Groundwater overexploitation in China has led to rapid declines in the water table, drying up rivers like this one.

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Plans to protect China's depleted groundwater

Groundwater is a hidden resource that can store 100 times as much as global freshwater lakes and rivers (*1*). In China, groundwater serves as the primary source for drinking water for 70% of the population (*2*). Historically, China has lagged behind developed countries in managing and protecting groundwater. Over the past several decades, China has rapidly depleted groundwater reserves (*2*). Overexploitation of groundwater for domestic, agricultural, and industrial uses, exacerbated by climate change, has resulted in about 920,000 km^2 with substantial land subsidence (*3*) and more than 10,000 km^2 of coastal areas affected by seawater intrusion (*4*). It has also contributed to the loss of more than 16,000 km^2 of wetlands (*5*) and to more than half of the country's 50,000 rivers drying up (*6*). Overuse has left China's groundwater in a perpetual state of crisis (*7*).

In November 2021, Chinese Premier Li Keqiang signed the Regulation on Groundwater Management (*8*). The legislation was created to comprehensively and explicitly address groundwater-related issues, including investigation and planning, monitoring, risk assessment, overdraft control, pollution prevention, site remediation, regulatory oversight, and sustainable management. The plan requires ongoing consideration of groundwater quantity and quality and their relations to ecosystems, climate change, and sustainability. National coordination and enforcement will facilitate the implementation of management strategies, and clear division of responsibilities and jurisdictions for different government agencies will help to minimize bureaucratic red tape. These changes mark an important first step to sustainable groundwater management.

To ensure that China's efforts toward sustainable groundwater supplies are successful, the government should mandate equitable funding to support groundwater research and protection. For example, out of several hundred "state key laboratories" in science, engineering, and medicine, not one is currently devoted primarily to groundwater. Enactment of protective legislation should go hand-in-hand with strict enforcement of existing regulations. Finally, data-sharing in the field of groundwater should become a norm rather than an exception to promote management transparency and scientific advances.

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Transparency crucial to Paris climate scenarios

In their Policy Forum "Can updated climate pledges limit warming well below 2°C?" (5 November 2021, p. 693), Y. Ou and coauthors explain that the updated pledges submitted as part of the Paris Agreement process, although an improvement, will only result in a ~33% chance of staying within 2°C of warming. We agree with Ou *et al.* that more ambition is required, but we think even the low chance of success they estimate is overly optimistic. The mitigation pathways based on Paris Agreement pledges lack transparency and immediacy, making them difficult to evaluate and decreasing the chances of success.

The updated pledges, if executed as written, will result in negligible global emission reductions of 1% by 2030, according to Ou *et al.* Substantive reductions are postponed until after 2030 on the assumption that countries will fulfill their softer commitment to "long-term strategies." In line with earlier studies using integrated assessment models (*1*), these strategies heavily depend on negative-emissions technologies. For example, US fossil fuels and industry emissions are expected to fall from 2.7 $GtCO_2$ to –1.1 $GtCO_2$ between 2030 and 2050 according to the "Updated pledges-Continued ambition" scenario proposed by Ou *et al.* However, implementing negative-emissions technologies at such a large scale remains highly speculative and would present serious challenges to other sustainability dimensions (*2*). Analyses of this nature need to be transparent about the extent to which negative-emissions technologies are used. Only then can we evaluate the inherent risk of this goal not being achieved.

Other uncertainties merit structural attention as well. An energy transition to low-carbon alternatives could result in a lower average energy return, leading to

additional energy costs and indirect emissions (*3*). Moreover, modeled transitions rely on decoupling gross domestic product and energy at a faster rate than historical trends, which underestimates rebound effects caused by energy-efficiency policies (*4*). In addition, differing levels of pledge ambition could lead to carbon leakage, where emissions are transferred to countries with weaker policies (*5*). The extent to which these neglected uncertainties are captured in current and future integrated assessment model studies of the Paris Agreement pathways needs to be transparent and, ideally, quantified.

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Response

King *et al.* raise important issues, several of which pertain to the broader policy discourse surrounding international climate negotiations and countries' climate pledges rather than the modeling conducted in our Policy Forum. We agree with King *et al.* that the updated Paris Agreement pledges could paint an overly optimistic picture of the future, especially if their success depends on postponing deeper reductions until after 2030. To illustrate a less-optimistic future, our Policy Forum includes scenarios showing what would happen if countries continued to implement current policies alone. The "Current policy" scenarios in the Policy Forum result in less than a 10% chance of limiting global warming to below 2°C this century, whereas the "Updated pledges" scenarios result in at least a 33% chance of achieving the same temperature goal. Additional policy measures could help bridge emission gaps between current policies, updated pledges, and the global emission levels needed to cost-effectively achieve the Paris Agreement's climate goals (*1*).

We also agree with King *et al.* that greater near-term ambition is necessary, particularly to set up the technological, political, and financial infrastructures required to achieve the long-term strategies and net-zero pledges (*2*). Delaying emission reductions would substantially reduce the likelihood of achieving the Paris temperature goal (*3*) and could prove to be very expensive (*4*). However, we disagree that the updated 2021 pledges result in negligible global emission reductions. Our Policy Forum suggests that the updated pledges alone—if successfully implemented—could result in a reduction of 2030 global greenhouse gas emissions of about 6.6 $GtCO_2$ (12%) compared with the 2015 pledges. The United Nations Environment Programme suggests reductions of 4 $GtCO_2$ (7.5%) (*5*).

The "Updated pledges-Continued ambition" scenario in our Policy Forum assumes that countries with net-zero pledges achieve those pledges in the specified target years. Achieving net-zero pledges will require large-scale deployment of negative-emissions technologies (*6*, *7*). Our study assumes the availability of bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC) technologies in addition to terrestrial sinks and makes conservative assumptions about their deployment compared to the literature (*7*). Our assumptions about BECCS and DAC are transparently documented in several publications [e.g., (*8*, *9*)]. Moreover, the entire model code and data files used in our study are publicly available (*10*). Future research should explore the implications of alternative assumptions about the type and scale of negative-emissions technologies.

Our Policy Forum addressed uncertainties in the climate system, but we only focused on one source of uncertainty in emissions trajectories: stringency of climate policy. The minimum decarbonization rate assumption (2% per year) in our "Continued ambition" scenarios is on the conservative side of historical trends [fig. S2 in (*11*)] and conservative compared to developed countries with decarbonization policies (tables S14 to S17 in our Policy Forum). By contrast, our "Increased ambition" scenarios assume a higher minimum decarbonization rate (5%), which is on the higher end of historically observed rates [fig. S2 in (*11*)]. Many other uncertainties—including and beyond those highlighted by King *et al.*—could affect future emissions trajectories (*12*). Future research should also explore the implications of these variables.

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