, Consistency, Completeness and Comparability). The IPCC guidelines provide good practice to guide inventory compilers to operationalize those principles in preparing GHG estimates and ancillary information and within the entire management process for the national GHG inventory. More information can be found in a powerpoint presentation on the UNFCCC website.[60] It is good practice to assess the quality of national level or site-specific level activity data. To see details please consult chapter 6, volume 1 of the '2006 IPCC Guidelines'.

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[58] Penman, J., et al. (2003). "Good practice guidance for land use, land-use change and forestry." Good practice guidance for land use, land-use change and forestry. Online: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf (accessed 10 September 2020)
[59] Methods and Guidance Documentation" of the Global Forest Observation Initiative (https://www.reddcompass.org/frontpage)
[60] UNFCCC (2012). *CGE Training Materials National Greenhouse Gas Inventories – National Arrangements*, version 2, https://unfccc.int/files/national_reports/non-annex_i_natcom/training_material/methodological_documents/application/mspowerpoint/1_-_national_arrangements.ppt (accessed 10 September 2020)

6. Uses and dissemination

6A. Potential presentation and dissemination formats

- **UNFCCC GHG database**: website of the United Nations Framework Convention on Climate Change that provides access to most recent data on national GHG emissions and removals. Available on http://unfccc.int/ghg_data/items/3800.php.

Figure 6.1: GHG Profiles for Annex I countries
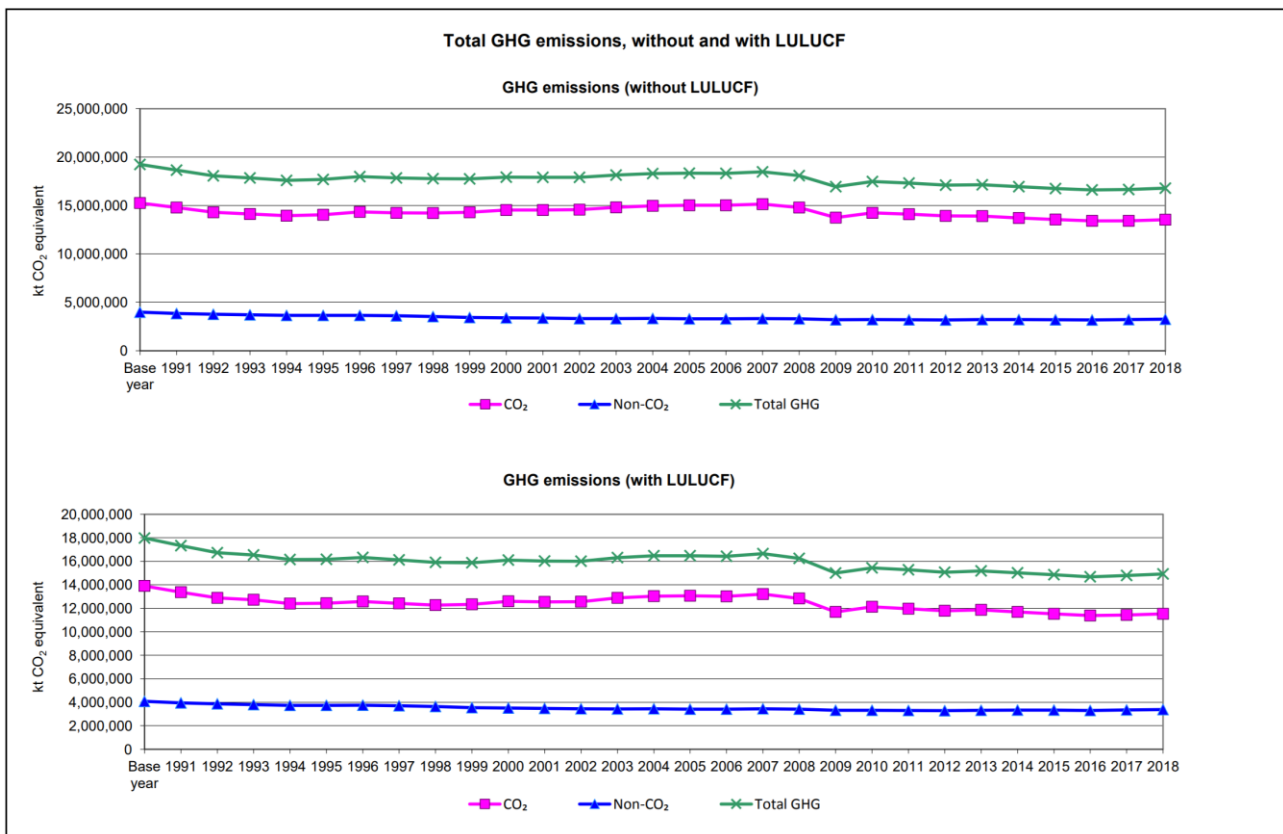
Source: UNFCCC, https://di.unfccc.int/ghg_profile_annex1

- **The FAOSTAT Emissions Database:** the FAOSTAT Emissions database provides a complete time series of GHG emissions for all countries, over a period 1961-present for agriculture, and 1990-present for land use, land use change and forestry. The user can choose to view the data in tables, graphs and maps. In addition, the FAOSTAT agri-environmental indicators contain time series on emission shares and emissions intensities (http://www.fao.org/faostat/es/#data).

**Figure 6.2: Net emissions/removals by country (CO2 equivalent)**

Net emissions/removals by country (CO2 equivalent), Land Use total + (Total)

Average 1990 - 2017
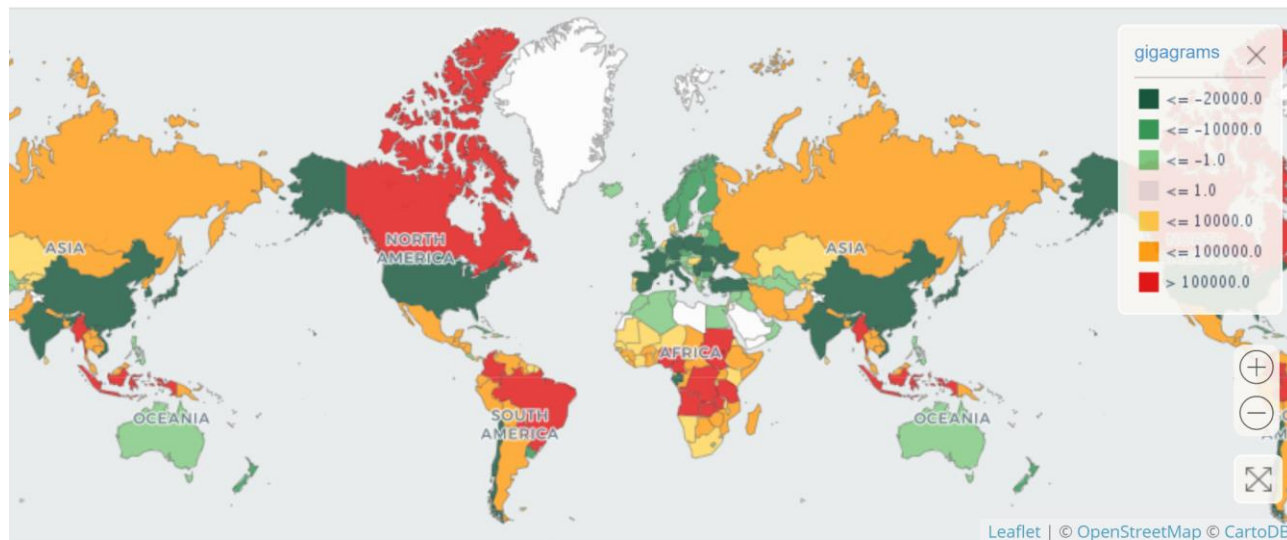
The designations employed and the presentation of material in the maps do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers. South Sudan declared its independence on July 9, 2011. Due to data availability, the assessment presented in the map for Sudan and South Sudan reflects the situation up to 2011 for the former Sudan.

Source: FAOSTAT, http://www.fao.org/faostat/en/#data/GL/visualize

Figure 6.3: Total annual anthropogenic GHG emissions
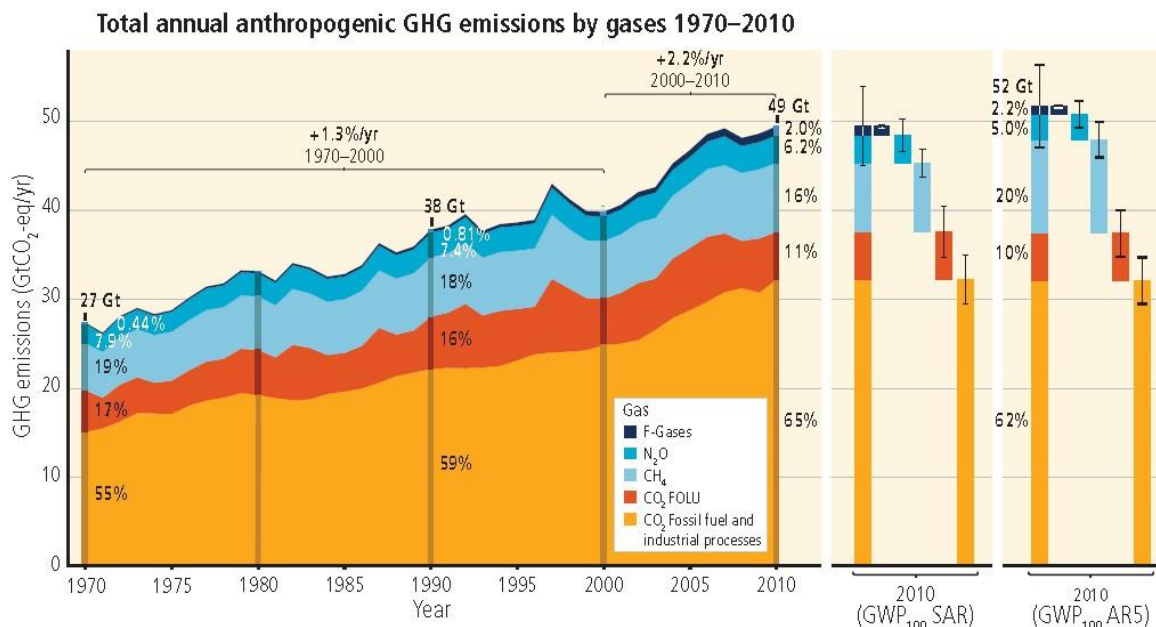
Source: IPCC (2014): http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

- **UNSD Environmental Indicators**: United Nations Statistics Division disseminates global environment statistics on 'Air and Climate' and other nine indicator themes compiled from a wide range of data sources. The themes and indicator tables were selected based on the current demands for international environmental statistics and the availability of internationally comparable data. Indicator tables, charts and maps with relatively good quality and coverage across countries, as well as links to other international sources, are provided under each theme. They are available on http://unstats.un.org/unsd/ENVIRONMENT/qindicators.htm.

- **FAO Infographics**: FAO has developed many infographics booklets about climate change, including GHG emissions from agriculture, forestry and other land use. They are available on http://www.fao.org/climate-change/resources/infographics/infographic-booklets/en.

Figure 6.4: Emissions from AFOLU on infographics

Source: FAO, http://www.fao.org/3/a-i6340e.pdf
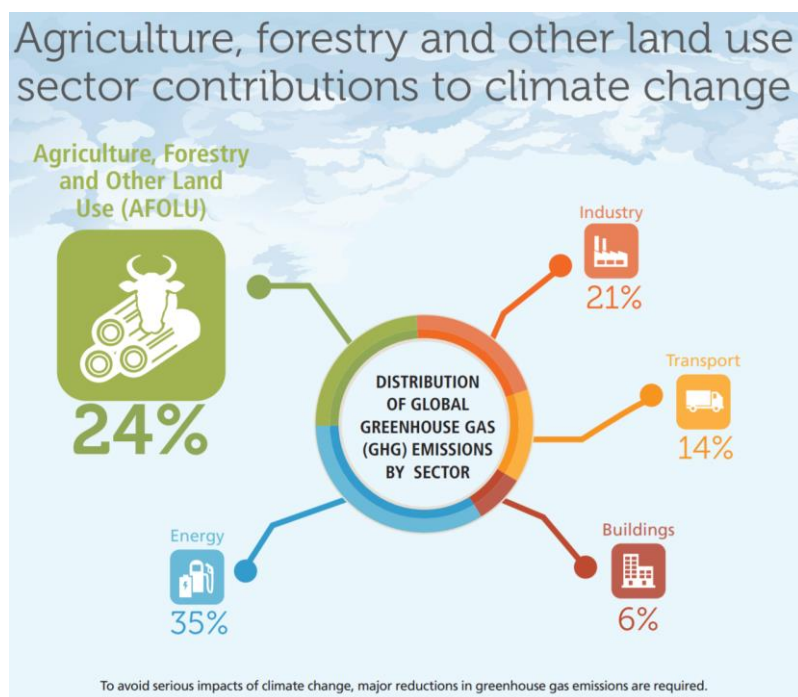
Other examples can be found in the following sites:

- **IPCC Data Distribution Centre**: http://www.ipcc-data.org/sim/gcm_clim/SRES_TAR/ddc_sres_emissions.html.

- **Quarterly estimate of greenhouse gas emissions produced by Statistics Netherlands**: http://www.unece.org/fileadmin/DAM/stats/pr/Netherlands_press_release.pdf.

- **WMO-GAW Annual Greenhouse Gas Bulletins, published by World Meteorological Organization** (Atmospheric Environment Research Division): http://library.wmo.int/pmb_ged/ghg-bulletin_11_en.pdf.

- **CDIAC – Carbon Dioxide Information Analysis Center:** http://cdiac.ornl.gov/trends/emis/tre_afr.html.

6B. SEEA accounts/tables that use these statistics

These statistics can also be used to populate environmental-economic accounts, in particular, if they are available according to the Standard Industrial Classification of All Economic Activities (ISIC). The SEEA air emissions account records the generation of air emissions by resident economic units, by type of substance. The SEEA air emissions account is presented in Table 3.7, page 82 of the SEEA Central Framework.[61]

It is important to highlight that the standard SEEA Central Framework tables only refer to gross emissions from industries and households, while removals (from the AFOLU sector) are not considered to the same full extent of the UNFCCC reporting tables. An exception are the air emission accounts currently developed under the SEEA AFF - Agriculture, Forestry and Fisheries, which include all emissions reported to UNFCCC in line with IPCC guidelines (https://seea.un.org/content/system-environmental-economic-accounting-agriculture-forestry-and-fisheries).

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[61] UN, EC, FAO, IMF, OECD and WB (2014). System of Environmental-Economic Accounting 2012 - Central Framework, pg. 82, https://seea.un.org/sites/seea.un.org/files/seea_cf_final_en.pdf (accessed 10 September 2020)

SEEA Experimental Ecosystem Accounting (EEA) addresses removals of CO_2 (termed carbon sequestration) as it is defined a key ecosystem service. It has to be noted that while IPCC covers emissions and removals from managed land and anthropogenic activities, the SEEA EEA places emphasis on 'natural' ones, e.g., carbon sequestration by the ecosystems.

There are other differences between UNFCCC reporting and SEEA air emission accounts, such as: the concept of SEEA differs principally on the allocation of transport to respective ISIC sector whereas energy balances – used by UNFCCC/IPCC Guidelines allocate all transport used by ISIC to the transport sector, allowing for bunkering, etc.; likewise, for other sectors like AFOLU/LULUCF the ecosystem accounts may give different land classifications[62] as compared to IPCC/UNFCCC.

6C. Commonly used indicators that incorporate these statistics
- National GHG reports to UNFCCC and its Kyoto Protocol

6D. SDG indicators that incorporate these statistics

- **Goal 9, Target 9.4, '**By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities'.
  - **Indicator 9.4.1. CO_2 emission per unit of value added (Tier I)**

Carbon dioxide (CO_2) emissions per unit value added is an indicator computed as ratio between CO_2 emissions from fuel combustion and the value added of associated economic activities. The indicator can be computed for the whole economy (total CO_2 emissions/GDP) or for specific sectors, notably the manufacturing sector (CO_2 emissions from manufacturing industries per manufacturing value added (MVA).

CO_2 emissions per unit of GDP are expressed in kilogrammes of CO_2 per USD constant 2010 PPP GDP. CO_2 emissions from manufacturing industries per unit of MVA are measured in kilogrammes of CO_2 equivalent per unit of MVA in constant 2015 USD. The indicator can be presented for national totals, for the manufacturing sector, and by industrial subsector. See computation guidance in the SDG metadata repository.[63]

- **Goal 13, Target 13.2**, 'Integrate climate change measures into national policies, strategies and planning' addresses the issue of national GHG emissions reduction. Two indicators were included in 2020:[64]
  - **13.2.1 Number of countries with nationally determined contributions, long-term strategies, national adaptation plans, strategies as reported in adaptation communications and national communications (Tier II).**[65]

The Paris Agreement requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) including mitigation, adaptation and support measures. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

  - **13.2.2 Total greenhouse gas emissions per year (Tier II).**[66]

The ultimate objective of the Climate Change Convention (UNFCCC) is to achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Estimating the levels of greenhouse gas (GHG) emissions and removals is an important element of the efforts to achieve this objective.

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[62] EC, OECD, UN and WB (2014). System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting, pg. 30, https://seea.un.org/sites/seea.un.org/files/seea_eea_final_en_1.pdf (accessed 10 September 2020)

[63] SDG Indicators, Metadata repository: https://unstats.un.org/sdgs/metadata/files/Metadata-09-04-01.pdf (accessed 10 September 2020)

[64] United Nations. Sustainable Development Goals, IAEG-SDG, Tier Classification for Global SDG Indicators: https://unstats.un.org/sdgs/files/Tier%20Classification%20of%20SDG%20Indicators_17%20July%202020_web.v2.pdf (accessed 10 September 2020)

[65] SDG Indicators, Metadata repository: https://unstats.un.org/sdgs/metadata/files/Metadata-13-02-01.pdf (accessed 10 September 2020)

[66] SDG Indicators, Metadata repository: https://unstats.un.org/sdgs/metadata/files/Metadata-13-02-02.pdf (accessed 10 September 2020)

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Manual on the Basic Set of Environment Statistics

2020