GREENHOUSE GAS ACCOUNTING METRICS UNDER THE PARIS AGREEMENT

A CAUTIONARY TALE OF THE IMPLICATIONS OF APPLYING NOVEL SCIENTIFIC CONCEPTS TO AN EXISTING POLICY CONTEXT

Executive Summary

The commonly agreed metric to aggregate emissions and removals of greenhouse gases (GHGs) under the UNFCCC and the Paris Agreement is the Global Warming Potential with a 100-year time-horizon (GWP100). Interpreting the Paris Agreement mitigation goal expressed in its Article 4 using GWP100 is fully consistent with achieving the Agreement's long-term temperature goal.

The GWP100 approach was adopted for reporting under the UNFCCC in 1996 following IPCC assessment of different time-horizons (20, 100, and 500 years) as balance of short, mid and long-term effects of emissions. Emphasizing the long term (500 year effects of GHGs) can result in higher rates of warming, whereas emphasizing the short-term (20 year effects of GHGs) would result in higher levels of CO_2 emissions and longer term warming.

Since the Paris Agreement was adopted, new scientific concepts have been discussed, for example a recently proposed accounting metric GWP* that addresses the well-known shortcomings of GWP100 in representing the near-term warming contributions of short-lived greenhouse gases such as methane. However, great care needs to be taken when applying new metrics that appear scientifically favourable to a specific national climate policy contexts, and that discount the longer term achievement of the Paris Agreement long term temperature goal, and specifically its 1.5°C limit.

Using accounting metrics other than GWP100 can lead to fundamental inconsistencies in the Paris Agreement's mitigation architecture. For GWP*, these inconsistencies could even undermine the integrity of the Agreement's mitigation goals altogether by preventing it delivering net-zero CO_2 emissions. Warming can only be limited by achieving net-zero CO_2. Just a new metric such as GWP* does not in any way change this core scientific finding of a finite CO_2 emissions budget, arguably one of the most important insights of the past decade of climate science.

The GWP* metric depends on past emissions, and hence raises questions of equity and fairness when applied to anything except the global level. Applying GWP* in the national context would benefit countries with high historic emissions and put those with low emissions - mainly developing countries - at a profound disadvantage.

A brief introduction into Global Warming Potentials

A number of greenhouse gases (GHGs) contribute to anthropogenic climate change. The dominant GHG - CO_2 - stays in the atmosphere for centuries to millennia (Myhre *et al* 2013). Unlike CO_2 and other long-lived GHGs, some other greenhouse gases, including methane, are short-lived: they decay in the atmosphere after emission on a timescale of years to decades.

Any method aiming at aggregating different GHGs has to account for the different nature of these gases. The most common approaches to account for different GHGs are using forcing centred metrics known as 'global warming potentials' (GWPs) that allow expressing a basket of GHGs in terms of CO_2 equivalent (CO_2eq). GWPs express the ratio of the time-integrated radiative forcing effect of a pulse emission of a certain GHG relative to the effect of a pulse emission of an equal mass of CO_2 (Myhre *et al* 2013).

The length over which this time integral is being considered reflects a value judgement with respect to short- and long-term priorities of mitigation and warming targets[1]. In order to reflect the need of global decarbonisation towards net-zero CO_2 as the prerequisite for stopping climate change, using a 100-year time horizon (GWP100) has emerged as the common approach under the UNFCCC since the mid-1990s. GWP100 is the agreed metric for reporting under the Kyoto Protocol (UNFCCC 1997) as well as the Paris Agreement (UNFCCC 2018).

Any time horizon chosen for GWP will always result in a compromise between representing well the effects of long-lived versus short-lived GHGs. The focus on the long-term effects of GHG emissions is leading to a misrepresentation of the warming effect of short lived GHGs in the near-term, an issue that has long been understood. Different approaches have been proposed to address this issue, including metrics focussing directly on the temperature effects like 'global temperature potentials' (Shine *et al* 2005).

More recently, a novel forcing-centred metric aiming at improving the warming representation of short lived GHGs has been proposed called GWP* (Allen *et al* 2016, 2018). In GWP* a sustained change in the rate of emission of a short-lived GHG is treated as being equivalent to a one-off pulse of emissions of CO_2 over a given time frame. By doing so, GWP* more accurately captures the direct impact of changes of emissions in short-lived GHGs on radiative forcing and temperature, while still representing the long-term effects of long-lived GHGs including CO_2.

GHG Metrics under the Paris Agreement

The mitigation goal of the Paris Agreement is expressed in its Article 4 and sets out to operationalize the long-term temperature goal of the Paris Agreement. Specifically, it also refers to achieving net-zero GHG emissions in the "second half of the 21st century". The timing of when net-zero GHG emissions is to be achieved is to be determined by the best available science in relation to emission pathways that are consistent with meeting the long-term temperature goal of the Paris Agreement. The implications of the timing of achieving net zero GHGs in relation to global mean temperature goal depends on the metric used to account for different GHGs (Fuglestvedt et al 2018).

The Paris Agreement does not specify an accounting metric. However, this does not mean that the metric is *unknown.* GWPs were first introduced in the IPCC First Assessment Report in 1990, subject to a special report on Radiative forcing in 1994, with the use of GWP100 agreed as the common metric for reporting under the UNFCCC adopted at COP2 in 1996 for Annex I countries and in 2002 for all[2]. Since then, GWP100 been the basis for the mitigation pathways and net zero targets assessed including in the IPCC Fourth' Assessment report in 2007. The mitigation pathways assessed in the Working Group III report of the IPCC Fifth' Assessment Report (IPCC 2014) provided the scientific base for Paris Agreement and its Article 4.1. and these were all reported in terms of GWP100 metrics.

[1] Climate Analytics, 2017, Why using 20-year Global Warming Potentials (GWPs) for emission targets are a very bad idea for climate policy

[2] See https://unfccc.int/process-and-meetings/transparency-and-reporting/methods-for-climate-change-transparency/common-metrics

The Paris Agreement was based on the science of the time, and is related to the UNFCCC so it is therefore only logical that GWP100 is the appropriate metric to assess the Paris Agreement. An assessment of the implications of the application of different metrics in the context of the global mitigation architecture reflected in Article 2.1a and Article 4 of the Paris Agreement can also provide useful insights into the compatibility of different metrics with the Agreement.

However, it must be understood that actual physical emissions of each individual GHG for a specific emissions pathway do not change by just changing the metric used for comparing GHGs with each other: the global temperature goal in Article 2 is still achieved, or not, for the specific pathway. But changing the metric would break the science-based link between Articles 2 and 4, in terms of the timing of peaking, reduction rates and the timing of achieving net zero GHG emissions in Article 4, which are based on GWP100-related science and that are used to operationalize the LTTG of Article 2.

The two articles and relevant implications are outlined in Box 1.

Box 1: Interpretations and implications of the long term temperature and mitigation goals of the Paris Agreement - (Based on(Schleussner *et al* 2019)

Elements of the Paris Agreement	Interpretation
Article 2.1: *"This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, […], including by:* *a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change"*	– The long-term temperature goal (LTTG) of the Paris Agreement constitutes one goal referencing two temperature levels, while establishing 1.5°C global mean temperature (GMT) rise above pre-industrial levels as the long-term warming limit (Schleussner *et al* 2016). – The LTTG caters for two interpretations: establishing a 1.5°C limit that should not be exceeded, or allowing for a temporarily exceedance (overshoot) of the 1.5°C limit, while warming should always remain "well below 2°C" (Mace 2016). – Specifically, the LTTG expresses the need to pursue (continuous) efforts towards 1.5°C which includes the need to peak and decline GMT and reduce GMT again below 1.5°C in the case of a temporary overshoot. – The IPCC SR1.5 SPM has reinforced this understanding in it is categorization of 1.5°C compatible pathways as those that allow only a limited overshoot (0.1°C or less) and return warming below 1.5°C by 2100 – The LTTG does not reference levels of temperature stabilization, but establishes warming levels that should not be exceeded. – The LTTG serves the purpose to "enhance the implementation" of the objective of the UNFCCC that is to achieve a "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The LTTG does not prejudge on where this GHG level would be nor does it imply in any form that stabilizing warming at e.g. 1.5°C would be sufficient to avoid dangerous interference. It is thereby not in contradiction with assessments that find that present levels of warming of 1°C may already constitute dangerous interference for the most vulnerable (UNFCCC 2015). – The LTTG is linked to assessments of the risks and impacts of climate change based on the science available at the time, i.e. as reflected in the IPCC AR5 and metrics used in therein (Pfleiderer *et al* 2018).

Article 4.1: *"In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, […], and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity,[…]"*	– The mitigation goal (MG) is explicitly linked to the LTTG and therefore also needs to cater for both the LTTG interpretations outlined above. – The MG establishes conditions under which the LTTG can be achieved. Ambiguity with respect to several of its elements exist, but any interpretation that achieves the MG cannot be fundamentally at odds with the LTTG. – The language on 'balance of sources and sinks' is equivalent to achieving net zero GHG emissions (Fuglestvedt *et al* 2018). – The reference to 'best available science' limits the space of potential 'rapid reductions thereafter' to pathways that are achieving the LTTG. – The MG constrains pathways up to the achievement of net zero GHG emissions. It does not speak to actions after this benchmark has been achieved. – The MG is embedded in the UNFCCC policy context including the concept of equity.

A thorough assessment of different emission pathways has recently been conducted (Schleussner *et al* 2019). Modifying a Paris Agreement compatible emissions pathway, this study has examined the implications of for Article 4 interpreted in the GWP100 and the GWP* metric, in relation the achievement of the LTTG in Article 2 of the Paris Agreement.

The study has found that interpreting Article 4 using GWP100 results in emission pathways that are fully consistent with the LTTG set out in Article 2. Therefore, applying GWP100 to operationalize Article 4 appears to be the scientifically sound approach that accounts for the full context of the Paris Agreement.

In contrast, Schleussner *et al* 2019 identify a range of issues with the application of GWP* to the operationalization of Article 4 that contradict the achievement if the LTTG of the Paris Agreement

Specifically:

- Achieving GWP* weighted net-zero GHGs in the second half of 21st century in line with Article 4 would lead to a median warming of about 1.8°C or more and could even exceed 2°C.
- In order to hold warming to 'well-below 2°C', achieving net-zero GHGs in GWP* terms <u>before</u> 2050 would be required.
- Achieving GWP* weighted net-zero GHGs could be achieved without achieving net-zero CO_2, which means that achieving Article 4 in GWP* terms cannot guarantee to halt global mean temperature rise.
- At best, achieving GWP* weighted net-zero GHGs * will lead to a stabilisation of global mean temperatures. A stabilisation of global mean temperature above 1.5°C is inconsistent with the 'pursuing efforts' objective set out in Article 2.1a of the Agreement. A stabilisation of global mean temperature below 1.5°C would require net-zero GHGs in GWP* well before 2050.

While GWP* has shown to be excellent at linking cumulative CO_2-equivalent emissions to the global mean temperature response, it performs poorly in linking emission benchmarks to long-term temperature outcomes such as Article 2 of the Paris Agreement. Article 4 of the Paris Agreement is expressed in terms of an evolution of annual emissions over time, as outlined in Box 1 (peak as soon as possible in a given year, a rapid decline in annual emissions, and a net zero GHG in a given year), not in terms of cumulative CO_2-equivalent emissions for which GWP* would be best placed. As we have shown, this discrepancy undermines the applicability of GWP* in the context of the Paris Agreement.

Attempting to operationalize Article 4 using GWP* weighted GHGs will not achieve the temperature goal set out in Article 2.1a and unless GWP* weighted GHGs reach zero well before mid-century, which is net zero GHG goal in Article 4.1 of the Paris Agreement.

GHG Metrics in the national context

The net-zero GHG target set out in Article 4 is not only applying to the global scale. A range of countries and other societal actors world-wide have already set out net-zero targets for themselves[3]. At the same time, a global market mechanism is foreseen under the Paris Agreement. A common market requires comparable metrics in the sense that every tonne of CO_2eq that is entering the market is a tonne that is actually emitted to the atmosphere and thus is independent of a national background or circumstance. This is the case for GWP100.

A challenge that arises with the use of GWP* is the path-dependency of its accounting of historical emissions. While this is not an issue on the global level, an application at any other level raises the question of 'ownership' of historical emissions that has to be addressed. This question is not a scientific one, but one of equity and fairness.

If GWP* was applied to a national or other non-global context without an appropriate reflection on this value judgement dimension, it would be the equivalent to a 'grandfathering' of historical emissions of short lived GHGs such as methane. Countries with high historical methane emissions could benefit strongly from using GWP*.

Countries with lower historical emissions, like many developing countries, that may look into future increases of their emissions as a result of growing populations or economic development would be heavily penalised. Box 2 below provides an overview of the effects of an accounting of methane for a selection of countries.

Box 2 Ranking of countries according to the per capita CH_4 emissions accounted for using GWP100 (left) and GWP* (right). Developed countries are marked in bold and with a gray shading, Russia as a major oil and gas producer in italics and major developing economies in normal font.*(from* (Rogelj and Schleussner 2019)

GWP-100 2015 per cap CH_4 emissions ranking	Tonne CO2eq per cap
New Zealand	8.3
Russian Federation	6.5
Australia	4.8
Republic of Ireland	3.2
United States of America	2.3
Brazil	2.2
China	1.2

*GWP** 2015 per cap CH_4 emissions ranking	Tonne CO2eq per cap
Russian Federation	8.0
Brazil	2.8
China	2.2
Senegal	1.2
New Zealand	0.9
India	0.1
Fiji	-0.3

[3] See e.g. the Net Zero Tracker: https://eciu.net/netzerotracker (retrieved: Nov 28 2019)

Fiji	1.1
European Union	1.0
Senegal)	0.8
India	0.4

United States of America	-1.8
Republic of Ireland	-2.1
European Union	-2.2
Australia	-2.2

Box 2 showcases how an application of GWP* would benefit developed countries and put developing countries at a profound disadvantage. Countries that reduce their methane emissions (like the USA or EU over the historical record) could even see 'negative CO_2eq' emissions from reducing methane if accounted for using GWP*.It is important to highlight that these are not physical 'negative emissions', but a GWP* accounting effect resulting from continued positive, but reduced methane emissions. This is a fundamental difference from actual physical carbon dioxide removal that effectively reduces long-term warming.

The higher the historical emissions, the bigger the potential 'negative CO_2eq' emissions. For example, if New Zealand decreases its CH4 emissions by 50% in 2035 below 2015 levels, this would equate to a perceived 'additional' CO_2 budget of about 2.5 times New Zealand's annual CO_2 emissions in the year 2015 (Rogelj and Schleussner 2019). Such 'negative' CO_2 emissions could lead to increased emissions of CO_2 and therefore more long-term warming.

Other fairness and equity approaches could of course be deployed to distribute the historical emissions leading to very different outcomes (Rogelj and Schleussner 2019), for high methane emitting countries such as New Zealand up to a factor of 40. Such equity approaches require value judgements by countries making the deployment of GWP*-like approaches effectively a political and not scientific choice.

The distributional problem of historical emissions under GWP* exists not only for countries, but on all levels including between sectors and even within sectors. If, for example, farmers in the same country were to apply a GWP* like approach to their methane accounting, farmers with high historic emissions would greatly benefit, completely distorting a levelled playing field. Smaller emitters, or those with expanding business would be decisively disadvantaged.

Similarly, distribution of emissions reductions between sectors with some sectors having a higher share of methane emissions than others (i.e. the fossil fuel or agriculture sector), would become extremely difficult to resolve.

To further add to the problem, GWP* in its simple form does not fully account for the full warming effect of short-lived climate forcers, but requires scenario specific corrections for carbon cycle and other feedbacks (Cain *et al* 2019). Such a correction cannot be known beforehand, further complicating the application of the metric in a non-scientific context.

Novel metrics in the climate policy context – a cautionary tale

GWP* clearly represents a scientific advancement in terms of our ability to assess the effects of different short and long-lived greenhouse gases to near-term warming globally. This, however, does not mean that it also is a superior approach in the science policy context. In fact, bringing novel metrics to a science policy context without reflecting on the specific context can lead to unintended and detrimental outcomes such as creating major inconsistencies or the shifting of goalposts (Tokarska *et al* 2019, Pfleiderer *et al* 2018).

We have shown how an interpretation of the net-zero target in the Paris Agreement using GWP* is inconsistent with the Paris Agreement's mitigation architecture and could fundamentally undermine its integrity. Even more so, an application of this metric to any but the global level would raise fundamental questions of equity and fairness and would put developing countries at a profound disadvantage.

The Paris Agreement rulebook requires reporting of GHGs in GWP100. Our findings show that this choice is consistent with the long-term goals of the Paris Agreement.

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