# Technical document – Approach and methods for estimating emission levels resulting from the implementation of nationally determined contributions and long-term visions, strategies and targets

## Abbreviations and acronyms

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| AR | Assessment Report of the Intergovernmental Panel on Climate Change |
| $CH_4$ | methane |
| $CO_2$ | carbon dioxide |
| $CO_2$ eq | carbon dioxide equivalent |
| GHG | greenhouse gas |
| GWP | global warming potential |
| GWP-100 | global warning potential values over a 100-year time-horizon |
| IEA | International Energy Agency |
| IMO | International Maritime Organization |
| INDC | intended nationally determined contribution |
| IPCC | Intergovernmental Panel on Climate Change |
| LT-LEDS | long-term low-emission development strategy(ies) |
| LULUCF | land use, land-use change and forestry |
| $N_2O$ | nitrous oxide |
| NDC | nationally determined contribution |
| SR1.5 | Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5 °C |
| SSP | Shared Socioeconomic Pathway |
| WG | Working Group of the Intergovernmental Panel on Climate Change |

## A. Approach[1]

1. The estimated total GHG emission levels of Parties in 2025, 2030 and 2050, taking into account implementation of their latest NDCs, including new or updated NDCs, and their LT-LEDS submitted as at 23 September 2022, are discussed in this report in relation to:

(a) The estimated levels of emissions for those years according to Parties' INDCs submitted as at 4 April 2016 and NDCs submitted as at 12 October 2021;[2]

(b) Historical levels of emissions for 1990, 2000, 2005, 2010, 2015 and 2019;

(c) The global emission levels corresponding to the AR6 WG III[3] scenarios consistent with limiting the global average temperature rise to likely below 2 °C (with over 67 per cent likelihood) above pre-industrial levels;[4]

(d) The global emission levels corresponding to the AR6 WG III scenarios consistent with holding the global average temperature rise to below 1.5 °C above pre-industrial levels by 2100 (with over 50 per cent likelihood) with no or limited overshoot during the twenty-first century;

(e) Per capita emission levels calculated on the basis of the most recent United Nations population data, historical estimates and the medium-variant projection.

2. For the purpose of this report:

(a) The information communicated by Parties in their latest NDCs, including new or updated NDCs, and their LT-LEDS was considered. The use of any additional information is described in chapter B below;

(b) The synthesis is focused on the targets, sectors and gases covered by the NDCs. GHG emissions that do not fall within the scope of the NDCs were assessed for Parties taken together as a group, as explained in paragraph 4(c) below;

(c) Information is presented for the Parties taken together as a group.

3. It was assumed that Parties will achieve the conditional and unconditional emission levels projected in their NDCs; no assumptions were made on the likelihood or implications of NDCs not being fully implemented or being overachieved.

## B. Methods

4. For the purpose of this report:

(a) The total emission levels of Parties in 2025, 2030 and 2050 resulting from implementation of their latest NDCs, including new or updated NDCs, and their LT-LEDS were estimated;

(b) The total emission levels of countries that are not Parties to the Paris Agreement were estimated for 2025 and 2030 using their INDCs, if available, or a low SSP reference scenario scaled down to the country level;[5]

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[1] Unless otherwise noted, the approach and methods described in document FCCC/PA/CMA/2021/8/Add.3, chap. III, were applied.

[2] As presented in the updated NDC synthesis report 2021 (FCCC/PA/CMA/2021/8/Rev.1).

[3] IPCC. 2022. Summary for Policymakers. *In*: PR Shukla, J Skea, R Slade, et al. (eds.). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg3/.

[4] Without giving precedence to the definition of 'pre-industrial', a proxy for pre-industrial times (before approximately 1750) has been chosen here to be the period 1850–1900, as this report follows the proxy used in the AR6 WG I contribution for pre-industrial reference levels. The best estimate by the IPCC for the temperature difference between 1750 and the 1850–1900 period is +0.1 °C (–0.1 to +0.3 °C) with an anthropogenic component of between 0.0 °C and 0.2 °C (see cross-chapter box 1.2 in the AR6 WG I contribution).

[5] As footnote 5 below.

(c) The levels of the emissions not covered by the NDCs in 2025, 2030 and 2050 were estimated using data on international bunker emissions and IPCC reference scenarios.[6]

5. The total GHG emission levels in 2025, 2030 and 2050 resulting from implementation of the latest NDCs, including new or updated NDCs, and LT-LEDS were estimated by summing the expected levels of emissions for the same year communicated in each NDC. The resulting emission levels are expressed as average values and minimum–maximum ranges owing to the uncertainties underlying the aggregation and the ranges and conditions expressed in the NDCs.

6. The estimates of total GHG emission levels in 2025 and 2030 are provided for:

(a) Full implementation of both the unconditional and the conditional elements of the NDCs;[7]

(b) Implementation of only the unconditional elements of the NDCs. For Parties that have conditional targets only, 'business as usual' reference scenarios were assumed;

(c) Implementation of the conditional elements of the NDCs, with Parties assumed to fully implement the unconditional and, if any, conditional elements of their NDCs.

7. Unless otherwise noted, the discussion of total GHG emission levels resulting from implementation of the NDCs or LT-LEDS is premised on the average of the implementation of either the unconditional or the unconditional and conditional elements of the NDCs, as described in paragraph 6(b) above.

8. Where a Party included in its NDC or LT-LEDS an expected absolute level of emissions for 2025, 2030 or later, that figure was used in the calculation of the total emission level.[8] Otherwise, the method used for quantifying the estimated level of emissions in the target year (2025, 2030 or 2050) depended on the type of target:

(a) For absolute emission reduction targets relative to a base year, the method involved subtracting the percentage emission reduction or limitation specified by the Party for the target year from the base-year level of the emissions covered by the NDC;

(b) For emission reductions below a 'business as usual' or other reference level, the method involved subtracting the emissions corresponding to the percentage reduction specified by the Party from the stated level of emissions in the target year;

(c) Cumulative annual emission reductions were assumed to increase linearly, except where cumulative reductions both up until 2030 and beyond were stated. In the latter case, reductions in 2030–2050 were assumed as a constant reduction over the stated target period. If both cumulative and absolute target levels for a specific year were specified, the latter figure was used;

(d) Net zero emission, climate-neutrality and carbon-neutrality targets were assumed to cover the same sectors and gases as the Party's NDC targets for 2030, unless otherwise noted in the NDC or LT-LEDS, and the following assumptions were applied for specific target types:

(i) For net zero emission targets, the assumption that the sum, weighted by GWP-100 values from the AR6, of the covered emissions in the target year equals zero;

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[6] Such estimates are based on emission figures for 2025, 2030 and 2050 for the countries, sectors and gases not covered by the NDCs derived from scenarios assessed by the IPCC in the SSP scenario database (available at https://tntcat.iiasa.ac.at/SspDb/dsd). The country-level estimates for the low SSP1 reference scenario follow Grutsch J, Jeffery ML, Günther A, et al. 2020. Country resolved combined emission and socio-economic pathways based on the RCP and SSP scenarios (Version 1.0). *Zenodo*. Available at http://doi.org/10.5281/zenodo.3638137. The SSP1 reference scenario was developed using the Integrated Model to Assess the Greenhouse Effect.

[7] Where Parties stated ranges of emissions for conditional or unconditional targets, for the purpose of calculating the total sum of emissions, the ranges were assumed to cover the lower-emission end of the range that assumes full implementation of the NDCs, including conditional elements, to the higher-emission end of the unconditional range.

[8] If necessary, a conversion was applied using GWP-100 values from the AR6.

(ii) For carbon-neutrality targets or net zero carbon emission targets, the assumption that their implementation covers only $CO_2$ emissions and that non-$CO_2$ emissions are kept constant at their 2030 level by the target year;

(iii) For climate-neutrality targets, the assumption that they are implemented as net zero emission targets;

(iv) For long-term targets stated for 2040, the assumption that they are to be maintained up until at least 2050, and for long-term targets stated for 2060 or 2070, the assumption that they are to be proportionally achieved by 2050. In the case of a stated target beyond 2050, the 2050 emission level is estimated as the 2030 emission level plus two thirds (or half) of the emission difference between the 2060 (2070) and 2030 emission levels;

(e) For Parties that communicated a combination of any of these targets, resulting in some cases in potential overlaps between covered sectors and/or gases, expected levels of emissions in 2025, 2030 or 2050 were estimated individually for each target, while for Parties that stated ranges of targets, both the upper and the lower end of the ranges were used to inform the range of global aggregate emission levels;

(f) For other types of targets, including in relation to mitigation co-benefits of adaptation actions and policies and measures, the effects were not quantified in this report unless estimates of resulting emission levels in 2025, 2030 or 2050 were provided in the NDCs or LT-LEDS.

9. If a Party did not indicate a target for 2025, the level of emissions in 2025 was estimated using linear interpolation between the latest historical emission level available and the estimated level of emissions in 2030 resulting from implementation of its NDC.

10. If a Party did not indicate a target for 2030, the emissions trajectory between the latest historical emission level available and 2025 was assumed to continue at the same rate after 2025.

11. The targets communicated by Parties in their latest NDCs, including new or updated NDCs, and LT-LEDs were used in the estimation of emission levels for this report, but that information was complemented, as necessary, by data contained in the latest GHG inventories, national communications, biennial update reports and biennial reports, and any remaining data gaps were filled using scientific global data sets.[9]

12. Given the temporary dip in mainly energy-related emissions in 2020 due to the coronavirus disease 2019 pandemic, the method used for this report extended Party-reported data for 2020 with growth rates from external data sources[10] up until 2021. The reason for doing so was to avoid a low bias in post-2020 emissions, given the scientific literature estimates that suggest a 2021 rebound in emissions.

13. In order to quantify the difference in estimated emissions since the INDCs, emissions for the covered sectors and gases for all Parties were complemented by information on non-covered sectors and gases. Similarly, non-covered sectors and gases were added at the total level to the sum of covered gases and sectors for the latest NDCs, including new or updated

[9] To ensure consistent aggregation of emissions, a gas-by-gas data basis was used to perform conversions from different metrics, such as GWP values from the AR2 or AR5 into GWP values from the AR6, which were used consistently for the aggregation presented in this report. Therefore, in some cases, it was necessary to use complementary data sets for estimating the total level of emissions associated with implementation of the NDCs. The primary complementary sources of gas-by-gas and sectoral data on the emissions of Parties were composite databases, including official submissions under the UNFCCC (such as GHG inventory submissions), with data gaps filled using sources such as the Food and Agriculture Organization of the United Nations and the Emission Database for Global Atmospheric Research.

[10] The 2020 to 2021 growth rates of $CO_2$ emissions related to fossil fuel burning were sourced from the BP Statistical Review of World Energy (available at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html) and those of cement-related $CO_2$ emissions from the September 2022 update of Andrew (2019) (available at https://zenodo.org/record/7081360#.Y2NP0OxBzgc). All other emissions were extrapolated from 2020 to 2021 using a linear regression over the preceding 15 years.

NDCs. Also, the INDCs were assessed using the same set of updated reported historical emission data as the new or updated NDCs, unless the INDCs referred to specific absolute emission or reference levels, including in GHG inventory reports, in which case those were used.

14. The long-term strategies were quantified as stated in the latest NDCs, including new or updated NDCs, or as stated in the long-term strategies officially reported[11] by Parties.

15. Total global GHG emissions in 2019 were estimated by summing the GHG emission data for individual Parties contained in their latest GHG inventories, national communications and biennial update reports, complemented by other data from global data sets to address any remaining data gaps.[12] Since emissions from international transport were not included in the sum of emissions for Parties with new or updated NDCs, but in the global totals, historical $CO_2$ emissions related to aviation and GHG emissions related to maritime transport were used to complement country data to arrive at the global total emission estimate.

16. Regarding the use of international market-based mechanisms, it was assumed that any international offset will lead to additional emission reductions in other countries. In other words, it was assumed that emission reductions arising from the implementation of one NDC are not double counted when implementing another.

17. The analysis took into account the specific GWP values that Parties indicated, namely GWP-100 values from the AR2, AR4 or AR5. GWP-100 values from the AR6 were used to sum the emissions covered in the NDCs. Where necessary, summed emissions were converted using those GWP values on the basis of Parties' historical $CO_2$, $CH_4$, $N_2O$ and other GHG emissions.

18. To facilitate comparison of projected and historical GHG emission estimates calculated using GWP-100 values from the AR6, AR5 and AR4, the total emission levels without LULUCF, calculated using the different GWP values, are provided in the table below.

**Estimates of historical emissions in 2010 and 2019 and projected emissions for 2025 and 2030 calculated using different global warming potential values, Gt $CO_2$ eq**

| | | *GWP-100 AR6* | *GWP-100 AR5* | *GWP-100 AR4* |
|---|---|---|---|---|
| 2010 | Historical | 47.4 | 47.2 | 46.5 |
| 2019 | Historical | 52.6 | 52.3 | 51.5 |
| 2025 | NDC implementation, unconditional elements | 54.2 (53.5–55) | 53.9 (53.1–54.7) | 53.2 (52.4–54) |
| 2025 | Full NDC implementation, including conditional elements | 52.6 (51.8–53.5) | 52.3 (51.4–53.2) | 51.6 (50.7–52.5) |
| 2030 | NDC implementation, unconditional elements | 54.2 (52.7–55.7) | 53.8 (52.3–55.3) | 53.1 (51.6–54.6) |
| 2030 | Full NDC implementation, including conditional elements | 50.7 (49.1–52.2) | 50.3 (48.8–51.8) | 49.6 (48.1–51.2) |

## C. Key methodological challenges and approaches to addressing them

19. A number of uncertainties and challenges linked to target specification and data availability and quality are involved in the approaches and methods applied in the analysis.

[11] See https://unfccc.int/process/the-paris-agreement/long-term-strategies.

[12] To fill sectoral and gas-by-gas data gaps, growth rates from international scientific databases with global coverage were used, as compiled in Gütschow J, M. Pflüger, A. Gùnther, R. Gieseke 2022. The PRIMAP-hist national historical emissions time series (1750-2021) v2.4. *Zenodo*. Available at https://zenodo.org/record/7179775#.Y2NPr-xBzgd.

20. One key challenge relates to the different ways in which Parties expressed their NDC targets in terms of time frame, reference year, and sectors and gases covered. Compared with those in the INDCs, the targets in the new or updated NDCs were generally more clearly defined in quantitative terms, with substantially fewer targets expressed in terms of emission and gross domestic product ratios (intensity targets), reductions below unquantified baselines, or policies and measures. A larger share of targets was communicated relative to a historical base year or quantified future reference level in the new or updated NDCs. Also, other types of targets were communicated that present fewer quantification challenges, such as targets specified in terms of absolute future emission levels, cumulative emission budgets and net zero emissions.

21. Further challenges relate to the methodologies used for estimating and projecting GHG emissions and to the quality, clarity and completeness of the data used, including missing information on metrics, such as which GWP values were applied (although more Parties specified the chosen GWP values in their new or updated NDCs); lack of gas-by-gas emission data for summing emissions using consistent metrics; missing or incomplete data on the 'business as usual' or other reference scenario; lack of clarity on approaches to LULUCF accounting; missing information in relation to the application of conditions in the target year; and lack of information on the use of international market-based mechanisms and how double counting was avoided.

22. To address the challenges, the following approaches were applied consistently:

(a) Uncertainties arising from the different ways of expressing targets were addressed by applying the method described in paragraph 8 above;

(b) The synthesis was based on data in the latest NDCs, including new or updated NDCs, and LT-LEDS, as noted in paragraph 5 above, and challenges related to missing data were addressed as described in paragraphs 9–15 above;

(c) Differences in the coverage of sectors and gases were addressed by limiting the Party-level analysis to the GHG emissions covered by the NDCs.

23. Uncertainties linked to conditions specified by Parties in their NDCs were addressed by separately estimating unconditional and conditional, and only unconditional, emission reduction levels and expressing the result as a range. Also, any uncertainties in relation to unconditional elements of the NDCs or any ranges of conditional reductions provided were taken into account as separate ranges. These ranges were used in estimating the overall ranges of projected emission levels resulting from implementation of the unconditional elements of NDCs, as well as the effect of the implementation of both unconditional and conditional NDC elements (see para. 6 above).

24. A major area of uncertainty relates to the approaches used for estimating, projecting and accounting for LULUCF emissions and removals. The results presented in this report are subject to the high sensitivity of the methods used for estimating global emissions in terms of how emissions and removals from the LULUCF sector were considered. For example, some Parties intend to follow specific LULUCF accounting rules, while others intend to pursue a full carbon accounting approach (i.e. to include LULUCF net emissions or removals in the same way as emissions from any other sector).[13]

25. For this report, the divergent treatments of the LULUCF sector were taken into account in estimating the total emission levels. For example, an approach using a relative target below a historical base-year level was applied to estimate the total national emissions including LULUCF if the Party stated its intention to account for LULUCF as for any other sector. To the extent quantifiable with the available data sources, exceptions were taken into account; for example, reported wildfire-related (and approximate estimates for insect-related) emissions were subtracted for the base year if emissions related to natural disturbances were intended not to be counted up until 2025 or 2030. In the absence of other methods for estimating LULUCF-related accounting for some Parties, a (discounted) continuation of credits or debits from the first commitment period of the Kyoto Protocol was assumed, where

[13] A few Parties specified in their NDCs how natural disturbances and harvested wood products are to be accounted for.

applicable. Where available, reported projections 'with existing measures' formed the basis for estimating future LULUCF emissions and removals, unless the Party provided LULUCF projections in its NDC. Alternatively, the latest available historical data points were assumed to remain constant or, where appropriate, a range of constant and projected LULUCF projections was assumed to reflect the inherent uncertainty of the quantification. Following the target quantification for the individual Parties including LULUCF, the implied emissions without LULUCF for the Parties were derived. Total emissions for groups of Parties are provided in this report without emissions and removals from LULUCF, whereas LULUCF emissions are included in global totals pursuant to the approach described in paragraph 27 below.

26. There is a difference in definition between the estimation of anthropogenic GHG emissions and removals from the LULUCF sector under the UNFCCC and the estimation of emissions related to land-use change as part of the global emission estimates of the IPCC (see figure 5.5 in chap. 5 of the AR6 WG I contribution[14]) and the scenarios in either the SR1.5[15] or the AR6 WG III[16] scenario databases. To enable comparison between estimated total emission levels and estimates from the two above-mentioned IPCC scenario databases in this report, the underlying calculations for estimating total emissions for 2025 and 2030 take into account LULUCF emission and removal estimates provided by Parties – but global LULUCF emissions are harmonized towards those in the SSP illustrative scenarios. The main difference between LULUCF emission data reported by Parties and the anthropogenic net emissions from land use that form the basis of the emissions scenarios in the IPCC databases is the treatment of indirectly anthropogenically induced $CO_2$ sinks on managed land.[17] In order to estimate total emissions for this report consistently with the global emission estimates of the ARs, global aggregate emissions have been adjusted for this indirectly induced $CO_2$ sink.[18] In the ARs and the derived milestones of 2030 emissions, net zero timing and remaining carbon budgets, only directly induced anthropogenic sinks are included in the anthropogenic emission estimates and indirectly induced sinks via $CO_2$ fertilization are considered part of the natural carbon cycle response. This methodological step enables the total emission estimates presented in this report to be comparable with those of the ARs.

27. According to the INDCs submitted as at 4 April 2016, the change in the total LULUCF emissions and projections is within the range of the change in land-use change emissions from current levels up until 2025 and 2030 presented in the AR5 reference scenarios.[19] Likewise, the resulting net anthropogenic LULUCF emissions are within the wide range of scientific estimates (see figure 5.5 in chap. 5 of the AR6 WG I contribution). This qualitatively supports the need to maintain the approach described in paragraph 26 above to presenting the global emission estimates in this report in order to maintain consistency with the global emissions scenarios assessed by the IPCC.

28. Emissions from international aviation and maritime transport are not considered in national emissions inventories. These 'bunker' emissions must be added to the aggregated Parties' emission time series in order to obtain global emissions that are comparable with the emissions scenarios assessed by the IPCC. For this report, estimates of $CO_2$ emissions from aviation bunkers are taken from IEA statistics,[20] with a linear extension of emissions in 2019 (619.2 Mt $CO_2$) to 2020 (295.4 Mt $CO_2$). The post-2020 carbon-neutral growth target of the

[14] IPCC. 2021. Summary for Policymakers. *In*: V Masson-Delmotte, P Zhai, A Pirani, et al. (eds.). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg1/.

[15] Available at https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/.

[16] Available at https://data.ece.iiasa.ac.at/ar6/.

[17] See Grassi G, Stehfest E, Rogelj J, et al. 2021. Critical adjustment of land mitigation pathways for assessing countries' climate progress. *Nature Climate Change*. 11(5): pp.425–434. Available at https://www.nature.com/articles/s41558-021-01033-6.

[18] Specifically, the indirectly induced $CO_2$ sinks according to the SSP1-1.9 scenario, as provided in supplementary table 8 in Grassi et al. (2021) (see footnote 13 above).

[19] See https://unfccc.int/files/focus/indc_portal/application/pdf/technical_annex_-_synthesis_report.pdf, chap. E.

[20] IEA data on $CO_2$ emissions from fuel combustion (available at http://dx.doi.org/10.1787/co2-data-en).

sector[21] is assumed to result in emissions being at the same level in 2025 and 2030 as in 2019. For marine bunkers, $CO_2$, $CH_4$ and $N_2O$ emissions in 2012–2018 are derived from the fourth IMO GHG study,[22] specifically the voyage-based emissions. The time series is completed by the respective $CO_2$ marine bunker growth rates from IEA statistics. Emissions from international maritime transport are illustratively assumed to decrease to approximately 17 per cent below the 2018 level by 2030, in line with a linear achievement of the IMO 2018 initial strategy goal[23] to reduce them by 50 per cent below the 2008 level (around 790 Mt $CO_2$ eq) by 2050. The assumed 17 per cent absolute GHG emission reduction is an illustration of the sector's 40 per cent emission intensity improvement target for 2030.

29. For calculating the difference in 2030 emissions from the latest IPCC-assessed emissions scenarios, a selection of scenarios from the AR6 WG III scenario database was used. Specifically, to illustrate the difference of NDC 2030 emission levels from pathways that lead to 1.5 °C warming, the 'C1a' category of scenarios was analysed: these scenarios limit warming below 1.5 °C (with over 50 per cent likelihood) by 2100 with no or limited overshoot and feature net zero GHG emissions in the second half of the century. To illustrate the 2030 emission difference from scenarios that limit warming likely below 2 °C (with over 67 per cent likelihood), the 'C3a' category of scenarios was analysed:[24] these scenarios feature an onset of concerted mitigation action by 2020. The emission differences are stated as medians and interquartile ranges from the distribution of differences between aggregate 2030 emission levels under the NDCs and these scenarios. Specifically, a Monte Carlo approach was chosen that samples randomly from a uniform distribution of the minimum–maximum range of 2030 emission quantifications under the NDCs and calculates the difference from a randomly chosen scenario of the selected category of IPCC scenarios. That process is repeated 100,000 times to obtain the 2030 emission differences, of which the median and interquartile ranges are then reported.

## D. Method to provide temperature assessments

30. Temperature projections in this report are closely aligned with the most recent AR6 WG I contribution findings on the carbon cycle and climatic uncertainties for global mean temperature projections. The main two methodological steps are the completion of a multi-gas emission time series until 2100 and the calculation of probabilistic global mean temperature outcomes as a result of such emissions trajectories. In the first step, existing methods[25] from the scientific literature that build on the SR1.5 scenario database are used. As for the second step, when estimating the temperatures based on the emissions, this is done by using a reduced complexity climate model, which has been calibrated to closely reproduce the findings from the AR6 WG I contribution. Overall, the methodological steps of harmonization to a joint global 2015 emission level, the infilling of missing GHGs and aerosols in line with the literature and the computation of probabilistic global mean

[21] See International Civil Aviation Organization resolution A40-18. Available at https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf. Also, using 2019 takes into account the Council's decision as per 30 June 2020 to only use 2019 as a base year for its carbon neutral growth pilot phase (https://www.icao.int/Newsroom/Pages/ICAO-Council-agrees-to-the-safeguard-adjustment-for-CORSIA-in-light-of-COVID19-pandemic.aspx).

[22] IMO. 2020. *Fourth IMO Greenhouse Gas Study*. London: IMO. Available at https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

[23] See https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx.

[24] See table SPM.2 in the AR6 WG III contribution.

[25] See, for example, Gidden MJ, Riahi K, Smith SJ, et al. 2019. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development*. 12(4): pp.1443–1475. Available at https://gmd.copernicus.org/articles/12/1443/2019/ and Lamboll RD, Nicholls ZRJ, Kikstra JS, et al. 2020. Silicone v1.0.0: an open-source Python package for inferring missing emissions data for climate change research. *Geoscientific Model Development*. 13(11): pp.5259–5275. Available at https://gmd.copernicus.org/articles/13/5259/2020/.

temperatures closely represent the steps that were taken to establish the AR6 WG III scenario database.

31. For the emission time series, infilling and harmonization at the global level were applied as for the scenarios in the AR6 WG III scenario database – with a gas-by-gas split and adjustments towards historical best estimates of global emission levels. Application of a small harmonization scaling factor then allows NDC-consistent emission projections, in line with historical emission estimates up until 2030, to be obtained. Illustrative post-2030 emission extensions project 2025–2030 emission trends up until 2050 and track thereafter the evolution of scenarios similar to 2030 level emissions in the SR1.5 scenario database using an adapted ‘equal quantile walk’ approach in line with approaches in the scientific literature.[26] The 2030–2050 illustrative linearized extension was chosen to address the issue that several scenarios in the SR1.5 scenario database were designed to change mitigation efforts around 2030. The subsequent post-2050 ‘equal quantile walk’ approach uses the global GHG emission levels in 2050 and tracks thereafter the same rank among scenarios in the scientific literature. Similarly, the GHG emission pathway is split into individual gas and aerosol emissions trajectories, following the same rank among the scenarios as in the scientific literature – a methodology that has been previously established and applied in published studies.[27] The aggregated global emission time series in this report does not consider a possible overachievement of stated target levels.

32. For the computation of global mean temperatures on the basis of emissions trajectories, the same methodology has been applied as was calibrated during the AR6 assessment cycle to perform a consistent temperature assessment of all the scenarios in the AR6 WG III scenario database. Specifically, the climate system uncertainty is emulated by reduced complexity climate models. This calibration to the findings from the AR6 WG I contribution has been documented in cross-chapter box 7.1 of the AR6 WG I contribution. As also used for the AR6 WG III scenario database, this report uses the calibrated MAGICC7.3 climate emulator,[28] running 600 ensemble members in order to derive an ensemble of global mean temperature projections for each aggregated global emissions trajectory. The stated warming ranges indicate best estimate (50 percentile) or 5 and 95 percentiles of peak temperature across NDC implementation (unconditional elements and full implementation).

[26] An extension based on the AR6 WG III scenario database would have equally been possible. Previous scientific studies (https://doi.org/10.1038/s41586-022-04553-z) used the former SR1.5 scenario database, which is here chosen for transparency and comparability given that different assumptions to extend emissions post-2030 can lead to a relatively wide range of temperature assessments over the twenty-first century.

[27] See, for example, Lamboll et al. (2020) (https://doi.org/10.5194/gmd-13-5259-2020) and Meinshausen et al. (2022) (https://doi.org/10.1038/s41586-022-04553-z).

[28] See cross-chapter box 7.1 in the AR6 WG I contribution or live.magicc.org.