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Timetables for Zero emissions and 2050 emissions reductions: State of the Science for the ADP Agreement

Joeri Rogelj
Michiel Schaeffer
Bill Hare

Climate Analytics gGmbH
Supporting science based policy to prevent dangerous climate change enabling sustainable development

Friedrichstraße 231 / Haus B
10969 Berlin / Germany

T / +49 (0)30 259 22 95 20
W / www.climateanalytics.org

CLIMATE ANALYTICS

This briefing note outlines suggested time frames for reaching zero global CO_2 and total greenhouse gas emissions for the 'below 2 °C' and 'below 1.5 °C by 2100' limits based on the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) and the 2014 UNEP Emissions Gap Report.

Summary

Elements in the ADP[1] agreement – under negotiation and to be adopted in Paris in December 2015 – are aimed at two different but related global warming limits: holding warming below a 2 °C increase above pre-industrial and to reduce global warming levels below 1.5 °C by 2100. Many countries and stakeholders have proposed that robust long-term emission reduction goals for 2050 (and beyond) consistent with the two warming limits be included in the agreement. In addition, the time frames for when all greenhouse gases (GHGs) and CO_2 emissions need to be zero under these warming limits have also been proposed. This analysis reviews the state-of-the-art of the science and suggests recommended numbers to reflect these goals within the ADP Agreement.

Recommended numbers for ADP Agreement

Based on an assessment of information available in the IPCC Fifth Assessment Report (AR5), the 2014 UNEP Emissions Gap Report and the scientific literature, a set of recommended emission benchmarks can be formulated which are in line with keeping warming to below 1.5 °C or 2°C, respectively.

Limit warming below 2 °C during the 21st century with a more than 66% chance:

- Global greenhouse gas emissions by 2050 are 40-70%[2] (35-55%) below 2010 (1990) levels
- Global greenhouse gas emissions reach zero by 2080-2100
- Global energy and industry CO_2 emissions[3] by 2050 are 35-80% (10-70%) below 2010 (1990) levels
- Global energy and industry CO_2 emissions reach zero around 2060-2075

Return warming below 1.5 °C by 2100 with a more than 50% chance[4]:

- Global greenhouse gas emissions by 2050 are 70-95%[2] (65-90%) below 2010 (1990) levels
- Global greenhouse gas emissions reach zero by 2060-2080
- Global energy and industry CO_2 emissions by 2050 are 95-120% (95-125%) below 2010 (1990) levels
- Global energy and industry CO_2 emissions reach zero around 2050 (range 2045-2055)

[1] Ad-hoc Working Group on the Durban Platform

[2] These numbers are drawn directly from the IPCC AR5 Working Group III Summary for Policymakers. The other numbers in this section draw from all scenarios assessed by the IPCC Fifth Assessment Report and the 2014 UNEP Emissions Gap Report and follow the methodologies of the 2014 UNEP Emissions Gap Report, to enable a direct comparison of these other numbers with the information provided in the 2014 UNEP Emissions Gap Report for 2 °C.

[3] Referred to by the IPCC as "CO_2 from fossil fuel and industrial sources" (see IPCC AR5 WGIII chapter 6 section 3.1.3).

[4] The 1.5°C scenarios underlying the emission numbers here have a more than 50% chance of returning to below 1.5°C by 2100 and simultaneously have a probability of about 85% to hold warming below 2°C during the 21st century.

The IPCC Fifth Assessment Report (AR5) is a starting point for this analysis, in particular for reductions by 2050 for both the 1.5 °C and 2 °C limits. However the IPCC does not directly provide all of the detailed numbers required to assess the timing of when emissions of all greenhouse gases (GHGs) and CO_2 emissions need to be zero. In addition, because the emission pathways are influenced by assumptions such as the probability of achieving a limit, the level of emissions in, for example, 2020, and the statistical selection of the range of scenarios used to describe the pathways, it is necessary to carry out some additional analysis. For this analysis, the methods and results of the 2014 UNEP Emissions Gap Report have been applied to the emissions scenarios assessed by the IPCC AR5 and the 2014 UNEP Emissions Gap Report.

Below 2 °C Limit

For the goal of holding warming below 2 °C, the IPCC Fifth Assessment Report (AR5) has assessed a range of 40-70% below 2010 for total GHG emissions by 2050 consistent with a likely (greater than 66% chance) probability of holding warming below 2 °C. This represents the 10-90th percentile range of scenarios. The UNEP Emissions Gap Report provides a somewhat narrower range 20-80th percentile ranges. In addition, the 2014 UNEP Emissions Gap Report shows that the reductions for 2050 span 45-65% and 50-75% depending on whether 2020 emissions are lower than the pledge levels or at the pledge levels. To meet the 2 °C limit, global GHG emissions would need to reach zero by 2080-2100[5], and would likely need to be negative in the years beyond[6].

Corresponding results for the 2 °C limit for global energy and industry CO_2 emissions[7] are 35-80% reductions below 2010 levels by 2050, zero emissions by 2060-2075, and negative thereafter.

Below 1.5 °C by 2100 limit[8]

To return warming **below 1.5 °C by 2100 with at least 66% chance** the IPCC AR5 assessed that a 70-95% reduction by 2050 below 2010 for total GHG emissions would be needed. Further analysis of low-emission scenarios from the IPCC AR5 database and other scientific literature[9], and adopting the 2014 UNEP Emissions Gap Report's approach of assessing a return of warming **below 1.5 °C by 2100 with at least 50% chance** shows that total global GHG emissions reach zero by 2060-2080, and need to be negative in the years beyond.[10] Global energy and industry CO_2 emissions reach zero around 2050 and are 95-120% below 2010 levels by that time.

[5] If emissions by 2020 were reduced considerably beyond current pledges and the 2020 Emissions Gap were closed, the time of zero total GHG emissions can be a decade later.
[6] Achieving global negative emissions means that the amount of CO_2 removed from the atmosphere is larger than any residual sources of CO_2. It does not mean that emissions are negative everywhere.
[7] Referred to by the IPCC as "CO_2 from fossil fuel and industrial sources" (see IPCC AR5 WGIII chapter 6 section 3.1.3).
[8] The 1.5°C scenarios underlying the emission numbers here have a more than 50% chance of returning to below 1.5°C by 2100 and simultaneously have a probability of about 85% to hold warming below 2°C during the 21st century.
[9] Including all scenarios assessed by the IPCC Fifth Assessment Report and the 2014 UNEP Emissions Gap Report
[10] If global total GHG emissions by 2020 were reduced beyond current pledges and below 50 $GtCO_2eq/yr$ (billion tons of annual CO_2 equivalent emissions), the time of zero total global GHG emissions can be a decade later and 2050 reductions can be less deep in the range of 65-85% below 2010 levels.

The numbers above are consistent with the emission reduction ranges in 2050 and 2100 assessed in IPCC AR5. For CO_2 only, these reductions need to be earlier and deeper, as explained and quantified further in this briefing note. Present emission projections and policy assessments indicate that current policies are not yet on track to meet the current pledges by 2020. Consequently it is assumed in this summary that this situation prevails (this means: the 2020 gap is not closed).

Background

The IPCC AR5 provides clear guidance that, for holding warming below any level, global carbon dioxide emissions need to reach zero, and total greenhouse gases (GHG) emissions, expressed in CO_2 equivalence (CO_2eq), soon thereafter. Sometimes, global carbon dioxide emissions reaching zero is referred to as *carbon neutrality* and total greenhouse gases (GHG) emissions reaching zero as *climate neutrality*.

The IPCC does not provide detailed numbers on the timing of reaching zero. The IPCC Synthesis Report (IPCC AR5 SYR) only provides guidance about total CO_2 and other GHGs combined, by stating that to limit warming to below 2 °C relative to pre-industrial levels substantial emissions reductions over the next few decades are required, and near zero emissions of CO_2 and other long-lived GHGs by the end of the century[11].

Relevant conclusions[12] from the IPCC AR5 include:

- "There are multiple mitigation pathways that are likely[13] to limit warming to below 2 °C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived GHGs by the end of the century" (IPCC AR5 SYR)
- Further specifications about the characteristics of likely below 2 °C scenarios are that:
    - Total CO_2eq GHG emissions are 40-70% below 2010 levels by 2050 in scenarios that keep warming likely to below 2 °C. By 2100 total GHG emissions are around 80% below 2010 levels or negative in such likely 2 °C scenarios.[14]
    - Global CO_2 emissions from energy supply need to phase out by 2040-2070. This implies a reduction of at least 90% or more below 2010 levels.[15]

[11] Figure SPM.5, panel a, of the IPCC Synthesis Report suggests that zero CO_2 emissions are reached somewhere in the second half of the 21st century by scenarios that fall within the lowest IPCC scenario Category 1.
[12] This represents the 10-90th percentile range of scenarios. This briefing note follows the methodologies of the UNEP Emissions Gap Reports, which provide somewhat narrower 20-80th percentile ranges.
[13] In the context of the IPCC, "likely" denotes a greater than 66% probability.
[14] "Emissions scenarios leading to GHG concentrations in 2100 of about 450 ppm CO_2eq or lower are likely to maintain warming below 2 °C over the 21st century relative to pre-industrial levels. These scenarios are characterized by 40% to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010, and emissions levels near zero or below in 2100." (IPCC AR5 SYR) Information in Table SPM.1 of the IPCC AR5 SYR
[15] "Mitigation scenarios reaching around 450 ppm CO_2eq concentrations by 2100 show large-scale global changes in the energy supply sector (robust evidence, high agreement). In these selected scenarios, global CO_2 emissions from the energy supply sector are projected to decline over the next decades and are characterized by reductions of 90 % or more below 2010 levels between 2040 and 2070. Emissions in many of these scenarios are projected to decline to below zero thereafter. [6.3.4, 6.8, 7.1, 7.11]" (IPCC AR5 WG3 SPM). Mitigation scenarios reaching around 450 ppm CO_2eq concentrations by 2100 have a likely chance of staying below 2 °C (Table SPM.1 IPCC AR5 WG3)

- Furthermore, for 1.5 °C pathways it was indicated that:
    - "A limited number of studies provide scenarios that are more likely than not to limit warming to 1.5 °C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2eq by 2100 and 2050 emission reduction between 70% and 95% below 2010." (IPCC AR5 SYR)

Global limits, likelihood levels and starting points

Two global limits are in play:

- The first is to hold warming below 2 °C, which is understood as meaning that warming should remain below 2 °C during the 21st century and beyond.
- The second limit is to return to below 1.5 °C by 2100, which us understood as meaning to limit peak warming as far below 2 °C as possible and to have warming reduce to below 1.5 °C by 2100.[16]

An important dimension of working out a policy-relevant emission pathway is deciding upon the likelihood by which the limit has to be achieved. The AR5 tended to focus on the 2 °C pathways that likely limited warming below this level ('likely' implying a greater than 66% chance). The choice of likelihood has an important influence on the timing of when emissions reach zero and on global reductions by 2050. For 1.5°C, virtually all pathways available from the scientific literature reach a peak warming level slightly above 1.5°C around mid-century, before dropping down to 1.5°C or below by 2100, with at least a 50% chance, consistent with the approach taken by the UNEP Emissions Gap Reports. The early emission reductions and often deep negative CO_2 emissions in these pathways in the 2nd half of the 21st century result in the fact that such 1.5°C pathways also hold warming well below 2°C during the whole of the 21st century, with a probability of around 85%. In addition, all these pathways are still on track by 2100 for a slow further decline in warming beyond 2100. Warming implied by the *likely* 2°C pathways mentioned above can be stabilizing, slowly declining, or still slowly increasing by 2100 and hence, potentially, beyond 2100.

A further issue are the emissions at which the pathways start, for example, their starting emissions levels in 2020. The 2014 UNEP Emissions Gap Report further disentangles these issues related to the starting level of emissions. Based on the same scenarios as the IPCC AR5 assessment, the 2014 UNEP Emissions Gap Report finds that in scenarios that achieve the pledges by 2020 and limit warming to below 2 °C relative to pre-industrial levels with at least 66% chance, global net CO_2 emissions reach zero between 2055 and 2070. Increasing action in the near term, beyond the current pledges, can postpone this timing by about five years to a decade. Or, in other words, if enhanced mitigation action is delayed, post-2020 emission reductions need to be faster and

[16] For example, the lowest of the IPCC representative concentration pathways, RCP2.6, has a peak warming of about 1.6-1.8°C and then reduces to around 1.6°C by 2100.

emissions need to reach zero earlier, which is all the harder given the later start. For total global GHG emissions[17] the 2014 UNEP Emissions Gap Report finds that global net zero levels are achieved between 2080 and 2100 for such scenarios. This timing is postponed by about a decade in scenarios that have a slightly lower chance of limiting warming to below 2 °C (50 to 66%)[18].

Suggested global zero emissions for different global goals

In this briefing, "zero emissions" relate to the concept of "carbon neutrality", as described in the 2014 UNEP Emissions Gap Report. In that report global carbon neutrality means that "annual anthropogenic carbon dioxide emissions are net zero on the global scale […]". It also specifies that "net zero implies that some remaining carbon dioxide emissions could be compensated by the same amount of carbon dioxide uptake (negative emissions) so long as the net input of carbon dioxide to the atmosphere due to human activities is zero". Such compensation can be applied between locations (for example, countries), sectors and sources.

Given all available information from the IPCC and UNEP[19], recommended global dates for reaching global net zero CO_2 emissions can be suggested. See also Tables 1 and 2.

- For limiting warming to **below 2 °C with a likely (greater than 66% chance)**[20]:
  - Global energy and industry CO_2 emissions zero around 2065 (2060-2075)
    - Five years later if emissions by 2020 decline considerably beyond the range of "current pledges" and the 2020 emissions gap were closed
  - Total global GHG reach zero before 2100 (2080-2100)
    - Up to one decade later if emissions by 2020 decline considerably beyond the range of "current pledges" and the 2020 emissions gap were closed
  - Total global GHG emissions by 2050 40% [35-55%] below 1990, equivalent to 50% [50-65%] below 2010
    - 40% [30-45%] below 1990 if emissions by 2020 decline considerably beyond the range of "current pledges" and the 2020 emissions gap were closed, equivalent to 50% [40-60%] below 2010

[17] The 2014 UNEP Emissions Gap Report counts the Kyoto-basket GHGs towards its total GHGs.
[18] See Appendix C to the 2014 UNEP Emissions Gap Report.
[19] This information includes the insight that the projected land-use (AFOLU) emissions over time for both baselines and mitigation scenarios are very similar, with large, overlapping uncertainties (Fig 6.5 and Fig 6.10 in IPCC AR5 WG3). This is not the case for energy and industry CO_2 emissions (logically inferred from Fig 6.7 in IPCC AR5 WG3). Therefore, the key CO_2 emissions sector to be affected are the latter energy and industry CO_2 emissions.
[20] Values computed by applying the methodology of the 2014 UNEP Emissions Gap Report to energy and industry CO_2 emissions reported in the IPCC AR5 scenario database.

- Global energy and industry CO_2 emissions by 2050 45% [10-70%] below 1990, equivalent to 65% [35-80%] below 2010
  - 45% [40-55%] below 1990 if emissions by 2020 decline considerably beyond the range of "current pledges" and the 2020 emissions gap were closed, equivalent to 60% [55-65%] below 2010

- For limiting warming to **below 2 °C with a very likely (greater than 90% chance)**[21]:
  - Global energy and industry CO_2 emissions zero by 2045
  - Total global GHG reach zero by 2065
  - Global energy and industry CO_2 emissions by 2050 120-130% below 1990, equivalent to 115-120% below 2010
  - Global GHG emissions by 2050 85-90% below 1990, equivalent to 90-95% below 2010
  - No scenarios are available if emissions by 2020 are in the range of "current pledges"

- For returning warming to **below 1.5 °C by 2100 with at least 50% chance**[22]**:**
  - Global energy and industry CO_2 emissions zero around 2050 (2045-2055)
    - One decade later if emissions by 2020 decline considerably beyond the range of "current pledges" to below 50 $GtCO_2eq/yr$
  - Total global GHG reach zero before 2080 (2060-2080)
    - Up to one decade later if emissions by 2020 decline considerably beyond the range of "current pledges" to below 50 $GtCO_2eq$ /yr
  - Total global GHG emissions by 2050 80% [65-90%] below 1990, equivalent to 85% [70-90%] below 2010
    - 60% [55-80%] below 1990 if emissions by 2020 decline considerably beyond the range of "current pledges" to below 50 $GtCO_2eq$ /yr, equivalent to 70% [65-85%] below 2010
  - Global energy and industry CO_2 emissions by 2050 110% [95-125%] below 1990, equivalent to 110% [95-120%] below 2010
    - 85% [75-110%] below 1990 if emissions by 2020 decline considerably beyond the range of "current pledges" to below 50 $GtCO_2eq$ /yr, equivalent to 90% [85-105%] below 2010

[21] No such scenarios are available in the IPCC AR5 scenario database. Therefore, these values are computed by applying the methodology of the 2014 UNEP Emissions Gap Report to scenarios from studies, which are mentioned in the IPCC AR5 WG3 report as having explored scenarios that limit CO_2eq concentrations below 430 ppm CO_2eq by 2100. In general, very few scenarios are available in the literature reaching such high probabilities of limiting warming to below 2 °C, and no scenarios are available with emissions in 2020 at the level of "current pledges".

[22] Very few such scenarios are available in the IPCC AR5 scenario database. Therefore, these values are computed by applying the methodology of the 2014 UNEP Emissions Gap Report to scenarios from studies, which are mentioned in the IPCC AR5 WG3 report as having explored such limits.

Other estimates for timing of zero global emissions

The estimates in this note are currently the only estimates based on the full information available in the IPCC AR5 and 2014 UNEP Emissions Gap Report assessments. They make use of the IPCC AR5 scenario database and their respective methodologies. They take into account the fact that emissions over the past couple of years have not been declining, as is the assumption in many of the scenarios in the IPCC AR5 scenario database that limit warming to below 2 °C. Other estimates [23] have interpreted more general statements made by the IPCC and 2014 UNEP Emissions Gap Report.

As the global-mean warming is to a large extent defined by the cumulative amount of CO_2 emissions into the atmosphere, implementing less emissions reductions in the near term has to be compensated by steeper emissions reductions thereafter to achieve the same temperature objective. The 2014 UNEP Emissions Gap Report notes that "the lower the annual emissions in the immediate future, including in the years up to 2020, the relatively higher they can be later, and the longer the time we have before exhausting the emissions budget. This would allow us to push back the timing of carbon neutrality and net-zero total emissions."

Therefore, if no distinction is made between scenarios with emissions much lower than the estimated 2020 pledge levels[24], this would result in the timing for reaching global zero CO_2 or GHG emissions being inconsistently late compared to the global emissions path that we are currently following.

[23] E.g., the recent "Net phase out of global greenhouse gas emissions" briefing prepared in the framework of the ACT 2015 project.

[24] 52-54 $GtCO_2e/yr$ in 2020 according to the 2014 UNEP Emissions Gap Report.

Table 1 Timing of zero emission levels and reductions by 2050 for 1.5 and 2 °C scenarios. Ranges indicate 20-80th percentile ranges, comparable to the convention used in UNEP Emissions gap reports. Note IPCC AR5 Working Group III applies a somewhat wider 10-90th percentile range.

Global goal	*Year global energy and industry related CO_2 emissions reach zero*	*By 2050: Reduction from 1990 emission levels for global energy and industry related CO_2 emissions (%)*	*Year total global CO_2 emissions reach zero*	*By 2050: Reduction from 1990 emission levels for total global CO_2 emissions (%)*	*Year total global GHG emissions reach zero*	*By 2050: Reduction from 1990 emission levels for total global GHG emissions (%)*
Very likely below 2 °C Least-cost[25]	2045	120-130%	2045	115-125%	2065	85-90%
Likely below 2 °C Least-cost[26]	2070 [2060-2080]	45% [40-55%]	2070 [2060-2075]	50% [45-65%]	2095 [2090-after 2100]	40% [30-45%]
Likely below 2 °C 2020 pledges	2065 [2060-2075]	45% [10-70%]	2065 [2055-2070]	65% [50-75%]	2085 [2080-2100]	40% [35-55%]
Medium (50-66%) below 2 °C Least-cost[27]	2080 [2070-2085]	30% [25-45%]	2075 [2070–2075]	45% [40-50%]	2095 [2090–after 2100]	30% [25-35%]
Medium (50-66%) below 2 °C 2020 pledges[28]	2070	30%	2065	40%	2095	30%
Below 1.5 °C (by 2100) 2020 <50 GtCO2e/year	2060 [2050-2070]	85% [75-110%]	2055 [2050-2060]	90% [85-110%]	2080 [2070-2085]	60% [55-80%]
Below 1.5 °C (by 2100) 2020 >50 GtCO2e/year[29]	2050 [2045-2055]	110% [95-125%]	2050 [2045-2050]	110% [95-125%]	2070 [2060-2080]	80% [65-90%]

[25] Given that only 3, very similar scenarios are available for this category, the scenario basis for these numbers is very narrow. Consequently only the median zero-year and minimum – maximum ranges for the emissions ranges are provided

[26] These scenarios assume that global net negative CO_2 emissions from energy and industry will be achieved in the 21st century

[27] These scenarios assume that global net negative CO_2 emissions from energy and industry will be achieved in the 21st century

[28] Given that only 4 scenarios are available in this category, only the median value was given.

[29] Due to the low number of scenarios in this category minimum – maximum ranges are provided instead of percentile ranges

Table 2 As table 1 for emission benchmarks relative to 2010 emission levels

Global goal	*By 2050: Reduction from 2010 emission levels for global energy and industry related CO_2 emissions (%)*	*By 2050: Reduction from 2010 emission levels for total global CO_2 emissions (%)*	*By 2050: Reduction from 2010 emission levels for total global GHG emissions (%)*
Very likely below 2 °C Least-cost[30]	115-120%	110-120%	90-95%
Likely below 2 °C Least-cost[31]	60% [55-65%]	65% [60-75%]	50% [40-60%]
Likely below 2 °C 2020 pledges	65% [35-80%]	70% [60-85%]	50% [50-65%]
Medium (50-66%) below 2 °C Least-cost[32]	50% [50-65%]	60% [55-65%]	45% [40-50%]
Medium (50-66%) below 2 °C 2020 pledges[33]	50%	55%	45%
Below 1.5 °C (by 2100) 2020 <50 GtCO2e/year	90% [85-105%]	95% [90-105%]	70% [65-85%]
Below 1.5 °C (by 2100) 2020 >50 GtCO2e/year[34]	110% [95-120%]	105% [95-115%]	85% [70-90%]

[30] Given that only 3, very similar scenarios are available for this category, the scenario basis for these numbers is very narrow. Consequently only the median zero-year and minimum – maximum ranges for the emissions ranges are provided

[31] These scenarios assume that global net negative CO_2 emissions from energy and industry will be achieved in the 21st century

[32] These scenarios assume that global net negative CO_2 emissions from energy and industry will be achieved in the 21st century

[33] Given that only 4 scenarios are available in this category, only the median value was given

[34] Due to the low number of scenarios in this category minimum – maximum ranges are provided instead of percentile ranges