Annex B: Definitions, Units & Conventions

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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 (WGIII AR6). The material presented in this annex documents metrics and common data sets that are typically used across multiple chapters of the report. In 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 three 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; and Part III provides more detailed background information about common data sources. 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.B.1 Regional classifications

In this report there are three different levels of regional classifications used to present results of analysis. These levels are High (5 regions), Intermediate (10) and Low (21). The high level classification is virtually identical to RC5 (Regional Categorisation 5) in WGIII AR5; the low level classification corresponds most closely to the 22 UN M49 (UNSD, 1999) intermediate regions. The regional classifications are presented below. Throughout the report it will be noted explicitly when individual chapters deviate from the classification set out below.

A.B.1.1. Low level of regional classification

Western Africa: Cape Verde, Côte d'Ivoire, Ghana, Nigeria, Saint Helena, Ascension and Tristan da Cunha, Benin, Burkina Faso, Gambia (the), Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger (the), Senegal, Sierra Leone, Togo

Eastern Africa: British Indian Ocean Territory (the), French Southern Territories (the), Kenya, Mauritius, Mayotte, Réunion, Seychelles, Zimbabwe, Burundi, Comoros (the), Djibouti, Eritrea, Ethiopia, Madagascar, Malawi, Mozambique, Rwanda, Somalia, South Sudan, Uganda, United Republic of Tanzania (the), Zambia

Southern and middle Africa: Botswana, Swaziland, Namibia, South Africa, Lesotho, Cameroon, Congo (the), Equatorial Guinea, Gabon, Angola, Central African Republic (the), Chad, Congo (the Democratic Republic of the), Sao Tome and Principe

Northern Africa: Algeria, Egypt, Libya, Morocco, Tunisia, Western Sahara, Sudan (the)

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

Caribbean: Anguilla, Antigua and Barbuda, Aruba, Bahamas (the), Barbados, Bonaire, Sint Eustatius and Saba, Virgin Islands (British), Cayman Islands (the), Cuba, Curaçao, Dominica, Dominican Republic (the), Grenada, Guadeloupe, Jamaica, Martinique, Montserrat, Puerto Rico, Saint Barthélemy, Saint Kitts and Nevis, Saint Lucia, Saint Martin (French part), Saint Vincent and the Grenadines, Sint Maarten (Dutch part), Trinidad and Tobago, Haiti, Turks and Caicos Islands (the), Virgin Islands (U.S.)

Meso America: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama

South America: Argentina, Bolivia (Plurinational State of), Bouvet Island, Brazil, Chile, Colombia, Ecuador, Falkland Islands (the) [Malvinas], French Guiana, Guyana, Paraguay, Peru, South Georgia and the South Sandwich Islands, Suriname, Uruguay, Venezuela (Bolivarian Republic of)

USA & Canada: United States of America (the), Canada

Greenland, Bermuda & others: Bermuda, Greenland, Saint Pierre and Miquelon

Eastern Asia: China, China Hong Kong Special Administrative Region, China Macao Special Administrative Region, Korea (the Republic of), Democratic People's Republic of Korea (the), Mongolia

India & Sri Lanka

Rest of Southern Asia: Maldives, Pakistan, Afghanistan, Bangladesh, Bhutan, Nepal

South-East Asia: Brunei Darussalam, Indonesia, Malaysia, Philippines (the), Singapore, Thailand, Viet Nam, Cambodia, Lao People's Democratic Republic (the), Myanmar, Timor-Leste

Developing Pacific: Fiji, New Caledonia, Papua New Guinea, Solomon Islands, Vanuatu, Guam, Marshall Islands (the), Micronesia (Federated States of), Nauru, Northern Mariana Islands (the), Palau, United States Minor Outlying Islands (the), Kiribati, American Samoa, Cook Islands (the), French Polynesia, Niue, Pitcairn, Samoa, Tokelau, Tonga, Wallis and Futuna, Tuvalu

Northern and western Europe: Åland Islands, Denmark, Estonia, Faroe Islands (the), Finland, Iceland, Ireland, Isle of Man, Latvia, Lithuania, Norway, Svalbard and Jan Mayen, Sweden, United Kingdom of Great Britain and Northern Ireland (the), Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, Netherlands (the), Switzerland, Guernsey, Jersey

Southern and eastern Europe: Andorra, Cyprus, Croatia, Gibraltar, Greece, Holy See (the), Italy, Malta, Portugal, San Marino, Slovenia, Spain, Bulgaria, Czech Republic (the), Hungary, Poland, Romania, Slovakia, Turkey, Albania, Bosnia and Herzegovina, Montenegro, Serbia, Ukraine

Australia & New Zealand

Asia-Pacific Developed (others): Japan, Christmas Island, Cocos (Keeling) Islands (the), Heard Island and McDonald Islands, Norfolk Island

Eurasia: Belarus, Russian Federation (the), Republic of North Macedonia, Republic of Moldova (the), Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan

International shipping

International Aviation

A.B.1.2. High and intermediate levels of regional classification

Table A.B.1 below presents the high, intermediate and low levels of regional classification. For country mapping to the low level of regional classification see section A.B.1.1 above.

Table: A.B.1 | Description of regions

WGIII AR6		
High Level (5)	**Intermediate level (10)**	**Low Level (21)**
Developed Countries (DEV)	North America	USA & Canada
		Greenland, Bermuda + others
	Europe	Northern and western Europe
		Southern and eastern Europe
	Asia-Pacific Developed	Australia & New Zealand
		Asia-Pacific Developed (others)
Eastern Europe and West-Central Asia (EEA)	Eurasia	Eurasia
Latin America and Caribbean (LAM)	Latin America and Caribbean	Caribbean
		Meso America
		South America
Africa and Middle East (AME)	Africa	Western Africa
		Eastern Africa
		Southern and middle Africa
		Northern Africa
	Middle East	Middle East
Asia and developing Pacific (APC)	Eastern Asia	Eastern Asia
	Southern Asia	India & Sri Lanka
		Rest of Southern Asia
	South-East Asia and developing Pacific	South-East Asia
		Developing Pacific
International Shipping & Aviation		International shipping,
		International Aviation

A.B.2. Standard units and unit conversions

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

A.B.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: A.B.2 | Système International (SI) units

Physical Quantity	Unit	Symbol
Length	meter	m

Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K
Amount of Substance	mole	mol

Table: A.B.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: A.B.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$2015
Emission- and Climate- related units	**Unit**	**Symbol**
Emissions	Metric tonnes	t
CO_2 Emissions	Metric tonnes CO_2	tCO_2
CO_2-equivalent Emissions[1]	Metric tonnes CO_2-equivalent	tCO_2-eq
Abatement Costs and Emissions Prices/Taxes	constant US Dollar 2015 per metric tonnes	USD2015 /t
CO_2 concentration or Mixing Ratio (µmol mol–1)	Parts per million (10^6)	Ppm
CH_4 concentration or Mixing Ratio (nmol mol–1)	Parts per billion (10^9)	Ppb
N_2O concentration or Mixing Ratio (nmol mol–1)	Parts per billion (10^9)	Ppb
Radiative forcing	Watts per square meter	W/m^2
Energy-related units	**Unit**	**Symbol**
Energy	Joule	J
Electricity and Heat generation	Watt Hours	Wh
Power (Peak Capacity)	Watt (Watt thermal, Watt electric)	W (Wth, We)
Capacity Factor	Percent	%
Technical and Economic Lifetime	Years	yr
Specific Energy Investment Costs	US Dollar 2015 per kW (peak capacity)	USD$_{2015}$ /kW

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[1] Based on GWP$_{100}$ metric, using AR6 values. Check section A.B10 below for details.

Energy Costs (e.g., LCOE) and Prices	constant US Dollar 2015 per GJ or US Cents 2015 per kWh	USD_{2015} /GJ and $USct_{2015}$ /kWh
Passenger-Distance	passenger-kilometre	pkm
Payload-Distance	tonne-kilometre[2]	tkm
Land-related units	**Unit**	**Symbol**
Area	Hectare	ha

Note that all monetary and monetary-related units should be expressed in constant US Dollar 2015 (USD_{2015}) or constant International Dollar 2015 ($Int\$_{2015}$).

Table: A.B.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.B.2.2. Physical units conversion

Table: A.B.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: A.B.7 | Conversion table for common volumetric units (IPCC, 2001).

To:		**gal US**	**gal UK**	**bbl**	**ft^3**	**l**	**m^3**
From:	**multiply by:**						

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[2] The tonne-kilometre 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 A.B.4.

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
Liter	L	2.64E-01	2.20E-01	6.30E-03	3.53E-02	1	1.00E-03
Cubic meter	m^3	2.64E+02	2.20E+02	6.29E+00	3.53E+01	1.00E+03	1

Table: A.B.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.

Where aggregate greenhouse gas emissions are reported, this report uses the Global Warming Potential with a time horizon of 100 years (GWP_{100}); for details see A.B.10.

A.B.2.3. Monetary unit conversion

To achieve comparability across cost und price information from different regions, where possible all monetary quantities reported in the WGIII AR6 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 was established which is described below.

In order to convert from year X local currency unit (LCU_X) to 2015 US Dollars (USD_{2015}) two steps are necessary:

1. in- /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 LCU_X -> LCU_{2015} -> USD_{2015} is adopted, i.e., national/regional deflators are used to measure country- or region-specific inflation between year X and 2015 in local currency and current (2015) exchange rates are then used to convert to USD_{2015}.

To reflect the change in prices of all goods and services that an economy produces, and to keep the procedure simple, the economy's GDP deflator is chosen to convert to a common base year. Finally, when converting from LCU_{2015} to USD_{2015}, official 2015 exchange rates, which are readily available, but on the downside often fluctuate significantly in the short term, are adopted for currency conversion in the report.

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 is used[3].

To summarize, 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:

$$GDP_{2015} \text{ (in } LCU_{2015} \text{ prices)} = GDP_{2010} \text{ (in } LCU_{2010} \text{ prices)} * \frac{LCU_{2010} \text{ GDP deflator}}{LCU_{2015} \text{ GDP deflator}}$$

2. Use the appropriate 2015 exchange rate to convert from LCU_{2015} to USD_{2015}.

Part II: Conventions

A.B.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. More specifically, the adopted 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 WGIII AR6 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.

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[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

A.B.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:

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

where $LCOE$ are the levelised cost of energy, E_t is the energy delivered in year t (which 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 $LCOE$:

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

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):

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

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

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

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., 2011). 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):

$$LCOE=\frac{\text{CRF}\cdot\text{I+O\&M+F}}{E} \tag{5}$$

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 payments for retrofit payments during the 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.B.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-efficiency alternative, and divides this quantity by the annual energy savings.

The conceptual formula for $LCCE$ is essentially the same as Equation (4) above, with ΔE meaning in this context the amount of energy saved annually (Suerkemper et al., 2011):

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

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

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

where ΔI 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; ΔE 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 i and the lifetime of the measure n in years as defined above. It should be stressed once more that this equation is only valid if $\Delta O\&M$ and ΔE are constant over the 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.B.3.3. Levelised cost of conserved carbon

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

The conceptual formula for $LCCC$ is essentially similar to Equation (6) above, with ΔC is the annual reduction in GHG 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:

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

where ΔI 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 ΔB 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 GHG 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 ΔB is bigger than the sum of the other two terms in the numerator.

A.B.4. Growth rates

A.B.4.1. Emissions growth rates

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

In reporting the annual growth rate of emissions in percent per year for adjacent years, one can use the following equation:

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

where E_{FF} stands for fossil fuel CO_2 emissions.

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:

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

solving for r:

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

A.B.4.2. Economic growth rates

As for calculating economic growth rates (e.g., GDP), a number of different methods exist, all of which lead to slightly different numerical results. If not stated otherwise, the annual growth rates shown have been 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 the following way:

$$r_{LD} = e^B - 1 \quad \text{with} \quad \beta = \frac{1}{T-1}\sum_{t=2}^{T} \Delta ln X_t \tag{13}$$

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

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

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

A.B.5. Decades

In order to undertake a timeseries calculation that includes a decade, the 10-year period should be defined following this example: from 1st of Jan 2001 to 31st of December 2010, that is 2001-2010.

In order to compare or contrast two different years, for instance comparing 2000 and 2010 cumulative CO_2 emissions, in such case 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.

A.B.6. Social discount rates

Throughout the report the process of discounting is applied on estimates of future periods' costs and benefits in order determining their present values and hence allow for comparing them with the current period costs and benefits. The value of the future streams of costs and benefits in today's terms is calculated by applying a discount factor to them. The rate at which this discount factor changes overtime is called discount rate, which can be static or dynamic. In the context of climate change, and other social issues, this rate is called social discount rate (SDR). Social discount rates could either be determined exogenously where the researchers apply the adopted SDR into the analysis or the model, or endogenously where the rate is computed by the model itself.

Across this report whenever discounting is implemented it will be stated explicitly what is the discount rate applied, whether it is acquired endogenously or exogenously and the rationale behind the adopted rate and method. This section will provide a general overview of SDRs.

In an intertemporal optimisation framework, Ramsey (1928) considers a representative agent who decides how to allocate her consumption, and hence saving, overtime subject to a resource constraint. Ramsey (1928) shows that the solution must always satisfy the Ramsey Equation, which provides the determinants of the social discount rate.

The Ramsey Equation is given as follows:

$$\rho = \delta + \eta g_t \qquad (15)$$

where ρ is the consumption discount rate (aka social discount rate), δ is the utility discount rate (aka pure time discount rate, or time preferences rate) which is a value judgement that determines the present value of a change in the utility experienced in the future and hence it is an ethical parameter, g_t is the growth rate of consumption per capita overtime, and η is the elasticity of marginal utility of consumption, which is also a value judgement and hence an ethical parameter. The parameter η is also a measure of risk aversion and a measure of society's aversion to inequality within and across generations. The choice of the values of these parameters has been a subject to a long debate in the literature which is covered in the Chapter 3 of WGIII contribution to AR6. Whenever the Ramsey Equation is used in the AR6 report, the choice of its parameters as well as the rationale behind the choice will be made explicit.

A.B.7. Primary energy accounting

Annex II of AR5, namely section A.II.4, includes a detailed discussion of the three alternative methods that are predominantly used to report primary energy from non-combustible energy sources, i.e., nuclear energy and all renewable energy sources except biomass. 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, i. e., 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; Nakicenovic and Swart, 2000; 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.B.8. Indirect emissions

Carbon dioxide emissions resulting from fuel combusted to produce electricity and heat are traditionally reported in the energy sector. Indirect emissions allocate these emissions to the end-use sectors (industry, buildings, transport, and agriculture) where the electricity and heat are ultimately consumed.

Attributing indirect emissions to the consuming sectors makes it possible to assess the full potential impact of demand mitigation actions resulting in reduction of electricity and heat consumption (de la Rue du Can et al., 2015).

In order to account for indirect emissions at the sector and subsector levels, a dataset developed by the International Energy Agency (IEA, 2020a) is used. The IEA adopted a new methodology in 2020 that is in line with the methodology used in Annex II of the WG III contribution to AR5 (Krey et al., 2014), namely section A.II.4. The IEA now estimates individual electricity and heat specific emission factors and allocate 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 allocate the reminding inputs to electricity production (IEA, 2020b).

The base data for estimating total global, regional and sectoral emissions in this report is the EDGAR database (see section A.B.12.). Since there is a discrepancy between the total electricity and heat CO_2 emissions in EDGAR and IEA, the following adjustment are made in order to ensure the emissions in EDGAR are appropriately allocated: first, the proportion of total indirect emissions relative to the IEA electricity and heat sector for each final sector in the IEA indirect emissions data is calculated (IEA, 2020a); then these values are multiplied through by the EDGAR electricity and heat sector.

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 IPCC2006 Guidelines (see section A.B.12.). 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 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 A.B.12.) 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.

Additionally, it is worth noting that a small discrepancy exists in the IEA dataset between the total of indirect emission at the end use level and the total emissions from the total electricity and heat generation. The discrepancy is equal to 0.008 Gt CO_2 and represents 0.06% of the total electricity and heat generation.

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.

A.B.9. 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 WGs 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, i.e., with focus on mitigation.

A.B.9.1. The definition of risk

The full definition of Risk in the AR6 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 wellbeing, 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.

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.B.9.2. DO's and DON'T's

DO:

- use risk where you're explicitly considering potential adverse outcomes and the uncertainty relating to those outcomes.
- use risk to improve the ability for decision-makers to understand and manage risk

Don't:

- use risk as simple substitute for probability/chance.
- use risk to describe physical hazards.
- use risk as generic term for 'anything bad that may happen in future'.

- Use 'hazard' as a generic term for climatic events or trends that may not have adverse consequences for all elements of an affected system.

A.B.9.3. 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, it will be difficult for any statement to describe "the" risk to food security. To be useful, most statements will have to be relative to some factors remaining unchanged, and to focus on the effect of specific changes. Such assumptions are important for analytical robustness. Nonetheless, it will be important to state any such assumptions clearly.

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' is closely related to risks arising from climate change impacts and climate-related hazards, while the term 'transition risk' typically refers to risks associated with transition to a low carbon economy.

Physical Risk

In much of the business and financial literature, the term 'physical risk' relates to those derived from the hazard × exposure × vulnerability framework, but the focus of this literature is often exclusively on changes in the hazard rather than exposure or vulnerability. Physical risks involve risks from climate change including risk to facilities and infrastructure, impact on operations, water and raw material availability and supply chain disruptions.

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 organizations. Transition risks, if realised, can result in stranded assets, loss of markets, reduced returns on investment, and financial penalties. A key issue is the stranding of assets that may not provide the expected financial returns and may end up as large financial liabilities.

Risk categories 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: refers to adverse consequences that cannot be quantified in probabilistic terms. This is different from how the term 'residual risk' is generally used in IPCC, where it means the risk remaining after adaptation and risk reduction efforts. Authors should take care to check the meaning of the term 'residual risk' where it is used in primary literature and avoid copying the term if it refers to quantifiable vs non-quantifiable risk to avoid confusion.

Appendix A.B.10: GHG emission metrics

Greenhouse gases and aerosols differ widely in their atmospheric lifetimes and the sign and magnitude of their impacts on global temperature and other aspects of the climate system. This presents challenges for climate policy in areas such as:

- **Reporting:** how to aggregate emissions and removals of gases and aerosols with differing impacts on climate reported in e.g. national emission inventories or Lifecycle Assessments
- **Mitigation:** how much weight to place on abating any given emission at any given time, relative to abatement of emissions of other gases
- **Pathways:** what emission trajectories for different gases and aerosols are consistent with and help deliver long-term climate change objectives, including the Paris Agreement and its long-term temperature goal.

GHG emission metrics provide simplified information about the effect on climate of emissions and removals of different gases. This information can support choices about priorities and trade-offs in mitigation policies and emission targets for multiple gases. Emission metrics also exist for aerosols but these are not commonly used in climate policy. This assessment focuses on GHG emission metrics only.

Limiting the rise in global average temperature to any level requires, at a minimum, global CO_2 emissions to be reduced to net-zero (see SR15; WGI Chap 1 and 5; WGIII Chapter 3). GHG emission metrics can inform policymakers about the benefits of mitigating non-CO_2 emissions *in addition to*, but *not instead of*, this global requirement. However, priorities may differ for individual countries or sectors, especially where relative shares of non-CO_2 emissions deviate strongly from the global average.

A wide range of GHG emission metrics has been developed in the scientific literature. These metrics differ with respect to (i) the key measure of climate change they consider, (ii) whether they consider climate outcomes for a specified point in time or integrated over a specified time horizon, (iii) the time horizon over which the metric is applied, (iv) whether they apply to a single emission pulse, to emissions sustained over a period of time, or to a combination of both, and (v) whether they consider the climate effect from an emission compared to the absence of that emission, or compared to a reference emissions level or climate state (see Glossary for "GHG emission metric" definition). Different choices in the design of metrics affect the weighting given to emissions of non-CO_2 gases relative to CO_2 (see e.g. Table A.B.9) and hence can suggest differing importance of their contribution to climate change, and the scale and timing of their abatement.

To inform climate policy in a transparent way, GHG emission metrics need to be sufficiently consistent with and guided by policy objectives. For example, the choice of GHG emission metric is highly relevant for net-zero GHG emission targets. This includes the interpretation of the balance of emissions and removals referred to in Article 4 of the Paris Agreement, since the GHG emission metric determines the 'equivalent' amount of CO_2 removal required to balance any remaining non-CO_2 emissions that are too hard to abate. However, the most appropriate choice of metric in this context cannot be determined by scientific considerations alone as it depends on the climate objectives that motivated the adoption of a net-zero GHG emissions target and its relationship with the temperature limit stated in Article 2.

Parties to the Paris Agreement have already decided to report aggregated emissions based on the Global Warming Potential with a time horizon of 100 years (GWP_{100}) from the IPCC AR5, or to use GWP_{100} values from a subsequent IPCC report as agreed upon by the CMA (18/CMA.1: UNFCCC 2019), and to account for their second and subsequent NDCs in accordance with this approach (4/CMA.1: UNFCCC 2019). However, Parties can report supplemental information about aggregate emissions using other GHG emission metrics. Apart from international reporting, some countries or sectors might consider other GHG emission metrics to help achieve specific domestic policy objectives. A clear assessment of metrics can help decision-makers determine the consistency between policy goals and metrics, and avoid potentially inadvertent consequences of alternative metric choices.

This Appendix seeks to inform choices about the use of GHG emission metrics by assessing a range of metrics from a WGIII (mitigation) perspective, including the performance of metrics against specific policy objectives. It builds on the physical science assessment by WGI (AR6 WGI Section 7.6). The discussion here focuses mostly on trade-offs between CO_2 and CH_4, given the dominant role of these two gases in climate forcing and the literature, but refers to other gases where relevant.

This Appendix also summarises the guidance provided to authors of the AR6 WGIII report on the consistent use of GHG emission metrics in their assessment.

A.B.10.1: Summary of insights based on AR5

The Global Warming Potential (GWP) and the Global Temperature change Potential (GTP) were the main metrics assessed in the AR5 (IPCC, 2014; Kolstad et al., 2014; Myhre et al., 2013) and continue to be the main metrics used in the scientific literature. These metrics compare the effect on climate of emitting a unit mass of a non-CO_2 gas over a chosen time horizon with the effect of emitting the same unit mass of CO_2. GWP compares CO_2 and non-CO_2 emissions based on the radiative forcing they would cause integrated over the entire time horizon, whereas GTP compares emissions based on the global mean surface temperature change they would cause only at the endpoint of this time horizon.

The most commonly used, static time horizon for GWP, including in reporting under the UNFCCC and the Paris Agreement, is 100 years (GWP_{100}), but other time horizons (e.g. GWP_{20}, GWP_{500}) have also been applied in the scientific literature (e.g. Skytt et al. 2020; Tanaka et al. 2013; Tanaka et al. submitted). The AR5 noted that the GWP resembles the Global Damage Potential, i.e. the estimated discounted economic damages over time caused by the emission of a unit quantity of a non-CO_2 gas compared to the damages from emitting a unit quantity of CO_2 (Kolstad et al., 2014).

For GTP, both static and dynamic time horizons are used in the literature. A static GTP evaluates warming due to an emissions pulse at the endpoint of the stated time horizon (K. Shine et al., 2005). For example, GTP_{100} would evaluate emissions occurring in 2020 based on the warming they would cause in the year 2120, whereas emissions occurring in 2030 would be evaluated based on the warming they would cause in the year 2130. This continuously advancing endpoint at which climate effects are evaluated, combined with the fact that GTP takes no account of temperature changes prior to this distant endpoint, makes it difficult to associate GTP_{100} with a clear climate policy objective or economic metric.

By contrast, the dynamic GTP (K. Shine et al., 2007) evaluates each emission based on its contribution to warming in a specified future target year. Depending on application, this can be the year in which global average temperature is expected to peak within a mitigation scenario, or any other time-bound temperature-related climate target. The time horizon of a dynamic GTP shrinks as the target year approaches, which increases over time the weight given to emissions of non-CO_2 short-lived climate forcers (SLCF) such as methane. For example, for a climate policy goal of limiting warming to 1.5°C, global average surface temperature would have to peak by around 2055 (J Rogelj et al., 2018). To compare the importance of abating non-CO_2 and CO_2 emissions in any given year relative to that policy goal, emissions occurring in the year 2020 would be evaluated using GTP_{35}, whereas emissions in 2030 would be evaluated using GTP_{25}, and so on (for illustrative metric values see Table A.B.9).

The AR5 noted that the dynamic GTP approximates a cost-effectiveness metric, i.e. every emission is evaluated based on the contribution it makes to achieving an externally defined climate outcome such as peak temperature in a given year (Kolstad et al., 2014). The GTP has larger uncertainties than the GWP because it includes additional physical processes to calculate temperature change (Myhre et al., 2013). Values for the dynamic GTP are not only subject to physical uncertainties but also depend critically on the choice of temperature goal and the range of potential target years implied in this choice, which adds further uncertainty.

The AR5 (IPCC, 2014; Kolstad et al., 2014; Myhre et al., 2013) found *robust evidence* and *high agreement* that the choice of the most appropriate metric and time horizon depends on the type of application and policy context, including judgements about how to value damages caused by today's emissions in the near-term vs more distant future. IPCC (2014) noted that such choices can strongly influence the weight given to SLCFs, resulting in trade-offs between CO_2 and non-CO_2 abatement: for example, a metric that gives consistently less weight to short-lived forcers such as CH_4 would result in less abatement of those gases and require earlier and more stringent CO_2 abatement to achieve similar climate outcomes over the 21st century. The AR5 concluded, based on *medium evidence* available at that time, that the choice of metric has a minor effect on global mitigation costs under scenarios of full participation but could be more significant for specific sectors or countries with a high proportion of non-CO_2 emissions (IPCC, 2014).

Metric values depend on atmospheric composition and therefore need to be updated over time (Myhre et al. 2013; WGI Chapter 7). Using constant metric values for future emissions thus introduces an error whose magnitude depends on the global emissions pathway (e.g. Reisinger et al. 2011; Cain et al. 2019). For CH_4, the metric value also depends on the fossil or biogenic origin of the gas, since fossil CH_4 emissions also introduce additional CO_2 into the atmosphere. The metric value for fossil methane for both GWP and GTP is therefore 2.75 units higher than the metric value for biogenic methane (a difference of less than 10% for GWP_{100}), unless the fossil component is already included as part of CO_2 emissions in GHG inventories (WGI Section 7.6.2; Boucher et al. 2009; Muñoz and Schmidt 2016).

A.B.10.2: Key developments in GHG emission metrics since the AR5

Since the AR5, additional metrics have been developed that compare CO_2 and non-CO_2 emissions based on key measures other than radiative forcing or global average temperature change, including precipitation, sea level rise and regional changes, and hybrids (e.g. Aamaas et al. 2016; Bright et al. 2016; Kirschbaum 2014; Kupiainen et al. 2019; Lund et al. 2017; Grewe and Dahlmann 2015; Shine et al. 2015). This allows for more nuanced comparisons of the effect of various emissions on climate, but such new metrics not yet been applied in actual policy contexts. WGI Chapter 7 assesses some of these more recent metrics from a climate science perspective.

WGI also provides updated values for GWP and GTP (for illustrative values see Table A.B.9, based on WGI Section 7.6.2). These now include the effect of climate-carbon cycle feedbacks for non-CO_2 emissions by default, which was considered an emerging issue in the AR5 (Myhre et al., 2013). Inclusion of such feedbacks recognises that warming from non-CO_2 gases also increases the atmospheric residence time of CO_2, which implies a somewhat greater net effect of non-CO_2 emissions on climate and hence increases metric values than if such feedbacks are omitted.

Table: A.B.9 | Illustrative Metric Values for CH4 and N2O under a Range of Metrics and Time Horizons

Values are taken from AR6 WGI chapter 7 SOD. GWP and GTP compare pulse emissions of non-CO_2 gases with a pulse emission of CO_2. CGTP compares a sustained step-change in non-CO_2 emissions with a pulse emission of CO_2. See the WGI assessment for values for other metrics and gases. [Note to reviewers: this table will be updated with final values based on the WGI assessment of these metrics]

	GWP_{100}	GTP_{20}	GTP_{50}	GTP_{100}	$CGTP_{50}$	$CGTP_{100}$
CH_4 (fossil)	34.8	65.8	17.4	9.5	3237	4075
CH_4 (biogenic)	32	63	14.6	6.7	3100	3800
N_2O	260	281	280	220		

A key limitation of pulse-emission metrics such as GWP and GTP, noted in the AR5, is that metric values depend strongly on the selected time horizon, given that warming from a CH_4 emission pulse declines over time, whereas warming from a pulse of CO_2 is nearly constant over centuries. Universal use of a single metric and time horizon can thus result in mismatches between policy goals and actual climate outcomes. Moreover, 'equivalence' based on GWP or GTP does not imply equivalent climate outcomes from cumulative or sustained emissions. This is illustrated in Figure 1, which shows that the warming from CH_4 emissions sustained at a constant rate is greater than the warming from an 'equivalent' (based on GWP_{100}) amount of sustained CO_2 emissions for the first 100 years, but the rate of warming from sustained CH_4 emissions declines over time and the absolute amount of warming becomes less than that from sustained GWP_{100}-equivalent CO_2 emissions beyond the first century.

The different cumulative behaviour of CO_2 and SLCF emissions is particularly relevant in stringent mitigation scenarios: even rapidly declining CO_2 emissions cause further warming in addition to the present until emissions reach net-zero. By contrast, rapidly declining SLCF emissions result in a declining SLCF contribution to global temperature since the warming from past emissions does not persist and declines over time (Allen et al., 2018). This behaviour is well known and can be readily replicated with simple climate models (see Figure 1), but cannot be captured if temperature change from cumulative SLCF emissions is assumed to be the same as from cumulative CO_2 emissions based on GWP_{100} (J. M. Lynch et al., 2020). Treating short- and long-lived gases interchangeably based on GWP_{100} as part of long-term emission targets thus creates ambiguity about actual climate outcomes (see WGI Section 7.6; Allen et al. 2016; Fuglestvedt et al. 2018; Tanaka and O'Neill 2018; Denison et al. 2019).

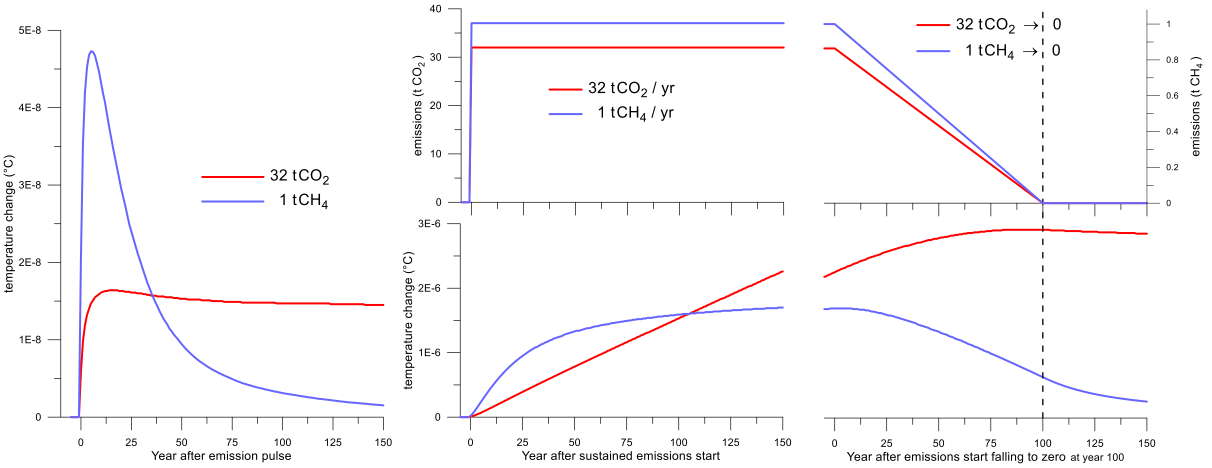

Figure 1. Temperature responses over time to emission pulses and sustained and declining emissions of CO_2 and CH_4. Left: single emissions pulse of 1 tCH_4 and 32 tCO_2. Middle panels: sustained annual

emission (top) of 1 tCH_4 and 32 tCO_2, and temperature response (bottom). Right: emissions linearly declining from 1t CH_4 and 32t CO_2 in year zero, to zero emissions of both gases in year 100 (top), and temperature outcome (bottom). The amount of 32 tCO_2 is chosen for illustrative purposes as it represents the "CO_2-equivalent" emission of 1t CH_4 based on GWP_{100}. [*Note to reviewers: Figure will be updated once WGI has been finalised to ensure full consistency.*]

A key innovation since the AR5 that seeks to address those limitations has been the development of combined step-change/pulse metrics, such as the combined global temperature change potential (CGTP; Collins et al. 2019) and GWP* (Allen et al., 2016, 2018; M Cain et al., 2019). These metrics are based on the insight that the temperature change from a pulse emission of CO_2 is much more similar to the temperature change from a *sustained step-change* of SLCF emissions rather than from a single SLCF emissions pulse. Equating CO_2 pulses with sustained step-changes in SLCF emissions therefore results in reduced dependence of the metric value on the choice of time horizon (Collins et al., 2019). Values for CGTP are much larger than for GTP, because this metric compares not a single SLCF pulse, but a sustained change in SLCF emissions (i.e. the cumulative effect of a series of SLCF pulses) with a one-off pulse emission of CO_2 (see Table A.B.9).

These new metrics enable a relatively simple estimation of the one-off CO_2 emission or removal that would result in the same approximate change in temperature as a sustained change in SLCF emission rates. As a result, these metrics provide a near-linear relationship between temperature and cumulative CO_2-equivalent SLCF emissions based on CGTP or GWP*, similar to the linear relationship between cumulative CO_2 emissions and temperature. While the CGTP is defined only for a single, permanent step-change in SLCF emissions, GWP* can also be applied to continuously varying CH_4 emissions trajectories (M Cain et al., 2019; J. M. Lynch et al., 2020). Lynch et al. (2020) demonstrated that GWP* gives an improved representation of temperature change for a range of CH_4 emissions scenarios, compared to using GWP_{100}, if warming is assumed to be a linear function of cumulative CO_2-equivalent emissions.

Even though GWP* and CGTP build on the same underlying physical climate processes as GWP and GTP, they differ in their use of reference emission levels, which has important implications for their potential applications in climate mitigation policy.

GWP and GTP describe the *marginal* effect of emissions, i.e. how much warmer the climate would be with, compared to without a specified emission. Consequently, these metrics provide information on how much warming could be avoided (over a given time period, or at a given future point in time) by avoiding the emission of a unit of an SLCF compared to avoiding a unit of CO_2.

By contrast, CGTP and GWP* describe the *additional* effect on climate from a given rate of SLCF emissions over and above the warming caused by a specified reference level of SLCF emissions, and compare this to the effect on temperature from the emission or removal of a unit of CO_2 (Allen et al., 2018; Collins et al., 2019). Depending on the reference emission level chosen, the value of CGTP or GWP* weighted CO_2-equivalent emissions can therefore be positive or negative, whereas marginal metrics like GWP or GTP always give positive values for any GHG.

While CGTP uses a fixed reference emissions level, GWP* uses a sliding reference level. This means that the CO_2-equivalent value of a SLCF emission in a given year based on GWP* is determined not by the absolute amount of that emission, but largely by the difference between that emission and the emission from the same source 20 years prior (with an adjustment proposed by Cain et al. (2019) to account for climate inertia and changing radiative efficacy under different global emission scenarios). This allows GWP* to express the additional warming (or relative cooling) from a continuous change in SLCF emissions in CO_2-equivalent terms that closely mirror the warming from successive CO_2 emissions or removals (M Cain et al., 2019; J. M. Lynch et al., 2020). However, a reference level greater than zero to calculate CO_2-equivalence does not provide information about the *marginal* warming from

SLCF emissions, since it combines the marginal warming caused by each emission with the decline in temperature resulting from the decay of prior emissions.

The different focus on marginal vs additional effect on temperature explains why rapidly declining CH_4 emissions are given a negative CO_2-equivalent value based on GWP* (rapidly declining SLCF emissions result in declining temperature, relative to the warming caused by past SLCF emissions at a previous point in time) but a positive CO_2-equivalent value based on GWP or GTP (each SLCF emission results in global average temperature being higher than it would be without this emission, even if the rate of SLCF emissions is declining). By contrast, for CO_2 emissions there is virtually no difference between the marginal or additional effect of an emission on temperature, given the persistence of warming from each prior emission. Figure 2 illustrates these differences by comparing the *marginal* warming from future CO_2 and CH_4 emissions (i.e. warming that would occur with, compared to without, emissions and removals from 2020 onwards) with the *additional* warming relative to 2020.

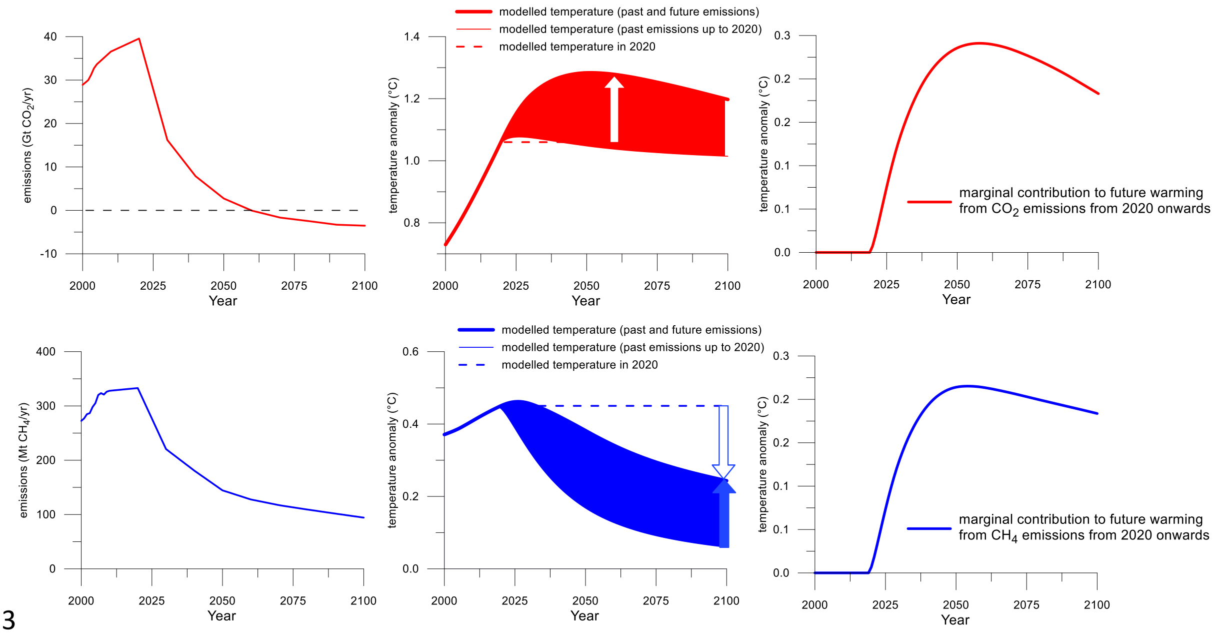

Figure 2. CO_2 (top) and CH_4 (bottom) emissions (left) and simulated temperature anomalies (middle and right), for an illustrative global emissions scenario that would limit warming to below 2°C. The middle panels show the modelled overall warming from the given CO_2 and CH_4 emissions trajectories (thick solid lines), the contribution to past and future warming from past emissions (up to 2020; thin solid lines), and the contribution to warming in the year 2020 from past emissions (dashed lines). The *marginal* warming from future CO_2 and CH_4 emissions (i.e. the difference between warming caused by emissions up to 2020, and warming caused by past and future emissions) are shown as shaded areas and solid arrows. The additional warming (i.e. the temperature change relative to the warming in 2020) is indicated by hollow arrows. The right panels show the marginal warming from CO_2 and CH_4 emissions from 2020 onwards (i.e. the increase in global average surface temperature that would occur with, compared to without, those future emissions). [*Note to reviewers: these calculations will be updated using the same temperature response functions as used in WGI AR6 once the WGI report has been finalised. The specific emissions scenario may be updated to use one of the illustrative pathways outlined in WGIII Chapter 3.*]

Whether a marginal or additional metric is more suited to a particular policy application depends on the policy goal and how the metric would be used to serve that goal (Myhre et al. 2013; Kolstad et al. 2014; IPCC 2014; see also WGI Box 7.3). A focus on marginal warming is generally relevant for policy applications that need to understand the contribution from future emissions to climate change relative to the absence of those emissions, and wherever decisions need to be made about how to value abatement of different gases based on the amount of climate change that such abatement would avoid.

Marginal metrics therefore form the conceptual basis of price-based approaches to mitigation (Kandlikar, 1996; Michaelis, 1992; Tol et al., 2012) including emissions trading schemes, but can also inform the appropriate level of ambition and costs implicit in non-price mitigation measures. The specific policy goal, as well as the emphasis placed on cost-effectiveness, cost-benefit or other criteria to achieve that goal, and whether the focus is on annual or sustained emissions, can then inform the specific choice of metric and time horizon (which can include the marginal pulse emission metrics GWP, GTP but also CGTP or GWP* if applied in a marginal sense; see sections A.B.10.3 and A.B.10.4 below).

By contrast, a focus on additional warming is generally useful where there is a need to evaluate the relative benefits or disbenefits of changing cumulative emission over time, relative to a specified reference emissions level or trajectory. Examples include the effect on climate from sustained process, technology or behavioural changes relative to a 'current policies' scenario, and quantifying the interactions between CO_2 and SLCF emissions within the remaining carbon budget. The remaining carbon budget depends on an assumed trajectory of non-CO_2 emissions (see WGI Chapter 5). Metrics like CGTP and GWP* can inform decision-makers about the trade-offs between further increasing or decreasing the long-term rate of SLCF abatement compared to the reference trajectory used to calculate the remaining carbon budget, and the corresponding increase or decrease in cumulative CO_2 emissions that would remain consistent with the stated global temperature limit (Allen et al. 2018; Collins et al. 2018, 2019; see also WGI Chapter 5, and WGIII Chapter 3).

A.B.10.3: New insights on marginal pulse emission metrics: GWP and GTP

Global perspectives

Recent theoretical analyses (Aaheim & Mideksa, 2017; Dharik S Mallapragada & Mignone, 2019; Dharik Sanchan Mallapragada & Mignone, 2017) confirm conclusions from the AR5 that integrated pulse emission metrics (such as GWP) are consistent with a cost-benefit framework, whereas end-point pulse emission metrics with an end-year target (such as dynamic GTP) are more aligned with a cost-effectiveness framework.

The GWP with a static time horizon approximates the Global Damage Potential, i.e. the notion that the emission of a non-CO_2 forcer at any point in time should be weighted by the marginal economic damages from this emission, relative to the marginal damages from emitting a unit mass of CO_2 (Deuber, Luderer, et al., 2013). The GWP time horizon is linked to the social discount rate used in the Global Damage Potential to calculate the net present value of economic damages over time from each emission. Recent studies (Dharik S Mallapragada & Mignone, 2019; Sarofim & Giordano, 2018) confirm earlier work (O. Boucher, 2012; Jan S Fuglestvedt et al., 2003) that for methane, GWP_{100} is consistent with a discount rate of about 3%, with the specific value depending on the gas and other assumptions such as non-linearity of damages with warming. Detailed sensitivity analysis by Sarofim and Giordano (2018) gives an interquartile range of 2.7 to 4.1% for the implied discount rate for GWP_{100} in the case of methane, depending on a range of assumptions about climate scenarios, shape of damage functions, climate feedbacks and global economic growth. GWP_{20} would imply much higher discount rates of 11.1 to 14.6%, given the stronger weighting of near-term effects on climate. Use of a single discount rate based on pure time preference and future growth in wealth and its effects (known as the simple Ramsey rule) can be problematic (Drupp et al., 2018) but no studies so far have evaluated metrics with varying discount rates over time.

Shindell et al. (2017) evaluated the social cost of methane emissions directly based on time-varying changes in climate and inferred economic damages, and found a wide range of possible values, reflecting the range of judgements in determining social costs of pollutants. However, their results are broadly consistent with a GWP_{100}-based weighting of CH_4 relative to CO_2 when similar discount rates and consistent assumptions about climate-related damages and the temperature dependence of damage functions are chosen for both gases.

These studies indicate that even though the GWP_{100} was not designed to meet any economic goals, the discount rate implied in GWP_{100} for methane is broadly similar (*medium confidence*) to social discount rates of 3-5% that are used in integrated assessment models (see Chapter 3) and investments with multi-decadal lifetimes (Giglio et al., 2015; HM Treasury, 2018).

In principle, GHG emission metrics focused on cost-effectiveness are better matched to the Paris Agreement's temperature goal than cost-benefit metrics, and are also supported by the UNFCCC principle that mitigation policies and measures should be cost-effective (Johansson, 2011; Tanaka et al., 2020; Tol et al., 2012). In cost-effectiveness metrics, metric values for SLCF emissions necessarily change over time since the closer SLCF emissions occur to the target year, the greater their contribution to climate change in that year. The dynamic GTP (K. Shine et al., 2007) reflects such a cost-effectiveness approach by providing information on the marginal contribution of SLCF emissions in any given year to the expected peak warming at a future date (Dharik Sanchan Mallapragada & Mignone, 2017; Tanaka et al., 2020; Tol et al., 2012). However, the dynamic GTP does not fully match the price ratio between gases in least-cost mitigation pathways (also referred to as the Global Cost Potential; e.g. Michaelis 1992; Manne and Richels 2001) because the most cost-effective weighting of each emission also depends on the discount rate (Johansson, 2011; Strefler et al., 2014; Tanaka et al., 2020).

The GTP with a static time horizon (e.g. GTP_{50} or GTP_{100}) is not clearly matched to either a cost-benefit or a cost-effectiveness framework, as the year for which temperature outcomes are evaluated would shift forward each year and hence would not match the year when the global temperature limit is reached (Edwards & Trancik, 2014; Dharik Sanchan Mallapragada & Mignone, 2017; Strefler et al., 2014; Tol et al., 2012). Use of GTP with a static time horizon may be relevant where it is applied to emissions only in a given year, rather than to evaluate emissions over successive years, if the time horizon matches a relevant climate policy goal (Balcombe et al., 2018; J S Fuglestvedt et al., 2010; Grewe & Dahlmann, 2015).

A number of studies since the AR5 have evaluated the impact of different pulse GHG emission metrics and time horizons on the global economic costs of limiting global average temperature change to a pre-determined level, including to well-below 2°C (Deuber et al., 2014; Ekholm et al., 2013; M. J. H. M. Harmsen et al., 2016; Huntingford et al., 2015; Strefler et al., 2014; Tanaka et al., 2020; Van Den Berg et al., 2015). These studies show consistently, with very few exceptions, that global costs to achieve the same temperature in 2100, or the same peak temperature before 2100, are higher if CH_4 emissions are weighted consistently less than indicated by GWP_{100} (e.g. if using GTP_{100} or GWP_{500}). The increase in global mitigation costs ranges from a few percent to more than 30 percent in most studies, depending not only on the specific metric values used but also on the temperature limit, degree of overshoot, and abatement costs and potentials of different gases assumed in those studies. These studies also indicate, albeit less consistently and less significantly than for GTP_{100}, that global mitigation costs would also increase if CH_4 emissions are valued consistently more highly than in GWP_{100} (e.g. using GWP_{20}). Collectively, these studies indicate that even though GWP_{100} does not represent the most cost-effective metric and time horizon choice possible (Tanaka et al., 2020), it is more cost-effective than any of the other static metrics and time horizons used widely in the scientific literature.

Studies available for the AR5 suggested that using a dynamic GTP or economic optimisation approaches, which defer high-cost CH_4 abatement until closer to the target year, could reduce global abatement costs compared to GWP_{100} by a few percent (Johansson, 2011; Manne & Richels, 2001; A Reisinger et al., 2012). More recent studies confirm this theoretical cost saving in principle (Ekholm et al. 2013; Harmsen et al. 2016; Strefler et al. 2014; Van Den Berg et al. 2015; Tanaka et al. 2020). However, these studies also demonstrate that the extent to which this cost saving would be realised depends on a range of assumptions, including the stringency of the target, degree of policy foresight, the speed with which CH_4 emissions can be reduced as metric values increase, allowance for any temporary temperature overshoot for end-of-century targets, the shape of marginal abatement cost curves, and the treatment of uncertainty.

One reason why the literature shows only a limited, if any, reduction in global mitigation costs from using dynamic GTP or economic optimisation compared to GWP_{100}, despite its theoretical advantage, lies in the similarity of the metric values or exchange rates for methane if the goal is to limit warming to well below 2°C (see Table A.B.9). For such temperature limits, peak temperature would be reached sometime between 2050 and 2080 (Rogelj et al. 2018; see also Chapter 3). This means that emissions occurring in the year 2030 would be weighted by GTP_{20} to GTP_{50}, but emissions in the year 2040 by GTP_{10} to GTP_{40}, and so on. Across such time horizons, the numerical values of the dynamic GTP for CH_4 (as the main short-lived GHG) over the next few decades are comparable on average to GWP_{100} (see Table A.B.9). For mitigation pathways aiming to limit temperature below 2°C or at 1.5°C as best estimate (i.e. RCP2.6 and below) and with limited overshoot, GWP_{100} therefore results in abatement choices that are not very different from those based on dynamic GTP or economic optimisation, even though GWP_{100} in itself reflects a cost-benefit framework.

A common feature of virtually all GHG metrics studies to date is that they use a single (static or dynamic, i.e. predictably changing) emission metric to inform abatement choices over the entire 21st century and beyond. This is not well matched to the new scenario logic proposed by Rogelj et al. (2019) for the Paris Agreement, which suggests separate policy choices exist regarding the timing and magnitude of the temperature peak and the post-peak rate of temperature decline. This scenario approach has not yet been used to evaluate GHG metrics, but Tanaka et al. (2020) show that cost reductions could be obtained by using GWP_{100} as a starting metric and updating the GWP time horizon in discrete steps depending on when and by how much the temperature goal might be exceeded based on actual emissions. This approach could reduce mitigation costs by a few percent, relative to GWP_{100} being used throughout the 21st century, in very high overshoot scenarios that reach the long-term temperature goal of 1.5 or 2°C only in the 22nd century. For such scenarios, the most cost-effective weighting of SLCF emissions is generally less than GWP_{100} in the next few decades but two to three times higher than GWP_{100} once temperature has peaked. These findings strengthen the conclusions by Tanaka and O'Neill (2018) and Fuglestvedt et al. (2018) that the choice of GHG metric is particularly important for the rate of temperature decline once net-zero GHG emissions have been reached.

In conclusion, a range of economic modelling studies since the AR5 gives *high confidence* that using GWP_{100} to inform abatement choices between gases would help meet the long-term temperature goal of the Paris Agreement at close to least global cost (based on least-cost pathways inferred from economic models), and with limited overshoot. However, this is to some extent coincidental as the GWP_{100} was not designed with any specific policy goal in mind. GWP_{100} would not necessarily perform equally well for higher temperature limits, very high overshoot scenarios, or if constraints are placed on the rate as well as magnitude of warming.

Based on those same studies, using the dynamic GTP instead of static GWP_{100} could reduce global mitigation costs by a few percent in theory (*high confidence*), but the ability to realise those cost reductions in practice depends on the temperature target, policy foresight and flexibility in abatement choices as the weighting of SLCF emissions increases over time (*medium confidence*). Limited evidence suggests that global mitigation cost reductions similar to those from using the dynamic GTP might be obtained by regularly reviewing and potentially updating the time horizon used in GWP based on actual emission trends compared to climate goals.

There are no studies yet that apply the novel mixed step-change/pulse emission metrics (CGTP or GWP*) in economic analyses. Further work is required to enable those metrics to be used in economic models, given that those models typically require information about the marginal climate benefits of abatement of emissions in each economic time period.

Country and sector-level perspectives

The AR5 already noted that the choice of metric and time horizon could have significant implications for regions or sectors with high fractions of SLCF emissions (Brennan & Zaitchik, 2013; IPCC, 2014; Myhre et al., 2013; Strefler et al., 2014). Specific emitters might prefer a metric that reduces costs to them even though it increases global abatement costs for the same climate outcome. The choice of GHG emission metric is therefore linked not only to cost-effectiveness but also to equity and burden sharing issues. Sectoral and national perspectives on mitigation pathways, including GHG emission metrics to inform such pathways, may therefore differ from a global least-cost perspective (Klinsky & Winkler, 2018), but the literature has not developed a consistent framework for assessing GHG emission metrics based on a wider set of equity principles.

The shifting of costs between emitters as a result of different metrics has been demonstrated for the case of agriculture in New Zealand, which has a high fraction of enteric methane emissions. Even though global mitigation costs to limit warming to below 2°C would be lower under GWP_{100} than GTP_{100}, costs to farmers would be greater under GWP_{100} than GTP_{100} if climate policy were to price all GHG emissions and place the cost burden on emitters (Dorner & Kerr, 2016).

Various studies evaluated the extent to which cost-effective sectoral abatement strategies might change under different climate metrics. These studies show that in some instances (e.g. for transport and fuel choices), the choice of metric can change abatement preferences and timing (Edwards et al., 2016, 2017; Edwards & Trancik, 2014). The magnitude of the climate impact from aviation when expressed in CO_2-equivalents depends strongly on the emission metric and time horizon choice, as SLCF emissions and contrails enhance warming significantly over days to decades, in addition to the warming from CO_2 that occurs over centuries to millennia (Azar & Johansson, 2012; Deuber, Sigrun, et al., 2013; J S Fuglestvedt et al., 2010; Lee et al., 2020; Lund et al., 2017). Tanaka et al. (2019) show that switching from coal to gas (which has lower CO_2 but higher CH_4 emissions) for energy supply offers consistent climate benefits regardless of metric and time horizon unless CH_4 leakage rates are very high.

For some sectors, mitigation strategies and the relative merit of specific technologies or practices compared to others (such as intensive vs extensive agricultural production and mitigation options, or choices to reduce air pollutants with a climate forcing effect) have been shown to be relatively robust against the choice of metric (Åström & Johansson, 2019; Ledgard & Reisinger, 2014; Andy Reisinger et al., 2017; Andy Reisinger & Ledgard, 2013). Clark et al. (2020) show that current emission trends in the global food system alone would be sufficient to exceed a 1.5°C temperature limit and associated global emission targets, regardless of whether methane emissions are aggregated into CO_2-equivalents using GWP_{100} or GWP*. However, the overall volume of CO_2-equivalent emissions from those sectors, and hence the cost to emitters if emissions were priced based on their CO_2-equivalent values, depends strongly on the GHG metric even if the most effective mitigation strategy does not.

Consistent with these divergent results, the UNEP-SETAC (Society of Environmental Toxicology and Chemistry) task force on Lifecycle Assessment recommended that at least two, but potentially even three metrics with divergent weightings for SLCFs (GWP_{100} and GTP_{100} and potentially also GWP_{20}) be used to better understand the extent to which GHG metric choices may implicitly or inadvertently affect reported carbon footprints (Cherubini et al., 2016; Jolliet et al., 2018; Levasseur et al., 2016). This matches recommendations by other researchers for the use of multiple metrics (Balcombe et al., 2018; Cooper et al., 2020; Grewe & Dahlmann, 2015; Ocko et al., 2017) especially where there is no unambiguous policy goal for a sectoral or entity-level LCA. While there is a strong consensus that using multiple metrics provides a more nuanced understanding of the climate effects of emissions (*very high confidence*), there is no consensus yet about which specific pairs or sets metrics should be used (e.g.

GWP_{20} and GWP_{100}, or GWP_{100} and GTP_{100}). The utility of GWP* in LCA, which would make the weighting given to SLCF emissions in any given year dependent on the magnitude of emissions from the same entity or process 20 years prior, has not yet been explored in the peer-reviewed literature.

Some studies use simple climate models or pulse-response functions to understand the climate impacts of emissions of different gases directly rather than relying on metrics (Cooper et al., 2020; Lee et al., 2020; J. Lynch & Pierrehumbert, 2019; Mayfield et al., 2019; A Reisinger & Clark, 2017). Treating GHGs with different lifetimes separately supports the explicit, targeted treatment of different pollutants and avoids value judgements about the climate outcome of concern, time horizons and reference levels being embedded in GHG emission metrics. This does not avoid the need for such value judgements to be made but can allow them to be made more explicitly.

A.B.10.4: Climate outcomes and metrics for sustained and cumulative emissions

Emission metrics such as GWP and GTP reflect the marginal effects on some aspect of climate (radiative forcing or temperature) from individual (pulse) emissions occurring in a given year (see section A.B.10.2), which is relevant for trade-off decisions on an annual or short time-horizon basis. However, in some policy contexts, information is required not on the climate effect from annual emissions but from emissions, or changes in emissions, that are sustained over several decades or more. Examples are the remaining carbon budget consistent with limiting warming to given level and the role of non-CO_2 emissions in this budget (see AR6 WGI chapter 5), and understanding the long-term climate benefit of adopting alternative processes and technologies that reduce SLCF emissions but might increase CO_2 emissions (J. Lynch & Pierrehumbert, 2019). Such information can also be relevant for setting long-term emission targets for sectors with a high fraction of SLCF emissions such as agriculture.

Common to those examples is a need for GHG emission metrics to express the temperature response to sustained SLCF emissions rather than to the emissions in any given year. Given the different temperature outcomes over time from sustained CO_2 and sustained SLCF emissions (see Figure 1), constraining an emissions pathway based on CO_2-equivalent emissions only but without specifying the balance between short- and long-lived gases does not result in equivalent temperature outcomes.

Both Tanaka and O'Neill (2018) and Fuglestvedt et al. (2018) demonstrated and discussed the implications of this for climate outcomes under Article 4.1 of the Paris Agreement. These studies show that achieving and sustaining a 'balance' of sources and sinks of all anthropogenic emissions and removals of GHGs would result in a peak in global temperature followed by a gradual decline if that balance is determined using GWP_{100}, a lesser rate of decline if GTP_{100} is used, and virtually constant temperature using GWP*. This implies that net-zero GHG emissions based on GWP_{100} would result in a gradual return to 1.5°C if temperature peaks above that limit, but not if net-zero GHG emissions are achieved based on GWP* (Schleussner et al., 2019).

Tanaka and O'Neill (2018) also showed, using a simplified economic model, that using GTP_{100} to define and achieve a net-zero emissions target at least cost would result in a higher peak temperature than if GWP_{100} is used. Their study indicates that achieving a net-zero GHG emissions goal on its own does not ensure achievement of a given temperature goal but depends on the GHG emission metric used as well as the emission trajectory to reach that target.

The choice of GHG emission metrics to provide an exchange rate between CO_2 and CH_4 emissions also affects transient temperature outcomes in stringent mitigation pathways (Denison et al., 2019; Huntingford et al., 2015). Figure 3 illustrates the effect of allowing full substitution of CO_2 and CH_4 emissions along the CO_2-equivalent emissions trajectory of an illustrative RCP2.6 scenario. For two hypothetical alternative scenarios with either a rapid reduction to zero or no reduction in CH_4 emissions, and a correspondingly less or more abatement of CO_2 based on GWP_{100}, results in peak temperatures that differ by up to 0.2°C in either direction. The scenario with more stringent CH_4 abatement and correspondingly less CO_2 abatement results in lower temperature during the 21st century, but this gradually reverses towards the end of the 22nd century. By contrast, using GWP* for the substitution between gases (with default parameters as in Lynch et al., 2020) results in smaller temperature deviations of up to about 0.1°C over the 21st century, and similar peak temperatures, demonstrating the improved ability of GWP* to simulate temperature change from sustained changes in SLCF emission rates. However, even though GWP* is designed to provide warming-equivalent emissions, temperature outcomes for the alternative scenarios shown in Figure 3 begin to diverge towards the end of the 21st and into the 22nd century. The reason for this divergence is that the calculation of GWP* based on Cain et al. (2019) and Lynch et al. (2020) relies on scenario-dependent parameters whose default values do not precisely match the actual emission scenario to which the metric is applied here.

Denison et al. (2019) explored these same trade-offs for variations in CH_4 emissions found across a broad range of Integrated Assessment Models and scenarios assessed in the IPCC Special Report on Global Warming of 1.5°C (J Rogelj et al., 2018). They found that for scenarios with identical CO_2-equivalent emission pathways but different combinations of CH_4 and CO_2 emissions, different metrics could vary temperature outcomes by up to 0.17°C across the range of pathways that limit warming between 1.5°C and 2°. This ambiguity in temperature outcomes is non-trivial, as it constitutes between a third and just under one fifth of the additional warming above present implied by a 1.5 and 2°C limit, respectively, but is only a minor uncertainty when considering that CO_2 and CH_4 emissions trajectories based on current global climate policies would result in warming of more than 3°C (see Chapters 3 and 4). These substitutions represent theoretical maximum deviations; they do not reflect a realistic range of potential trade-offs between either CO_2 or CH_4 abatement, as e.g. abatement of fossil CO_2 is expected to result in similar abatement of co-emitted CH_4 from fossil fuel extraction and use (Joeri Rogelj et al., 2014).

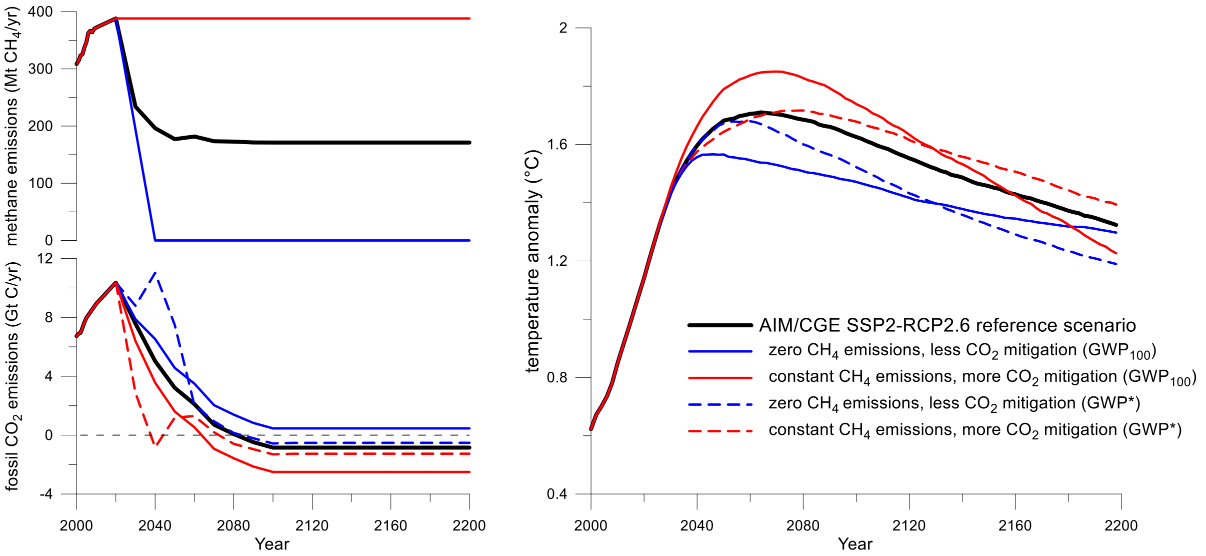

Figure 3. Temperature change under an illustrative mitigation scenario (AIM/CGE SSP2-RCP2.6) and hypothetical alternative CO_2 and CH_4 emission trajectories. The left panels show the default (solid black line) CH_4 (top) and CO_2 (bottom) emissions for this scenario, along with two hypothetical variants where CH_4 emissions are either held constant at 2020 levels (red) or reduced to zero by 2040 (blue). CO_2 emissions are adjusted such that the total CO_2-equivalent emissions of both gases are identical to the default, with the equivalence based on GWP_{100} (solid red and blue lines) and GWP* (dashed red and blue lines). The right panel shows the best-estimate temperature change for each scenario based on MAGICC6 (Meinshausen et al., 2011). Note the alternative scenarios are hypothetical, shown to illustrate the temperature consequences of full substitution between gases using different GHG emission metrics. They do not represent socio-economically plausible alternatives.

Lynch et al. (2020) demonstrated that cumulative CO_2-equivalent CH_4 emissions based on GWP* result in a better simulation of temperature change compared to GWP_{100} for a wide range of hypothetical emission scenarios. Based on this insight, GWP* can be used to estimate not only the additional but also marginal warming from future CH_4 emissions (i.e. the contribution of future CH_4 emissions to warming compared to those emissions not occurring, and hence the climate benefit of avoiding those future emissions, compared to avoiding future emissions of CO_2). Figure 4 shows the marginal warming from future CH_4 emissions from 2020 onwards, for the same mitigation scenario used in Figure 1, along with the marginal warming calculated from cumulative CO_2-equivalent emissions based on GWP_{100} and GWP*. To represent the marginal warming from future emissions only, emissions prior to 2020 are set to zero in the calculation of GWP*. Figure 4 shows that GWP*, if used in this way, provides an improved estimation of the marginal contribution of future cumulative CH_4 emissions to temperature change compared to GWP_{100}, but implies markedly more variable CO_2-equivalent emissions over time. GWP*-based CO_2-equivalent emissions are significantly higher than those based on GWP_{100} in the next two decades (reflecting the significant near-term marginal contribution to warming from future CH_4 emissions), before turning to negative values, which reflects the reduced contribution to warming as CH_4 emissions decline over time.

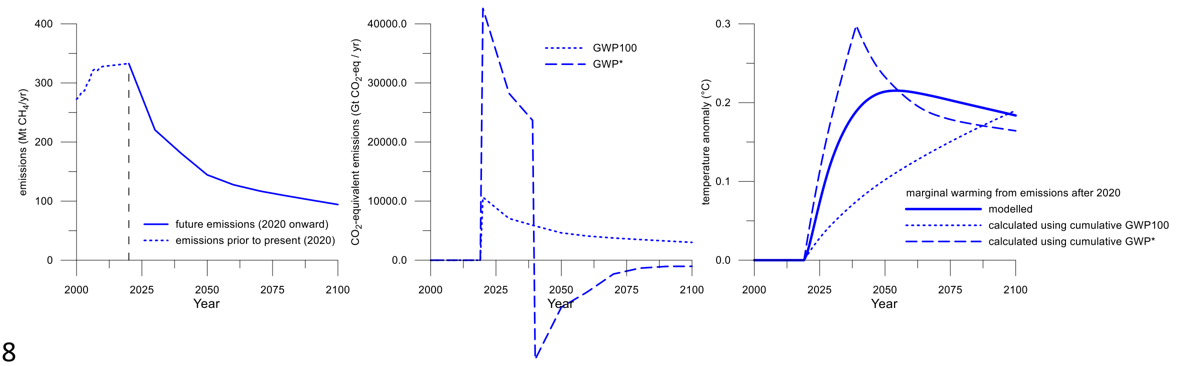

Figure 4: CH_4 emissions (left) and simulated temperature anomalies (right) in a stringent mitigation scenario (same scenario as in Figure 1). The middle panel shows the calculated CO_2-equivalent emissions from 2020 onward based on GWP_{100} and GWP* (using parameters given in Lynch et al. 2020, and with emissions prior to 2020 set to zero to obtain the marginal contribution to warming from future emissions). The right panel shows the marginal warming from those emissions, modelled using a pulse-response function (solid line) and simulated based on cumulative CO_2-equivalent emissions based on GWP_{100} and GWP*.

In summary, while the number of studies demonstrating the use of these novel metrics is still limited, there is *high agreement* between studies and they are consistent with well-established underlying physical principles. Collectively, these studies therefore provide at least *medium confidence* that CGTP and GWP* allow a simple and more accurate way of estimating temperature change based on cumulative, CO_2-equivalent SLCF emissions than GWP or GTP, particularly for scenarios with rapidly falling SLCF emissions. This includes the interaction between more or less ambitious SLCF mitigation, particularly methane, and the remaining carbon budget within a given temperature limit.

Despite its scientific merits, the use of GWP* in climate policy, particularly to inform national or sectoral emission targets, has been contested, but the scientific literature on this is very limited (Michelle Cain et al., 2020; Joeri Rogelj & Schleussner, 2019, 2020).

The key issue underlying this debate is that GWP* as used in the literature to date provides no information on the marginal contribution of future emissions to global climate change, and hence the amount of climate change that could be avoided by avoiding those future emissions. For example, in the formulation of Cain et al. (2019) and Lynch et al. (2020), two different sources emitting 1 Mt and of 100 Mt CH_4/yr would both be described as constituting zero CO_2-equivalent emissions based on GWP* as long as those emissions already occurred 20 years in the past and are declining by about 0.3% per year. However, the marginal contribution of those emissions to global temperature (i.e. the amount by which global temperature is greater with, compared to without either of those emissions) differs by two orders of magnitude. As a result, using GWP* to define 'net-zero' GHG emission targets at country or sector level raises issues of distributional fairness and economic efficiency, as emitters with higher recent SLCF emissions adopting such targets would retain an ability to emit SLCFs at higher rates than emitters whose recent emissions were lower. Cain et al. (2020) argue that a metric that gives an improved representation of temperature outcomes from cumulative emissions cannot be unfair but is simply more accurate and transparent. The debate highlights that disagreement about GWP* and similar metrics like CGTP is mostly not related to their scientific merits, but to their appropriate application in specific policy contexts, including the role of historical emissions in setting future emission targets.

Another concern has been raised regarding a potential inconsistency between Articles 2 and 4 of the Paris Agreement if GWP* were used to interpret the 'balance of sources and sinks in the second half of this century' stated in Article 4.1 of the agreement (Schleussner et al., 2019). Emission pathways consistent with 1.5°C achieve net-zero GHG emissions much earlier if GWP* rather than GWP_{100} is used to calculate aggregate emissions and removals, because GWP* equates rapidly declining CH_4 emissions with negative CO_2 emissions (see Figure 5). The sharp decline of CH_4 emissions in these pathways results from the rapid reduction in fossil CH_4 emissions alongside reductions in fossil CO_2 (Joeri Rogelj et al., 2014) as well as the relatively low-cost abatement potential for some biogenic CH_4 emissions (Harmsen et al. 2019a,b; see also Chapter 7). Stringent mitigation pathways consistent with 1.5°C therefore imply net-zero GHG emissions to occur well before 2050 if net-zero emissions are calculated using GWP* rather than GWP_{100}, rather than only in the second half of the 21st century as stipulated in Article 4.1. Again contestation in this area does not relate to the ability of GWP* to reproduce temperature change from cumulative emission, but whether the application of the metric would be consistent with an overall set of existing policy objectives and their interpretation.

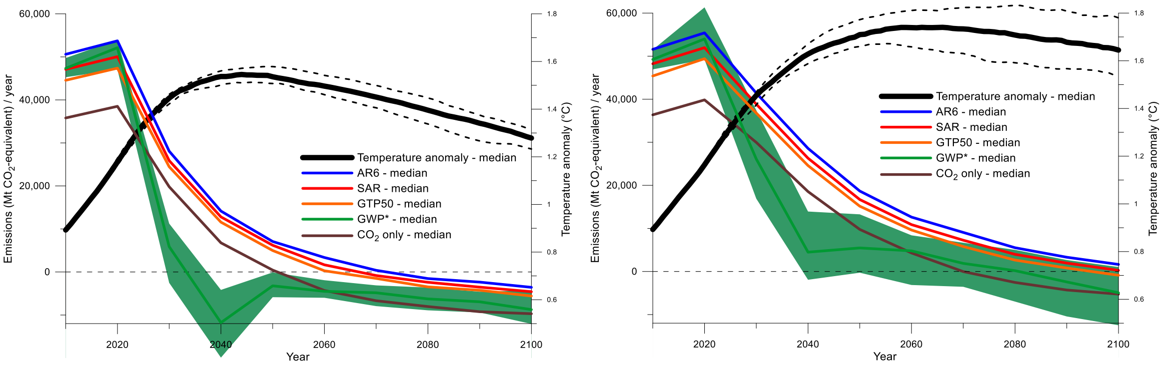

Figure 5. Aggregate net GHG emissions for emission pathways consistent with 1.5°C with no or limited overshoot (left) and with remaining below 2°C (right) from Integrated Assessment Models, with net emissions calculated using a range of different GHG emission metrics. ***[Note to reviewers: emission pathways shown in this figure draft are from the SR15 database and will be updated using the AR6 database.]***

A.B.10.5: Issues related changes in GHG emission metrics used in climate policy

The scientific literature to date has focused on the performance of metrics against specific (assumed) objectives, and some studies conclude that some objectives could be met better by changing metrics or time horizons at certain points in time. However, the role of IPCC to provide policy-relevant information to governments creates the potential for an 'inadvertent consensus' that could impede such change (K. Shine, 2009): IPCC seeks to provide information on emissions and abatement potentials in terms consistent with metric choices made by the UNFCCC, while parties to the UNFCCC may adopt metrics based on their prominent use in previous IPCC reports.

Numerous studies have reflected on the relevance of changing metrics to match different policy goals (e.g. Shine 2009; Jolliet et al. 2018; Tanaka et al. 2020; Balcombe et al. 2018; Grewe and Dahlmann 2015), but no studies have explicitly evaluated when the benefits of changing metrics outweigh the procedural cost of change. However, several observations can be made based on the existing literature.

Changing GHG emission metrics, but retaining the same quantitative CO_2-equivalent emissions targets, would necessarily result in different climate outcomes (see e.g. Fuglestvedt et al. 2018; Tanaka and O'Neill 2018; Allen et al. 2018; Schleussner et al. 2019). A change in GHG emission metrics would therefore require a re-evaluation and re-formulation of existing emission targets at sectoral, national and global levels to avoid an implicit and potentially inadvertent change to currently stated levels of mitigation ambition and intended climate outcomes (*very high confidence*).

The objective determination of whether a GHG emission metric is superior to another metric depends on clearly stated, specific policy objectives and evaluation criteria. In practice, climate policy reflects a range of climate and non-climate policy goals, often with unclear weightings and preferences (Geden, 2016). Determining whether alternative GHG emission metrics would perform better in a real-world context therefore relies on judgements and understanding of the role and limitations of GHG emission metrics by decision-makers as well scientific expert bodies.

GWP_{100} metric values for CH_4 have changed significantly over the past 25 years. This suggests that changing metric values do not necessarily act as impediment for climate policy, especially if future changes are predictable as with e.g. the dynamic GTP. However, the degree to which the benefits of changing metrics can be realised does depend on foresight and flexibility of emitters to make alternative abatement choices (M. J. H. M. Harmsen et al., 2016). To date, only a small fraction of CH_4 emissions globally have been subject to price-based policies where a change in their CO_2-equivalent emissions has materially altered mitigation incentives. The fact that past changes in GWP_{100} values have not been noted as major impediment to climate policy implementation is therefore not a sufficient indication of the potential future implications of changing metrics under more ambitious and comprehensive climate policies.

The scientific literature has been slow to adopt new metric values, with some recent studies still using GWP_{100} values from the IPCC Second Assessment Report, published in 1996. In addition, many studies report only CO_2-equivalent emissions based on GWP_{100} and do not easily allow disaggregation into individual gases (e.g. Lynch 2019). Policy decisions to change GHG emission metrics could therefore take considerable time to permeate the scientific literature.

A.B.10.6: Use of GHG metrics in WGIII contribution to AR6: guidance to authors

Author teams in the Working Group III contribution to the AR6 have been requested to report emissions and mitigation options for individual gases wherever possible, and reports CO_2-equivalent emissions where this is judged to be policy relevant by the author teams only in addition to, not instead of individual gases. This approach aims to reduce the inevitable ambiguity regarding actual climate outcomes over time when any simplifying emission metric is used. However, in some cases the existing primary literature provides information only on CO_2-equivalent emissions, and it may not be possible or feasible for author teams to disaggregate individual gases. In such situations, authors have been requested to provide at least a qualitative indication of the relative shares of non-CO_2 and especially short-lived gases.

This Annex shows that a variety of GHG emission metrics can be justified to report CO_2-equivalent emissions or abatement where such information is policy-relevant, depending on the policy context and specific objectives such as cost-effectiveness or various dimensions of equity. Nonetheless, to allow consistent reporting of emissions and abatement across chapters, the contribution of WGIII to the AR6 had to make a choice for a single GHG emission metric to be used across this report.

GWP_{100} was chosen for both procedural and scientific reasons as default GHG emissions metric to report CO_2-equivalent emissions and abatement potentials in the WGIII contribution to the AR6.

Procedural reasons are to provide continuity with past IPCC reports, and to match decisions made by Governments as part of the Paris Agreement rulebook to use GWP_{100} for reporting of emissions from 2021 and for accounting of emissions under future NDCs (4/CMA.1 and 18/CMA.1: UNFCCC 2019). Scientific reasons are that GWP_{100} has been shown (see section A.B.10.3) to approximate the relative damages caused by each GHG emission (especially the two main GHGs CO_2 and CH_4) if social discount rates of around 3% are used. In addition, use of GWP_{100} to determine relative prices in global economic models results in mitigation pathways that are close to, though not fully consistent with, globally cost-effective pathways to limit temperature to levels consistent with the Paris Agreement.

The choice of GWP_{100} does *not* imply that GWP_{100} is recommended or the most suitable metric for climate policy, as the assessment in this appendix has shown that such judgements depend on the specific context, climate policy objectives and way in which a metric would be used.

The WGIII contribution to the AR6 uses GWP_{100} values from AR6 WG1 wherever possible and unless stated otherwise (for a full set of values, see table A.B.10), to increase numerical consistency of the contribution of individual Working Group reports to the AR6. [*Note to reviewers: metric values and figures will be updated for the final draft to be fully consistent with the final draft of WGI once this is completed.*] The main limitation to this approach is that existing literature uses a range of GWP_{100} values when reporting CO_2-equivalent emissions or abatement; for CH_4, these may 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). In some cases, it is not possible or feasible for author teams to disentangle conclusions from this existing literature into individual gases and then re-aggregate those emissions consistently into CO_2-equivalents using GWP_{100} values from the AR6. In these cases, especially if non-CO_2 emissions constitute only a minor fraction of total emissions or abatement, author teams have been requested to note that their reported CO_2-equivalent emissions are not fully consistent with CO_2-equivalents based on the AR6, and to provide an indication of the potential magnitude of inconsistency.

Table: A.B.10 | GWP_{100} values and atmospheric lifetimes for a range of GHGs, based on WGI Chapter 7.

[*Note to reviewers: these numbers are subjected to change and will be updated for the final draft of WGIII, following finalisation of the final draft report by WGI*]

Gas	GWP_100	Lifetime
CO_2	1	
CH_4 (biogenic)	32	12.2
CH_4 (fossil)	34.75	12.2
N_2O	261	109
HFC-32	753	5.4
HFC-143a	5468	51
CF_4	6651	50000

C_2F_6	11734	10000
C_3F_8	9512	2600
C_4F_{10}	9661	2600
C_5F_{12}	9156	4100
C_6F_{14}	8340	3100
C_7F_{16}	8251	3000
c-C_4F_8	10255	3200
HFC-125	3644	30
HFC-134a	1446	14
HFC-152a	160	1.6
HFC-227ea	3390	36
HFC-23	13422	228
HFC-236fa	8217	213
HFC-245fa	933	7.9
HFC-365mfc	853	8.7
HFC-43-10-mee	1591	17
SF6	25016	1258

A.B.11. Methodology adopted for assessing the feasibility of mitigation response options

In this report “feasibility” is used as a frame to understand the different factors that influence the deployment of individual mitigation options. This recognises that feasibility can be changed not only by technological and economic interventions but by a broad array of context-dependent influences. The sectoral chapters in the WGIII contribution to the AR6 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 A.B.11). The feasibility of systems-level changes is further addressed in Chapter 3. The assessment recognises that feasibility is malleable and can be enhanced when constraints are removed, and enablers are strengthened.

The sectoral chapters in this report assess to what extent the indicators in Table A.B.11 would be enablers or barriers to implementation using the following scores:

-	The indicator has a negative impact on the feasibility of the option, e.g., 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, e.g., 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

Table: A.B.11 | Feasibility dimensions and indicators to assess the barriers and enablers of implementing mitigation options

Metric	Indicators
Geophysical feasibility	• Physical potential: extent to which there are physical constraints to implement the option • Geophysical resource availability (including geological storage capacity): extent to which resources needed to implement the option are available • Land use: extent to which the implementation of the option would require additional claims on land
Environmental-ecological feasibility	• Air pollution: extent to which emissions of air pollutants (e.g., NH_4, CH_4, fine dust) would be reduced or increased • Toxic waste, ecotoxicity and eutrophication: changes in manure load on soil and ground water or linear consumption going e.g. to renewable feedstock and recycling of wood products and bioplastics instead of steel and plastics • Water quantity and quality: changes in amount of water available for other uses, including groundwater • Biodiversity: changes in area of conserved primary forest, grassland or management that affect biodiversity
Technological feasibility	• Simplicity: is the option technically simple to operate, maintain and integrate • Technology scalability: can the option be scaled up, technically, and will technology costs decrease • 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, and hidden costs • Employment effects and economic growth: decrease or increase in jobs and economic welfare
Socio-cultural feasibility	• Public acceptance: extent to which the public supports the option and changes behaviour accordingly • Effects on health and wellbeing • Distributional effects: effects on equity and justice across groups, regions, and generations, including energy security, water security, food security and poverty
Institutional feasibility	• Political acceptance: extent to which politicians and governments support the option • Institutional capacity and governance, cross-sectoral coordination: capability of institutions to implement and handle the option, to coordinate it with other sectors, and to collaborate with stakeholder and civil society • Legal and administrative capacity: extent to which supportive legal and administrative changes can be achieved

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.

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 temperature goal (e.g., 1.5°C versus 2°C). Synergies and trade-offs may occur between the feasibility dimensions, and between specific mitigation options. Chapter 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. Chapter 5 (demand, services and social aspects of mitigation), Chapter 13 (policies and institutions), Chapter 14 (international collaboration), Chapter 15 (investment and finance) and Chapter 16 (innovations and technology) address technological, economic, socio-cultural and institutional enabling conditions that can enhance the feasibility of options.

Part III: Emissions Data sets

In this section we report on the historical emissions data used in the report (section A.B.12), the sectoral mapping on emissions sources (A.B.12.1), and the methane emissions sources (A.B.12.2).

A.B.12. 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 split of countries and regions.

Our primary data source is the Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al., 2019). 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) energy and emissions estimates. Section 2.2.1 in Chapter 2 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., 2019) 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 Ch2 Section 2.2.1.

A.B.12.1. Mapping of emission sources to sectors

The list below shows how emission sources in EDGAR are mapped to sectors throughout the WGIII AR6. 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 refer to the definitions by the IPCC Task Force on National Greenhouse Gas Inventories (TFI) (IPCC, 2006). EDGAR includes further disaggregated sources in each category, for example, the biomass component of fuel combustion, which marked as “biom.” in the EDGAR description and “…x” in the EDGAR emissions code (conversely, ‘fos.’ indicates the fossil component, where such a distinction is needed).

A.B.12.1.1 Energy Systems (Chapter 6)

Emission Source description in EDGAR	IPCC emissions code in EDGAR	Gases emitted
Public Electricity Generation	1A1a1	CO_2, N_2O, CH_4
Public Combined Heat and Power gen.	1A1a2	CO_2, N_2O, CH_4
Public Heat Plants	1A1a3	CO_2, N_2O, CH_4
Public Electricity Generation (own use)	1A1a4	CO_2, N_2O, CH_4
Electricity Generation (autoproducers)	1A1a5	CO_2, N_2O, CH_4
Combined Heat and Power gen. (autoprod.)	1A1a6	CO_2, N_2O, CH_4
Heat Plants (autoproducers)	1A1a7	CO_2, N_2O, CH_4
Public Electricity Generation (biomass)	1A1ax1	N_2O, CH_4
Public Combined Heat and Power gen. (biom.)	1A1ax2	N_2O, CH_4
Public Heat Plants (biomass)	1A1ax3	N_2O, CH_4
Public Electricity Gen. (own use) (biom.)	1A1ax4	N_2O, CH_4
Electricity Generation (autoproducers) (biom.)	1A1ax5	N2O, CH4
Combined Heat and Power gen. (autopr.) (biom.)	1A1ax6	N_2O, CH_4
Heat Plants (autoproducers) (biomass)	1A1ax7	N_2O, CH_4
Refineries	1A1b	CO_2, N_2O, CH_4
Refineries (biomass)	1A1bx	N_2O, CH_4
Gas works	1A1c3	CO_2, N_2O, CH_4
Other transformation sector (BKB, etc.)	1A1c5	CO_2, N_2O, CH_4
Gas works (biom.)	1A1cx3	N_2O, CH_4
Fuel comb. charcoal production (biom.)	1A1cx4	N_2O, CH_4
Other transf. sector (BKB, etc.) (biom.)	1A1cx5	N_2O, CH_4
Hard coal mining (gross)	1B1a1	CH_4
Methane recovery from coal mining	1B1a1r	CH_4
Abandoned mines	1B1a2	CH_4
Brown coal mining	1B1a3	CH_4
Fuel transformation in gas works	1B1b2	CO_2
Fuel transformation charcoal production	1B1b3x	N_2O, CH_4
Fuel transformation of solid fuels (BKB Plants, coal liquefaction, patent fuel plants)	1B1b4	CO_2
Oil production	1B2a1	CO_2, N_2O, CH_4
Oil production (biom.)	1B2a1x	CH_4
Oil transmission	1B2a2	CO_2, CH_4
Tanker loading	1B2a3-l	CH_4
Tanker oil transport (crude and NGL)	1B2a4-l	CH_4
Transport by oil trucks	1B2a4-t	CO_2, CH_4
Oil refineries (evaporation)	1B2a5(e)	CH_4
Fuel transformation from liquid fuels (petrochemical plants)	1B2a6	CH_4
Gas production	1B2b1	CH_4
Gas transmission	1B2b3	CH_4
Gas distribution	1B2b4	CH_4

Fuel transformation of gaseous fuels (GTL, Blend, (re-)gasif./Liquef., NSF)	1B2b5	CO_2
Venting and flaring during oil and gas production	1B2c	CO_2, N_2O, CH_4
Electrical Equipment Use (incl. site inst.)	2F8b	Fgas
Coal fires (underground)	7A1	CO_2, N_2O, CH_4
Oil fires (Kuwait)	7A2	CO_2, N_2O, CH_4
Indirect N_2O from NOx emitted in cat. 1A	7B1	N_2O
Indirect N_2O from NH_3 emitted in cat. 1A	7C1	N_2O

A.B.12.1.2 AFOLU (Chapter 7)

Emission Source description in EDGAR	IPCC emissions code in EDGAR	Emission source category
Agriculture and forestry (fos.)	1A4c1	CO_2, N_2O, CH_4
Agriculture and forestry (biom.)	1A4c1x	N_2O, CH_4
Off-road machinery: agric./for. (diesel)	1A4c2	CO_2, N_2O, CH_4
Fishing (fos.)	1A4c3	CO_2, N_2O, CH_4
Fishing (biom.)	1A4c3x	N_2O, CH_4
Non-specified other (fos.)	1A4d	CO_2, N_2O, CH_4
Non-specified other (biom.)	1A4dx	N_2O, CH_4
Dairy cattle	4A1-d	CH_4
Non-dairy cattle	4A1-n	CH_4
Buffalo	4A2	CH_4
Sheep	4A3	CH_4
Goats	4A4	CH_4
Camels and Lamas	4A5	CH_4
Horses	4A6	CH_4
Mules and asses	4A7	CH_4
Swine	4A8	CH_4
Manure Man.: Dairy Cattle (confined)	4B1-d	N_2O, CH_4
Manure Man.: Non-Dairy Cattle (confined)	4B1-n	N_2O, CH_4
Manure Man.: Buffalo (confined)	4B2	N_2O, CH_4
Manure Man.: Sheep (confined)	4B3	N_2O, CH_4
Manure Man.: Goats (confined)	4B4	N_2O, CH_4
Manure Man.: Camels and llamas (confined)	4B5	N_2O, CH_4
Manure Man.: Horses (confined)	4B6	N_2O, CH_4
Manure Man.: Mules and asses (confined)	4B7	N_2O, CH_4
Manure Man.: Swine (confined)	4B8	N_2O, CH_4
Manure Man.: Poultry (confined)	4B9	N_2O, CH_4
Rice cultivation	4C	CH_4
Synthetic Fertilizers	4D11	N_2O
Animal Manure Applied to Soils	4D12	N_2O
Direct soil emissions	4D13	N_2O
Crop Residue	4D14	N_2O
Cultivation of Histosols	4D15	N_2O
Pasture, Range and Paddock Manure	4D2	N_2O
Indirect N_2O: Atm. Depos. - agricult. (4D)	4D3a	N_2O

Indirect N_2O: Leaching and Run-Off - agri.	4D3b	N_2O
CO_2 from urea application	4D4a	CO_2
CO_2 from agricultural lime application	4D4b	CO_2
Savannah fires	4E	N_2O, CH_4
Field burning of agric. res.: cereals	4F1	N_2O, CH_4
Field burning of agric. res.: pulses	4F2	N_2O, CH_4
Field burning of agric. res.: tuber and roots	4F3	N_2O, CH_4
Field burning of agric. res.: sugar cane	4F4	N_2O, CH_4
Field burning of agric. res.: other	4F5	N_2O, CH_4
Agriculture and forestry (fos.)	1A4c1	CO_2, N_2O, CH_4

A.B.12.1.3 Buildings (Chapter 9)

Emission Source description in EDGAR	IPCC emissions code in EDGAR	Emission source category
Commercial and public services (fos.)	1A4a	CO_2, N_2O, CH_4
Commercial and public services (biom.)	1A4ax	N_2O, CH_4
Residential (fos.)	1A4b	CO_2, N_2O, CH_4
Residential (biom.)	1A4bx	N_2O, CH_4
Fire Extinguishers	2F3	Fgas
Aerosols	2F4	Fgas
Adiabatic prop.: shoes and others	2F9a	Fgas
Soundproof windows	2F9c	Fgas

A.B.12.1.4 Transport (Chapter 10)

Emission Source description in EDGAR	IPCC emissions code in EDGAR	Emission source category
Domestic air transport	1A3a	CO_2, N_2O, CH_4
Road transport (incl. evap.) (foss.)	1A3b	CO_2, N_2O, CH_4
Road transport (incl. evap.) (biom.)	1A3bx	N_2O, CH_4
Non-road transport (rail, etc.) (fos.)	1A3c	CO_2, N_2O, CH_4
Non-road transport (rail, etc.)(biom.)	1A3cx	N_2O, CH_4
Inland shipping (fos.)	1A3d	CO_2, N_2O, CH_4
Inland shipping (biom.)	1A3dx	N_2O, CH_4
Non-road transport (fos.)	1A3e	CO_2, N_2O, CH_4
Non-road transport (biom.)	1A3ex	N_2O, CH_4
International air transport	1C1	CO_2, N_2O, CH_4
International marine transport (bunkers)	1C2	CO_2, N_2O, CH_4
International marine transport (biom.)	1C2x	N_2O, CH_4
Adiabatic prop.: tyres	2F9b	Fgas

A.B.12.1.5 Industry (Chapter 11)

Emission Source description in EDGAR	IPCC emissions code in EDGAR	Emission source category
Fuel combustion coke ovens	1A1c1	CO_2, N_2O, CH_4
Blast furnaces (pig iron prod.)	1A1c2	CO_2, N_2O, CH_4

Iron and steel	1A2a	CO_2, N_2O, CH_4
Iron and steel (biomass)	1A2ax	N_2O, CH_4
Non-ferrous metals	1A2b	CO_2, N_2O, CH_4
Non-ferrous metals (biomass)	1A2bx	N_2O, CH_4
Chemicals	1A2c	CO_2, N_2O, CH_4
Chemicals (biomass)	1A2cx	N_2O, CH_4
Pulp and paper	1A2d	CO_2, N_2O, CH_4
Pulp and paper (biomass)	1A2dx	N_2O, CH_4
Food and tobacco	1A2e	CO_2, N_2O, CH_4
Food and tobacco (biomass)	1A2ex	N_2O, CH_4
Other industries (stationary) (fos.)	1A2f	CO_2, N_2O, CH_4
Off-road machinery: construction (diesel)	1A2f1	CO_2, N_2O, CH_4
Off-road machinery: mining (diesel)	1A2f2	CO_2, N_2O, CH_4
Other industries (stationary) (biom.)	1A2fx	N_2O, CH_4
Off-road machinery: mining (diesel)	1A5b1	CO_2, N_2O, CH_4
Fuel transformation coke ovens	1B1b1	CO_2, CH_4
Cement production	2A1	CO_2
Lime production	2A2	CO_2
Limestone and Dolomite Use	2A3	CO_2
Soda ash production	2A4a	CO_2
Soda ash use	2A4b	CO_2
Glass production	2A7a	CO_2
Ammonia production (gross CO_2)	2B1g	CO_2
CO_2-ammonia stored in urea	2B1s	CO_2
Nitric acid production	2B2	N_2O
Adipic acid production	2B3	N_2O
Silicon carbide production	2B4a	CO_2, CH_4
Calcium carbide production	2B4b	CO_2
Carbon black production	2B5a	CO_2, CH_4
Ethylene production	2B5b	CO_2, CH_4
Styrene production	2B5d	CH_4
Methanol production	2B5e	CO_2, CH_4
Caprolactam production	2B5f	N_2O
Other bulk chemicals production	2B5g	CO_2, CH_4
Urea production	2B5g1	CO_2
Vinyl chloride production	2B5g2	CO_2
Glyoxal production	2B5h1	N_2O
Crude steel production total	2C1a	CO_2
Blast furnaces	2C1b	CO_2
Sinter production	2C1d	CH_4
Ferro Alloy production	2C2	CO_2, CH_4
Aluminium production (primary)	2C3a	CO_2, Fgas
Aluminium production (secondary)	2C3b	CO_2
Magnesium foundries: SF_6 use	2C4a	Fgas
Aluminium foundries: SF_6 use	2C4b	Fgas
Lead production (primary)	2C5lp	CO_2

Magnesium production (primary)	2C5mp	CO_2
Zinc production (primary)	2C5zp	CO_2
Production of halocarbons	2E1	Fgas
Refrigeration and Air Conditioning	2F1a	Fgas
Foam Blowing	2F2	Fgas
F-gas as Solvent	2F5	Fgas
Semiconductor Manufacture	2F7a	Fgas
Flat Panel Display (FPD) Manufacture	2F7b	Fgas
Photo Voltaic (PV) Cell Manufacture	2F7c	Fgas
Electrical Equipment Manufacture	2F8a	Fgas
F-gas/ODP consumption	2F9	Fgas
Accelerators/HEP	2F9d	Fgas
Misc. (AWACS, other military and misc.)	2F9e	Fgas
Unknown SF6 use	2F9f	Fgas
Non-energy use of lubricants/waxes (CO_2)	2G1	CO_2
Other Non-energy use of fuels (CO_2 only)	2G2	CO_2
Solvents in paint	3A	CO_2
Degreasing and dry cleaning	3B	CO_2
Chemical products	3C	CO_2
Other product use	3D	CO_2
Use of N_2O as anaesthesia	3D1	N_2O
Use of N_2O in aerosol spray cans	3D3	N_2O
Managed waste disposal on land	6A1	CH_4
Industrial wastewater	6B1	N_2O, CH_4
Domestic and commercial wastewater	6B2	N_2O, CH_4
Waste incineration - hazardous	6C	CH_4
Waste incineration - biogenic	6Cax	N_2O, CH_4
Waste incineration - uncontrolled MSW burning*	6Cb1	CO_2, N_2O, CH_4
Waste incineration - other non-biogenic	6Cb2	CO_2, N_2O, CH_4
Other waste	6D	N_2O, CH_4
Indirect N_2O from NOx emitted in cat. 2-3	7B2	N_2O

* MSW stands for "Municipal Solid Waste"

A.B.12.2. 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 A.B.12 above). These trends and mitigation opportunities are, in most cases and whenever possible, reported in CO_2eq using IPCC AR6 GWP100 values (section A.B.10) as well as the native unit of gas. 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 A.B.13 below for a comprehensive list.

There are two GWP100 values assigned to methane depending on its source: a GWP100 value of 32 for biogenic methane and fossil methane (combustion), and a higher GWP100 value of 34.75 for fossil methane (fugitive and process). The difference between these two GWP values arises from treatment of the effect of methane conversion into CO_2 during its chemical decay in the atmosphere. The higher GWP 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 GWP 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 (combustion vs fugitive vs process). 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 A.B.12) 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 2006 (Eggleston, et al. 2006) 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 2018 using a GWP100 value of 32 across all related sources results in 11.2 Gt CO_2eq, compared to 11.5 Gt CO_2eq 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 A.B.12 | Summary of methane GWP100 values depending on type and source.

CH_4	GWP100 value
CH_4 (biogenic)	32
CH_4 (fossil - combustion)	32
CH_4 (fossil – fugitive and process)	34.75

1 **Table A.B.13 | Methane Sources and Types**

Sector	Subsector	Sector code	Description	CH_4 type
Energy systems	6.1	1A1a1	Public Electricity Generation	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a2	Public Combined Heat and Power gen.	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a3	Public Heat Plants	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a4	Public Electricity Generation (own use)	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a5	Electricity Generation (autoproducers)	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a6	Combined Heat and Power gen. (autoprod.)	CH_4 Fossil (Combustion)
Energy systems	6.1	1A1a7	Heat Plants (autoproducers)	CH_4 Fossil (Combustion)
Energy systems	6.2	1A1ax1	Public Electricity Generation (biomass)	CH_4 Biogenic
Energy systems	6.2	1A1ax2	Public Combined Heat and Power gen. (biom.)	CH_4 Biogenic
Energy systems	6.2	1A1ax3	Public Heat Plants (biomass)	CH_4 Biogenic
Energy systems	6.2	1A1ax4	Public Electricity Gen. (own use) (biom.)	CH_4 Biogenic
Energy systems	6.2	1A1ax5	Electricity Generation (autoproducers) (biom.)	CH_4 Biogenic
Energy systems	6.2	1A1ax6	Combined Heat and Power gen. (autopr.) (biom.)	CH_4 Biogenic
Energy systems	6.2	1A1ax7	Heat Plants (autoproducers) (biomass)	CH_4 Biogenic
Energy systems	6.2	1A1bx	Refineries (biomass)	CH_4 Biogenic
Energy systems	6.2	1A1cx3	Gas works (biom.)	CH_4 Biogenic
Energy systems	6.2	1A1cx4	Fuel comb. charcoal production (biom.)	CH_4 Biogenic

Energy systems	6.2	1A1cx5	Other transf. sector (BKB, etc.) (biom.)	CH_4 Biogenic
Energy systems	6.2	1B1b3x	Fuel transformation charcoal production	CH_4 Biogenic
Energy systems	6.2	1B2a1x	Oil production (biom.)	CH_4 Biogenic
Energy systems	6.3	1A1b	Refineries	CH_4 Fossil (Combustion)
Energy systems	6.4	1B1a1	Hard coal mining (gross)	CH_4 Fossil (Fugitive)
Energy systems	6.4	1B1a1r	Methane recovery from coal mining	CH_4 Fossil (Fugitive)
Energy systems	6.4	1B1a2	Abandoned mines	CH_4 Fossil (Fugitive)
Energy systems	6.4	1B1a3	Brown coal mining	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a1	Oil production	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a2	Oil transmission	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a3-l	Tanker loading	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a4-l	Tanker oil transport (crude and NGL)	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a4-t	Transport by oil trucks	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2a5(e)	Oil refineries (evaporation)	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2b1	Gas production	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2b3	Gas transmission	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2b4	Gas distribution	CH_4 Fossil (Fugitive)
Energy systems	6.5	1B2c	Venting and flaring during oil and gas production	CH_4 Fossil (Fugitive)
Energy systems	6.6	1A1c3	Gas works	CH_4 Fossil (Combustion)

Energy systems	6.6	1A1c5	Other transformation sector (BKB, etc.)	CH_4 Fossil (Combustion)
Energy systems	6.6	7A1	Coal fires (underground)	CH_4 Fossil (Combustion)
Energy systems	6.6	7A2	Oil fires (Kuwait)	CH_4 Fossil (Combustion)
AFOLU	7.1	4A1-d	Dairy cattle	CH_4 Biogenic
AFOLU	7.1	4A1-n	Non-dairy cattle	CH_4 Biogenic
AFOLU	7.1	4A2	Buffalo	CH_4 Biogenic
AFOLU	7.1	4A3	Sheep	CH_4 Biogenic
AFOLU	7.1	4A4	Goats	CH_4 Biogenic
AFOLU	7.1	4A5	Camels and Lamas	CH_4 Biogenic
AFOLU	7.1	4A6	Horses	CH_4 Biogenic
AFOLU	7.1	4A7	Mules and asses	CH_4 Biogenic
AFOLU	7.1	4A8	Swine	CH_4 Biogenic
AFOLU	7.2	4B1-d	Manure Man.: Dairy Cattle (confined)	CH_4 Biogenic
AFOLU	7.2	4B1-n	Manure Man.: Non-Dairy Cattle (confined)	CH_4 Biogenic
AFOLU	7.2	4B2	Manure Man.: Buffalo (confined)	CH_4 Biogenic
AFOLU	7.2	4B3	Manure Man.: Sheep (confined)	CH_4 Biogenic
AFOLU	7.2	4B4	Manure Man.: Goats (confined)	CH_4 Biogenic
AFOLU	7.2	4B5	Manure Man.: Camels and llamas (confined)	CH_4 Biogenic
AFOLU	7.2	4B6	Manure Man.: Horses (confined)	CH_4 Biogenic
AFOLU	7.2	4B7	Manure Man.: Mules and asses (confined)	CH_4 Biogenic
AFOLU	7.2	4B8	Manure Man.: Swine (confined)	CH_4 Biogenic
AFOLU	7.2	4B9	Manure Man.: Poultry (confined)	CH_4 Biogenic
AFOLU	7.3	4C	Rice cultivation	CH_4 Biogenic
AFOLU	7.6	4E	Savannah fires	CH_4 Biogenic
AFOLU	7.6	4F1	Field burning of agric. res.: cereals	CH_4 Biogenic

AFOLU	7.6	4F2	Field burning of agric. res.: pulses	CH_4 Biogenic
AFOLU	7.6	4F3	Field burning of agric. res.: tuber and roots	CH_4 Biogenic
AFOLU	7.6	4F4	Field burning of agric. res.: sugar cane	CH_4 Biogenic
AFOLU	7.6	4F5	Field burning of agric. res.: other	CH_4 Biogenic
AFOLU	7.9	1A4c1	Agriculture and forestry (fos.)	CH_4 Fossil (Combustion)
AFOLU	7.9	1A4c1x	Agriculture and forestry (biom.)	CH_4 Biogenic
AFOLU	7.9	1A4c2	Off-road machinery: agric./for. (diesel)	CH_4 Fossil (Combustion)
AFOLU	7.9	1A4c3	Fishing (fos.)	CH_4 Fossil (Combustion)
AFOLU	7.9	1A4c3x	Fishing (biom.)	CH_4 Biogenic
AFOLU	7.9	1A4d	Non-specified other (fos.)	CH_4 Fossil (Combustion)
AFOLU	7.9	1A4dx	Non-specified other (biom.)	CH_4 Biogenic
Buildings	9.1	1A4a	Commercial and public services (fos.)	CH_4 Fossil (Combustion)
Buildings	9.1	1A4ax	Commercial and public services (biom.)	CH_4 Biogenic
Buildings	9.2	1A4b	Residential (fos.)	CH_4 Fossil (Combustion)
Buildings	9.2	1A4bx	Residential (biom.)	CH_4 Biogenic
Transport	10.1	1A3a	Domestic air transport	CH_4 Fossil (Combustion)
Transport	10.2	1A3b	Road transport (incl. evap.) (foss.)	CH_4 Fossil (Combustion)
Transport	10.2	1A3bx	Road transport (incl. evap.) (biom.)	CH_4 Biogenic
Transport	10.3	1A3c	Non-road transport (rail, etc.) (fos.)	CH_4 Fossil (Combustion)
Transport	10.3	1A3cx	Non-road transport (rail, etc.)(biom.)	CH_4 Biogenic
Transport	10.4	1A3d	Inland shipping (fos.)	CH_4 Fossil (Combustion)

Transport	10.4	1A3dx	Inland shipping (biom.)	CH_4 Biogenic
Transport	10.5	1A3e	Non-road transport (fos.)	CH_4 Fossil (Combustion)
Transport	10.5	1A3ex	Non-road transport (biom.)	CH_4 Biogenic
Transport	10.6	1C1	International air transport	CH_4 Fossil (Combustion)
Transport	10.7	1C2	International marine transport (bunkers)	CH_4 Fossil (Combustion)
Transport	10.7	1C2x	International marine transport (biom.)	CH_4 Biogenic
Industry	11.1	1A1c1	Fuel combustion coke ovens	CH_4 Fossil (Combustion)
Industry	11.1	1A1c2	Blast furnaces (pig iron prod.)	CH_4 Fossil (Combustion)
Industry	11.1	1A2a	Iron and steel	CH_4 Fossil (Combustion)
Industry	11.1	1A2ax	Iron and steel (biomass)	CH_4 Biogenic
Industry	11.1	1A2b	Non-ferrous metals	CH_4 Fossil (Combustion)
Industry	11.1	1A2bx	Non-ferrous metals (biomass)	CH_4 Biogenic
Industry	11.1	1B1b1	Fuel transformation coke ovens	CH_4 Fossil (Fugitive)
Industry	11.1	2C1d	Sinter production	CH_4 Fossil (Process)
Industry	11.1	2C2	Ferro Alloy production	CH_4 Fossil (Process)
Industry	11.2	1A2c	Chemicals	CH_4 Fossil (Combustion)
Industry	11.2	1A2cx	Chemicals (biomass)	CH_4 Biogenic
Industry	11.2	2B4a	Silicon carbide production	CH_4 Fossil (Process)
Industry	11.2	2B5a	Carbon black production	CH_4 Fossil (Process)
Industry	11.2	2B5b	Ethylene production	CH_4 Fossil (Process)
Industry	11.2	2B5d	Styrene production	CH_4 Fossil (Process)
Industry	11.2	2B5e	Methanol production	CH_4 Fossil (Process)
Industry	11.2	2B5g	Other bulk chemicals production	CH_4 Fossil (Process)
Industry	11.4	6A1	Managed waste disposal on land	CH_4(Biogenic)
Industry	11.4	6B1	Industrial wastewater	CH_4(Biogenic)

Industry	11.4	6B2	Domestic and commercial wastewater	CH_4(Biogenic)
Industry	11.4	6C	Waste incineration - hazardous	CH_4 Fossil (Combustion)
Industry	11.4	6Cax	Waste incineration - Biogenic	CH_4(Biogenic)
Industry	11.4	6Cb1	Waste incineration - uncontrolled MSW burning	CH_4 Fossil (Combustion) /Biogenic
Industry	11.4	6Cb2	Waste incineration - other non-Biogenic	CH_4 Fossil (Combustion)
Industry	11.4	6D	Other waste	CH_4 Fossil (Process/Fugitive) /Biogenic
Industry	11.5	1A2d	Pulp and paper	CH_4 Fossil (Combustion)
Industry	11.5	1A2dx	Pulp and paper (biomass)	CH_4 Biogenic
Industry	11.5	1A2e	Food and tobacco	CH_4 Fossil (Combustion)
Industry	11.5	1A2ex	Food and tobacco (biomass)	CH_4 Biogenic
Industry	11.5	1A2f	Other industries (stationary) (fos.)	CH_4 Fossil (Combustion)
Industry	11.5	1A2f1	Off-road machinery: construction (diesel)	CH_4 Fossil (Combustion)
Industry	11.5	1A2f2	Off-road machinery: mining (diesel)	CH_4 Fossil (Combustion)
Industry	11.5	1A2fx	Other industries (stationary) (biom.)	CH_4 Biogenic
Industry	11.5	1A5b1	Off-road machinery: mining (diesel)	CH_4 Fossil (Combustion)

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