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Importance of different greenhouse gases in achieving Paris Goals

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This is a summary of the role that different greenhouse gases play in climate change and its mitigation. A science-based treatment of short-lived pollutants such as methane is required to meet the Paris Agreement targets for both limiting warming and for achieving "balance" of greenhouse gases.

Stabilisation of Climate

In order to meet the Paris Goals, the global mean surface temperature (GMST) will have to stabilise at a level well below 2C. To achieve stabilisation, two things must happen. First, the amount of, and therefore the warming from, CO_2 in the atmosphere will have to stabilise. For this to happen, CO_2 emissions will have to be net-zero, because CO_2 emissions are cumulative. If we overshoot the temperature target, we would have to remove CO_2 from the atmosphere to then bring temperature back below 2C.

Second, non-CO_2 pollutants will also have to stabilise in the atmosphere. For long-lived pollutants such as N_2O, this will mean reducing emissions to net-zero as well. This is likely to mean offsetting any N_2O emissions that cannot be eradicated by removal of CO_2 from the atmosphere. Given the lifetime of N_2O is more than a century, the exchange of an emission of N_2O for a removal of CO_2 is straightforward when considering the relative impact on climate over the next 100 years. The amount of "equivalent" carbon dioxide that would need to be captured to offset the release of a tonne of nitrous oxide is relatively unambiguous, at about 265 tonnes, where 265 is the "100-year Global Warming Potential" (GWP_{100}) of nitrous oxide[1].

There are key two issues that arise for methane, because of its 12-year lifetime. First, in order to stabilise methane concentrations in the atmosphere, net-zero emissions are not required. This is because some methane is destroyed in the atmosphere on relatively short timescales, so net-zero methane emissions would cause the amount of methane in the atmosphere to decline over the following decades. Second, if it is deemed necessary to compensate for ongoing methane emissions by removing CO_2, it is not a like-for-like exchange as it is for N_2O. Many policy instruments, including the 2008 UK Climate Change Act (UKCCA), treat methane emissions as "carbon dioxide equivalent" (CO_2-e) using GWP_{100}: one tonne of methane is considered equivalent to approximately 28 tonnes of carbon dioxide. Under this method, a one-off removal of CO_2 has a longer-term effect on climate than the one-off emission of CH_4 it would be ostensibly offsetting.

The relative contributions of CO_2 and non-CO_2 pollutants in the atmosphere is not important for the temperature per se, as long as the combination limits warming to 2C. The longer it takes to reduce CO_2 to net-zero, the larger the cumulative amount of CO_2 in the atmosphere will be, and the more non-CO_2 emissions will have to reduce to keep warming below 2C. On the other hand, if CO_2 emissions reach net-zero more rapidly, the amount non-CO_2 pollutants in the atmosphere could be higher and still comply with the 2C limit.

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[1] Myhre, G., et al., 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Misrepresentations of the climate impact of methane emissions

It has long been known[2] that treating short-lived climate pollutants (SLCPs) such as methane as carbon-dioxide-equivalent using GWP_{100} misrepresents their impact on GMST, but the impact of this misrepresentation is limited as long as emissions are rising and/or methane emissions comprise a relatively small fraction of the total. Under conditions in which methane emissions are stable or falling, and methane makes a substantial contribution to total emissions, GWP_{100} is not fit for purpose as a metric of the impact of greenhouse gas emissions on GMST. It understates the immediate impact of methane emissions on warming trends, and simultaneously overstates their cumulative impact on total warming.

The relevance of this point for Ireland is demonstrated by comparing figures 1 and 2. Figure 1 shows an illustration of Ireland's emissions[3] of carbon dioxide, methane and nitrous oxide from 1970 to 2035 expressed as carbon-dioxide-equivalent using the standard GWP_{100} metric. Figure 2 shows (left panel) the impact of Ireland's emissions on the rate of increase in GMST calculated with a standard simple climate model, and on the right the impact of these emissions on the total increase in GMST since 1970. After 2010, there is a cooling in response to declining methane emissions (fig 2, blue), which is not well represented in the CO_2-equivalent (CO_2-e) emissions in figure 1.

Comparing figures 1 and 2, it is clear that annual emission rates of carbon dioxide and nitrous oxide, expressed as carbon dioxide equivalent using GWP_{100}, accurately indicate their respective contributions to the rate of increase in GMST, while cumulative emissions of these gases indicate their contributions to total warming. The picture is entirely different for methane. GWP100 overstates the cumulative impact of methane emissions, which have contributed only about one third of the warming of CO_2 emissions that has occurred since 1970, whereas methane's cumulative CO_2-e emissions are nearly half that of CO_2. The warming trend is not well represented by the CO_2-e emissions for methane, as it is for CO_2 and N_2O. For methane, the warming arising from increasing methane emissions is under-represented by GWP_{100}, and the cooling arising from declining emissions is represented by a warming. **Under any future scenarios where methane emissions were reducing, this would also be represented as a warming using GWP_{100}.**

Science-based comparison of emissions

Because of this simultaneous over- and under-statement of different aspects of the impact of methane emissions, simply adopting a higher or lower "conversion rate" to convert a tonne of methane into tonnes of carbon-dioxide-equivalent does not solve the problem. There is, however, a simple solution, which is to treat a permanent increase in methane emission rate as equivalent to one-off release of a fixed number of tonnes of carbon dioxide.[4] This approach has been shown[5] to reflect the impact of methane emissions on GMST much better than GWP_{100} or any alternative traditional conversion factor, because it accurately reflects the well-established science of how methane and carbon dioxide emissions behave.[6]

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[2] Pierrehumbert, R. T. Short-Lived Climate Pollution. Annual Review of Earth and Planetary Sciences 42, 341-379, doi:doi:10.1146/annurev-earth-060313-054843 (2014).
[3] Emissions have been assembled from the following sources: EDGAR, CDIAC, European Environment Agency, Irish EPA for projections. This timeseries has been assembled for illustrative purposes.
[4] Allen, MR, Fuglestvedt, JS, Shine, KP, Reisinger, A, Pierrehumbert, RT, & Forster, PM: A new use of Global Warming Potentials to compare cumulative and short-lived climate pollutants, Nature Climate Change, 6, 773- 776 (2016).
[5] Allen, MR, Shine, KP, Fuglestvedt, JS, Millar, RJ, Cain, M, Frame, DJ, & Macey, AH: A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Climate and Atmospheric Science, 1(1), 16. https://doi.org/10.1038/s41612-018-0026-8 (2018).
[6] Lauder, AR, Enting, IG, Carter, JO et al: Offsetting methane emissions – An alternative to emission equivalence metrics, Int. J. Greenhouse Gas Control, 12, 419-429 (2013).

This is demonstrated in figure 3, which shows Ireland's emissions since 1970 expressed in terms of GWP*, a revised usage of GWP that accounts for the different behaviour of SLCPs like methane. Carbon dioxide and nitrous oxide emissions are unchanged, but methane emissions, expressed as carbon-dioxide-equivalent using GWP*, now much more accurately reflect their impact on GMST shown in figure 2.

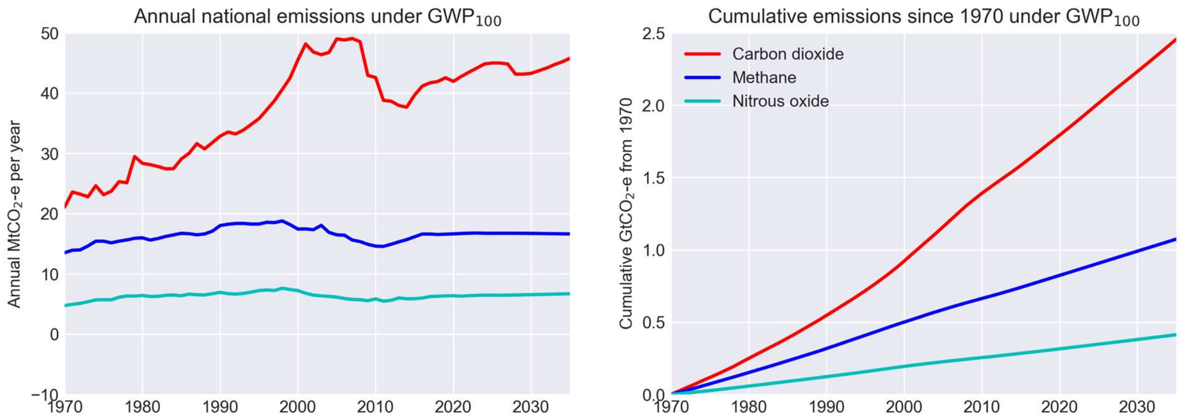

Figure 1: Illustration of Ireland's greenhouse gas emissions (from the EDGAR dataset extended with data from the CDIAC database pre-1990, the European Environment Agency between 1990 and 2016, and projections from the Irish EPA up to 2035) expressed in terms of CO_2-e calculated with conventional GWP_{100}. Left panel shows annual rate of emissions in millions of tonnes CO_2-e per year, right panel shows cumulative emissions since 1970 in billions of tonnes CO2-e, for the three major gases, carbon dioxide, methane and nitrous oxide.

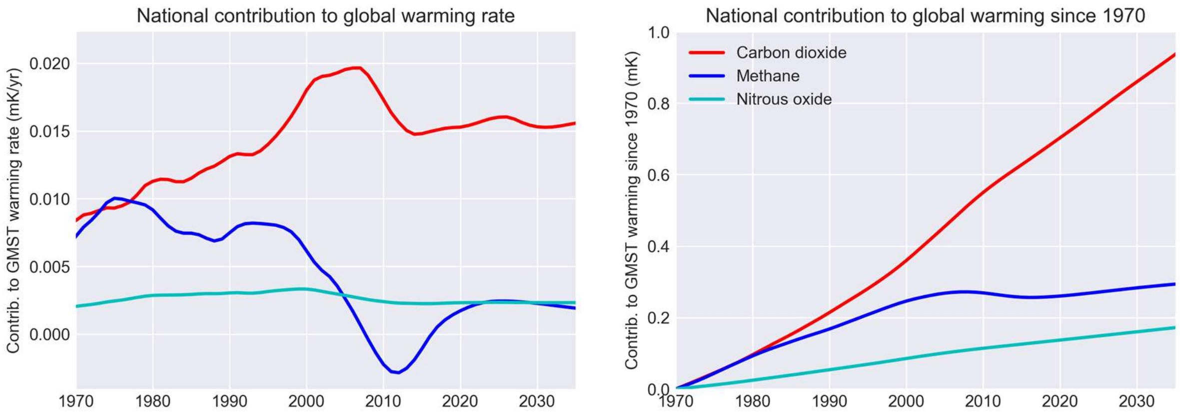

Figure 2: Contribution of Ireland's emissions to global warming, expressed as (left panel) contribution to the rate of increase in global mean surface temperature (GMST) and (right panel) total increase in GMST since 1970, computed by subtracting Ireland's emissions from observed and projected global totals and calculating the impact on GMST computed using the multigas variant of the FaIR simple climate model[7] with default climate system properties. Relative size of warming due to different gases is unaffected by uncertainties in climate system response on these timescales.

[7] Smith, CJ, Forster, PM, Allen, MR et al FAIR v1.3: a simple emissions-based impulse response and carbon cycle model, Geosci. Model Dev., 11, 2273-2297, (2018).

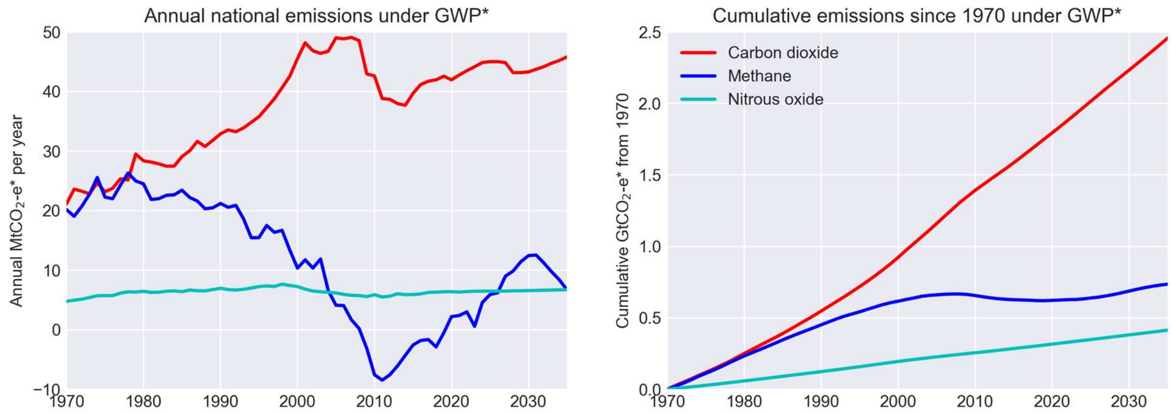

Figure 3: Ireland's greenhouse gas emissions recalculated using GWP*. Left panel shows annual rate of emissions in millions of tonnes CO_2-e* per year, right panel shows cumulative emissions since 1970 in billions of tonnes CO_2-e*, for the three major gases. Carbon dioxide and nitrous oxide emissions are unchanged from figure 1, but methane emissions are larger when the trend in emissions is rising, and are lower (even negative) when the trend is declining, much better reflecting their contribution to the change in GMST shown in figure 2.

Summary

Simply treating all gases as carbon-dioxide-equivalent using GWP_{100} could be seen as both unfair and inefficient. Unfair, because a farmer who is reducing their rate of methane emissions by 0.4% per year would not be contributing at all to further global warming (see appendix), would feel themselves penalised for those remaining methane emissions in exactly the same way that a power-station-owner was being penalised for ongoing carbon dioxide emissions, which would be acting to increase GMST. It would also be inefficient, because GWP_{100} understates the impact of changing methane emission rates, potentially undervaluing many methane-related mitigation opportunities.

It is possible to design policies that accurately reflect the impact of methane and carbon dioxide on GMST over a broad range of timescales. It is often argued that comparing emissions of different greenhouse gas involves an inescapably subjective decision regarding the time-scale of interest. Figures 2 and 3 show this is not the case: when measured in a way that reflects their geophysical behaviour, cumulative emissions of methane, carbon dioxide and nitrous oxide predict their respective impacts on GMST remarkably accurately.

Appendix:

Calculating carbon-dioxide-equivalent emissions using GWP*

The formula used to express methane emissions as carbon-dioxide-equivalent in figure 3 is as follows:

$$E^*_{CO_2e} = \left(0.7 \times \frac{\Delta E_{CH_4}}{\Delta t} \times GWP_H \times H\right) + \left(0.3 \times E_{CH_4} \times GWP_H\right)$$

where E and E^* are the annual rates of methane and carbon-dioxide-equivalent emissions, respectively, $\Delta E_{\mathrm{CH_4}}$ is the change in methane emission rate over the preceding Δt time interval (20 years in figure 3), H is the GWP time-horizon (100 years in this example) and $\mathrm{GWP_H}$ is the conventional GWP of methane. Methane emissions declining at a rate of $0.3/(0.7\times H) = 0.4\%$ per year are therefore equivalent to a zero rate of carbon-dioxide-equivalent emissions, in that neither contributes to any further increase in GMST.