ECONOMICS

Risk Communication on Climate: Mental Models and Mass Balance

Public confusion about the urgency of reductions in greenhouse gas emissions results from a basic misconception.

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The strong scientific consensus on the causes and risks of climate change stands in stark contrast to widespread confusion and complacency among the public (*1*, *2*). Why does this gulf exist, and why does it matter? Policies to manage complex natural and technical systems should be based on the best available scientific knowledge, and the Intergovernmental Panel on Climate Change (IPCC) provides rigorously vetted information to policy-makers. In democracies, however, the beliefs of the public, not only those of experts, affect government policy.

Effective risk communication is grounded in deep understanding of the mental models of policy-makers and citizens (*3*). What, then, are the principal mental models shaping people's beliefs about climate change? Studies show an apparent contradiction: Majorities in the United States and other nations have heard of climate change and say they support action to address it, yet climate change ranks far behind the economy, war, and terrorism among people's greatest concerns, and large majorities oppose policies that would cut greenhouse gas (GHG) emissions by raising fossil fuel prices (*1*, *2*).

More telling, a 2007 survey found a majority of U.S. respondents (54%) advocated a "wait-and-see" or "go slow" approach to emissions reductions. Larger majorities favored wait-and-see or go slow in Russia, China, and India (*1*, *2*). For most people, uncertainty about the risks of climate change means costly actions to reduce emissions should be deferred; if climate change begins to harm the economy, mitigation policies can then be implemented. However, long delays in the climate's response to anthropogenic forcing mean such reasoning is erroneous.

Wait-and-see works well in simple systems with short lags. We can wait until the teakettle whistles before removing it from the flame because there is little lag between the boil, the whistle, and our response. Similarly, wait-and-see would be a prudent response to climate change if there were short delays in the response of the climate system to intervention. However, there are substantial delays in every

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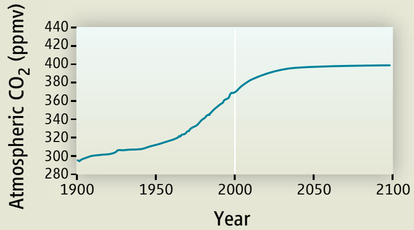
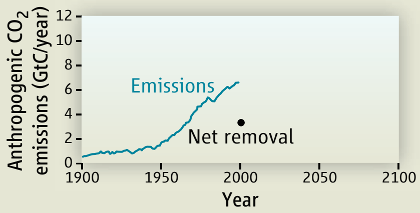
Consider a scenario in which the concentration of CO_2 in the atmosphere gradually rises to 400 ppm, about 8% higher than the level in 2000, then stabilizes by the year 2100, as shown here:



The graph below shows anthropogenic CO_2 emissions from 1900–2000, and current net removal of CO_2 from the atmosphere by natural processes. Sketch:

a. Your estimate of likely future net CO_2 removal, given the scenario above.
b. Your estimate of likely future anthropogenic CO_2 emissions, given the scenario above.



The climate stabilization task. Subjects were first given an excerpt from the IPCC SPM explicitly describing the accumulation of CO_2 in the atmosphere [see (*2*)].

link of a long causal chain stretching from the implementation of emissions abatement policies to emissions reductions to changes in atmospheric GHG concentrations to surface warming to changes in ice sheets, sea level, agricultural productivity, extinction rates, and other impacts (*4*–*6*). Mitigating the risks therefore requires emissions reductions long before additional harm is evident. Wait-and-see policies implicitly presume the climate is roughly a first-order linear system with a short time constant, rather than a complex dynamical system with long delays, multiple positive feedbacks, and nonlinearities that may cause abrupt, costly, and irreversible regime changes (*7*, *8*).

Obviously, few people are trained in climatology or nonlinear dynamics, and public understanding of these topics is poor (*9*–*11*). But there is a deeper problem: poor understanding of stocks and flows—the concept of accumulation. Accumulation is pervasive in everyday experience: Our bathtubs accumulate the inflow of water through the faucet less the outflow through the drain, our bank accounts accumulate deposits less withdrawals, and we all struggle to control our weight by managing the inflows and outflows of calories through diet and exercise. Yet, despite their ubiquity, research shows that people have difficulty relating the flows into and out of a stock to the level of the stock, even in simple, familiar contexts such as bank accounts and bathtubs. Instead, people often assess system dynamics using a pattern-matching heuristic, assuming that the output of a system should "look like"—be positively correlated with—its inputs (*12*, *13*).

Although sometimes useful, correlational reasoning fails in systems with important accumulations. Since 1950, the U.S. federal budget deficit and national debt have risen dramatically and are highly correlated (r = 0.84, $P < 0.0001$). Correlational reasoning predicts that cutting the deficit would also cut the debt. However, because the national debt is a stock that accumulates the deficit, it keeps rising even if the deficit falls; debt falls only if the government runs a surplus.

Poor understanding of accumulation leads to serious errors in reasoning about climate change (see charts, left, and on page 533). Sterman and Booth Sweeney (*14*) gave 212 graduate students at the Massachusetts Institute of Technology (MIT) a description of the relationships among GHG emissions, atmospheric concentrations, and global mean temperature. The description was excerpted from the IPCC's "Summary for Policymakers" (SPM), a document intended for nonspecialists (*4*). Participants were then asked to sketch the emissions trajectory required to stabilize atmospheric CO_2. To highlight the stock-flow structure, participants were first directed to estimate future net removal of CO_2 from the atmosphere (net CO_2 taken up by the oceans and biomass), then draw the emissions path needed to stabilize atmospheric CO_2 [the SOM (*2*) provides details].

Knowledge of climatology or calculus is not needed to respond correctly. The dynamics are easily understood using a bathtub analogy in which the water level represents the stock of atmospheric CO_2. Like any stock, atmospheric CO_2 rises when the inflow to the tub (emissions) exceeds the outflow (net removal), is unchanging when inflow equals outflow, and falls when outflow exceeds inflow. Participants were informed that anthropogenic CO_2 emissions are now roughly double net removal, so the tub is filling.

Yet, 84% drew patterns that violated the principles of accumulation. If emissions followed the path in the typical example shown, atmospheric CO_2 would continue to rise. Nearly two-thirds of the participants asserted that atmospheric GHGs can stabilize even though emissions continuously exceed removal—analogous to arguing a bathtub continuously filled faster than it drains will never overflow. Most believe that stopping the growth of emissions stops the growth of GHG concentrations. The erroneous belief that stabilizing emissions would quickly stabilize the climate supports wait-and-see policies but violates basic laws of physics.

Training in science does not prevent these errors. Three-fifths of the participants have degrees in science, technology, engineering, or mathematics (STEM); most others were trained in economics. Over 30% hold a prior graduate degree, 70% of these in STEM. These individuals are demographically similar to influential leaders in business, government, and the media, though with more STEM training than most.

It is tempting to respond to these discouraging results by arguing that poor public understanding of climate change is unimportant because policy should be informed by scientific expertise. Many call for a new Manhattan Project to address the challenge (*15*, *16*). The desire for such technical solutions is understandable. In 1939, scientists directly alerted the nation's leaders to developments in atomic physics, then, by focusing enough money and genius in the deserts of New Mexico, created nuclear weapons in just 6 years. Science has arguably never affected geopolitical outcomes more decisively.

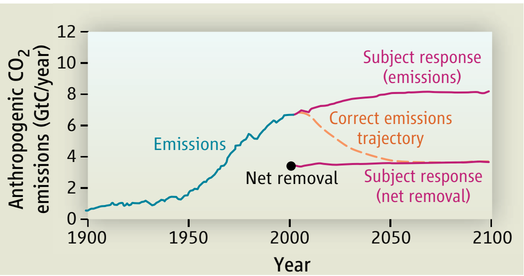
But a Manhattan Project cannot solve the climate problem (*17*). The bomb was developed in secret, with no role for the public. In contrast, reducing GHG emissions requires billions of individuals to cut their carbon footprints by, e.g., buying efficient vehicles, insulating their homes, using public transit, and, crucially, supporting legislation implementing emissions abatement policies. Changes in people's views and votes create the political support elected leaders require to act on the science. Changes in buying behavior create incentives for businesses to transform their products and operations. The public cannot be ignored.

The civil rights movement provides a better analogy for the climate challenge. Then, as now, entrenched interests vigorously opposed change. Political leadership and legislation often lagged public opinion and grass-roots action. Success required dramatic changes in people's beliefs and behavior, changes both causing and caused by the courageous actions of those who spoke out, registered voters, and marched in Washington and Selma (*18*).

Building public support for action on climate change is in many ways more challenging than the struggle for civil rights. Science is not needed to recognize the immorality of racism but is critical in understanding how GHG emissions can harm future generations. The damage caused by segregation was apparent to anyone who looked, but the damage caused by GHG emissions manifests only after long delays.

The scientific community has a vital role to play in building public understanding. First, the SPM is far too technical to change people's mental models. The IPCC should issue its findings in plain language. Second, clarity, while necessary, is not sufficient. When "common sense" and science conflict, people often reject the science (*3*). Even if people sincerely wish to mitigate the risks of climate change, wait-and-see will seem prudent if they misunderstand basic concepts of accumulation and erroneously believe that stopping the growth of emissions will quickly stabilize the climate. The implications go beyond the failure to understand accumulation. People's intuitive understanding of dynamics, including stocks and flows, time delays, and feedbacks, is poor (*11*). Analogous to common biases and errors in probabilistic reasoning (*19*), these errors are unlikely to be corrected merely by providing more information (*13*). We need new methods for people to develop their intuitive systems thinking capabilities. Bathtub analogies and interactive "management flight simulators" through which people can discover, for themselves, the dynamics of accumulation and impact of policies have proven effective in other settings (*20*) and may help here (*21*). Third, climate scientists should partner with psychologists, sociologists, and other social scientists to communicate the science in ways that foster hope and action rather than denial and despair. Doing so does not require scientists to abandon rigor or objectivity. People of good faith can debate the costs and benefits of policies to mitigate the risks of climate change, but policy should not be based on mental models that violate fundamental physical principles.

Of course, we need more research and technical innovation—money and genius are always in short supply. But there is no purely technical solution for climate change. For public policy to be grounded in the hard-won results of climate science, we must now turn our attention to the dynamics of social and political change.



A typical response to the climate stabilization task. Future emissions are erroneously correlated with atmospheric CO_2. Gold dashed line indicates the correct emissions path to stabilize CO_2 given the subject's estimate of net removal.

References and Notes

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