**Simple formula for the calculation of CO2-fe carbon budgets**

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A simple way of accounting for non-CO2 forcing in carbon budgets is to convert everything to CO2 forcing-equivalent (CO2-fe) emissions, or the time-history of CO2 emissions that would give a particular radiative forcing path . This provides the most accurate definition of an ‘all-pollutants CO2 budget’ and is discussed in detail in Jenkins *et al.* ,2019 (in prep). This requires an invertible carbon cycle model, but on decade-to-century timescales CO2-fe emissions may be approximated by the following relationship

(1)

where is the Absolute Global Warming Potential of CO2, or the forcing integrated over time-horizon resulting from a one-tonne pulse emission of CO2, and is a constant. To understand why, consider the instantaneous forcing at time resulting from a sustained one tonne-per-year emission of CO2 starting at time zero, or (Shine *et al.*, 2005). This is equivalent, for a linear response, to the AGWP*H*, and increases approximately linearly over these timescales (figure 8.29 of Myhre *et al.*, 2013). Hence and the RHS of equation (1) becomes , the LHS.

The value of depends on the fractional rate at which forcing is expected to decline over the decades after CO2 emissions are set to zero. This depends on the past forcing history, but an indication is given by noting that zero CO2 emissions is consistent with stable temperatures, and forcing would need to decline at a rate to maintain stable temperatures in the decades immediately following forcing stabilisation after a 70-year linear increase, where ECS is the Equilibrium Climate Sensitivity, TCR the Transient Climate Response and the longer of the two adjustment timescales7,8 of the physical climate system. This implies per year and with years.8–10

If non-CO2 forcing is defined using effective radiative forcing, then human-induced warming ΔT over a multi-decade time-interval is

(2)

where the TCRE is the transient climate response to emissions11,12, represents cumulative CO2 emissions, the average and the change in non-CO2 radiative forcing over that time-interval. This expression does not capture sub-decadal adjustments, so must be defined between periods each of at least a decade in duration.

Parties to the UNFCCC have agreed to aggregate emissions using consistent GWP100 values. If and only if emissions of long-lived pollutants (those with lifetimes longer than 100 years) are aggregated separately, this allows a further simplification of equation (2) for future warming (with ):

(3)

Change this to an average over the 20 years (so 3.75 \* deltaF and 0.25 \* F) and link to dual metric stuff? i.e. 3.75 roughly looks like GWP20, 0.25 roughly looks like GTP100?

where and are future cumulative long-lived and short-lived climate pollutants and is the change in SLCP emission rate between the most recent decade and the decade prior to peak warming, all expressed as aggregate CO2-equivalent using GWP100.

Figure 1 is based on figure 2 in Jenkins *et al.* (2019, in prep.). Figure 1a shows the median RF scenario from all 1.5℃-compatible scenarios in the SR15 scenario database[!!]. Figure 1b shows the CO2-fe emissions timeseries resulting from the application of equation 1. Panel 1c show the corresponding temperature responses by component. Here, the solid lines plot the cumulative CO2-fe emissions of each pollutant, while dotted lines show the equivalent conversion using the commonly used GWP100 metric. Cumulative CO2-fe emissions track the warming response shape, while GWP100 emissions timeseries fail for short-lived climate pollutants.

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**Figure 1**: Panel a shows the stacked contributions from components of the total anthropogenic radiative forcing in the median 1.5℃-compatible scenario in the SR15 scenarios database. Panel b shows the annual CO2-fe emissions timeseries as calculated by inverting the FaIRv1.0 carbon cycle model (dotted) and using equation 1 to approximate (solid). Panel c shows the temperature response from pre-industrial (1850-1900) for the anthropogenic radiative forcing, coloured by contribution from each component. Solid lines show the cumulative CO2-fe emissions of each pollutant, which track the temperature response better than the GWP100 converted cumulative emissions (dotted).

**References**