RCP8.5 tracks cumulative CO_2 emissions

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Climate simulation-based scenarios are routinely used to characterize a range of plausible climate futures. Despite some recent progress on bending the emissions curve, RCP8.5, the most aggressive scenario in assumed fossil fuel use for global climate models, will continue to serve as a useful tool for quantifying physical climate risk, especially over near- to midterm policy-relevant time horizons. Not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative CO_2 emissions (within 1%), but RCP8.5 is also the best match out to midcentury under current and stated policies with still highly plausible levels of CO_2 emissions in 2100.

climate change | business as usual | CO_2 emissions

Because future climate depends on future human behavior, which is inherently unpredictable, scenarios are used to characterize a range of plausible climate futures and to illustrate the consequences of policy choices. For the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5) four scenarios known as Representative Concentration Pathways (RCPs) were developed. The RCP scenarios as used in global climate models use historical greenhouse gas emissions until 2005, and projected emissions subsequently. A widely used scenario and the most aggressive in assumed fossil fuel use, RCP8.5, by design has an additional 8.5 W/m^2 radiative forcing by 2100. Recent comments in the scientific community (1, 2) as well as in magazine-style pieces and the gray literature argue that contemporary emissions forecasts from the International Energy Agency (IEA) make it increasingly unlikely that RCP8.5 describes a plausible future climate outcome. RCP8.5 is characterized as extreme, alarmist, and "misleading" (1), with some commentators going so far as to dismiss any study using RCP8.5. This line of argumentation is not only regrettable, it is skewed.

The defining property of the RCP family of scenarios is radiative forcing. A radiative forcing is the additional amount of energy in Earth's climate system, with each RCP having a prescribed increase by 2100 relative to preindustrial levels. For purposes of driving forward global climate simulations, a single emissions trajectory consistent with the specified radiative forcing was chosen for each RCP. RCP8.5 uses emissions at the 90th percentile level of baseline scenarios then available (3) and depicts "a relatively conservative business as usual case with low income, high population and high energy demand" (4). The "business as usual" descriptor for RCP8.5 has been used repeatedly, if somewhat inconsistently and controversially (1, 2, 5). Our discussion here, as well as in the broader literature on the usefulness of RCP8.5, centers on these chosen emissions trajectories.

In evaluating any RCP scenario, it is fundamental that scenarios are not predictions, which is why they are not associated with likelihoods (3). Rather, scenarios are used to present decision makers with the outcomes of as broad a range of plausible choices as possible, so as to inform their decisions. It is meaningless to characterize a scenario as "misleading"—that assumes that we know the true future and are deliberately predicting a different one. We should instead focus on how useful scenarios may be. Focusing solely on end-of-century outcomes is an inadequate way to evaluate the usefulness of a given RCP. For purposes of informing societal decisions, shorter time horizons are highly relevant, and it is important to have scenarios which are useful on those horizons. Looking at midcentury and sooner, RCP8.5 is clearly the most useful choice.

Since the increase in the global-mean temperature is determined by cumulative emissions of greenhouse gases, cumulative emissions are an important metric by which to assess the usefulness of scenarios. We note that climate system feedbacks also influence the global temperature increase, but these, too, are strongly influenced by cumulative human greenhouse gas emissions. By this metric, among the RCP scenarios, RCP8.5 agrees most closely—within 1% for 2005 to 2020 (Fig. 1)—with total cumulative CO_2 emissions (6). The next-closest scenario, RCP2.6, underestimates cumulative emissions by 7.4%. Therefore, not using RCP8.5 to describe the previous 15 y assumes a level of mitigation that did not occur, thereby skewing subsequent assessments by lessening the severity of warming and associated physical climate risk. It is significant here that the design choices for RCP8.5 were articulated *ex ante* and without any attempt to predict the future, yet this close agreement should not surprise. In previous IPCC scenario catalogs historical emissions have been in closer agreement with more extensive fossil fuel use scenarios (7). Finally, we note that the usefulness of RCP8.5 is not changed due the ongoing coronavirus disease 2019 pandemic. Assuming pandemic restrictions remain in place until the end of 2020 would entail a reduction in emissions of −4.7 Gt CO_2 (8). This represents less than 1% of total cumulative CO_2 emissions since 2005 for all RCPs and observations.

Moving out to midcentury, consistent with the policy window in the context of the Paris Accord as well as time horizons of large capital expenditures, we focus on total cumulative CO_2 emissions from 2005 to both 2030 and 2050. Our baseline is historical emissions combined with IEA (9) forward scenarios on energy-related emissions plus land use and industrial emissions. We use both the Stated Policies (STEPS; announced policy intentions or "business as intended") and Current Policy (CPS; only in-place policies or "business as usual") scenarios and compare these with all four RCPs (Fig. 1). We find that total cumulative CO_2 emissions for either IEA scenario are between RCP8.5 and RCP4.5. The former overestimates emissions, whereas the latter underestimates total CO_2 emissions. The offsets are similar in magnitude. For example, in 2030 using the IEA "business as usual" scenario, RCP8.5 overestimates cumulative emissions by 76.7 Gt CO_2 (slightly less than 2 y of 2020 emissions), whereas RCP4.5 underestimates by 88.1 Gt CO_2 (slightly more than 2 y of 2020 emissions). Focusing on 2050 the story is similar: RCP8.5 overestimates the IEA "business as usual" scenario by 234.5 Gt CO_2, and RCP4.5 underestimates by 385.5 Gt CO_2.

Given two IEA scenarios that land roughly midway between RCP8.5 and RCP4.5 for total cumulative CO_2 emissions, why should we select the upper-range scenario instead of the lower-range scenario as our preferred near-term modeling tool? In addition to the issue of path dependency—recall that RCP8.5 2005 to 2020 total cumulative CO_2 emissions are within 1% of

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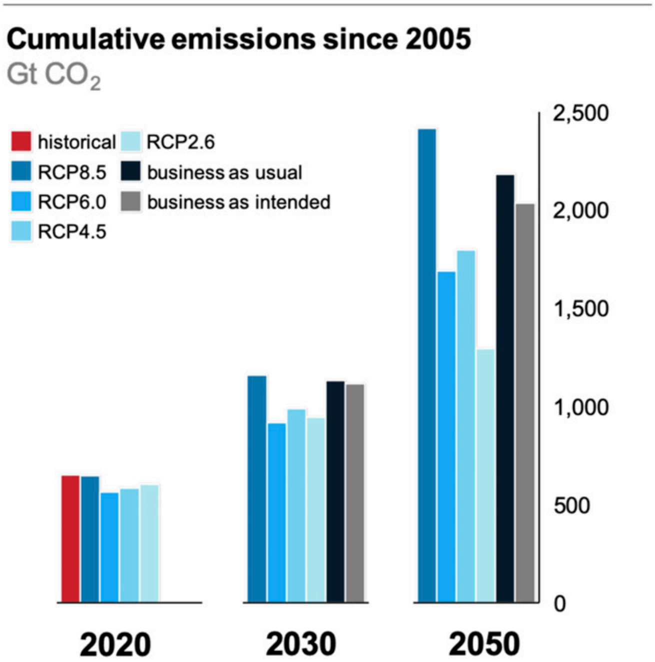

Fig. 1. Total cumulative CO_2 emissions since 2005 through 2020, 2030, and 2050. Data sources: Historical data from Global Carbon Project (6); emissions consistent with RCPs are from RCP Database Version 2.0.5 (https://tntcat.iiasa.ac.at/RcpDb/); "business as usual" and "business as intended" are from IEA Current Policies and Stated Policies scenarios, respectively (9). IEA data (fossil fuel from energy use only) was combined with future land use and industrial emissions to estimate total CO_2 emissions. Future land use emissions estimated from linear trend fit to 2005 to 2019 Global Carbon Project land use emissions data (6). Industrial emissions estimated as 10% of total emissions. Final IEA data use historical values through 2020 and scenario values thereafter. Biotic feedbacks are not included in any IEA-based estimate. Note that RCP forcing levels are intended to represent the sum of biotic feedbacks and human emissions.

historical emissions—the issue of missing carbon cycle climate feedbacks is critical. In effect, these will act to raise both IEA scenarios toward the cumulative emissions represented by RCP8.5 and away from RCP4.5. These missing biotic feedbacks include permafrost thaw, changes in soil carbon dynamics, changes to forest fire frequency and severity, and spread of pests (10). While it is unclear the extent to which these missing pathways would close the emissions gap—our level of understanding here is low (10)—all act to increase the atmospheric burden of CO_2. State-of-the-art estimates show that the 2 °C carbon budget would be reduced by 150 Gt CO_2 (and up to 500 Gt CO_2 for the 95th percentile of additional forcing) to account for missing carbon feedbacks (11). This strongly suggests that while RCP8.5 and the IEA scenarios will not—indeed, cannot—be exact analogs, choosing RCP4.5 would be a definitive underestimate of physical climate risk. Missing feedbacks effectively accelerate warming outcomes—thus pulling them forward in time—further supporting using RCP8.5 out to midcentury.

Even though our focus here is through 2050, it is significant that moving to 2100 does not render RCP8.5 "misleading." End-of-century warming outcomes in RCP8.5 range from 3.3 °C to 5.4 °C (5th to 95th percentile) with a median of 4.5 °C. The level of overlap with outcomes under policies in place, where warming is anticipated to range from 2.3 °C to 4.1 °C with a median value of 3.0 °C (12), is indeed modest. While this is cause for guarded optimism, given the additional degradation of coupled human–natural systems that 4.5 °C would entail relative to a 3 °C world, it does not make using RCP8.5 "misleading" or useless. Furthermore, expert elicitation-based estimates of 2100 CO_2 emission levels range from 54.4 to 71.4 Gt CO_2/y (expert median range from three elicitations) (13). While this central estimate is smaller than the 105.6 Gt CO_2/y prescribed in RCP8.5, the same elicitation revealed 90th percentile estimates extending to 125 Gt CO_2/y in each experiment (13). Turning to integrated assessment models, the median estimate in 2100 is 94.3 Gt CO_2/y with a range of 28.5 to 272.7 Gt CO_2/y (5th to 95th percentile) (14). Furthermore, moving from emissions to concentrations in the context of forecasting long-term economic growth, the likelihood that CO_2 concentrations will exceed those assumed in RCP8.5 by 2100 is at least 35% (15). The implied probability of occurrence similar to RCP8.5 even at the end of the century is large enough to merit its continued use. Even so, we emphasize that scenarios are not competing forecasts but rather tools to assess risk.

It is important to note that no RCP was designed to project existing trends forward—the common assumption of what a "business as usual" scenario would entail. Relative to historical and anticipated trends the stylized facts underpinning RCP8.5 show faster economic growth, overestimates in carbon intensity, overaggressive coal use, and overpricing renewables relative to fossil fuels (1, 2). However, these issues are not yet at the threshold to substantially degrade the similarity between total cumulative CO_2 emissions and current policies to midcentury. Indeed, if the atmospheric burden of CO_2 tracks RCP8.5 the truthfulness of these stylized facts is largely moot when assessing physical climate risk. Given the agreement of 2005 to 2020 historical and RCP8.5 total CO_2 emissions and the congruence between current policies and RCP8.5 emission levels to midcentury, RCP8.5 has continued utility, both as an instrument to explore mean outcomes as well as risk. Indeed, if RCP8.5 did not exist, we'd have to create it.

Data Availability. All data used for analysis are publicly available from refs. 6 and 9 as well as from RCP Database Version 2.0.5 (https://tntcat.iiasa.ac.at/RcpDb/).

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