How to calculate emissions impacts using climate metrics

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A climate, or emissions equivalency, metric is an exchange rate that converts emissions of one greenhouse gas into equivalent emissions of another gas, typically carbon dioxide (CO_2), where "equivalency" is determined by the relative climate impacts of the two gases. We can use a climate metric to convert emissions of methane (CH_4), plus additional emissions of CO_2, to a single, CO_2-equivalent value, thereby allowing these gases to be compared on a single scale:

$$\text{Grams } CO_2\text{-equivalent} = \text{Grams } CO_2 + (\text{Grams } CH_4 \times CH_4\text{-to-}CO_2 \text{ Metric})\,.$$

The units of the climate impact are grams CO_2-equivalent per gram CH_4, which means we are adding quantities of the same units. The above equation can also be expanded to include other greenhouse gases, such as nitrous oxide (N_2O).

Greenhouse gases may have very different properties [1], which means there is no single metric that converts the climate impact of one greenhouse gas into an equivalent impact in terms of another gas: a climate policy goal must come into play. CH_4, for instance, has a shorter lifetime (decades) than CO_2 (centuries to millennia), but while in the atmosphere CH_4 traps more heat. The conventional Global Warming Potential (GWP) metric addresses this issue by comparing emissions based on the amount of heat they trap over 100 years, taking into account how much heat is trapped per molecule and how long the emission is expected to remain in the atmosphere.

However, if we use the GWP to make decisions we risk missing near-term climate policy targets, because the GWP undervalues decade-scale gases like CH_4 [2]. We propose two metrics that compare emissions in terms of their impact relative to a 3 W/m^2 radiative forcing stabilization target, which in equilibrium is roughly associated with a 2°C temperature change, a commonly-cited policy goal to reduce the risk of dangerous interference with the climate system [3]. The instantaneous climate impact (ICI) metric compares emissions based on their impacts in an expected stabilization year (around mid-century), whereas the cumulative climate impact (CCI) metric compares impacts over all years up to the stabilization year (see [2] for more details).

Unlike the GWP, the impact value that the ICI and CCI place on greenhouse gases depends on the time at which they are emitted. A gas like CH_4, which is relatively short-lived compared to CO_2, is initially assigned a low impact value, but this value is increased as the intended time of stabilization approaches. This is because, if a short-lived gas is emitted far from an intended time of stabilization, it has relatively little impact on whether stabilization is reached (most of it will be removed from the atmosphere before then), but if it is emitted close to stabilization, it can have a significant impact. The ICI and CCI both capture this phenomenon.

The ICI and CCI belong to the same 'family' of metrics but differ in that applying the ICI results in a faster approach to the radiative forcing stabilization target and in that way is less conservative than the CCI from a climate change perspective. The ICI may also permit a temporary overshoot of the stabilization level, so the CCI is recommended for situations where large amounts of CH_4 are being evaluated (e.g. policies and technology evaluations at the national and global level), whereas the ICI is recommended in other situations, and may permit strategic short-term use of technologies with high CH_4 while meeting climate targets.

The ICI or CCI can be used to evaluate emissions impacts of technologies or economic activity against a common policy goal of 3 W/m^2 radiative forcing stabilization (corresponding to a roughly 2°C temperature change). The spreadsheet metricsTool.xlsx provides a form for calculating CO_2-equivalent impacts using the three metrics discussed here. It can be used freely with attribution. Please cite Edwards and Trancik 2014 [2] and this document [4].

References

[1] T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, editors. *Climate Change 2013: The Physical Science Basis*. Intergovernmental Panel on Climate Change, Cambridge University Press, 2013.

[2] M. R. Edwards and J. E. Trancik. Climate impacts of energy technologies depend on emissions timing. *Nature Clim. Change*, 4(5):347–352, 2014.

[3] United Nations Framework Convention on Climate Change. *Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009*, number FCCC/CP/2009/11/Add.1, March 2010.

[4] *How to calculate emissions impacts using climate metrics*. Trancik Lab, Engineering Systems Divsion, Massachusetts Institute of Technology, 2014.