LETTER

Temperature change vs. cumulative radiative forcing as metrics for evaluating climate consequences of energy system choices

Alvarez et al. (1) proposed assessing the relative climate benefits of alternative energy technologies for policy purposes by comparing a time-integrated approximation to the radiative forcing produced by each alternative. In contrast, Myhrvold and Caldeira (2) propose comparing the change in global mean temperature that each alternative technology would produce under various schedules of deployment.

Myhrvold and Caldeira (2) propose that temperature at some time t after deployment of the system can be approximated by a one-dimensional diffusive column,

$$\frac{\partial T(t,z)}{\partial t} = \kappa \frac{\partial^2 T(t,z)}{\partial z^2}, \qquad \mathbf{[1]}$$

where $T(t, z)$ is the temperature perturbation to the ocean at depth z at time t (*cf.* ref. 3). The upper boundary condition is

$$\kappa \rho c_p \frac{\partial T(t,z)}{\partial t}\bigg|_{z=0} = \mathrm{RF}(t) - \lambda T(t,0), \qquad \mathbf{[2]}$$

where $\mathrm{RF}(t)$ is the radiative forcing at time t from the energy system under consideration (2). When appropriately calibrated, these simple equations closely follow the global mean temperature results of more complex 3D coupled atmosphere–ocean simulations (4). A characteristic timescale τ for this system is

$$\tau = \kappa \left(\frac{\rho c_p}{\lambda}\right)^2. \qquad \mathbf{[3]}$$

Representative parameter values are $\kappa = 10^{-4}\ \mathrm{m^2 \cdot s^{-1}}$, $\rho = 10^3\ \mathrm{kg \cdot m^{-3}}$, $c_p = 4 \times 10^4\ \mathrm{J \cdot kg^{-1} \cdot K^{-1}}$, and $\lambda = 1.25\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$ (2). For these parameter values, $\tau = 10^9$ s or about 32 y. On timescales that are short relative to τ, the climate response is governed largely by effective heat capacity whereas on longer timescales it is governed largely by equilibrium climate response (i.e., RF/λ). A weakness of the metrics proposed by Alvarez et al. (1) is that it fails to take these climate system characteristics into account and thus can misstate the climate impact of a technology and the timescale on which it occurs.

For example, century-scale consequences of a pulse of methane released at year zero are very different from those of a sustained constant CO_2 emission rate, even if both scenarios have the same cumulative radiative forcing and thus the same metric by the Alvarez et al. (1) method. End-of-century climate would be much warmer in the CO_2 case. Or consider effects of a deforestation event occurring 50 y ago vs. an equivalent one 500 y ago. Today, the cumulative radiative forcing from the older deforestation event would be far greater than that from the more recent event, but the older event would have far less impact on current climate. The metric proposed by Alvarez et al. (1) fails to measure differences that could be important to policy choices between energy system alternatives.

Temperature is a physical parameter that is easily understood by policymakers and has direct environmental consequences. It is a better metric for policy consideration than an artificial construct like integrated radiative forcing that reflects neither the temporal dynamics of the climate-system response nor the temporal discounting common in economic assessment. The temperature change approach used by Myhrvold and Caldeira (2) is physically justified; it can be incorporated easily into economic assessment models (*cf.* ref. 5) and is applicable to many energy technologies besides natural gas and coal (2).

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