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COMMENT

Comment on 'Unintentional unfairness when applying new greenhouse gas emissions metrics at country level'

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1. Overview

Rogelj and Schleussner (2019) (RS19) raise a number of important issues in their critique of the use of warming-equivalent emissions to relate very long-lived (and hence cumulative) climate pollutants (LLCPs) and short-lived climate pollutants (SLCPs), but in the process introduce some errors and misrepresentations that merit a response. Although RS19 focuses on GWP* (Allen *et al* 2016, 2018, Cain *et al* 2019), their arguments would apply to any metric that accounts for the key difference between SLCPs and LLCPs. Increasing emissions of an SLCP have a much greater impact on global mean surface temperature (GMST) per tonne of SLCP emitted than constant emissions of that SLCP while LLCPs have approximately the same impact on GMST per tonne of LLCP emitted, regardless of emission trajectory. Metrics that capture this difference include forcing-equivalent emissions (Wigley 1998, Jenkins *et al* 2018), global temperature-change potential for a sustained emission (GTP_S) (Shine *et al* 2005), mixed metrics (Lauder *et al* 2013), or combined global temperature-change potential (CGTP) (Collins *et al* 2020). The point of GWP* was not to capture this behaviour *per se*, which was already well known, but to demonstrate that it could be captured relatively simply, and retain the use of the familiar global warming potential (GWP) values.

To emphasise the simplicity of using GWP* we can rearrange equation (1) in Cain *et al* (2019) to give equation (3) in Lynch *et al* (2020):

$$E^*(t) = E_{LLCP}(t) + 4 \times E_{SLCP}(t) - 3.75 \times E_{SLCP}(t-20),$$

where $E^*(t)$ is CO_2-warming-equivalent (CO_2-we) emissions in year *t*, $E_{LLCP}(t)$ and $E_{SLCP}(t)$ are emissions of LLCPs and SLCPs in year *t*, both in conventional GWP_{100} CO_2-equivalent (CO_2-e) units, while $E_{SLCP}(t-20)$ is CO_2-e emissions of SLCPs in the year 20 years prior to *t* (SLCPs here include all forcing agents with lifetimes of up to a couple of decades). Earlier variants of GWP* (Allen *et al* 2016, 2018) replaced both factors of 4 and 3.75 with 5. It appears that RS19 used this earlier form. The most recent recommendation for GWP* values are published in Smith *et al* (2021).

Calculating the current rate of CO_2-warming-equivalent (CO_2-we) emissions using GWP* (E^*) involves differencing two rates of GWP_{100}-based CO_2-e emissions, and hence is entirely compatible with the United Nations Framework Convention on Climate Change (UNFCCC) decision to report emissions using GWP_{100}. For methane, using a GWP_{100} value of 28,

$$E^*(t) = 112 \times E_{CH_4}(t) - 105 \times E_{CH_4}(t-20).$$

Cumulative CO_2-we emissions over any multi-decade period have approximately the same impact on global temperature over that period regardless of the gas considered and hence:

$$\Delta T = \mathrm{TCRE} \times \sum_t E^*(t),$$

where TCRE stands for the transient climate response to emissions. CO_2-we emissions, calculated using GWP* or any of these other methods, can therefore be used to estimate contributions of countries, sectors, gases or even individual projects both to historical warming and to current and projected warming, independent of the timescale considered. In contrast, similar CO_2-e emissions only indicate similar warming on a specific timescale that also depends on the LLCPs and SLCPs compared (about 40 years when using GWP_{100} to compare CO_2 vs. methane, 20 years for CO_2 vs. black carbon, Allen *et al* 2016). Warming-equivalent emissions may therefore be useful to inform progress to a long-term temperature goal that does not specify a timescale, such as the Paris Agreement. Several authors already point out that aggressive SLCP mitigation can provide near-term reductions in global warming rate but cannot replace the need for CO_2 emissions mitigation (e.g. Shindell *et al* 2012). Hence there is no inconsistency between warming-equivalent emissions and the Paris architecture, and since all metrics are based on a linearization, to allow the responses to different emissions to be added up, there is also no reason to restrict their application to global emissions.

We document specific problems with RS19 below, but to provide relevant context, it is helpful to step back and consider what greenhouse gas metrics are actually for. In the words of the IPCC First Assessment Report that introduced the GWP concept: 'To evaluate possible policy options, it is useful to know the relative radiative effect (and, hence, potential climate effect) of equal emissions of each of the greenhouse gases.' Metrics were introduced to inform and evaluate policy options, not to dictate policy outcomes.

There is nothing inherently unfair or inconsistent in the use of a metric that more accurately reflects impact on GMST to inform decisions under a policy architecture with a long-term global temperature goal, such as the Paris Agreement. Using GWP* makes it clear that the historical contribution of a country's methane emissions to temperature change scales with their current methane emission rate plus a contribution from past methane emissions. This is not true of CO_2. Two countries that both have the same annual CO_2 emission rate today could have quite different historical responsibilities for temperature change, depending on their past emission trajectories. Aggregate CO_2-e emissions under GWP_{100} obscure this distinction, while aggregate CO_2-we emissions make it clear. Whether or not these historical contributions are taken into account in burden-sharing discussions is a matter for policymakers to decide, but the use of a metric that reflects the impact of all gases on GMST makes it easier to include methane in discussions of historical responsibility, not the reverse.

In contrast, reliance on inaccurate metrics can cause unfairness and inconsistency through confusion. GWP_{100} overstates the GMST impact of a long-established source of methane by a factor of four, while understating the impact of a new source, also by a factor of four over the 20 years following the change. Failure to recognise this fact may itself cause unfairness. Consider three methane sources, A, B and C, all emitting 1 $tCH_4\ yr^{-1}$ over a multi-decade period, but with a different prior history. A was already emitting at 1 $tCH_4\ yr^{-1}$ before this period, B began emitting 1 $tCH_4\ yr^{-1}$ in year 1 having previously emitted nothing, while C reduced their emissions to 1 $tCH_4\ yr^{-1}$ in year 1 from a previous rate of 2 $tCH_4\ yr^{-1}$. Under GWP*, A's emissions are equated with 7 $tCO_2e^*\ yr^{-1}$ throughout while B and C's emissions are equated with 112 and −98 $tCO_2e^*\ yr^{-1}$ for the first 20 years, respectively, followed by 7 $tCO_2e^*\ yr^{-1}$ from then on. Emissions of CO_2 equal to these CO_2e^* emissions would have a similar impact on GMST as the original methane emissions over a broad range of timescales: hence the phrase 'warming-equivalent'. A's emissions cause a slow warming throughout, while B's cause a rapid initial warming and C's an initial reduction in temperature (just as active CO_2 removal cools global temperatures), in both cases followed by a slow warming (Lynch *et al* 2020). GWP_{100} would suggest all three sources are equivalent to 28 $tCO_2e\ yr^{-1}$, causing a steady warming, throughout. This exaggerates the GMST impact of A's emissions, while completely ignoring the impact of the changes in methane emission rates implemented by B and C.

To object 'but over the period considered, A, B and C all emit the same amount of methane' misses the point that, following the Paris Agreement, climate policy is focused on limiting warming, not emissions per se, and changes in emission rates of SLCPs such as methane have a disproportionate impact on global temperature, while changes in emission rates of cumulative pollutants such as CO_2 do not. The point of CO_2-warming-equivalence is simply to capture this distinction: ethical discussions about the relative merits of different policy outcomes will always need to take other considerations into account.

2. Specific issues in RS19

The abstract incorrectly states that 'The use of GWP* would put most developing countries at a disadvantage compared to developed countries, because when using GWP* countries with high historical emissions of short-lived greenhouse gases (GHGs) are exempted from accounting for avoidable future warming'. The use of a metric should not dictate policy decisions such as the treatment of historical contributions, whether climate policy should utilise a single- or multi-basket structure, or the appropriate mix of emissions reductions of different gases in a country's climate plan. Moreover, it is a value judgment to consider failure to reduce methane emissions as 'avoidable', but not failure to implement active CO_2 removal, which would have the same impact on global temperature. Which is more feasible depends on the policy context. There is nothing inherent in the metric that dictates the outcome.

RS19 correctly state that 'the GHG metric which determines how different GHGs are accounted for in pathways … is not explicitly specified [in the Paris Agreement'. They then state that 'it can be inferred [to be GWP_{100}] based on information and reports that fed into the development of the Paris Agreement', citing evidence from the IPCC's AR5, and a 2016 UNFCCC document. It cannot be asserted that the members of the Paris Agreement—the sole authority for its interpretation—construed its meaning as contingent on or flowing from any particular metric. That GWP_{100} has been used as the default metric to date should not be taken to imply it is therefore the metric of choice, especially in the context of SLCP emissions in a climate agreement with a temperature-based target (which the Paris Agreement's precursor the Kyoto Protocol did not have).

Similarly, while it is true that the UNFCCC uses GWP_{100} as 'a common accounting metric', UNFCCC documentation does not presuppose its general use within the Paris Agreement. At COP24, in December 2018, an explicit decision was taken to adopt the GWP_{100} values from AR5[1] in the context of reporting national emissions and removals (rather than for setting targets). This decision noted that parties 'may in addition also use other metrics (e.g. global temperature potential)'. Even in the case of GWP_{100}, there is ambiguity; AR5 presents two sets of tables for metrics (including and excluding climate-carbon feedbacks). The UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) has repeatedly been unable to reach agreement on metric choice. Although it was an agenda item[2] for COP25 (December 2019) because its June 2019 meeting, 'was not able to conclude its considerations on this matter', COP25 was similarly unable to make progress in reaching a conclusion[3] and deferred discussion to the next (2020) SBSTA session; earlier SBSTA meetings[4] explicitly noted 'the limitations in the use of GWPs based on the 100 year time horizon in evaluating the contribution to climate change of emissions of GHGs with short lifetimes'.

RS19 state that 'applying novel metrics to a predefined policy context is problematic if no appropriate measures are taken to ensure internal consistency with the earlier use of other metrics in policy'. This suggests the policy context is immutable, but it is not: it evolves with new science (such as the observation that impact on GMST can be captured simply using a simple difference of already-reported indices) and evolving ambitions (such as the progress between the Kyoto Protocol and the Paris Agreement). It also sidesteps the issue that the GWP_{100} values are themselves varying. The methane GWP_{100} used in the Kyoto Protocol has a value of 21, based on IPCC's SAR, as does documentation on the UNFCCC website[5]. The AR5 value, including climate-carbon feedback (which 'likely provides a better estimate' Myhre *et al* 2013) is 34. A 60% spread in possible values hardly ensures internal consistency and yet UNFCCC do not seem to perceive this as problematic.

Despite the arbitrary nature of many aspects of GWP_{100} noted above, which the authors do not discuss, they do note that their results 'show that national emission estimates that use *GWP** are very sensitive to arbitrary choices'. In fact, every different metric or metric value will give a different national emissions estimate, and therefore any choice of metric could be deemed arbitrary. This arbitrariness and ambiguity can be avoided by treating each greenhouse gas separately, as recommended by Denison *et al* (2019). However, even with this approach, the target to aim for would have to be chosen using some consistent measure across gases. Given the warming targets in the Paris Agreement, actors may wish to choose a metric which aligns with those warming targets, for which warming-equivalent emissions are useful.

A fundamentally flawed assumption underlies RS19's use of the term 'grandfathering', as they make no clear distinction between grandfathering emissions and grandfathering warming. They state that 'when applying equation (2) at the level of a specific country this is equivalent to implementing a "grandfathering" principle because GWP* takes a country's historic emissions level as its starting point. The grandfathering principle is often regarded as being inequitable and hence strongly criticised'. In the three references then cited, two do not distinguish SLCPs from long lived emissions. The third, Peters *et al* (2015) did not estimate contributions of non-CO_2 gases, and notes that because of the limitations to GWP_{100}, a better route to dividing up remaining non-CO_2 budgets would be to 'share the "remaining" temperature to reach 2 °C'. This concept is one that has motivated the development of using GWP* to calculate CO_2-warming-equivalent (CO_2-we) emissions to allow discussions of historical responsibility. Using CO_2-we emissions provides a solution to problems related to grandfathering consistent with the arguments laid out in Peters *et al* (2015).

The problem of 'grandfathering' emissions demonstrated using GWP* applies equally to historical CO_2 emissions. Whether different ethical

[1] https://unfccc.int/sites/default/files/resource/cma2018_3_add2_new_advance.pdf#page=25 (Annex II, part D).
[2] https://unfccc.int/sites/default/files/resource/SBSTA2019_03E.pdf.
[3] https://unfccc.int/event/sbsta-51#eq-21.
[4] https://unfccc.int/resource/docs/2011/sbsta/eng/02.pdf.
[5] https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials.

standards should be applied to methane and CO_2 (namely that countries should undo past warming caused by their methane emissions, but not that caused by their CO_2 emissions) is a matter for policy debate that GWP* facilitates by making the issue transparent. RS19 do not discuss this issue, which should be at the heart of any discussion of grandfathering and equity.

The use of GWP* does not imply that RS19's 'grandfathering' approach should be used, or that the correct target for every country is net zero CO_2-we calculated using GWP* for all GHG emissions. To refer to 'the grandfathering approach of the original GWP*' is incongruous, as the original GWP* was not applied to any specific policy. As RS19 demonstrate, there are many ways to apply GWP*, all of which are consistent with the original definition (although the equation appears to be incorrectly applied in RS19's 'zero reference' case). The 'limitations' and 'unintended consequences' they note are specific to the policy framework in which RS19 presuppose GWP* to be embedded. They are not a limitation of the metric itself.

In the first section, RS19 directly and inaccurately assert that Cain (2019) misunderstands well established climate science by 'suggesting that reducing methane emissions would result in global cooling'. Cain (2019) does not use the phrase 'global cooling', and is clear about the role of methane reductions on climate, consistent with established climate science such as in Solomon *et al* (2010).

In the discussion, RS19 incorrectly state that choice of time interval Δt used to determine rates of change of emissions $\Delta E/\Delta t$ strongly alters results. This is not true of cumulative warming-equivalent emissions, nor is it true of annual emissions when these are changing smoothly over time, as in most policy scenarios, and from which the GWP* concept was derived. RS19 instead discuss the impacts of setting a zero-methane-emissions baseline to report annual CO_2-we emissions; a use of GWP* which they are the first to introduce. In any case, altering Δt does not alter the total amount of cumulative CO_2-we emissions, just how they are spread across a number of years. By altering Δt from 20 years to 1 year without making the commensurate change to ΔE, they describe a completely different emissions pathway with different warming implications, which therefore should and does correspond to a different level of warming-equivalent emissions in year t, although no change in cumulative warming-equivalent emissions over a 20 year period. This suggests RS19 have made an error in the rate of change contribution in the GWP* equation, and it is unclear from the manuscript whether the equation was correctly applied to the emissions data to create figure 3.

Finally, we note that conventional GWP_{100} is also unnecessary to address some of the equity discussions raised. RS19 imply that reporting annual methane emissions per capita using GWP_{100} can facilitate equitable policy design by highlighting how a number of developed countries are responsible for a disproportionate share of contemporary methane emissions (as shown in table 2). This point could be made just as (if not more) clearly by simply reporting the direct methane emissions per capita. Scaling by GWP_{100} to express this in terms of CO_2e serves no purpose except to mislead by suggesting these emissions have an equivalent effect to the reported amount of CO_2, which—as stated above and acknowledged by RS19—they do not.

3. Summary

Many of the claims of 'unintentional unfairness' that RS19 claim arise from innovations in metrics would apply not only to GWP*, but to any metrics which successfully mimic the warming effects of a flow of gases, such as CGTP (Collins *et al* 2020). Furthermore, it can easily be shown that there are important conditions under which the approach favoured by RS19 might be considered more unfair than equal weighting of warming-equivalent emissions. There is no ethical reason that warming from one source ought to be represented differently from warming from another source. Under mitigation policies there may be reasons to distinguish among sources or sectors, for example in terms of burden-sharing. However, the effects of those decisions should be fully transparent in their warming implications, consistent with the Paris Agreement. That is what the use of GWP* would enable.

Data availability statement

No new data was created or analysed in this study.

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