**Title**
IPCC, 2022: Annex II: Definitions, Units and Conventions



**Authors**
Al Khourdajie, Alaa
van Diemen, Renee
Lamb, William F
et al.

**Publication Date**
2022-04-01

AII

# Annex II: Definitions, Units and Conventions

**Coordinating Lead Author:**
Alaa Al Khourdajie (United Kingdom/Syria)

**Lead Authors:**
Renée van Diemen (the Netherlands/United Kingdom), William F. Lamb (Germany/United Kingdom), Minal Pathak (India), Andy Reisinger (New Zealand), Stéphane de la Rue du Can (the United States of America), Jim Skea (United Kingdom), Raphael Slade (United Kingdom), Shreya Some (India), Linda Steg (the Netherlands)

**This chapter should be cited as:**
IPCC, 2022: Annex II: Definitions, Units and Conventions [Al Khourdajie, A., R. van Diemen, W.F. Lamb, M. Pathak, A. Reisinger, S. de la Rue du Can, J. Skea, R. Slade, S. Some, L. Steg (eds)]. In IPCC, 2022: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.021.

# Table of Contents



AII

This annex on *Definitions, Units and Conventions* provides background information on material used in the Working Group III contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6 WGIII). The material presented in this annex documents metrics and common datasets that are typically used across multiple chapters of the report. In a few instances there are no updates to what was adopted by WGIII during the production of the Fifth Assessment Report (AR5), in which case this annex refers to Annex II of AR5 (Krey et al. 2014).

The annex comprises four parts: Part I introduces standards, metrics and common definitions adopted in the report; Part II presents methods to derive or calculate certain quantities and identities used in the report; Part III provides more detailed background information about common data sources; and Part IV presents integrative methodologies used in the assessment. While this structure may help readers to navigate through the annex, it is not possible in all cases to unambiguously assign a certain topic to one of these parts, naturally leading to some overlap between the parts.

## Part I: Definitions and Units

### A.II.1 Classification Schemes for Countries and Areas

In this report, two different levels of classification are used as a standard to present the results of analysis. The basis for the classification is the UN Statistics Division *Standard Country or Area Codes for Statistical Use*, also known as the M49 Standard (UNSD 1999). This covers geographical regions and, at the time of the literature cut-off date, identified developed regions, developing regions and least developed countries.

The high-level classification has six categories (Table 1): one covering North America, Europe, and Australia, Japan and New Zealand, labelled 'developed countries', and five covering other countries, all classified as developing using the M49 standard at the cut-off date. The high-level classification is an expansion of the RC5 (Regional Categorisation 5) adopted in AR5 WGIII, with Africa and the Middle East now identified separately. The low-level classification (ten categories) divides developed countries into three geographical regions, and Asia and Pacific into three sub-regions.

The high- and low-level classification schemes reflect schemes used in many global models and statistical sources. Where the report synthesises data, only these standard classification schemes have been used. On occasions, the underlying literature may deviate from the standard classification scheme and direct citations may unavoidably refer to alternative classifications. This is dealt with on a case-by-case basis and does not imply any endorsement of the scheme used in the underlying literature by the IPCC or the authors of this report.

The detailed allocation of countries and areas to the low-level classification is shown in Section 1.1. Following AR5, the classification scheme deviates from the UN regional classification with the result that Annex I, Annex II and non-Annex I countries as defined under the UN Framework Convention on Climate Change (UNFCCC) are distinguished. Some Annex I countries in Western Asia and countries in Eastern Europe which are not members of the European Union are allocated to Eastern Europe and West-Central Asia (EEA). In AR5, these formed part of the Economies in Transition group. The remainder of Western Asia (non-Annex I) is allocated to the Middle East.

Following the practice of the UN Statistics Division, we note that the designations employed and the presentation of material in this report do not imply the expression of any opinion by the United Nations, the IPCC or the authors of this report concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The term 'country' as used in this material also refers, as appropriate, to territories or areas.

#### A.II.1.1 Low Level of Regional Groupings

**Africa:** Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Côte d'Ivoire, Cabo Verde, Cameroon, the Central African Republic, Chad, the Comoros, the Congo, the Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, the Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, the South Sudan, the Sudan, Togo, Tunisia, Uganda, the United Republic of Tanzania, Zambia, Zimbabwe.

**Middle East:** Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, the State of Palestine, the Syrian Arab Republic, the United Arab Emirates, Yemen.

**Latin America and Caribbean:** Antigua and Barbuda, Argentina, the Bahamas, Barbados, Belize, Plurinational State of Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, the Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Bolivarian Republic of Venezuela.

**North America:** Canada, the United States of America.

**Eastern Asia:** China, the Republic of Korea, the Democratic People's Republic of Korea, Mongolia.

**Southern Asia:** Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka.

**South-East Asia and Pacific:** Brunei Darussalam, Cambodia, Cook Islands, Fiji, Indonesia, Kiribati, the Lao People's Democratic Republic, Malaysia, the Marshall Islands, Federated States of Micronesia, Myanmar, Nauru, Niue, Palau, Papua New Guinea, the Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam.

**Europe:** Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom of Great Britain and Northern Ireland.

**Australia, Japan, and New Zealand**

**Eastern Europe and West-Central Asia:** Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, the Republic of Moldova, the Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

**International Shipping and Aviation**

### A.II.1.2 High, Low Levels of Regional Groupings

**Table 1 | Classification schemes for countries and areas.**

| WGIII AR6 | |
|---|---|
| **High Level (6)** | **Low Level (10)** |
| Developed Countries (DEV) | North America |
| | Europe |
| | Australia, Japan and New Zealand |
| Eastern Europe and West-Central Asia (EEA) | Eastern Europe and West-Central Asia |
| Latin America and Caribbean (LAM) | Latin America and Caribbean |
| Africa (AFR) | Africa |
| Middle East (ME) | Middle East |
| Asia and Pacific (APC) | Eastern Asia |
| | Southern Asia |
| | South-East Asia and Pacific |
| International Shipping and Aviation | |

## A.II.2 Standard Units and Unit Conversions

The following sections introduce standard units and unit conversions used throughout this report.

### A.II.2.1 Standard Units

Standard units of measurements include Système International (SI) units, SI-derived units, and other non-SI units as well the standard prefixes for basic physical units.

**Table 2 | Système International (SI) units.**

| Physical quantity | Unit | Symbol |
|---|---|---|
| Length | metre | m |
| Mass | kilogram | kg |
| Time | second | s |
| Thermodynamic temperature | kelvin | K |
| Amount of substance | mole | mol |

**Table 3 | Special names and symbols for certain SI-derived units.**

| Physical quantity | Unit | Symbol | Definition |
|---|---|---|---|
| Force | Newton | N | kg m $s^2$ |
| Pressure | Pascal | Pa | kg $m^{-1}$ $s^{-2}$ (= N $m^{-2}$) |
| Energy | Joule | J | kg $m^2$ $s^{-2}$ |
| Power | Watt | W | kg $m^2$ $s^{-3}$ (= J $s^{-1}$) |
| Frequency | Hertz | Hz | $s^{-1}$ (cycles per second) |
| Ionizing radiation dose | sievert | Sv | J $kg^{-1}$ |

**Table 4 | Non-SI standard units.**

| Monetary units | Unit | Symbol |
|---|---|---|
| Currency (market exchange rate, MER) | Constant US Dollar 2015 | USD2015 |
| Currency (purchasing power parity, PPP) | Constant International Dollar 2015 | Int$2015 |
| **Emission- and climate-related units** | **Unit** | **Symbol** |
| Emissions | Metric tonnes | t |
| $CO_2$ emissions | Metric tonnes $CO_2$ | $tCO_2$ |
| $CO_2$-equivalent emissions[1] | Metric tonnes $CO_2$-equivalent | $tCO_2$-eq |
| Abatement costs and emissions prices/taxes | Constant US dollar 2015 per metric tonne | USD2015 $t^{-1}$ |
| $CO_2$ concentration or mixing ratio (μmol $mol^{-1}$) | Parts per million ($10^6$) | Ppm |
| $CH_4$ concentration or mixing ratio (nmol $mol^{-1}$) | Parts per billion ($10^9$) | ppb |
| $N_2O$ concentration or mixing ratio (nmol $mol^{-1}$) | Parts per billion ($10^9$) | ppb |
| Radiative forcing | Watts per square meter | W/$m^2$ |
| **Energy-related units** | **Unit** | **Symbol** |
| Energy | Joule | J |
| Electricity and heat generation | Watt hours | Wh |
| Power (peak capacity) | Watt (Watt thermal, Watt electric) | W (Wth, We) |
| Capacity factor | Percent | % |
| Technical and economic lifetime | Years | yr |
| Specific energy investment costs | US dollar 2015 per kW (peak capacity) | USD2015/kW |
| Energy costs (e.g., LCOE) and prices | Constant US dollar 2015 per GJ or US cents 2015 per kWh | USD2015/GJ and USct2015/kWh |
| Passenger-distance | Passenger-kilometre | pkm |
| Payload-distance[2] | Tonne-kilometre | tkm |
| **Land-related units** | **Unit** | **Symbol** |
| Area | Hectare | ha |

Note that all monetary and monetary-related units are expressed in constant US Dollar 2015 (*USD*2015) or constant International Dollar 2015 (*Int*$2015).

[1] A measure of aggregate greenhouse gas (GHG) emissions. This report uses the GHG metric Global Warming Potential with a time horizon of 100 years (GWP100); for details see Section 8.

[2] The is a unit of measure of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode (road, rail, air, sea, inland waterways, pipeline etc.) over a distance of one kilometre. The tonne measure here is not the same unit of measure as metric tonnes earlier in the third row of Table 4.

**Table 5 | Prefixes for basic physical units.**

| Multiple | Prefix | Symbol | Fraction | Prefix | Symbol |
|---|---|---|---|---|---|
| 1E+21 | zeta | Z | 1E-01 | deci | d |
| 1E+18 | exa | E | 1E-02 | centi | c |
| 1E+15 | peta | P | 1E-03 | milli | m |
| 1E+12 | tera | T | 1E-06 | micro | µ |
| 1E+09 | giga | G | 1E-09 | nano | n |
| 1E+06 | mega | M | 1E-12 | pico | p |
| 1E+03 | kilo | k | 1E-15 | femto | f |
| 1E+02 | hecto | h | 1E-18 | atto | a |
| 1E+01 | deca | da | 1E-21 | zepto | z |



## A.II.2.2 Physical Units Conversion

**Table 6 | Conversion table for common mass units (IPCC 2001).**

| *To:* | | kg | t | lt | st | lb |
|---|---|---|---|---|---|---|
| *From:* | Multiply by: | | | | | |
| Kilogram | kg | 1 | 1.00E-03 | 9.84E-04 | 1.10E-03 | 2.20E+00 |
| Tonne | t | 1.00E+03 | 1 | 9.84E-01 | 1.10E+00 | 2.20E+03 |
| Long ton | lt | 1.02E+03 | 1.02E+00 | 1 | 1.12E+00 | 2.24E+03 |
| Short Ton | st | 9.07E+02 | 9.07E-01 | 8.93E-01 | 1 | 2.00E+03 |
| Pound | lb | 4.54E-01 | 4.54E-04 | 4.46E-04 | 5.00E-04 | 1 |

**Table 7 | Conversion table for common volumetric units (IPCC 2001).**

| *To:* | | gal US | gal UK | bbl | ft$^3$ | l | m$^3$ |
|---|---|---|---|---|---|---|---|
| *From:* | Multiply by: | | | | | | |
| US gallon | gal US | 1 | 8.33E-01 | 2.38E-02 | 1.34E-01 | 3.79E+00 | 3.80E-03 |
| UK/imperial gallon | gal UK | 1.20E+00 | 1 | 2.86E-02 | 1.61E-01 | 4.55E+00 | 4.50E-03 |
| Barrel | bbl | 4.20E+01 | 3.50E+01 | 1 | 5.62E+00 | 1.59E+02 | 1.59E-01 |
| Cubic foot | Ft$^3$ | 7.48E+00 | 6.23E+00 | 1.78E-01 | 1 | 2.83E+01 | 2.83E-02 |
| Litre | L | 2.64E-01 | 2.20E-01 | 6.30E-03 | 3.53E-02 | 1 | 1.00E-03 |
| Cubic metre | M$^3$ | 2.64E+02 | 2.20E+02 | 6.29E+00 | 3.53E+01 | 1.00E+03 | 1 |

**Table 8 | Conversion table for common energy units (NAS 2007; IEA 2019).**

| *To:* | | TJ | Gcal | Mtoe | Mtce | MBtu | GWh |
|---|---|---|---|---|---|---|---|
| *From:* | Multiply by: | | | | | | |
| Tera joule | TJ | 1 | 2.39E+02 | 2.39E-05 | 3.41E-05 | 9.48E+02 | 2.78E-01 |
| Giga calorie | Gcal | 4.19E-03 | 1 | 1.0E-06 | 1.43E-07 | 3.97E+00 | 1.16E-03 |
| Mega tonne oil equivalent | Mtoe | 4.19E+04 | 1.0E+08 | 1 | 1.43E+00 | 3.97E+07 | 1.16E+04 |
| Mega tonne coal equivalent | Mtce | 2.93E+04 | 7.0E+06 | 7.00E-01 | 1 | 2.78E+07 | 8.14E+03 |
| Million british thermal units | MBtu | 1.06E-03 | 2.52E-01 | 2.52E-08 | 3.60E-08 | 1 | 2.93E-04 |
| Giga watt hours | GWh | 3.60E+00 | 8.60E+02 | 8.60E-05 | 1.23E-4 | 3.41E+03 | 1 |

In addition to the above physical units, datasets often report carbon emissions in either units of carbon (C) or carbon dioxide ($CO_2$). In this report we report carbon dioxide ($CO_2$) emissions where possible, using the conversion factor (44/12) to convert from units of C into $CO_2$. Finally, we note that the conversion from GJ to kWh is as follows: 1 GJ = ~277.78 kWh.

Where aggregate greenhouse gas emissions are reported, this report uses the Global Warming Potential with a time horizon of 100 years (GWP100); for details see Section 8.

### A.II.2.3 Monetary Unit Conversion

To achieve comparability across cost und price information from different regions, where possible monetary quantities reported in the AR6 WGIII have been expressed in constant US Dollar 2015 (*USD*2015) or constant International Dollar 2015 (*Int*$2015), as suitable.

To facilitate a consistent monetary unit conversion process, a simple and transparent procedure to convert different monetary units from the literature to USD2015 is established and described below.

In order to convert from year X local currency unit ($LCU_x$) to 2015 US Dollars (*USD*2015) two steps are needed:

1. Inflating or deflating from year X to 2015, and
2. Converting from *LCU* to *USD*.

In practice, the order of applying these two steps will lead to different results. In this report, the conversion route adopted is $LCU_x \rightarrow LCU2015 \rightarrow USD2015$, i.e., national or regional deflators are used to measure country- or region-specific inflation between year X and 2015 in local currency, then current (2015) exchange rates are used to convert to *USD*2015. The reason for adopting this route is when the economy's GDP deflator is used to convert to a common base year, that is, 2015, it captures the changes in prices of all goods and services that the economy produces. To convert from *LCU*2015 to *USD*2015, the official 2015 exchange rates are used. Note that exchange rates often fluctuate significantly in the short term.

In order to be consistent with the choice of the World Bank databases as the primary source for gross domestic product (GDP) and other financial data throughout the report, deflators and exchange rates from the World Bank Development Indicators are used.[3]

To summarise, the following procedure has been adopted to convert monetary quantities reported in $LCU_x$ to *USD*2015:

1. Use the country-/region-specific deflator and multiply with the deflator value to convert from $LCU_x$ to *LCU*2015. In case national/regional data are reported in non-LCU units (e.g., $USD_x$ or $Euro_x$), which is often the case in multi-national or global studies, apply the corresponding currency deflator to convert to 2015 currency (i.e., the US deflator and the Eurozone deflator in the examples above).

   Example of converting GDP from *LCU*2010 prices to *LCU*2015 prices:

   $$GDP2015 \text{ (in } LCU2015 \text{ prices)} = GDP2010 \text{ (in } LCU2010 \text{ prices)} * \frac{LCU_{2010}\, GDP\ deflator}{LCU_{2015}\, GDP\ deflator}$$

2. Use the appropriate 2015 exchange rate to convert from *LCU*2015 to *USD*2015.

## Part II: Conventions

### A.II.3 Levelised Cost Metrics

Across this report, a number of different metrics to characterise cost of climate change mitigation are employed. To facilitate a meaningful economic comparison across diverse options at the technology level, the metric of 'levelised costs' is used throughout several chapters of this report in various forms. The most used metrics are the levelised cost of energy (LCOE), the levelised cost of conserved energy (LCCE), and the levelised cost of conserved carbon (LCCC). These metrics are used throughout the AR6 WGIII to provide a benchmark for comparing different technologies or practices of achieving the respective output. Each comes with a set of context-specific caveats that need to be taken into account for correct interpretation. Various literature sources caution against drawing too strong conclusions from these metrics. Annex II in AR5, namely Section A.II.3.1, includes a detailed discussion on interpretations and caveats. Below is an introduction to each of these metrics and how they are derived.

#### A.II.3.1 Levelised Cost of Energy

The levelised cost of energy (LCOE) can be defined as the unique break-even cost-price where discounted revenues (price x quantities) are equal to the discounted net expenses (Moomaw et al. 2011), which is expressed as follows:

$$\sum_{t=0}^{n} \frac{E_t * LCOE}{(1+i)^t} = \sum_{t=0}^{n} \frac{Expenses_t}{(1+i)^t} \quad (1)$$

where $E_t$ is the energy delivered in year *t* (might vary from year to year), expenses cover all (net) expenses in the year *t*, *i* is the discount rate and *n* the lifetime of the project.

solving for *LCOE*:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{Expenses_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}} \quad (2)$$

The lifetime expenses comprise investment costs *I*, operation and maintenance cost *O&M* (including waste management costs), fuel costs *F*, carbon costs *C*, and decommissioning costs *D*. In this case, levelised cost can be determined by (IEA 2010):

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + O\&M_t + F_t + C_t + D_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t *}{(1+i)^t}} \quad (3)$$

[3] For instance, the data for GDP deflators for all countries can be downloaded following this link: https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?locations=US.

Assuming energy $E$ provided annually is constant during the lifetime of the project, one can rewrite (3) as follows:

$$LCOE = \frac{CRF \cdot NPV\,(Lifetime\ Expenses)}{E} = \frac{Annuity\,(Lifetime\ Expenses)}{E} \qquad (4)$$

where $CRF = \frac{i}{1-(1-i)^{-n}}$ is the capital recovery factor and $NPV$ the net present value of all lifetime expenditures (Suerkemper et al. 2012).

For the simplified case, where the annual costs are also assumed constant over time, this can be further simplified to (*O&M* costs and fuel costs $F$ constants):

$$LCOE = \frac{CRF \cdot I + O\&M + F}{E} \qquad (5)$$

Where $I$ is the upfront investment, *O&M* are the annual operation and maintenance costs, $F$ are the annual fuel costs, and $E$ is the annual energy provision. The investment $I$ should be interpreted as the sum of all capital expenditures needed to make the investment fully operational discounted to $t = 0$. These might include discounted retrofit payments during the project lifetime and discounted decommissioning costs at the end of the lifetime. Where applicable, annual *O&M* costs have to take into account revenues for by-products and existing carbon costs must be added or treated as part of the annual fuel costs.

### A.II.3.2 Levelised Cost of Conserved Energy

The levelised cost of conserved energy (LCCE) annualises the investment and operation and maintenance cost differences between a baseline technology and the energy-efficient alternative and divides this quantity by the annual energy savings.

The conceptual formula for *LCCE* is essentially the same as Equation (4) above, with $\Delta E$ measuring in this context the amount of energy saved annually (Suerkemper et al. 2012):

$$LCCE = \frac{CRF.NPV(\Delta Lifetime\ Expenses)}{\Delta E} = \frac{Annuity(\Delta Lifetime\ Expenses)}{\Delta E} \qquad (6)$$

In the case of assumed annually constant *O&M* costs over the project lifetime, one can rewrite (6) as follows:

$$LCCE = \frac{CRF \cdot \Delta I + \Delta O\&M}{\Delta E} \qquad (7)$$

where $\Delta I$ is the difference in investment costs of an energy saving measure (e.g., in USD) as compared to a baseline investment; $\Delta O\&M$ is the difference in annual operation and maintenance costs of an energy saving measure (e.g., in USD) as compared to the baseline in which the energy-saving measure is not implemented; $\Delta E$ is the annual energy conserved by the measure (e.g., in *kWh*) as compared to the usage of the baseline technology; and *CRF* is the capital recovery factor depending on the discount rate and the lifetime of the measure in years as defined above. It should be stressed once more that this equation is only valid if $\Delta O\&M$ and $\Delta E$ are constant over the project lifetime. As *LCCE* are designed to be compared with complementary levelised cost of energy supply, they do not include the annual fuel cost difference. Any additional monetary benefits that are associated with the energy-saving measure must be taken into account as part of the *O&M* difference.

### A.II.3.3 Levelised Cost of Conserved Carbon

The levelised cost of conserved carbon can be used for comparing mitigation costs per unit of avoided carbon emissions and comparing these specific emission reduction costs for different options. This concept can be applied to other pollutants.

The conceptual formula for *LCCC* is similar to Equation (6) above, with $\Delta C$ is the annual reduction in carbon emissions, which can be expressed as follows:

$$LCCC = \frac{CRF.NPV(\Delta Lifetime\ Expenses)}{\Delta C} = \frac{Annuity(\Delta Lifetime\ Expenses)}{\Delta C} \qquad (8)$$

In the case of assumed annually constant *O&M* costs over the lifetime, one can rewrite (8) as follows:

$$LCCC = \frac{CRF \cdot \Delta I + \Delta O\&M - \Delta B}{\Delta C} \qquad (9)$$

where $\Delta I$ is the difference in investment costs of a mitigation measure (e.g., in USD) as compared to a baseline investment; $\Delta O\&M$ is the difference in annual operation and maintenance costs (e.g., in USD) and $\Delta B$ denotes the annual benefits, all compared to a baseline for which the option is not implemented. Note that annual benefits include reduced expenditures for fuels, if the investment project reduces emissions via a reduction in fuel use. As such *LCCC* depend on energy prices. An important characteristic of this equation is that *LCCC* can become negative if $\Delta B$ is bigger than the sum of the other two terms in the numerator.

## A.II.4 Growth Rates

### A.II.4.1 Emissions Growth Rates

In order to ensure consistency throughout the reported growth rates for emissions in AR6 WGIII, this section establishes the convention for calculating these rates.

The annual growth rate of emissions in percent per year for adjacent years is given by:

$$r = \frac{\left(E_{FF}(t_0 - 1) - E_{FF}(t_0)\right)}{E_{FF}(t_0)} * 100 \qquad (10)$$

where $E_{FF}$ stands for fossil fuel $CO_2$ emissions, but can also be applied to other pollutants.

When relevant a leap-year adjustment is required in order to ensure valid interpretation of annual growth rates in the case of adjacent years. A leap-year affects adjacent years growth rate by approximately 0.3% $yr^{-1}$ $\left(\frac{1}{365}\right)$ which causes growth rates to go up approximately 0.3% if the first year is a leap year, and down 0.3% if the second year is a leap year (Friedlingstein et al. 2019).

The relative growth rate of $E_{FF}$ over time periods of greater than one year is derived as follows.

Starting from:

$$E_{FF}(t+n) = E_{FF}(t) * (1+r)^n \quad (11)$$

solving for $r$:

$$r = \left(\frac{E_{FF}(t+n)}{E_{FF}(t)}\right)^{1/n} - 1 \quad (12)$$

#### A.II.4.2 Economic Growth Rates

A number of different methods exist for calculating economic growth rates (e.g., GDP), all of which lead to slightly different numerical results. If not stated otherwise, the annual growth rates shown in the report are derived using the *Log Difference Regression* technique *or Geometric Average* techniques which can be shown to be equivalent.

The Log Difference Regression growth rate $r_{LD}$ is calculated as follows:

$$r_{LD} = e^{\beta} - 1 \text{ with } \beta = \frac{1}{T-1}\sum_{t=2}^{T} \Delta lnX_t \quad (13)$$

The Geometric Average growth rate $r_{GEO}$ is calculated as shown below:

$$r_{GEO} = \left(\frac{X_T}{X_1}\right)^{\frac{1}{T-1}} - 1 \quad (14)$$

Other methods that are used to calculate annual growth rates include the Ordinary Least Square technique and the Average Annual Growth Rate technique.

## A.II.5 Trends Calculations Between Years and Over Decades

In order to compare or contrast trends between two different years, for instance comparing 2000 and 2010 cumulative $CO_2$ emissions, the year 2000 runs from 1st of January to 31st of December and similarly the year 2010 runs from 1st of January to 31st of December.

In order to undertake a timeseries calculation over a decade, the 10-year period should be defined as follows: from 1st of January 2001 to 31st of December 2010, that is 2001–2010.

## A.II.6 Primary Energy Accounting

Primary energy accounting methods are used to report primary energy from non-combustible energy sources, in other words, nuclear energy and all renewable energy sources except biomass. Annex II of AR5, namely Section A.II.4, includes a detailed discussion of the three main methods dominant in the literature. The method adopted in AR6 is the *direct equivalent method* which counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy, that is, 1 kWh of electricity or heat is accounted for as 1 kWh = 3.6 MJ of primary energy. This method is mostly used in the long-term scenarios literature, including multiple IPCC reports (IPCC 1995, Morita et al. 2001, Fisher et al. 2007, Fischedick et al. 2011), because it deals with fundamental transitions of energy systems that rely to a large extent on low-carbon, non-combustible energy sources.

## A.II.7 The Concept of Risk

The concept of risk is a key aspect of how the IPCC assesses and communicates to decision-makers the potential adverse impacts of, and response options to, climate change. For the AR6 cycle, the definition of risk was revised (see below). Authors and IPCC Bureau members from all three Working Groups produced a Guidance (Reisinger et al. 2020) for authors on the concept of risk in order to ensure a consistent and transparent application across Working Groups.

This section summarises this Guidance briefly with a focus on issues related to WGIII, in other words, with focus on mitigation.

#### A.II.7.1 The Definition of Risk

Definition (see Annex I: Glossary):

Risk is the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as *human responses to climate change*. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

- In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also risk management, adaptation, mitigation).

- In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals. Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.

### A.II.7.2 The Definition of Risk Management

Plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (see also risk assessment, risk perception, risk transfer).

### A.II.7.3 The Uses of the Term Risk and Risk Management

In this report, with the aim of improving the ability of decision-makers to understand and manage risk, the term is used when considering the potential for adverse outcomes and the uncertainty relating to these outcomes.

The term risk is not used as a simple substitute for probability or chance, to describe physical hazards, or as generic term for 'anything bad that may happen in future'. While the probability of an adverse outcome does not necessarily have to be quantified, it needs to be characterised in some way to allow a risk assessment to inform responses via risk management.

In the AR6, risk refers to the potential for *adverse* consequences only. The term hazard is used where climatic events or trends has an identified potential for having adverse consequences to specific elements of an affected system. The contribution of Working Group I to the AR6 uses the more general term 'climatic impact driver' where a specific change in climate could have positive or negative consequences, and where a given climatic change may therefore act as a driver of risk or of an opportunity.

### A.II.7.4 Examples of Application in the Context of Mitigation

*Food Security*

Climate-related risk to food security arises from multiple drivers that include both climate change impacts, responses to climate change and other stressors.

In the context of responses to climate change, drivers of risk include the demand for land from climate change responses (both adaptation and mitigation), the role of markets (e.g., price spikes related to biofuel demand in other countries), governance (how are conflicts about access to land and water resolved) and human behaviour more generally (e.g., trade barriers, dietary preferences).

Given the multitude of drivers, the risk to food security depends on assumptions about what drivers of risk are changing and which are assumed to remain constant. Such assumptions are important for analytical robustness and are stated where relevant.

*Risk in the Investment and Finance Literature*

The investment and finance literature and practitioner community broadly distinguish between 'physical risk' and 'transition risk'. The term 'physical risk' generally refers to risks arising from climate change impacts and climate-related hazards, while the term 'transition risk' typically refers to risks associated with the transition to a low carbon economy. These two types of risk may interact and create cascading or compounding risks.

*Physical Risk*

In much of the business and financial literature, the term 'physical risk' relates to those derived from the hazard × exposure × vulnerability framework. Physical risks arise from the potential for climate change impacts on the financial value of assets such as industrial plants or real estate, risks to facilities and infrastructure, impact on operations, water and raw material availability and supply chain disruptions. Physical risks have direct financial consequences for organisations where those risks are realised, as well as up-front insurance and investment related costs and downstream effects for users of relevant goods and services.

*Transition Risk*

Transition risks typically refer to risks associated with transition to a low carbon economy, which can entail extensive policy, legal, technology, and market changes to address mitigation and adaptation requirements related to climate change. Depending on the nature, speed, and focus of these changes, transition risks may pose varying levels of financial and reputational risk to organisations. Transition risks, if realised, can result in stranded assets, loss of markets, reduced returns on investment, and financial penalties, as well as adverse outcomes for governance and reputation.

A key issue is the stranding of assets that may not provide the expected financial returns and may end up as large financial liabilities.

Examples of types of transition risk relating to business, finance and investments:

- Risk related to an asset losing its value: the potential for loss of investment in infrastructure.
- Risk related to losing some or all of the principal of an investment (or invested capital).
- Solvency risk: the risk from reduction in credit ratings due to potential adverse consequences of climate change or climate policy. This includes liquidity risk or the risk of not being able to access funds. Another example is suffering a downgraded credit rating.
- Risk of lower-than-expected return on investment.
- Liability risk: lack of response to climate change creates risk of liability for failure to accurately assess risk of climate change to infrastructure and people.

- Technology risk: reliance on a particular technology to achieve an outcome creates the potential for adverse consequences if the technology fails to be developed or deployed.
- Policy risk: changes in policy or regulations in response to climate change could result in the loss of value of some assets.
- Market risk: changes in relative prices from increased prices of $CO_2$ for instance, could reduce financial returns and hence increase risks to investors.
- Residual risk: in parts of the financial literature, this concept refers to adverse consequences that cannot be quantified in probabilistic terms. Note that this is different from how the term 'residual risk' is generally used in IPCC, especially Working Group II, where it means the risk remaining after adaptation and risk reduction efforts.



## A.II.8 GHG Emission Metrics

Comprehensive mitigation policy relies on consideration of all anthropogenic forcing agents, which differ widely in their atmospheric lifetimes and impacts on the climate system. GHG emission metrics[4] provide simplified information about the effect that emissions of different GHGs have on global temperature or other aspects of climate, usually expressed relative to the effect of emitting $CO_2$. An assessment of different GHG emission metrics from a mitigation perspective is provided in Cross-Chapter Box 2 and Chapter 2 Supplementary Material, building on the assessment of GHG emission metrics from a physical science perspective in AR6 WGI (Forster et al., 2021, Section 7.6).

The WGIII contribution to the AR6 reports aggregate emissions and removals using updated values for the Global Warming Potential with a time horizon of 100 years (GWP100) from AR6 WGI unless stated otherwise. These updated GWP100 values reflect updated scientific understanding of the response of the climate system to emissions of different gases, and include a methodological update to incorporate climate-carbon cycle feedbacks associated with the emission of non-$CO_2$ gases (Forster et al. 2021). For the second-most important anthropogenic greenhouse gas, methane, the updated GWP100 value of 27 is similar but slightly lower than the value of 28 reported in the AR5 without climate-carbon cycle feedbacks. A full set of GWP100 values used in this report, based on the assessment of WGI (Forster et al. 2021, Section 7.6 and Table 7.SM.7), is provided in Table 9.

GWP100 was chosen in the WGIII contribution to the AR6 as the default GHG emissions metric for both procedural and scientific reasons.

Procedural reasons are to provide continuity with the use of GWP100 in past IPCC reports and the dominant use of GWP100 in the literature assessed by WGIII, and to match decisions made by Governments as part of the Paris Agreement Rulebook. Parties to the Paris Agreement decided to report aggregated emissions and removals (expressed as $CO_2$-eq) based on the Global Warming Potential with a time horizon of 100 years (GWP100), using values from IPCC AR5 or from a subsequent IPCC report as agreed upon by the CMA,[5] and to account for future nationally determined contributions (NDCs) in accordance with this approach. Parties may also report supplemental information on aggregate emissions and removals, expressed as $CO_2$-eq, using other GHG emission metrics assessed by the IPCC (4/CMA.1 and 18/CMA.1: UNFCCC 2019).

Scientific reasons for the use of GWP100 as default GHG emission metric in WGIII are that GWP100 approximates the relative damages caused by the two most important anthropogenic GHGs $CO_2$ and $CH_4$ for social discount rates around 3%. In addition, for pathways that limit warming to 2°C (>67%) or lower, using GWP100 to inform cost-effective abatement choices between gases would achieve these long-term temperature goals at close to least global cost within a few percent (*high confidence*) (see Cross-Chapter Box 2 in Chapter 2).

However, all emission metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions. The most suitable metric for any given climate policy application, depends on judgements about the specific context, policy objectives and the way in which a metric would be used.

Wherever emissions, removals and mitigation potentials are expressed as $CO_2$-eq in this report, efforts have been made to recalculate those values consistently in terms of GWP100 values from AR6 WGI. However, in some cases it was not possible or feasible to disentangle conclusions from the existing literature into individual gases and then re-aggregate those emissions using updated GWP100 values. The existing literature assessed by WGIII uses a range of GWP100 values from previous IPCC reports; for $CH_4$, these values vary between 21 (based on the *IPCC Second Assessment Report*) to 28 or even 34 (based on the *IPCC Fifth Assessment Report* and depending on whether the study included or excluded climate-carbon cycle feedbacks). Consistent application of any metric is challenging as individual GHG emission species are not always provided in the literature assessed by WGIII. Where a full recalculation of $CO_2$-eq emissions or mitigation potentials into GWP100 AR6 values was not possible or feasible, and especially if non-$CO_2$ emissions constitute only a minor fraction of total emissions or abatement, individual chapters note this inconsistency and provide an indication of the potential magnitude of inconsistency.

To further reduce ambiguity regarding actual climate outcomes over time from any given set of emissions, the WGIII contribution to the AR6 reports emissions and mitigation options for individual gases where possible based on the available literature, and reports $CO_2$-eq emissions where this is judged to be policy relevant by author teams in addition to, not instead of individual gases.

[4] Emission metrics also exist for aerosols, but these are not commonly used in climate policy. This assessment focuses on GHG emission metrics only.

[5] The CMA is the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

**Table 9 | GWP100 values and atmospheric lifetimes for a range of GHGs, based on AR6 WGI (Forster et al. 2021).**

| Gas | AR6 – GWP100 | Lifetime |
|---|---|---|
| $CO_2$ | 1 | N/A |
| $CH_4$ (biogenic) | 27.0 | 11.8 |
| $CH_4$ (fossil – combustion)[6] | 27.0 | 11.8 |
| $CH_4$ (fossil – fugitive and process) | 29.8 | 11.8 |
| $N_2O$ | 273 | 109 |
| HFC-32 | 770 | 5.4 |
| HFC-143a | 5807 | 51 |
| CF4 | 7379 | 50,000 |
| C2F6 | 12,410 | 10,000 |
| C3F8 | 9289 | 2600 |
| C4F10 | 10,022 | 2600 |
| C5F12 | 9218 | 4100 |
| C6F14 | 8617 | 3100 |
| C7F16 | 8409 | 3000 |
| c-C4F8 | 13,902 | 3000 |
| HFC-125 | 3744 | 30 |
| HFC-134a | 1526 | 14 |
| HFC-152a | 164 | 1.6 |
| HFC-227ea | 3602 | 36 |
| HFC-23 | 14,590 | 228 |
| HFC-236fa | 8689 | 213 |
| HFC-245fa | 962 | 7.9 |
| HFC-365mfc | 913 | 8.9 |
| HFC-43-10-mee | 1599 | 17 |
| SF6 | 25,184 | 3200 |
| NF3 | 17,423 | 569 |

## Part III: Emissions Datasets

In this section we report on the historical emissions data used in the report (Section 9), the sectoral mapping on emissions sources (Section 9.1), the methane emissions sources (Section 9.2), and indirect emissions (Section 10).

### A.II.9 Historical Data

Historic emissions data for countries, regions and sectors are presented throughout the report, but especially in Chapters 2, 6–7, 9–11, the Technical Summary and Summary for Policymakers. To ensure consistency and transparency we use the same emissions data across these chapters, with a single methodology, division of emissions sources, and following the classification scheme of countries and areas in Section 1 above.

Our primary data source is the Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al. 2021, Minx et al. 2021). This dataset provides annual $CO_2$, $CH_4$, $N_2O$ and F-gas emissions on a country and emissions source level for the time span 1970 to 2019. The fossil fuel combustion component of EDGAR is closely linked to and sourced from International Energy Agency (IEA 2021) energy and emissions estimates. Section 2.2.1 in Chapter 2 of this report describes the differences between and coverage of different global emissions datasets.

In addition to EDGAR, land-use $CO_2$ emissions are sourced as the mean of three bookkeeping models, in a convention established by the Global Carbon Project (Friedlingstein et al. 2020) and consistent with the Working Group I approach. The bookkeeping models are BLUE (Bookkeeping of Land Use Emissions), Hansis et al. (2015), Houghton and Nassikas (2017) and OSCAR (Gasser et al. 2020).

Global total greenhouse gas emissions reported throughout AR6 are the sum of EDGAR and land-use $CO_2$ emissions. Significant uncertainties are associated with each gas and emissions source. These uncertainties are comprehensively treated in Section 2.2.1 of Chapter 2.

#### A.II.9.1 Mapping of Emission Sources to Sectors

The list below shows how emission sources in EDGAR are mapped to sectors throughout the AR6 WGIII. This defines unambiguous system boundaries for the sectors as represented in Chapters 6, 7 and 9–11 in the report and enables a discussion and representation of emission sources without double-counting.

Emission sources follows the definitions by the IPCC Task Force on National Greenhouse Gas Inventories (TFI) (IPCC 2019). EDGARv6 identifies each source as either 'Fossil' or 'Bio'. The 'Bio' label indicates the biomass component of fuel combustion, while 'Fossil' is the default label for all other emissions sources (including, for example, agricultural GHG emissions).



6 The biogenic $CH_4$ GWP100 value applies here, given Tier 1 IPCC $CO_2$ emissions factors which are based on total carbon content. The associated emissions are estimated on the bases of complete (100%) oxidation to $CO_2$ of carbon contained in combusted mass.

**Table 10 | Mapping emission sources to sectors.**

| Chapter title | Subsector title | EDGAR code | IPCC 2019 | Gases |
|---|---|---|---|---|
| AFOLU | Biomass burning ($CO_2$, $CH_4$) | 4F1 (bio), 4F2 (bio), 4F3 (bio), 4F4 (bio), 4F5 (bio) | 3.C.1.b (bio) | $CH_4$, $N_2O$ |
| AFOLU | Enteric fermentation ($CH_4$) | 4A1-d (fossil), 4A1-n (fossil), 4A2 (fossil), 4A3 (fossil), 4A4 (fossil), 4A5 (fossil), 4A6 (fossil), 4A7 (fossil), 4A8 (fossil) | 3.A.1.a.i (fossil), 3.A.1.a.ii (fossil), 3.A.1.b (fossil), 3.A.1.c (fossil), 3.A.1.d (fossil), 3.A.1.e (fossil), 3.A.1.f (fossil), 3.A.1.g (fossil), 3.A.1.h (fossil) | $CH_4$ |
| AFOLU | Managed soils and pasture ($CO_2$, $N_2O$) | 4D12 (fossil), 4D13 (fossil), 4D14 (fossil), 4D15 (fossil), 4D2 (fossil), 4D3a (fossil), 4D3b (fossil), 4D4a (fossil), 4D4b (fossil) | 3.C.4 (fossil), 3.C.5 (fossil), 3.C.6 (fossil), 3.C.3 (fossil), 3.C.2 (fossil) | $N_2O$, $CO_2$ |
| AFOLU | Manure management ($N_2O$, $CH_4$) | 4B1-d (fossil), 4B1-n (fossil), 4B2 (fossil), 4B3 (fossil), 4B4 (fossil), 4B5 (fossil), 4B6 (fossil), 4B7 (fossil), 4B8 (fossil), 4B9 (fossil) | 3.A.2.a.i (fossil), 3.A.2.a.ii (fossil), 3.A.2.b (fossil), 3.A.2.c (fossil), 3.A.2.i (fossil), 3.A.2.d (fossil), 3.A.2.e (fossil), 3.A.2.f (fossil), 3.A.2.g (fossil), 3.A.2.h (fossil) | $CH_4$, $N_2O$ |
| AFOLU | Rice cultivation ($CH_4$) | 4C (fossil) | 3.C.7 (fossil) | $CH_4$ |
| AFOLU | Synthetic fertiliser application ($N_2O$) | 4D11 (fossil) | 3.C.4 (fossil) | $N_2O$ |
| Buildings | Non-$CO_2$ (all buildings) | 2F3 (fossil), 2F4 (fossil), 2F9a (fossil), 2F9c (fossil) | 2.F.3 (fossil), 2.F.4 (fossil), 2.G.2.c (fossil) | c-C4F8, C4F10, CF4, HFC-125, HFC-227ea, HFC-23, HFC-236fa, HFC-134a, HFC-152a |
| Buildings | Non-residential | 1A4a (bio), 1A4a (fossil) | 1.A.4.a (bio), 1.A.4.a (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Buildings | Residential | 1A4b (bio), 1A4b (fossil) | 1.A.4.b (bio), 1.A.4.b (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Energy systems | Coal mining fugitive emissions | 1B1a1 (fossil), 1B1a1r (fossil), 1B1a2 (fossil), 1B1a3 (fossil), 1B1b2 (fossil), 1B1b4 (fossil) | 1.B.1.a (fossil), 1.B.1.c (fossil) | $CO_2$, $CH_4$ |
| Energy systems | Electricity and heat | 1A1a1 (bio), 1A1a1 (fossil), 1A1a2 (bio), 1A1a2 (fossil), 1A1a3 (bio), 1A1a3 (fossil), 1A1a4 (bio), 1A1a4 (fossil), 1A1a5 (bio), 1A1a5 (fossil), 1A1a6 (bio), 1A1a6 (fossil), 1A1a7 (bio), 1A1a7 (fossil) | 1.A.1.a.i (bio), 1.A.1.a.i (fossil), 1.A.1.a.ii (bio), 1.A.1.a.ii (fossil), 1.A.1.a.iii (bio), 1.A.1.a.iii (fossil) | $CO_2$, $CH_4$, $N_2O$ |
| Energy systems | Oil and gas fugitive emissions | 1B2a1 (bio), 1B2a1 (fossil), 1B2a2 (fossil), 1B2a3-l (fossil), 1B2a4-l (fossil), 1B2a4-t (fossil), 1B2a5(e) (fossil), 1B2b1 (fossil), 1B2b3 (fossil), 1B2b4 (fossil), 1B2b5 (fossil), 1B2c (fossil) | 1.B.2.a.iii.2 (bio), 1.B.2.a.iii.2 (fossil), 1.B.2.a.iii.3 (fossil), 1.B.2.a.iii.4 (fossil), 1.B.2.b.iii.2 (fossil), 1.B.2.b.iii.4 (fossil), 1.B.2.b.iii.5 (fossil), 1.B.2.b.iii.3 (fossil), 1.B.2.b.ii (fossil), 1.B.2.a.ii (fossil) | $CO_2$, $CH_4$, $N_2O$ |
| Energy systems | Other (energy systems) | 1A1c3 (bio), 1A1c3 (fossil), 1A1c4 (bio), 1A1c5 (bio), 1A1c5 (fossil), 1A4c1 (bio), 1A4c1 (fossil), 1A4d (bio), 1A4d (fossil), 1B1b3 (bio), 2F8b (fossil), 7A1 (fossil), 7A2 (fossil), 7B1 (fossil), 7C1 (fossil) | 1.A.1.c.ii (bio), 1.A.1.c.ii (fossil), 1.A.1.c.i (bio), 1.A.1.c.i (fossil), 1.A.4.c.i (bio), 1.A.4.c.i (fossil), 1.A.5.a (bio), 1.A.5.a (fossil), 1.B.1.c (bio), 2.G.1.b (fossil), 5.B (fossil), 5.A (fossil) | $CO_2$, $CH_4$, $N_2O$, SF6 |
| Energy systems | Petroleum refining | 1A1b (bio), 1A1b (fossil) | 1.A.1.b (bio), 1.A.1.b (fossil) | $CO_2$, $CH_4$, $N_2O$ |
| Industry | Cement | 2A1 (fossil) | 2.A.1 (fossil) | $CO_2$ |
| Industry | Chemicals | 1A2c (bio), 1A2c (fossil), 2A2 (fossil), 2A3 (fossil), 2A4a (fossil), 2A4b (fossil), 2A7a (fossil), 2B1g (fossil), 2B1s (fossil), 2B2 (fossil), 2B3 (fossil), 2B4a (fossil), 2B4b (fossil), 2B5a (fossil), 2B5b (fossil), 2B5d (fossil), 2B5e (fossil), 2B5f (fossil), 2B5g (fossil), 2B5g2 (fossil), 2B5h1 (fossil), 2E (fossil), 2E1 (fossil), 3A (fossil), 3B (fossil), 3C (fossil), 3D (fossil), 3D1 (fossil), 3D3 (fossil) | 1.A.2.c (bio), 1.A.2.c (fossil), 2.A.2 (fossil), 2.A.4.d (fossil), 2.A.4.b (fossil), 2.A.3 (fossil), 2.B.1 (fossil), 2.B.2 (fossil), 2.B.3 (fossil), 2.B.5 (fossil), 2.B.8.f (fossil), 2.B.8.b (fossil), 2.B.8.c (fossil), 2.B.8.a (fossil), 2.B.4 (fossil), 2.B.6 (fossil), 2.B.9.b (fossil), 2.D.3 (fossil), 2.G.3.a (fossil), 2.G.3.b (fossil) | $CH_4$, $N_2O$, $CO_2$, c-C4F8, C2F6, C3F8, C4F10, C5F12, C6F14, CF4, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-32, HFC-365mfc, NF3, SF6, HFC-23 |
| Industry | Metals | 1A1c1 (fossil), 1A1c2 (fossil), 1A2a (bio), 1A2a (fossil), 1A2b (bio), 1A2b (fossil), 1B1b1 (fossil), 2C1a (fossil), 2C1b (fossil), 2C1d (fossil), 2C2 (fossil), 2C3a (fossil), 2C3b (fossil), 2C4a (fossil), 2C4b (fossil), 2C5lp (fossil), 2C5mp (fossil), 2C5zp (fossil) | 1.A.1.c.i (fossil), 1.A.1.c.ii (fossil), 1.A.2.a (bio), 1.A.2.a (fossil), 1.A.2.b (bio), 1.A.2.b (fossil), 1.B.1.c (fossil), 2.C.1 (fossil), 2.C.2 (fossil), 2.C.3 (fossil), 2.C.4 (fossil), 2.C.5 (fossil), 2.C.6 (fossil) | $CO_2$, $CH_4$, $N_2O$, C2F6, CF4, SF6 |
| Industry | Other (industry) | 1A2d (bio), 1A2d (fossil), 1A2e (bio), 1A2e (fossil), 1A2f (bio), 1A2f (fossil), 1A2f1 (fossil), 1A2f2 (fossil), 1A5b1 (fossil), 2F1a (fossil), 2F1b (fossil), 2F1c (fossil), 2F1d (fossil), 2F1e (fossil), 2F1f (fossil), 2F2a (fossil), 2F2b (fossil), 2F5 (fossil), 2F6 (fossil), 2F7a (fossil), 2F7b (fossil), 2F7c (fossil), 2F8a (fossil), 2F9 (fossil), 2F9d (fossil), 2F9e (fossil), 2F9f (fossil), 2G1 (fossil), 7B2 (fossil), 7C2 (fossil) | 1.A.2.d (bio), 1.A.2.d (fossil), 1.A.2.e (bio), 1.A.2.e (fossil), 1.A.2.f (bio), 1.A.2.f (fossil), 1.A.2.k (fossil), 1.A.2.i (fossil), 1.A.5.b.iii (fossil), 2.F.1.a (fossil), NA (fossil), 2.F.5 (fossil), 2.E.1 (fossil), 2.E.2 (fossil), 2.E.3 (fossil), 2.G.1.a (fossil), 2.G.2.c (fossil), 2.G.2.b (fossil), 2.G.2.a (fossil), 2.D.1 (fossil), 5.A (fossil) | $CH_4$, $N_2O$, $CO_2$, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, HFC-32, HFC-365mfc, C3F8, C6F14, CF4, HFC-43-10-mee, HFC-134, HFC-143, HFC-23, HFC-41, c-C4F8, C2F6, NF3, SF6, HCFC-141b, HCFC-142b, C4F10 |
| Industry | Waste | 6A1 (fossil), 6B1 (fossil), 6B2 (fossil), 6C (fossil), 6Ca (bio), 6Cb1 (fossil), 6Cb2 (fossil), 6D (fossil) | 4.A.1 (fossil), 4.D.2 (fossil), 4.D.1 (fossil), 4.C.1 (fossil), 4.C.2 (bio), 4.C.2 (fossil), 4.B (fossil) | $CH_4$, $N_2O$, $CO_2$ |

| Chapter title | Subsector title | EDGAR code | IPCC 2019 | Gases |
|---|---|---|---|---|
| Transport | Domestic Aviation | 1A3a (fossil) | 1.A.3.a.ii (fossil) | $CO_2$, $CH_4$, $N_2O$ |
| Transport | Inland Shipping | 1A3d (bio), 1A3d (fossil) | 1.A.3.d.ii (bio), 1.A.3.d.ii (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Transport | International Aviation | 1C1 (fossil) | 1.A.3.a.i (fossil) | $CO_2$, $CH_4$, $N_2O$ |
| Transport | International Shipping | 1C2 (bio), 1C2 (fossil) | 1.A.3.d.i (bio), 1.A.3.d.i (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Transport | Other (transport) | 1A3e (bio), 1A3e (fossil), 1A4c2 (fossil), 1A4c3 (bio), 1A4c3 (fossil) | 1.A.3.e.i (bio), 1.A.3.e.i (fossil), 1.A.4.c.ii (fossil), 1.A.4.c.iii (bio), 1.A.4.c.iii (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Transport | Rail | 1A3c (bio), 1A3c (fossil) | 1.A.3.c (bio), 1.A.3.c (fossil) | $CH_4$, $N_2O$, $CO_2$ |
| Transport | Road | 1A3b (bio), 1A3b (fossil) | 1.A.3.b_RES (bio), 1.A.3.b_RES (fossil) | $CH_4$, $N_2O$, $CO_2$ |



### A.II.9.2 Methane Emissions Sources

In order to identify emission trends and mitigation opportunities by sector WGIII allocates each emission source to a sector and subsequently a subsector (check Section 9 above). These trends and mitigation opportunities are, in most cases and whenever possible, reported in the native unit of gases as well as in $CO_2$-eq using IPCC AR6 GWP100 values (Section 8). In the case of methane ($CH_4$), it has two different GWP100 values according to its source. The relevant sources of methane are: biogenic methane, fossil methane (source: combustion) and fossil methane (source: fugitive and process).

The majority of biogenic methane emissions result from the AFOLU sector due to livestock and other agricultural practices, but also from the energy systems, building, transport and industry (waste) sectors. Meanwhile, fossil methane (combustion) emissions result from electricity and heat generation in the energy systems sector as well as various combustion activities in all other sectors. Finally, fossil methane (fugitive and process) is emitted from the extraction and transportation of fossil fuels (fugitive methane), in addition to some activities in the industry sector (fugitive and process methane). See Table 12 below for a comprehensive list.

There are two GWP100 values assigned to methane depending on its source: a GWP100 value of 27 for biogenic methane and fossil methane (combustion), and a higher GWP100 value of 29.8 for fossil methane (fugitive and process), see Table 11 below. The difference between these two GWP100 values arises from treatment of the effect of methane conversion into $CO_2$ during its chemical decay in the atmosphere. The higher GWP100 value takes account of the warming caused by $CO_2$ that methane decays into, which adds to the warming caused by methane itself, while the lower GWP100 value does not.

In the case of biogenic methane, the correct GWP100 value is always the low value irrespective of the specific source. This is because all $CO_2$ originated from biomass is either already estimated and reported as $CO_2$ emissions from AFOLU sector, or in the case of short-rotation biomass, the original removal of $CO_2$ from the atmosphere is not reported and hence neither does the release of $CO_2$ back into the atmosphere need to be reported.

For fossil methane, the correct GWP100 value depends on the source, in other words, combustion source vs fugitive and process sources. Fossil methane (fugitive and process) should use the higher GWP100 value because $CO_2$ converted from methane in the atmosphere is not estimated anywhere else.

For fossil methane (combustion), despite it being fossil, the correct GWP100 value is always the low one, for the dataset reported here. This is due to the fact that the emissions data provider EDGAR (Section 9) considers a complete oxidation to $CO_2$ of all the carbon contained in the fossil fuel upon combustion, which is then reflected in the $CO_2$ emissions factors for the different sources based on the carbon content of fuels. In other words, IPCC (IPCC 2019) methods and defaults (Tier 1 IPCC $CO_2$ emissions factors) have been used where the associated $CO_2$ emissions are estimated on the basis of complete (100%) oxidation to $CO_2$ of carbon contained in combusted mass, which includes not only $CO_2$ directly released to the atmosphere but also $CO_2$ generated in the atmosphere from the carbon released as methane and converted to $CO_2$ only subsequently.

There are two exceptions applied to the above categorisation, both belong to the industry sector, sector codes 6Cb1 (Waste incineration – uncontrolled municipal solid waste (MSW) burning) and 6D (other waste). Uncontrolled MSW burning (6Cb1) includes both biogenic and fossil material, with incomplete oxidation for this source even when the IPCC Tier 1 default emission/oxidation factor is used. The GWP100 value adopted for this source is the low one, given that the fossil-origin methane component is unlikely to be very large. The 'other waste' (6D) source may also include both biogenic and fossil methane. However, it is unclear what type of waste handling is included here. Furthermore, the associated $CO_2$ emissions are not estimated. Therefore, the high GWP100 value is used.

In total, the estimation of EDGAR methane emissions in 2019 using a GWP100 value of 27 across all related sources results in 10.2 $GtCO_2$-eq, compared to 10.6 $GtCO_2$-eq using the higher GWP100 value as described. This is primarily driven by the readjustment of methane emissions from hard coal mining, gas production, and venting and flaring (sectors 1B1a1, 1B2b1 and 1B2c).

**Table 11 | Summary of methane GWP100 values in AR6 depending on type and source.**

| $CH_4$ | GWP100 value |
|---|---|
| $CH_4$ (biogenic) | 27 |
| $CH_4$ (fossil – combustion) | 27 |
| $CH_4$ (fossil – fugitive and process) | 29.8 |

Table 12 | Methane sources and types.

| Sector code | Description | Sector | Subsector | $CH_4$ type |
|---|---|---|---|---|
| 1A1a1 | Public Electricity Generation (biomass) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a1 | Public Electricity Generation | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a2 | Public Combined Heat and Power gen. (biom.) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a2 | Public Combined Heat and Power gen. | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a3 | Public Heat Plants (biomass) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a3 | Public Heat Plants | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a4 | Public Electricity Gen. (own use) (biom.) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a4 | Public Electricity Generation (own use) | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a5 | Electricity Generation (autoproducers) (biom.) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a5 | Electricity Generation (autoproducers) | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a6 | Combined Heat and Power gen. (autopr.) (biom.) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a6 | Combined Heat and Power gen. (autoprod.) | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1a7 | Heat Plants (autoproducers) (biomass) | Energy systems | Electricity and heat | $CH_4$ Biogenic |
| 1A1a7 | Heat Plants (autoproducers) | Energy systems | Electricity and heat | $CH_4$ Fossil (Combustion) |
| 1A1b | Refineries (biomass) | Energy systems | Petroleum refining | $CH_4$ Biogenic |
| 1A1b | Refineries | Energy systems | Petroleum refining | $CH_4$ Fossil (Combustion) |
| 1A1c1 | Fuel combustion coke ovens | Industry | Metals | $CH_4$ Fossil (Combustion) |
| 1A1c2 | Blast furnaces (pig iron prod.) | Industry | Metals | $CH_4$ Fossil (Combustion) |
| 1A1c3 | Gas works (biom.) | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1A1c3 | Gas works | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |
| 1A1c4 | Fuel comb. charcoal production (biom.) | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1A1c5 | Other transf. sector (BKB, etc.) (biom.) | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1A1c5 | Other transformation sector (BKB, etc.) | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |
| 1A2a | Iron and steel (biomass) | Industry | Metals | $CH_4$ Biogenic |
| 1A2a | Iron and steel | Industry | Metals | $CH_4$ Fossil (Combustion) |
| 1A2b | Non-ferrous metals (biomass) | Industry | Metals | $CH_4$ Biogenic |
| 1A2b | Non-ferrous metals | Industry | Metals | $CH_4$ Fossil (Combustion) |
| 1A2c | Chemicals (biomass) | Industry | Chemicals | $CH_4$ Biogenic |
| 1A2c | Chemicals | Industry | Chemicals | $CH_4$ Fossil (Combustion) |
| 1A2d | Pulp and paper (biomass) | Industry | Other (industry) | $CH_4$ Biogenic |
| 1A2d | Pulp and paper | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1A2e | Food and tobacco (biomass) | Industry | Other (industry) | $CH_4$ Biogenic |
| 1A2e | Food and tobacco | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1A2f | Other industries (stationary) (biom.) | Industry | Other (industry) | $CH_4$ Biogenic |
| 1A2f | Other industries (stationary) (fos.) | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1A2f1 | Off-road machinery: construction (diesel) | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1A2f2 | Off-road machinery: mining (diesel) | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1A3a | Domestic air transport | Transport | Domestic Aviation | $CH_4$ Fossil (Combustion) |
| 1A3b | Road transport (incl. evap.) (biom.) | Transport | Road | $CH_4$ Biogenic |
| 1A3b | Road transport (incl. evap.) (foss.) | Transport | Road | $CH_4$ Fossil (Combustion) |
| 1A3c | Non-road transport (rail, etc.) (biom.) | Transport | Rail | $CH_4$ Biogenic |
| 1A3c | Non-road transport (rail, etc.) (fos.) | Transport | Rail | $CH_4$ Fossil (Combustion) |
| 1A3d | Inland shipping (biom.) | Transport | Inland Shipping | $CH_4$ Biogenic |
| 1A3d | Inland shipping (fos.) | Transport | Inland Shipping | $CH_4$ Fossil (Combustion) |
| 1A3e | Non-road transport (biom.) | Transport | Other (transport) | $CH_4$ Biogenic |
| 1A3e | Non-road transport (fos.) | Transport | Other (transport) | $CH_4$ Fossil (Combustion) |
| 1A4a | Commercial and public services (biom.) | Buildings | Non-residential | $CH_4$ Biogenic |
| 1A4a | Commercial and public services (fos.) | Buildings | Non-residential | $CH_4$ Fossil (Combustion) |
| 1A4b | Residential (biom.) | Buildings | Residential | $CH_4$ Biogenic |
| 1A4b | Residential (fos.) | Buildings | Residential | $CH_4$ Fossil (Combustion) |

| Sector code | Description | Sector | Subsector | $CH_4$ type |
|---|---|---|---|---|
| 1A4c1 | Agriculture and forestry (biom.) | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1A4c1 | Agriculture and forestry (fos.) | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |
| 1A4c2 | Off-road machinery: agric./for. (diesel) | Transport | Other (transport) | $CH_4$ Fossil (Combustion) |
| 1A4c3 | Fishing (biom.) | Transport | Other (transport) | $CH_4$ Biogenic |
| 1A4c3 | Fishing (fos.) | Transport | Other (transport) | $CH_4$ Fossil (Combustion) |
| 1A4d | Non-specified other (biom.) | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1A4d | Non-specified other (fos.) | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |
| 1A5b1 | Off-road machinery: mining (diesel) | Industry | Other (industry) | $CH_4$ Fossil (Combustion) |
| 1B1a1 | Hard coal mining (gross) | Energy systems | Coal mining fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B1a1r | Methane recovery from coal mining | Energy systems | Coal mining fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B1a2 | Abandoned mines | Energy systems | Coal mining fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B1a3 | Brown coal mining | Energy systems | Coal mining fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B1b1 | Fuel transformation coke ovens | Industry | Metals | $CH_4$ Fossil (Fugitive) |
| 1B1b3 | Fuel transformation charcoal production | Energy systems | Other (energy systems) | $CH_4$ Biogenic |
| 1B2a1 | Oil production (biom.) | Energy systems | Oil and gas fugitive emissions | $CH_4$ Biogenic |
| 1B2a1 | Oil production | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2a2 | Oil transmission | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2a3-l | Tanker loading | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2a4-l | Tanker oil transport (crude and NGL) | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2a4-t | Transport by oil trucks | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2a5(e) | Oil refineries (evaporation) | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2b1 | Gas production | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2b3 | Gas transmission | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2b4 | Gas distribution | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1B2c | Venting and flaring during oil and gas production | Energy systems | Oil and gas fugitive emissions | $CH_4$ Fossil (Fugitive) |
| 1C1 | International air transport | Transport | International Aviation | $CH_4$ Fossil (Combustion) |
| 1C2 | International marine transport (biom.) | Transport | International Shipping | $CH_4$ Biogenic |
| 1C2 | International marine transport (bunkers) | Transport | International Shipping | $CH_4$ Fossil (Combustion) |
| 2B4a | Silicon carbide production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2B5a | Carbon black production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2B5b | Ethylene production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2B5d | Styrene production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2B5e | Methanol production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2B5g | Other bulk chemicals production | Industry | Chemicals | $CH_4$ Fossil (Process) |
| 2C1d | Sinter production | Industry | Metals | $CH_4$ Fossil (Process) |
| 2C2 | Ferroy Alloy production | Industry | Metals | $CH_4$ Fossil (Process) |
| 4A1-d | Dairy cattle | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A1-n | Non-dairy cattle | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A2 | Buffalo | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A3 | Sheep | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A4 | Goats | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A5 | Camels and Lamas | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A6 | Horses | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A7 | Mules and asses | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4A8 | Swine | AFOLU | Enteric Fermentation ($CH_4$) | $CH_4$ Biogenic |
| 4B1-d | Manure Man.: Dairy Cattle (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B1-n | Manure Man.: Non-Dairy Cattle (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B2 | Manure Man.: Buffalo (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B3 | Manure Man.: Sheep (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B4 | Manure Man.: Goats (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B5 | Manure Man.: Camels and llamas (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |

| Sector code | Description | Sector | Subsector | $CH_4$ type |
|---|---|---|---|---|
| 4B6 | Manure Man.: Horses (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B7 | Manure Man.: Mules and asses (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B8 | Manure Man.: Swine (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4B9 | Manure Man.: Poultry (confined) | AFOLU | Manure management ($N_2O$, $CH_4$) | $CH_4$ Biogenic |
| 4C | Rice cultivation (CH4) | AFOLU | Rice cultivation ($CH_4$) | $CH_4$ Biogenic |
| 4F1 | Field burning of agric. res.: cereals | AFOLU | Biomass burning ($CH_4$, $N_2O$) | $CH_4$ Biogenic |
| 4F2 | Field burning of agric. res.: pulses | AFOLU | Biomass burning ($CH_4$, $N_2O$) | $CH_4$ Biogenic |
| 4F3 | Field burning of agric. res.: tuber and roots | AFOLU | Biomass burning ($CH_4$, $N_2O$) | $CH_4$ Biogenic |
| 4F4 | Field burning of agric. res.: sugar cane | AFOLU | Biomass burning ($CH_4$, $N_2O$) | $CH_4$ Biogenic |
| 4F5 | Field burning of agric. res.: other | AFOLU | Biomass burning ($CH_4$, $N_2O$) | $CH_4$ Biogenic |
| 6A1 | Managed waste disposal on land | Industry | Waste | $CH_4$ Biogenic |
| 6B1 | Industrial wastewater | Industry | Waste | $CH_4$ Biogenic |
| 6B2 | Domestic and commercial wastewater | Industry | Waste | $CH_4$ Biogenic |
| 6C | Waste incineration – hazardous | Industry | Waste | $CH_4$ Fossil (Combustion) |
| 6Ca | Waste incineration – biogenic | Industry | Waste | $CH_4$ Biogenic |
| 6Cb1 | Waste incineration – uncontrolled MSW burning | Industry | Waste | $CH_4$ Fossil (Combustion) |
| 6Cb2 | Waste incineration – other non-biogenic | Industry | Waste | $CH_4$ Fossil (Combustion) |
| 6D | Other waste | Industry | Waste | $CH_4$ Fossil (Process) |
| 7A1 | Coal fires (underground) | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |
| 7A2 | Oil fires (Kuwait) | Energy systems | Other (energy systems) | $CH_4$ Fossil (Combustion) |

## A.II.10 Indirect Emissions

Carbon dioxide emissions resulting from fuel combusted to produce electricity and heat are traditionally reported in the energy sector. An indirect emissions accounting principle allocates these emissions to the end-use sectors (industry, buildings, transport, and agriculture) where the electricity and heat are ultimately consumed. Attributing indirect emissions to consuming sectors makes it possible to assess the full potential impact of demand-side mitigation actions that reduce electricity and heat consumption (de la Rue du Can et al. 2015).

In order to estimate the indirect emissions of sectors and subsectors, the $CO_2$ Emissions from Fuel Combustion dataset of the International Energy Agency (IEA 2020a) is used. This database reports direct and indirect $CO_2$ emissions for IEA sectors, which are related to the IPCC (IPCC 2019) classification of emissions sources. The IEA adopted a new methodology in 2020 that is in line with the methodology used in Annex II of the WGIII contribution to AR5 (Krey et al. 2014), namely Section A.II.4. The IEA now estimates individual electricity and heat specific emission factors and allocates indirect emissions related to electricity and heat in the sectors where these forms of energy are used respectively (IEA 2020b). In order to estimate the share of energy input that results in the production of heat from the share that results in the production of electricity in Combined heat and Power plants, the IEA fixes the efficiency for heat production equal to 90%, which is the typical efficiency of a heat boiler and then allocates the remaining inputs to electricity production (IEA 2020b).

The base data for total global, regional and sectoral emissions in this report is the EDGAR database (see Section 9). Since there are some discrepancies between the electricity and heat emissions totals in EDGAR and IEA, we make some adjustments in order to estimate indirect emissions in EDGAR using the IEA data. First, we match the sectors in EDGAR and IEA. Second, for each country and emissions source available in the IEA database, we take the IEA indirect emissions value and divide it by the total IEA value for electricity and heat. Third, we multiply these values through by the EDGAR value for electricity and heat. This procedure ensures that indirect emissions, in principle, sum to the correct total (EDGAR) value of electricity and heat that we use elsewhere in the reporting. However, total indirect emissions still do not sum to the total electricity and heat sector. This is due to an incomplete allocation of electricity and heat emissions in the IEA dataset, equal to 0.008 $GtCO_2$ in 2018, or about 0.06% of the total electricity and heat generation.

Additionally, a couple of adjustments were made to allocate emissions from IEA sector categories to IPCC categories from IPCC Task force definition as described in IPCC (2019) Guidelines (see Section 9). These include:

- Other non-specified sector: the IEA energy statistics report final energy and electricity use for three end-use sectors: industry, transport, and other. The 'other' category is further subdivided into agriculture, fishing, commercial and public services, residential, and non-specified other. The 'non-specified other' category includes energy used for agriculture, fishing, commercial and public services, and residential sectors that has not been allocated to these end-use sectors by the submitting countries. In most cases, there is no entry in the non-specified other category, indicating that all end-use energy consumption has been allocated to other end-use sectors. However, for some countries the energy reported in the non-specified other category needed to be allocated to the appropriate end-use sectors. To perform this allocation, the energy use in the non-specified

**Table 13 | Feasibility dimensions and indicators to assess the barriers and enablers of implementing mitigation options.**

| Metric | Indicators |
|---|---|
| Geophysical feasibility | – Physical potential: physical constraints to implementation.<br>– Geophysical resource availability (including geological storage capacity): availability of resources needed to implementation.<br>– Land use: claims on land when option would be implemented. |
| Environmental-ecological feasibility | – Air pollution: increase or decrease in air pollutants, such as $NH_4$, $CH_4$ and fine dust.<br>– Toxic waste, mining, ecotoxicity and eutrophication.<br>– Water quantity and quality: changes in amount of water available for other uses, including groundwater.<br>– Biodiversity: changes in conserved primary forest or grassland that affect biodiversity, and management to conserve and maintain land carbon stocks. |
| Technological feasibility | – Simplicity: is the option technically simple to operate, maintain and integrate.<br>– Technology scalability: can the option be scaled up, quickly.<br>– Maturity and technology readiness: R&D and time needed to implement to option. |
| Economic feasibility | – Costs now, in 2030 and in the long term, including investment costs, costs in USD $tCO_2$-$eq^{-1}$, and hidden costs.<br>– Employment effects and economic growth. |
| Socio-cultural feasibility | – Public acceptance: extent to which the public supports the option and changes behavior accordingly.<br>– Effects on health and well-being.<br>– Distributional effects: equity and justice across groups, regions, and generations, including security of energy, water, food and poverty. |
| Institutional feasibility | – Political acceptance: extent to which politicians and governments support the option.<br>– Institutional capacity and governance, cross-sectoral coordination: capability of institutions to implement and handle the option, and to coordinate it with other sectors, stakeholder and civil society.<br>– Legal and administrative capacity: extent to which supportive legal and administrative changes can be achieved. |

other category was allocated to the other end-use sectors based on the share of energy allocated to each of these sub-sectors for each region.

- Other energy industry own use: emissions from this category in the IEA statistics corresponds to the IPCC Source/Sink categories 1A1b and 1A1c (see Section 9) and contains emissions from fuel combusted in energy transformation industries that are not producing heat and/or power and therefore include oil refineries, coal mining, oil and gas extraction and other energy-producing industries. These emissions were not reallocated to the end use sectors where final products are ultimately consumed due to the lack of data.

Finally, it is also worth noting that indirect emissions only cover $CO_2$ emissions and that a small portion of non-$CO_2$ are not included in the IEA dataset and therefore have not been allocated to the end use sectors. Non-$CO_2$ emissions from total electricity and heat generation represents 0.55% of all GHG emissions from that sector.

## Part IV: Assessment Methods

In this section we report on assessment methods adopted in the report. Section 11 describes the methodology adopted for assessing the feasibility of mitigation response options. Section 12 describes the methodology adopted for assessing synergies and trade-offs between mitigation options and the SDGs.

### A.II.11 Methodology Adopted for Assessing the Feasibility of Mitigation Response Options

The feasibility assessment aims to identify barriers and enablers of the deployment of mitigation options and pathways. The assessment organises evidence to support decision making on actions and policies that would improve the feasibility of mitigation options and pathways, by removing relevant barriers and strengthening enablers of change.

#### A.II.11.1 Feasibility of mitigation response options

The sectoral chapters in AR6 WGIII assess six dimensions of feasibility, with each dimension comprising a key set of indicators that can be evaluated by combining various strands of literature (see Table 13). The feasibility of systems-level changes is addressed in Chapter 3 of this report.

The sectoral chapters in this report assess to what extent the indicators in Table 13 would be enablers or barriers to implementation using the following scores (Nilsson et al. 2016):

– The indicator has a negative impact on the feasibility of the option, for example, it is associated with prohibitively high costs, levels of pollution or land use, or low public or political acceptance.

± Mixed evidence: the indicator has mixed positive and negative impacts on the feasibility of the option (e.g., more land use in some regions, while lower in other regions).

\+ The indicator has a positive impact on the feasibility of the option, for example, it is associated with low costs, pollution, land use, or high public or political acceptance.

0/NA The indicator does not affect the feasibility of the option/criterion is not applicable for the option.

NE No evidence available to assess the impact on the feasibility of the option.

LE Limited evidence available to assess the impact on the feasibility the option.

### A.II.11.2 Assessment

Each sectoral chapter assesses to what extent the indicators listed above would be an enabler or barrier to the implementation of selected mitigation options, by using the above scores. Then the total number of minus and plus points were computed, relative to the maximum possible number of points, per feasibility dimensions, for each option; a + counts as two plus points, a – as two minus points, and a ± as one plus and one minus point. The resulting scores reveal the extent to which each feasibility dimension enables or inhibits the deployment of the relevant option, and indicates which type of additional effort would be needed to reduce or remove barriers as to improve the feasibility of relevant options.



The assessment is based on the literature, which is reflected in a line of sight. When appropriate, it is indicated whether the feasibility of an option varies across context (e.g., region), scale (e.g., small, medium, full scale), time (e.g., implementation in 2030 versus 2050) and warming level (e.g., 1.5°C versus 2°C).

Synergies and trade-offs may occur between the feasibility dimensions, and between specific mitigation options. Therefore, Chapters 3 and 4 employ a systems perspective and discuss the feasibility of mitigation scenarios and pathways in the long term and near to mid-term, respectively, on the basis of the feasibility assessments in the sectoral chapters taking into account such synergies and trade-offs. Chapter 5 (demand, services and social aspects of mitigation), Chapter 13 (national and sub-national policies and institutions), Chapter 14 (international cooperation), Chapter 15 (investment and finance) and Chapter 16 (innovation, technology development and transfer) address technological, economic, socio-cultural and institutional enabling conditions that can enhance the feasibility of options and remove relevant barriers.

## A.II.12 Methodology Adopted for Assessing Synergies and Trade-offs Between Mitigation Options and the SDGs

Adopting climate mitigation options can generate multiple positive (synergies) and negative (trade-offs) interactions with sustainable development. Understanding these are crucial for selecting mitigation options and policy choices that maximise the synergies, minimise trade-offs, and potentially offset trade-offs (Roy et al. 2018). Chapter 5 in the IPCC's Special Report on Global Warming of 1.5°C examines the synergies and trade-offs of adaptation and mitigation measures with sustainable development and UN's Sustainable Development Goals (SDGs). Building on this, the sectoral chapters in the WGIII contribution to the AR6 include a qualitative assessment of the synergies and trade-offs between mitigation options in different sectors and the SDGs based on existing literature. All these assessments are collated and presented in Chapter 17 with a supplementary table including the details of the synergies and trade-offs with a line of sight (Section 17.3.3.7, Figure 17.1 and Supplementary Material Table 17.1). The assessment also recognises that interactions of mitigation options with the SDGs are context-specific and therefore provides a detailed explanation in the supplementary table of Chapter 17.

For the assessment, the mitigation options were shortlisted from each of the sectoral chapters. The sectoral chapters assessed the literature in terms of the impacts of each of these mitigation options on the 17 SDGs. The assessment uses three signs:

+ to denote positive interaction only (synergies),

– to denote negative interaction only (trade-offs) and

± to denote mixed interactions.

In some cases, where there is gap in literature, these are left blank denoting that these impacts have not been assessed in the literature included in the sectoral chapters. To support these signs, brief statements are provided followed by uncertainty qualifiers in the supplementary table of Chapter 17. These uncertainty qualifiers denote the confidence levels (low, medium and high).

## References

Crippa, M. et al., 2021: EDGAR v6.0 Greenhouse Gas Emissions. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/97a67d67-c62e-4826-b873-9d972c4f670b.

de la Rue du Can, S., L. Price, and T. Zwickel, 2015: Understanding the full climate change impact of energy consumption and mitigation at the end-use level: A proposed methodology for allocating indirect carbon dioxide emissions. *Appl. Energy*, **159**, 548–559, doi:10.1016/j.apenergy.2015.08.055.

Fischedick, M., R. Schaeffer, A. Adedoyin, M. Akai, T. Bruckner, L. Clarke, V. Krey, I. Savolainen, S. Teske, D. Ürge-Vorsatz, R. Wright, 2011: *Mitigation Potential and Costs*. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Fisher, B.S., N. Nakicenovic, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-Ch. Hourcade, K. Jiang, M. Kainuma, E. La Rovere, A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, R. Warren, 2007: Issues related to mitigation in the long-term context. In *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel of Climate Change* [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 169–250.

Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi:10.1017/9781009157896.009.

Friedlingstein, P. et al., 2019: Global Carbon Budget 2019. *Earth Syst. Sci. Data*, **11(4)**, 1783–1838, doi:10.5194/essd-11-1783-2019.

Friedlingstein, P. et al., 2020: Global Carbon Budget 2020. *Earth Syst. Sci. Data*, **12(4)**, 3269–3340, doi:10.5194/essd-12-3269-2020.

Gasser, T. et al., 2020: Historical $CO_2$ emissions from land use and land cover change and their uncertainty. *Biogeosciences*, **17(15)**, 4075–4101, doi:10.5194/BG-17-4075-2020.

Hansis, E., S.J. Davis, and J. Pongratz, 2015: Relevance of methodological choices for accounting of land use change carbon fluxes. *Global Biogeochem. Cycles*, **8(9)**, doi:10.1002/2014GB004997.

Houghton, R.A. and A.A. Nassikas, 2017: Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochem. Cycles*, **31(3)**, 456–472, doi:10.1002/2016GB005546.

IEA, 2010: *Projected Costs of Generating Electricity – 2010 Edition*. International Energy Agency, Paris, France.

IEA, 2019: *World Energy Outlook 2019*. International Energy Agency (IEA) and Organisation for Economic Co-operation and Development (OECD), Paris, France, 810 pp.

IEA, 2020a: *$CO_2$ Emissions from Fuel Combustion: Database Documentation (2020 edition)*. International Energy Agency, Paris, France.

IEA, 2020b: *Emissions Factors: Database Documentation (2020 edition)*. International Energy Agency (IEA), Paris, France.

IEA, 2021: *World Energy Balances*. 1st ed. International Energy Agency (IEA), Paris, France.

IPCC, 1995: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R., M.C. Zinyowera, and R. Moss, (eds.)]. Cambridge University Press, Cambridge, UK, 861 pp.

IPCC, 2001: Appendix – IV Units, Conversion Factors, and GDP Deflators. In: *Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O. Davidson, R. Swart, and J. Pan, (eds.)]. Cambridge University Press, Cambridge, UK, pp. 727–732.

IPCC, 2019: *Refinement to the 2006 IPCC Guidelines for National Greenhouse gas Inventories*. [Buendia, E.C., S. Guendehou, B. Limmeechokchai, R. Pipatti, Y. Rojas, R. Sturgiss, K. Tanabe, and T. Wirth (eds.)]. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

Krey V., O. Masera, G. Blanford, T. Bruckner, R. Cooke, K. Fisher-Vanden, H. Haberl, E. Hertwich, E. Kriegler, D. Mueller, S. Paltsev, L. Price, S. Schlömer, D. Ürge-Vorsatz, D. van Vuuren, and T. Zwickel, 2014: Annex II: Metrics & Methodology. 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.

Minx, J.C. et al., 2021: A comprehensive dataset for global, regional and national greenhouse gas emissions by sector 1970–2019. *Earth Syst. Sci. Data*, **13(11)**, doi:10.5194/essd-2021-228.

Moomaw, W., P. Burgherr, G. Heath, M. Lenzen, J. Nyboer, A. Verbruggen, et al., 2011: Annex II: Methodology. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 973–1000.

Morita, T., J.B. Robertson, A. Adegbulugbe, J. Alcamo, 2001: Greenhouse gas emission mitigation scenarios and implications. In: *Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O. Davidson, R. Swart, and J. Pan, (eds.)]. Cambridge University Press, Cambridge, UK, 115–166.

NAS, 2007: *Coal: Research and Development to Support National Energy Policy*. [Committee on Coal Research and Technology and National Research Council, (ed.)]. The National Academies Press, Washington, DC, USA.

Nilsson, M., D. Griggs, and M. Visbeck, 2016: Policy: Map the interactions between Sustainable Development Goals. *Nature*, **534(7607)**, 320–322, doi:10.1038/534320a.

Reisinger, A., M. Howden, C. Vera, et al., 2020: The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 15 pp. https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf.

Roy, J., P. Tschakert, H. Waisman, S. Abdul Halim, P. Antwi-Agyei, P. Dasgupta, B. Hayward, M. Kanninen, D. Liverman, C. Okereke, P.F. Pinho, K. Riahi, and A.G. Suarez Rodriguez, 2018: Sustainable Development, Poverty Eradication and Reducing Inequalities. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University

Press, Cambridge, UK and New York, NY, USA, pp. 445–538. https://doi.org/10.1017/9781009157940.007.

Suerkemper, F., S. Thomas, D. Osso, and P. Baudry, 2012: Cost-effectiveness of energy efficiency programmes—evaluating the impacts of a regional programme in France. *Energy Effic.*, **5(1)**, 121–135, doi:10.1007/s12053-011-9112-z.

UNFCCC, 2019: *Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on the third part of its first session, held in Katowice from 2 to 15 December 2018. Addendum, Part 2: Action taken by the Conference of the Parties servi*. Katowice, Poland.

UNSD, 1999: *Standard Country or Area Codes for Statistical Use, Revision 4*. https://unstats.un.org/unsd/methodology/m49/.