Constraining future greenhouse gas emissions by a cumulative target

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By 1994 all major industrialized nations, including the United States, had ratified the United Nations Framework Convention on Climate Change (UNFCCC), yet 15 years later policymakers still debate how best to formulate emissions legislation. Article 2 of the UNFCCC calls for “stabilization of greenhouse gas concentrations... at a level that would prevent dangerous anthropogenic interference with the climate system.” Emissions targets are commonly quoted as a percentage reduction relative to a baseline year. A different framework for emissions targets is presented in a recent issue of PNAS (1), wherein the targets are set as a cumulative emissions inventory, spelling out to policymakers the net emissions allowable to avoid the worst impacts of climate change.

Setting emissions targets around a net cumulative quota is a familiar paradigm for policymakers. It is analogous to planning for expenditure against a net income or setting a catch quota to maintain a sustainable fishery. In such cases, the available resource is fundamentally limited in a cumulative sense; harvest or spend too much and things become unsustainable. For the global harvesting of fossil fuels the message becomes clear: burn beyond a cumulative cap and you commit the planet to a high risk of dangerous anthropogenic climate change.

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Fig. 1. Historical and future scenarios of global carbon emissions (Upper) and their cumulative growth (Lower) in PgC (1 PgC = 1 × 1015 g of carbon). Pathways 1–3 show three scenarios where total post-2000 emissions accumulate to 590 PgC, giving a 66% chance that long-term warming will not exceed 2 °C (1). Curve 4 yields 170 PgC post-2000 emissions and a 90% probability of avoiding 2 °C warming. Curve 5 shows an example of rapid decarbonization (25% reduction by 2020 and 80% reduction by 2100, relative to a 2007 baseline), but with weaker mitigation into the future, resulting in ongoing increasing cumulative emissions beyond 2100. Error bars at right indicate the range in post-2000 emissions for the 66% and 90% probability cases of 2 °C warming, when a suite of climate sensitivities and carbon feedbacks are taken into account. Scenario 6 shows business as usual for several decades to come, with emissions peaking in 2050 before gradually declining over the ensuing century (cumulative post-2000 emissions eventually stabilize at ~1,890 PgC). This net emission yields a ~50–50 chance of exceeding 4 °C warming using the median climate sensitivity and carbon feedback range examined by Zickfeld et al. (1).

Carbon feedbacks occur when there are climate-induced changes in the net fluxes of carbon between the land/ocean and the atmosphere. The strength of the feedback depends on the scale of physical climate change and biophysical processes in the ocean and land systems. A simple example of an ocean carbon feedback is caused by the solubility of CO2, which varies inversely with temperature. Ocean warming reduces the capacity of seawater to dissolve CO2, which weakens the solubility pump as the planet warms (3). Carbon feedbacks are particularly uncertain for the terrestrial biosphere (4, 5), with changes in atmospheric quantities directly affecting vegetation type, properties, and physiological function. These can then affect land carbon uptake via both positive and negative feedbacks (4).

The anthropogenic carbon stored in the oceans and terrestrial biosphere has acted as a tremendous buffer of climate change to date; these systems have absorbed more than half of our industrial emissions (6). Yet the ability of these stores to sequester carbon is changing over time. Fifty years ago natural carbon sinks removed ~600 kg of every ton of CO2 emitted to the atmosphere. Today, these sinks remove only ~550 kg per ton emitted (6), and this amount is expected to continue to fall (3, 4). There are also risks of abrupt change in the terrestrial carbon sink; for example, climate change could trigger Amazon forest die-back (7), and permafrost melt could expose northern peatlands to large releases of carbon (8), both resulting in strong positive feedbacks. In short, the carbon sinks that have served us so well are by no means stable: they are changing and, unfortunately, changing in the wrong sense. Add to this land clearing and the associated release of CO2 and loss of natural carbon storage (9), and the combined land–ocean sink is showing diminishing returns in time.

Carbon feedbacks can thus greatly reduce the allowable emissions to stabilize at some policy-prescribed target. Yet these feedbacks are generally not incorporated into future climate projections. By doing an inverse calculation within their model, Zickfeld et al. (1) are able to progressively track an emissions pathway that leads to a given stabilization target for global warming, while also incorporating carbon feedbacks. This approach differs from the conventional methodology in that they (i) use an inverse method working back from a given temperature target to quantify the allowable CO2 emissions; (ii) explicitly link CO2 emissions with CO2 concentrations, taking into account the coupled carbon cycle; (iii) quantify the emissions in terms of a cumulative target that turns out to be more robust than the time-dependent pathway, and (iv) use a 3D coupled carbon cycle model. This procedure allows an examination of the evolution of the coupled

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climate-carbon cycle toward temperature stabilization, consistently deriving cumulative emissions along the way. Zickfeld et al. (1) present their results in a probabilistic framework, incorporating ensembles of simulations adopting a wide range of climate sensitivity levels, and a suite of model estimates of the carbon feedback magnitude.

Zickfeld et al. (1) show that to have a decent chance of stabilizing warming to <2 °C above preindustrial, net carbon emissions (accumulated from the year 2000) must not exceed ≈590 PgC (1 PgC = 1 × 10¹⁵ g of carbon, or equivalently 3.67 Pg of CO₂). This value is the median across a range of climate sensitivities and carbon feedback rates (see Fig. 1). Here, a “decent” chance is defined as P > 0.66, equivalent to “likely” in Intergovernmental Panel on Climate Change (IPCC) lexicon. alarmingly, in the first 15 years from 2000, net carbon emissions will reach ≈100 PgC, approximately a sixth of the cumulative emissions budgeted for above. If policymakers seek even greater certainty to avoid crossing the 2 °C threshold, say moving into the “very likely” range in IPCC lexicon (P = 0.9), then it is estimated we need to cap post-2000 emissions at only 170 PgC. Assuming unmitigated greenhouse gas emissions over the next few years, we will exceed this cumulative quota as soon as 2017, which is a sobering metric in the lead-up to Copenhagen this year.

Zickfeld et al. (1) further show that the allowable cumulative emissions for a given stabilization target are robust to the chosen pathway toward stabilization. This finding agrees with three recent studies (10–12), each exhibiting remarkably consistent cumulative emissions targets. What this result implies is that aiming for percentage reductions relative to a baseline year is not enough: cumulative emissions must also be capped. This is demonstrated in Fig. 1, which shows six different emissions trajectories out to the year 2200, along with the corresponding cumulative emissions. Among the pathways shown are three scenarios (labeled 1–3) that are likely (P = 0.66) to yield a long-term global warming of <2 °C. Also shown is an emissions pathway (trajectory 4) that gives a very likely chance (P = 0.9) of stabilizing warming at or below 2 °C, an ambitious yet uncapped trajectory that sees cumulative emissions still growing by 2200, and a “business-as-usual” scenario that sees emissions not peaking until 2050 before gradually declining over the ensuing century. Curves 1–4 in Fig. 1 are based on the median values obtained by Zickfeld et al. (1), spanning a range of climate sensitivities and carbon feedback rates.

Apparent in scenarios 1–3 in Fig. 1 is the strong tradeoff between the date of peak emissions and the subsequent required rate of decarbonization of the economy. Put simply, if policymakers still significant action for too long, then the required rate of decommissioning fossil fuel technologies shoots up. Apparent in scenario 5 is the need for urgent and sustained reduction strategies: in that case deep emissions reductions are achieved in the near term, but the phasing out of carbon-intensive technologies then progresses slowly, leading to the continued growth of net emissions beyond the end of this century. This scenario is unlikely to stabilize global warming <2 °C.

Perhaps the most troubling of the scenarios is trajectory 4, which sees emissions plunge dramatically from today, capping at a mere 170 PgC of post-2000 emissions. According to the median estimates of Zickfeld et al. (1), this cumulative emission yields a 90% chance of avoiding a 2 °C warming. Although this task is daunting, indeed all but impossible, Article 2 of the UNFCCC suggests this goal should be firmly in the minds of policymakers. Unfortunately, the past 15 years of inaction has very real policy implications today.

There are, of course, uncertainties in the magnitude of carbon feedback and climate sensitivity, as also described by Zickfeld et al. (1); two examples are shown on the right side of Fig. 1. These indicate the range of cumulative emissions allowable for the 66% and 90% likelihoods of avoiding 2 °C warming. So, at the high end of carbon feedback and climate sensitivity, being 90% sure of avoiding the 2 °C threshold would have required that emissions and land-clearing ceased in the middle of the last century (~220 PgC). Today, this would require active removal of greenhouse gasses from the atmosphere. At the extreme, taking the questionable risk of assuming very low climate sensitivity and carbon feedback, we still need to cap post-2000 emissions at only 700 PgC. This requires a peak in emissions within the next few decades followed by rapid decarbonization.

A global mean warming of 2 °C could still have devastating impacts on climate (13), ecosystems, human health, and infrastructure. This level of warming, for example, is likely to significantly reduce food productivity over the tropics, substantially increase the risk of extinction for 20–30% of species worldwide, bleach most of the world’s coral reefs, and increase the likelihood of severe weather and extreme climate events (14). Global warming to ≈2.7 °C could additionally trigger a gradual but irreversible disintegration of the West Antarctic Ice Sheet, with still lower thresholds thought to apply to the Greenland Ice Sheet (15), ultimately raising sea level by >10 m and displacing hundreds of millions of people worldwide.

Two degrees Celsius warming should thus not be seen as a mere aspirational target: it surely has to be the maximum stabilization target for global warming, with recognition that even this carries significant global-scale risks. Worryingly, this once-modest target is becoming increasingly difficult to achieve, requiring deep emissions cuts over a confronting time frame, something that must be secured in Copenhagen this year.


