surface roughness, that regulate the transfer of heat to the atmosphere[7,8].

Management can impact the climate forcing of a piece of land in different ways and to different extents. For example, fertilization and irrigation of crops and pastures can increase the productivity of a land-cover type, thereby increasing its leaf area index, reducing surface reflectivity and increasing carbon uptake and water loss. Other management activities, such as the grazing of grasslands, the type of agricultural tillage, the timing of planting and forest thinning, can invoke a variety of positive and negative feedbacks, which can lead to warming or cooling. We also have to consider that changes in management and land cover alter greenhouse gas emissions. Practices that perturb carbon pools stored in vegetation and the soil promote carbon losses and increase the atmospheric CO_2 burden. Fertilization produces the emission of ultra-strong greenhouse gases like nitrous oxide, which has a radiative forcing about 300 times stronger than CO_2 (on a molecule per molecule basis over 100 years). Consequently, the assessment of how land management affects climate on short and long timescales requires full greenhouse gas accounting[9,10].

Alterations to biophysical processes are important at the local and regional scales as they may change the surface-energy balance by tens of Watts per square metre (W m^{-2}), compared with the low radiative forcing (3 W m^{-2}) that is induced by the current greenhouse gas burden in the atmosphere[11]. To compare the effects these forces have on the Earth's climate, however, it is necessary to consider the spatial scale at which they act. Greenhouse gas radiative forcing may be relatively small on an areal basis, but it is applied across the entire planet. Conversely, the radiative forcing attributed to land-cover change and management is concentrated in space and can change with time.

Naturally, a number of unresolved issues that warrant further investigation remain. How the enhancement or suppression of clouds will affect the albedo of the planetary boundary layer[12,13] is a particularly important question. More paired management studies that control the degree and type of management in a prescribed and incremental way would also strengthen future analysis. ❐

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CLIMATE CHANGE MITIGATION

Deposing global warming potentials

Accounting for time-dependent mechanisms in greenhouse gas radiative forcing and evaluating the performance of mitigation technologies in the context of climate stabilization targets can better inform technology choices today and in the future.

Alissa Kendall

The performance of technologies targeting greenhouse gas mitigation is nearly always measured using global warming potentials (GWPs). However, anecdotes, including my own unscientific survey, suggest that many researchers and practitioners working in fields related to climate change mitigation do not understand the actual meaning of GWPs, nor do they understand the application of GWPs in calculations of carbon dioxide equivalency (CO_2e) and carbon footprints — a peculiar state of affairs given that these metrics and indicators are important for assessing the performance of the very solutions those researchers are developing. Moreover, most stakeholders in the climate change mitigation discourse have unquestioningly adopted the Intergovernmental Panel on Climate Change's GWP as the method for characterizing and comparing greenhouse gases (GHGs). Only a relatively small (but growing) group of researchers have questioned, attempted to improve on and argued for change in the methods and metrics we use to track, trade and value different GHG emissions. Now, as they describe in *Nature Climate Change*, Morgan Edwards and Jessika Trancik offer new metrics that target technology assessment in relation to an explicit climate change mitigation goal[1].

Current GHG characterization practices apply GWPs to convert non-CO_2 GHGs to CO_2e, typically using a 100-year analytical time horizon. The conversion is made by taking the ratio of cumulative radiative forcing, over the selected analytical time horizon, for equal masses of CO_2 and the GHG being evaluated. GWP calculations include a few important simplifications: (1) both gases are evaluated over a particular analytical time horizon, regardless of when an emission or removal from the atmosphere occurs; and (2) the changing background concentrations of gases in the atmosphere are ignored, despite their effects on the radiative efficiency of a gas, and thus its radiative forcing. Starting around the year 2000, there have been calls for addressing some of these limitations, including the timing of emissions and sequestration[2,3] and the presumption that cumulative radiative forcing should be used as the indicator of the climate impact of a GHG[4]. Since then, researchers have continued to propose new metrics, many of which increase the level of complexity (of the metric's formulation and use) and which sometimes result in tailored metrics for particular technologies, sectors or applications. These include metrics tailored to biofuels[5], the transport sector[6], carbon mitigation projects[7] or carbon intensity calculations[8], to name only a few.

Edwards and Trancik[1] have entered the dialogue on alternatives to GWP with clear and well-defined intent — to contextualize technology performance within climate stabilization targets and to respond to major shortcomings of GWPs; particularly arbitrary analytical time horizon selections, the omission of changing background GHG concentrations in the atmosphere and the exclusion of emissions timing. They also propose both a cumulative metric, the cumulative climate intensity (CCI), and an instantaneous metric, the instantaneous climate intensity (ICI). The novelty and value of these metrics goes beyond addressing timing and background concentration levels; for example, they have particular value in understanding pathway-dependent factors like technology penetration rates or the optimal retirement age for particular technologies, all in the context of reaching a policy-relevant stabilization target.

In their findings, Edwards and Trancik[1] highlight the different effects of near-term and future technologies with relatively high methane emissions. Because methane is shorter-lived than CO_2 but has a higher radiative efficiency, it is necessary to retire technologies with high methane emissions to achieve radiative forcing targets as the stabilization year nears. Although others have previously concluded that the impacts of methane emissions may be underestimated when GWPs are used[9], the CCI and ICI metrics reflect policy targets and can yield specific recommendations for technology adoption and retirement over time.

Despite the richness of the CCI and ICI metrics, they face a critical limitation; those of us who want to use them in our own analyses cannot. Like many of the more comprehensive and dynamic metrics intended to supplant (or supplement) GWPs, a potential user has no practical way to apply these metrics short of building their own model. The next step for those hoping to see adoption of alternatives to GWPs is to devise an open-source tool, or some other practical solution, for helping all of us who have been convinced that it is time for a change. ❐

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