Discrepancies in historical emissions point to a wider 2 °C benchmarks and aggregated national mitigation pledges

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Abstract
Aggregations of greenhouse gas mitigation pledges by countries are frequently used to indicate whether resulting global emissions in 2020 will be ‘on track’ to limit global temperature increase to below specific warming levels such as 1.5 or 2 °C. We find that historical emission levels aggregated from data that are officially reported by countries to the UNFCCC are lower than independent global emission estimates, such as the IPCC SRES scenarios. This discrepancy in historical emissions could substantially widen the gap between 2020 pledges and 2020 benchmarks, as the latter tend to be derived from scenarios that share similar historical emission levels to IPCC SRES scenarios. Three methods for resolving this discrepancy, here called ‘harmonization’, are presented and their influence on ‘gap’ estimates is discussed. Instead of a 3.4–9.2 Gt CO2eq shortfall in emission reductions by 2020 compared with the 44 GtCO2eq benchmark, the actual gap might be as high as 5.4–12.5 GtCO2eq (a 22–88% increase of the gap) if this historical discrepancy is accounted for. Not applying this harmonization step when using 2020 emission benchmarks could lead to an underestimation of the insufficiency of current mitigation pledges.

Keywords: climate change, greenhouse gas emissions, global warming, climate negotiations, UNFCCC

1. Introduction
Following the Climate Summit of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2009 in Copenhagen, several studies have been published which intend to track, assess and communicate the levels of mitigation action which can be expected from the pledges put forth. Analysts from research institutes, government agencies, non-governmental organizations and from the private sector alike (Climate Analytics and Ecofys 2010, Climate Interactive 2010, den Elzen et al. 2010, European Commission 2010b, Levin and Bradley 2010, Lowe et al. 2010, Macintosh 2010, PIE 2010, Project Catalyst 2010, PwC 2010, Risø Center UNEP 2010, Rogelj et al. 2010a, 2010b, Stern 2009, Stern and Taylor 2010, UNEP 2010) project emission levels in 2020 based on international pledges made in
Figure 1. Overview of global emission benchmarks for 2020 as found in the literature in terms of global total anthropogenic emissions in GtCO₂eq (black ranges at the left), the range of resulting emissions based on pledges under the Copenhagen Accord for nine illustrative studies (narrow bounded light grey ranges), and the range used for this study before harmonization (wide bounded light grey shaded range) and after harmonization (wide dark grey shaded ranges). The x-axis indicates the studies as well as the climate goals the respective benchmarks were developed for in the case of 2020 benchmarks, and the harmonization methods for the projected 2020 emission ranges under the Copenhagen Accord, respectively.

Deciding whether assessed 2020 greenhouse gas (GHG) emission levels are likely to be consistent with emission paths that can limit global warming to 2 °C can be done in several ways. Two main approaches are found in the literature: (a) the ‘benchmark approach’, which compares estimated emissions to a benchmark emission level considered as a test of consistency with the temperature goal or (b) the ‘full century approach’, which involves running a reduced complexity climate model with explicit post-2020 emission pathway assumptions. The benchmark approach compares the assessment of emission levels in 2020 to a predefined level or range (hitherto called ‘the benchmark’), which is assessed to be in line with 2 °C. The path followed by global emissions after 2020 is not explicitly modelled, but derived from the assumptions of the studies providing the benchmark. The ‘full century approach’, which runs an entire emission pathway, or set of pathways, through a climate model, is used less often but has the advantage that post-2020 assumptions are made explicit. In this analysis we show that unconsidered application of the benchmark approach can lead to imprecise conclusions of emission assessments concerning the 2 °C compliance of a 2020 emission level (see figure 1). In this paper, we quantify the mismatch in emission levels which are officially reported by countries, and the emissions levels initially used by different groups to construct the 2020 emission benchmarks. Three illustrative methodologies for approaching this issue are suggested and their influence quantified.

2. Benchmark definition

All the studies in the literature that apply the benchmark approach use 2020 as the year in which estimated emission levels are compared to the benchmark. The fact that this provides a link to the Copenhagen Accord (UNFCCC 2009b) and ongoing climate negotiations (UNFCCC 2010a) supports this approach.
2.1. 2020 emission benchmarks

Several studies have estimated what global 2020 emission levels in gigatones carbon dioxide equivalence (GtCO$_2$eq) could be considered as an appropriate 2°C benchmark level (Bowen and Ranger 2009, European Commission 2010a, Meinshausen et al 2009, Project Catalyst 2010) (see figure 1). An analysis of the methodologies used by these assessments reveals that they all use harmonized historical emissions drawn from the Intergovernmental Panel on Climate Change’s (IPCC) Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart 2000) to determine their climate-related benchmarks. These harmonized historical emissions are defined for the so-called Kyoto greenhouse gas (Kyoto-GHG) basket which consists of carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs) and sulfur hexafluoride (SF$_6$) and takes into account contributions of fossil fuels, industry, land use and land-use change and forestry, international shipping and international aviation.

When comparing temperature benchmarks to 2020 emissions levels resulting from the assessments of mitigation action compilations (for example the Copenhagen Accord), it is paramount that the assumptions used in framing the studies providing the benchmarks are taken into account and, if necessary, adjusted for, so there is consistency in the temperature comparison. An aggregated indicator of whether a consistent set of assumptions is applied in both the studies providing the benchmarks and the pledge assessments is global historical emission levels. As explained above, all studies which provide temperature benchmarks are assuming historical emission from the IPCC SRES scenarios. In the remainder of this analysis, all examples therefore focus on a harmonization to these historical emission values.

2.2. Variability in 2000 values

The issue that arises is that historical estimates based on other methodologies or data sets can differ from the estimates of the SRES data set (see figure 2). Looking at the literature, global fossil fuel emission estimates for 2000 differ by up to 5%, which is comparable to the ±6% uncertainty assessed by Prather et al (2009) for reported emissions, and the variation increase for other sources, where either the underlying emission and activity estimates are uncertain or different methodologies are used to account and report for emissions from activities. Additionally, each emission estimate methodology has its own intrinsic uncertainty range (Bun et al 2010, Jonas et al 2010, Winiwarter and Muik 2010). Figure 2 provides an overview of historical 2000 emission levels from various sources and their uncertainty ranges.

3. Historical emission estimates

Various studies have made historical emission inventories and have estimated historical anthropogenic emission levels, e.g. for the year 2000 (Boden et al 2009, Houghton 2008, IEA 2009, IPCC 2007b, JRC and PBL 2009, Meinshausen et al 2011, Nakicenovic and Swart 2000). Important uncertainties exist for those historical levels and for virtually every gas in the Kyoto-GHG basket (see figure 2). These uncertainties result in a range of estimates for the final total global anthropogenic GHG emission basket from the same set of global activities. As the SRES estimates result from a coordinated effort among various research groups, they provide a good reference point. Figure 3 illustrates that the IPCC SRES levels are within the uncertainty ranges of other estimates.

3.1. Officially reported data

Emission assessments relating to international climate policy negotiations rely on data which are officially reported by countries according to agreed methodologies and reviewed by expert review teams. Under articles 4.1 and 12 of the UNFCCC, all parties to the convention must ‘develop, periodically update, publish and make available (...) national inventories of anthropogenic emissions (...)’ as well as submit periodically national communications (UNFCCC 2009c). Non-Annex I countries submit national inventories as part of their national communications. Those Annex I countries that have ratified the Kyoto Protocol must also provide additional information in both their national communications and their annual national inventory submissions (UNFCCC 2009a) to show compliance with the Kyoto Protocol.

Annex I inventory reporting rules, guidelines and methodologies are quite complex and involve important and agreed assumptions about when and how emissions from activities with latent release potential are accounted for (e.g. release of HFCs from in use applications, deforestation with slow release of carbon from oxidizing soils, etc). Furthermore, estimates made of the release of CO$_2$ from fossil fuel combustion within a country have an uncertainty of ±6% (Prather et al 2009). Therefore, for different data sources, emissions from national estimates and global estimates will not match perfectly. For example, the USA officially reported to the UNFCCC that CO$_2$ emissions from fossil fuel and mineral production in 2000 were 5.95 GtCO$_2$ (UNFCCC 2009a). The US Energy Information Administration reported 5.89 GtCO$_2$ (EIA 2010) for the same emission sectors. A lower estimate of 5.74 GtCO$_2$ is reported in the CDIAC database (Boden et al 2009), and the International Energy Agency estimates 5.66 GtCO$_2$ (IEA 2009). For this specific case the standard deviation across the different estimates is 2.5% around a mean. This does not take into account the uncertainties of the respective estimates and the fact that some data sources do not use the exact same emission sector definitions.

3.2. Composite historical emission estimates

While the data in the Annex I national inventory submissions are reported annually, national communications of non-Annex I countries only contain emissions for certain years, sometimes only up to 1994. To define 2000 global emission levels, the latter values thus have to be projected from their last reported year up to the year 2000. To quantify the sensitivity of estimated 2000 values to assumptions, a set of three different composite emissions pathways—all starting from officially
Figure 2. Comparison between scenario and inventory data for global anthropogenic GHGs in 2000. (a) CO₂ emissions from fossil fuel and mineral production; (b) CO₂ emissions from land-use change, forestry and peat decay; (c) methane emissions; (d) nitrous oxide emissions; (e) HFCs, PFCs and SF₆; (f) GWP-weighted (IPCC 1996) aggregate emissions of all greenhouse gas emissions controlled under the Kyoto Protocol (sum of emissions shown in panels (a)–(e)). The dashed lines show harmonized RCP values (Meinshausen et al 2011, van Vuuren et al 2011), and the dotted lines SRES values (Nakicenovic and Swart 2000). Values are shown for the Synthesis Report of the IPCC Fourth Assessment Report (IPCC 2007b), the Emission Database for Global Atmospheric Research (EDGAR), release 4.0 (JRC and PBL 2009) and release 4.1 (Olivier and Peters 2010), the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al 2009, Houghton 2008) and the World Energy Outlook 2009 (WEO2009) from the International Energy Agency (IEA 2009). Values of WEO2009 were extrapolated linearly from the first reported global values in 2005. In panel (f), contributions of missing GHGs were taken from EDGAR4.0 and IPCC AR4 SYR for the completion of EDGAR4.1 and CDIAC data, respectively. Specific uncertainty ranges are calculated for EDGAR4.0 (derived from Olivier et al 1999) and CDIAC (derived from Houghton 2003, Marland and Rotty 1984). When not explicitly referenced, the uncertainty ranges are derived from the respective source publications. For each study cited, sources of uncertainty are different, because their methodologies are different. This figure only shows the aggregated uncertainty ranges for all sources of uncertainty.

reported data—is developed. For creating these composite emissions pathways, we use the composite source generator method of the Potsdam Real-time Integrated Model for the Probabilistic Assessment of Emission Paths (PRIMAP) (Nabel et al 2011). This method generates a composite emission path based on a hierarchical list of initial sources. We use three different sets of literature data to complement the officially reported data (see table 1). Data contained in sources with the highest priority are used unmodified, while lower priority sources are used to complement, inter- or extrapolate.

Table 1 lists the initial sources which were used for the respective emission projections. Following the officially reported data, the PRIMAP A projection uses scaled growth rates from a composite scenario based on a downsampling of the SRES A1B pathway which was developed in the framework of the Ad Hoc Group for the Modelling and Assessment of Contributions of Climate Change (MATCH) (Höhne et al 2010), the PRIMAP B projection uses country resolution historical emission data from fossil fuel and cement production from the Carbon Dioxide Information Analysis

![Figure 2](image-url)
Figure 3. Overview of historical emission levels in 2000 derived from various global studies for both (a) global total anthropogenic emissions excluding land-use related emissions for the Kyoto-GHG basket (CO₂, CH₄, N₂O, HFCs, PFCs and SF₆) and (b) global anthropogenic land-use related CO₂ emissions, compared to the values from composite PRIMAP baselines based on data officially reported by countries to the UNFCCC. Black bars indicate the inventory estimates, grey bars indicate uncertainties as reported by the studies. CDIAC only provides values for CO₂ from fossil fuel and cement, and from land-use change. To allow comparability, CDIAC’s missing emissions (CH₄, N₂O, HFCs, PFCs and SF₆) have been complemented with the emission contribution estimates published in the IPCC AR4, therefore this source is marked with an asterisk. For anthropogenic land-use related CO₂ emissions in panel (b), in addition to year 2000 values (thick solid bars), the annual time series from 1996 to 2005 is shown (thin solid line) as well as the decadal average (dashed line) for the values of the PRIMAP projections based on data officially reported to the UNFCCC.

Table 1. Overview of emission data sources used for the construction of projections based on officially reported historical data.

| Emission projection name | PRIMAP A | PRIMAP B | PRIMAP C |
|--------------------------|----------|----------|----------|
| Hierarchical list of sources* | 1. CRF | 1. CRF | 1. CRF |
| 2. NATCOM | 2. NATCOM | 2. NATCOM |
| 3. MATCH | 3. CDIAC | 3. CDIAC |
| 4. IEA | 4. CDIAC | |
| 5. EDGAR | 5. MATCH | |
| 6. POLES | |
| 7. MATCH | |
| 8. MNP SRESA1B | |

Global GHG emissions excl. land-use related CO₂ emissions in 2000 (GtCO₂eq)

| | PRIMAP A | PRIMAP B | PRIMAP C |
|--------------------------|----------|----------|----------|
| Global GHG emissions excl. land-use related CO₂ emissions in 2000 (GtCO₂eq) | 32.8 | 32.8 | 33.1 |

Global land-use related CO₂ emissions in 2000 (GtCO₂)

| | PRIMAP A | PRIMAP B | PRIMAP C |
|--------------------------|----------|----------|----------|
| Global land-use related CO₂ emissions in 2000 (GtCO₂) | 0.40 | 0.41 | 0.41 |

* Explanation: PRIMAP: Potsdam Real-time Integrated Model for the Probabilistic Assessment of Emission Paths (Nabel et al 2011); CRF: national inventory submissions to the UNFCCC—‘officially reported’ (UNFCCC 2009a); NATCOM: national communications to the UNFCCC—‘officially reported’ (UNFCCC 2009c); MATCH: downscaled SRESA1B scenario from the Ad Hoc Group for the Modelling and Assessment of Contributions of Climate Change (Höhne et al 2010); CDIAC: Carbon Dioxide Information and Analysis Center (Boden et al 2009); EDGAR: Emission Database for Global Atmospheric Research (JRC and PBL 2009); IEA: International Energy Agency, World Energy Outlook 2009 (IEA 2009); POLES: Prospective Outlook on Long-term Energy Systems model (ENERDATA 2009); MNP SRESA1B: downscaled SRESA1B scenario of the Netherlands Environmental Assessment Agency (van Vuuren et al 2006).
2000 and for most non-Annex I countries the nearest point for extrapolation is 1994, with a small set of non-Annex I countries also reporting data for 2000. The three land-use emission estimates derived from officially reported data show an even smaller spread as fewer historical growth assumptions on a country level are available in the peer-reviewed literature (Höhne et al 2010, Houghton 2008), and therefore these estimates have a similar evolution.

3.3. Composite official estimates versus other sources

A comparison of the 2000 emission values based on officially reported data with the SRES 2000 emission values shows significant discrepancies. For global total anthropogenic emissions excluding land-use related emissions this discrepancy is of the order of 5–6% of SRES 2000 values. Estimates based on officially reported data are in general at the very low end, and even below (cf the IPCC AR4 estimates) the uncertainty ranges of other global emission inventory exercises.

For anthropogenic land-use related emissions the relative discrepancy is an order of magnitude larger, with emissions based on officially reported data being 90% lower than SRES estimates in 2000 and below all uncertainty ranges of other emission inventories. Land-use related emissions show a high interannual variability which is smoothed in top down assessments like SRES. Therefore also the yearly values for the decade encompassing the year 2000 are given, together with the average level in this time period (see figure 3). This decadal average shows an even larger discrepancy between officially reported land-use related emissions and other global inventories, including a change of sign and amounting to 126% relative to SRES values in 2000. Some reasons for these discrepancies are probably (a) the often low capacity currently in non-Annex I countries to make inventories over their entire national territory, (b) inventories that do not necessarily span all GHG emissions and all sectors, and (c) strategic issues related to the negotiations of future allowances and compliance.

The discrepancies between land-use related emissions based on officially reported data and other inventories are large, and none of the analyses in the literature incorporate officially reported data for land-use related emissions in their global estimates. Other sources are used which are based on global historical estimates (Houghton 2008, Nakicenovic and Swart 2000). In this paper we will therefore focus on the harmonization of emissions excluding land-use related emissions.

4. Harmonization methodologies

Three harmonization methodologies are presented and their influence quantified and discussed: uniform scaling harmonization, tapered scaling harmonization and offset harmonization. The uniform scaling harmonization approach looks at the relative difference between the 2000 emission levels ($E$) from a given pathway and the reference values ($E_{ref}$), and scales the entire pathway for all years ($t$) to get the harmonized emissions ($E_{harmo}$):

$$E_{scale}^{harmo}(t) = E(t) \frac{E_{ref}(2000)}{E(2000)}.$$  

The tapered scaling harmonization approach starts from the same point as the previous method, but relaxes the scaling from the starting year $t_0$ over time until a year $t_{match}$ is reached. After year $t_{match}$ no scaling is applied:

$$t < t_{match}: E_{taper}^{harmo}(t) = E(t) \left( \frac{E_{ref}(2000)}{E(2000)} \right) + \left( 1 - \frac{E_{ref}(2000)}{E(2000)} \right) \left( \frac{t-t_0}{t_{match} - t_0} \right)$$

$$t \geq t_{match}: E_{taper}^{harmo}(t) = E(t).$$

Finally, the offset harmonization methodology offsets the entire emission pathway with the difference in emission levels observed in the year 2000:

$$E_{offset}^{harmo}(t) = E(t) + (E_{ref}(2000) - E(2000)).$$

The three harmonization procedures are applied to the PRIMAP B pathway described above together with historical SRES emissions as reference values, and their influence on 2020 emission levels resulting from an assessment of the pledges under the Copenhagen Accord (Rogelj et al 2010a) is analysed and discussed. The latter assessment developed two sensitivity cases: one pessimistic (case 1) and one optimistic (case 2). We look at the range defined by both cases and compare it to an illustrative 2020 emission benchmark of 44 GtCO2eq (see figure 1) to see how they would influence policy advice. For the tapered scaling harmonization, 2050 is chosen as the year in which the scaling factor returns to 1, consistent with the default choice for harmonizing the emissions of the new IPCC scenarios named Representative Concentration Pathways (RCP) (Meinshausen et al 2011).

The three presented harmonization methods implicitly assume that the discrepancy in historical emissions is to be attributed to different reasons. Uniform scaling harmonization could be interpreted as the appropriate method if officially reported data are spanning all sectors, but emission values for each sector are consistently reported to be lower than in reality. It also assumes that countries will continue to do so to the same extent in the future. Tapered scaling harmonization could also be interpreted in that sense, but assumes that emissions at a certain point in the future will be subject to solid and integer international rules in a way such that the discrepancy between reported and real emissions is minimized. Finally, offset harmonization might be interpreted as implicitly assuming that officially reported emission inventories missed a constant source of emissions or did not span all the emission sectors of other emissions inventory exercises. Therefore, a fixed offset might be considered an appropriate method to cope with this kind of discrepancy.

5. Results and discussion

All methods yield significant increases in 2020 emission levels of 4–6% (see table 2), with the largest increase for
Table 2. Overview of the influence of three harmonization methods on (a) absolute 2020 emission levels, (b) relative changes of 2020 emission levels and (c) the resulting gap resulting between the absolute 2020 emission levels and an illustrative 2020 benchmark in line with a 2°C target.

| Scenario | Before harmonization (GtCO2eq) | Uniform scaling | Tapered scaling | Offset |
|----------|-------------------------------|----------------|----------------|--------|
| Case 1   | 53.2                          | 56.5           | 55.2           | 55.4   |
| Case 2   | 47.4                          | 50.4           | 49.2           | 49.6   |
| % increase of 2020 emission levels with respect to no harmonization |
| Case 1 (%) | 0                             | 6              | 4              | 4      |
| Case 2 (%) | 0                             | 6              | 4              | 5      |

Illustrative 2°C ‘gap’: absolute difference from illustrative benchmark of 44 GtCO2eq (GtCO2eq)

| Case 1   | 9.2                           | 12.5           | 11.2           | 11.4   |
| Case 2   | 3.4                           | 6.4            | 5.4            | 5.6    |
| % increase of the ‘Gap’ with respect to no harmonization |
| Case 1 (%) | 0                             | 36             | 22             | 24     |
| Case 2 (%) | 0                             | 88             | 53             | 65     |

The uniform scaling method. Although the latter method inflates the 2020 levels the most, it is the only method which would conserve the relationship between base and target year emissions for emission targets that are defined relatively. For example, a reduction target like the one put forth by the USA of 17% from 2005 levels would remain intact with this approach. This method, however, implies that also negative emissions are scaled in the opposite direction. This could be alternatively executed by offsetting the pathway by its maximum negative value during scaling. However, given the fact that negative emissions as emission targets are far from the current negotiation reality (UNFCCC 2010a), and 2020 emission levels are virtually certain to not be negative in any scenario, this drawback of uniform scaling is minimal for 2020 emission assessments. With tapered scaling harmonization and offset harmonization, the relationship for relatively defined emission targets is not conserved. Furthermore the offset method would not increase sinks. Finally, a drawback of offset harmonization is the fact that it will influence the year of a possible future switch to negative emissions. Both scaling harmonization methods do preserve this year in their pathways.

The presented harmonization approaches are not exhaustive and should not be imperatively applied homogeneously to all countries. As an illustrative example, emission inventories of industrialized countries might cover all sectors but systematically underestimate actual emissions, while developing countries could have only a partial sectoral coverage. In line with the discussion above, differentially applying the uniform scaling method to industrialized countries and the offset method to developing countries could therefore be considered. This differentiated approach results in an increase of the gap in 2020 of 36–124%. This is higher than the three homogeneous approaches shown in table 2.

An alternative harmonization approach would be to perform adjustments on historical data before calculation of future emission levels. However, IPCC SRES emission data are not available on a country level. Scaling single countries’ historical emissions before calculation of future emission levels would therefore not yield very different results. This kind of harmonization could alternatively involve an analysis at the sector level of each country’s emissions. This approach lies outside the scope of this paper.

In the harmonization methodology we present here, the emissions of the IPCC SRES scenarios are used as the historical reference. This choice is motivated by the fact that all studies which provide 2020 emission benchmarks in line with a temperature target are relying on these historical SRES emissions estimates. However, if benchmark studies were to become available which were based on other historical emission estimates (for example the RCPs), the harmonization should be adjusted accordingly.

Assessing 2020 emission levels does not unambiguously define the probability of exceeding a certain temperature target (Meinshausen et al. 2009). Cumulative emissions (Allen et al. 2009, Matthews et al. 2009, Meinshausen et al. 2009, Zickfeld et al. 2009) are in that respect a much more robust indicator. Due to constraints on the economic and technical rate of change, a 2020 emission level correlates with the minimum amount of cumulative emissions over a longer period, as modelled in socio-economically and technologically feasible pathways (Clarke et al. 2009, den Elzen et al. 2007, Edenhofer et al. 2009, IPCC 2007a, Knopf et al. 2009, O’Neill et al. 2009). Therefore, 2020 emissions levels can provide a reasonable and policy-relevant indicator as to whether global emissions are ‘on track’ for pathways which can limit global mean temperature increase to 2°C or lower. Finally, the implication of the explored mismatch between officially reported data and global emission estimates is important for studies using the benchmark approach to define whether we are ‘on track’ on, for example, a 2°C path. Many of the above-mentioned studies calculate the difference between where current pledges add up to and the 2°C benchmark of their choice. This so-called ‘gap’ is then communicated as the central message of those studies. Whereas before harmonization the emission 2020 levels resulting from the optimistic scenario (case 2) in Rogelj et al. (2010a) might have been considered compliant with ‘emission levels that limit the probability of exceedance of 2°C to 50%’, all three harmonization methods yield emissions levels which are outside that range (see figure 1). The latter statement can...
therefore not be supported anymore, as the lowest forecasted 2020 emission level shifts from 47.4 to 49.2 GtCO2e, i.e. from below to above the upper limit of the above-mentioned 2°C benchmark range (48 GtCO2e). Furthermore, the gap between the 44 GtCO2e benchmark and the forecasted 2020 emission levels would increase from 3.4–9.2 GtCO2e to 5.4–12.5 GtCO2e, or a relative increase of 22–88%, based on the harmonization methods discussed here.

This paper shows that a rigorous adjustment for the historical emission levels linked to the benchmark approach (in line with IPCC SRES), consistently increases the gap in 2020 and thereby influences the conclusions and policy messages based on it. Using the benchmark approach without the harmonization step presented here could underestimate the insufficiency of current mitigation pledges.

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