LISA REINDORF *Tsunami City*, 2020. Oil and acrylic gel on panel, 40 x 60 inches.

In her work, Lisa Reindorf combines knowledge from architecture and environmental science. Her paintings examine the environmental impact of climate change on water. In aerial-view landscapes, she creates interpretations of coastal areas, in particular rising seas.

ROGER PIELKE JR. AND JUSTIN RITCHIE

How Climate Scenarios Lost Touch With Reality

A failure of self-correction in science has compromised climate science's ability to provide plausible views of our collective future.

The integrity of science depends on its capacity to provide an ever more reliable picture of how the world works. Over the past decade or so, serious threats to this integrity have come to light. The expectation that science is inherently self-correcting, and that it moves cumulatively and progressively away from false beliefs and toward truth, has been challenged in numerous fields—including cancer research, neuroscience, hydrology, cosmology, and economics—as observers discover that many published findings are of poor quality, subject to systemic biases, or irreproducible.

In a particularly troubling example from the biomedical sciences, a 2015 literature review found that almost 900 peer-reviewed publications reporting studies of a supposed breast cancer cell line were in fact based on a misidentified skin cancer line. Worse still, nearly 250 of these studies were published even after the mistaken cell line was conclusively identified in 2007. Our cursory search of Google Scholar indicates that researchers are *still* using the skin cancer cell line in breast cancer studies published in 2021. All of these erroneous studies remain in the literature and will continue to be a source of misinformation for scientists working on breast cancer.

In 2021, climate research finds itself in a situation similar to breast cancer research in 2007. Our research (and that of several colleagues) indicates that the scenarios of greenhouse gas (GHG) emissions through the end of the twenty-first century are grounded in outdated portrayals of the recent past. Because climate models depend on these scenarios to project the future behavior of the climate, the outdated scenarios provide a misleading basis both for developing a scientific evidence base and for informing climate policy discussions. The continuing misuse of scenarios in climate research has become pervasive and consequential—so much so that we view it as one of the most significant failures of scientific integrity in the twenty-first century thus far. We need a course correction.

In calling for this change, we emphasize explicitly and unequivocally that human-caused climate change is real, that it poses significant risks to society and the environment, and that various policy responses in the form of mitigation and adaptation are necessary and make good sense. However, the reality and importance of climate change does not provide a rationale or excuse for avoiding questions of research integrity any more than does the reality and importance of breast cancer. To the contrary, urgency makes attention to integrity that much more important.

Scenarios and baselines

A policy is a prediction. Committing to a particular course of action reflects expectations for the outcomes of choosing one option over others. Effective policymaking, which leads to desired outcomes, therefore requires some ability to discern and map the future. Not surprisingly, policy in the context of climate change, which will occur over many decades and centuries, requires methods for distinguishing alternative paths into the future.

One fundamental approach to conducting research on the climate is based on scenarios. In the 1960s, Herman Kahn adopted use of the word *scenario* to characterize a formalized vision of the future. A military strategist for the RAND Corporation, Kahn befriended actors and directors in Southern California and was likely one of the models for the eponymous character in Stanley Kubrick's *Dr. Strangelove*.

Kahn explained that "scenarios are simply a more or less imaginative sequence of events that are put together so that each event forms a context for the other events and so that there is some continuity over time in the 'narrative.'" The idea of "scenario planning" caught on, and by 1972 Shell Corporation had sought out Kahn as it developed its methods of scenario planning to shape company strategy.

Scenarios are an important tool for analysis because the world is incredibly complex and humans need tools to envision the contours of this complexity. As the anthropologist James C. Scott observes, "any large social process or event will inevitably be far more complex than the schemata we can devise, prospectively or retrospectively, to map it." We thus need tools to simplify the world's complexities to help us invent and evaluate action alternatives, ultimately for purposes of implementation. However, such maps of the world are not simply reflections of an underlying reality. As the geographer Alan MacEachren explains, "When we build these abstract representations (either concrete ones in map form or cognitive ones prompted by maps) we are not revealing knowledge as much as we are creating it."

Climate research was a natural fit for the use of scenarios, given its roots in long-term planning and the energy industry. Early scenarios were highly idealized and focused on exploring what would happen if carbon dioxide concentrations doubled from their preindustrial levels or increased at a steady rate of 1% per year. The Intergovernmental Panel on Climate Change (IPCC) introduced scenarios not just to explore scientific questions, but to project or predict alternative futures. In 1990, the first IPCC report adopted a concept from the scenario literature called "business as usual," a term to describe where the world is presently headed. A business-as-usual scenario is meant to create a baseline expectation of the future in the absence of unforeseen events or concerted efforts to change that future. This baseline expectation can then structure an evaluation of benefits that might come from taking an alternative path.

The notion of a baseline (or business-as-usual, or reference) projection in scenario planning was reinforced by the adoption of cost-benefit analysis as a central tool for understanding the potential effects of proposed government regulations. In 1981, for instance, the Reagan administration issued an executive order that required federal regulations to undergo a formal cost-benefit analysis prior to implementation. A key feature of such analysis is a comparison of multiple futures—typically one without regulation (the baseline scenario) and one with various policy interventions (a policy scenario). Under such a methodology, analysts view the baseline as a prediction of the most likely future in the absence of specific policy interventions to avoid that future. As climate science took shape in the following decades, the field inherited this legacy of baseline scenarios.

THINK ABOUT WATER

An Ecological Artist Collective

Think About Water is a collective of ecological artists and activists who got together to use art to elevate the awareness and discussion of water issues. Created by the painter and photographer Fredericka Foster in early 2020, the collective was intended to celebrate, as the organizers describe it, "our connection to water over a range of mediums and innovative projects that honor this precious element." *Think About Water* is a call to action that invites viewers to a deeper engagement with the artwork.

The collective's first group exhibition is titled *Think About Water*. Curated by collective member Doug Fogelson, the exhibit was presented in virtual space through an interactive virtual reality gallery. Artists included the exhibit were Diane Burko, Charlotte Coté, Betsy Damon, Leila Daw, Rosalyn Driscoll, Doug Fogelson, Fredericka Foster, Giana Pilar González, Rachel Havrelock, Susan Hoffman Fishman, Fritz Horstman, Basia Irland, Sant Khalsa, Ellen Kozak, Stacy Levy, Anna Macleod, Ilana Manolson, Lauren Rosenthal McManus, Randal Nichols, Dixie Peaslee, Jaanika Peerna, Aviva Rahmani, Lisa Reindorf, Meridel Rubenstein, Naoe Suzuki, Linda Troeller, and Adam Wolpert.

For more information about the collective and the show, visit www.thinkaboutwater.com.

Images courtesy of Think About Water and the individual artists.

FREDERICKA FOSTER *River Revisited*, 2017. Oil on canvas, 40 x 60 inches.

Fredericka Foster has been painting the surfaces of moving water in their infinite variety for years. She believes that painting, using tools of color and composition, can be an aid to societal change: "Art accesses another way of knowing, and it takes both rationality and emotional connection to create lasting change."

The future isn't what it used to be

Efforts to understand the future of climate change depend on scenarios of future GHG emissions because these emissions are centrally responsible for any excursion of the climate's behavior beyond its natural variability. Emissions scenarios are thus a key input for the climate models that aim to project the future behavior of the climate. But emissions scenarios are themselves dependent on variables such as population growth, economic growth, technological change, land use change, and so on.

One obvious challenge for constructing plausible emissions scenarios then is that these key variables are continually changing, sometimes in quite unexpected directions. And yet, as the world has evolved in incredible and unanticipated ways over the three decades since the first IPCC report in 1990, the future envisioned by the IPCC has remained remarkably static. For instance, the first IPCC report in 1990 adopted a business-as-usual scenario for carbon dioxide emissions that resulted in a projected GHG concentration level for the year 2100 of more than 1,200 parts per million (ppm) carbon dioxide equivalent, a radiative forcing (a measure of the greenhouse effect) of 10 watts per square meter (W/m^2), and a global temperature increase of between 2.9 and 6.2 degrees Celsius above preindustrial values. The Sixth Assessment Report of the IPCC, planned for publication this year, will use a baseline scenario with a projected GHG concentration level for 2100 of about 1,200 ppm, a radiative forcing of 8.5 W/m^2, and a temperature increase of 3.0 to 5.1 degrees Celsius.

This remarkable continuity of characteristics among different generations of climate scenarios facilitates the comparison of research conducted over many decades using the different scenarios. But it also creates a problem. The emissions scenarios the climate community is now using as baselines for climate models depend on portrayals of the present that are no longer true. And once the scenarios lost touch with reality, so did the climate, impact, and economic models that depend on them for their projections of the future. Yet these projections are a central part of the scientific

ILANA MANOLSON *Current*, 2019. Acrylic on Yupo paper, 69 x 75 inches.

Artist and naturalist Illana Manolson finds herself drawn to the edges of swamps, ponds, rivers, and oceans. "As water changes, it changes its environment whether through erosion, flooding, nutrition, or drought. And what we as humans do upstream, will, through the water, affect what happens downstream."

basis upon which climate policymakers are now developing, debating, and adopting policies.

How emissions scenarios got off track is a long and technical story (which we relate in a 20,000 word article, for those interested). Here is the short version.

Four futures

Scientists and policymakers have learned over and over that accurate predictions of society's future are not just difficult but fundamentally impossible. Scenario planning helps to address limited foresight by envisioning a set of alternative possible futures, thus enabling consideration of policies that can be effective despite uncertainties and ignorance. But scenarios of the future need constant updating because the possibilities for the future change as events unfold in the present.

A baseline or business-as-usual scenario is, by definition, an expectation of the most likely future in the absence of actions taken to alter that future. Having adopted one baseline and three policy scenarios (each reflecting a different mix of future climate policies) in its early reports, the leaders of the IPCC recognized by the late 1990s that the organization needed to update its scenarios. The IPCC community actively debated whether new scenarios should adopt the baseline-policy distinction of earlier IPCC assessments or instead present scenarios without any consideration of their likelihood.

The late climate expert Stephen Schneider argued for including likelihoods in the scenarios. He explained that "policy analysts needed probability estimates to assess the seriousness of the implied impacts; otherwise they would be left to work out the implicit probability assignments for themselves." But other scientists involved in creating IPCC scenarios argued that assessing likelihoods of scenarios a century into the future was fundamentally impossible and they should not do it, lest it mislead their users about the foreseeability of the future. Both sides have good arguments.

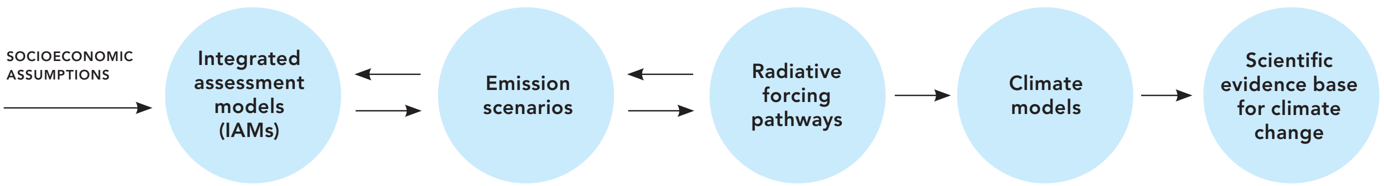
The latter perspective won out. When the IPCC published its Special Report on Emission Scenarios (SRES) in 2000, it presented the new family of emissions scenarios with no likelihoods. Thus it made no distinction between baseline and policy scenarios. In fact, the report emphasized four scenarios, spanning a wide range of outcomes, so that scenario users such as climate modelers would not be tempted to interpret a middle scenario as representing the most likely baseline future. The IPCC SRES report concluded, "The broad consensus among the SRES writing team is that the current literature analysis suggests the future is inherently unpredictable and so views will differ as to which of the storylines and representative scenarios could be more or less likely. Therefore, the development of a single 'best guess' or 'business-as usual' scenario is neither desirable nor possible."

This decision was not without its critics. For instance, in a 2012 review of IPCC assessments, Detlef van Vuuren and his colleagues at the Netherlands Environmental Assessment Agency noted that the failure to assign likelihoods "was strongly criticized by some environmental NGOs [nongovernmental organizations] as it would suggest that autonomous developments could also lead to a (modest) reduction of emissions." In other words, if one scenario suggested that the world might evolve toward a lower emissions future in the absence of aggressive climate policies, it might reduce motivation to develop policies to actually create such a future. Here is evidence that scenarios are not simply lenses to help envision possible futures, but also fulcrums to motivate action—for turning desired futures into reality. Scenarios are thus never neutral because different futures reflect different choices among policy options.

The sum of all forcings

To develop emissions scenarios, scientists begin with assumptions about the future of socioeconomic variables such as economic growth, population growth, and energy consumption, as well as a range of other variables, such as changes in land use (farming, grazing, forestry, and so on) and particulate pollution. They plug these variables into models of society and the economy called integrated assessment models to generate plausible pathways of future emissions—these are the emissions scenarios. These scenarios project the future not only of carbon dioxide emissions, but also of other chemicals that affect the climate, such as methane and nitrous oxide. Emissions scenarios, in turn, are necessary to determine another variable, called radiative forcing, a measure of changes in the net transfer of energy (i.e., heat) in the atmosphere. Radiative forcing pathways (changes in forcing over time) are a key input for the climate models that project the future behavior of climate.

Figure 1. **SCENARIO DEVELOPMENT PROCESS FLOW CHART**



The IPCC scenarios serve the needs of the climate modeling community, which has exacting technical requirements for inputs into their climate models. As scientific understanding of the complexity of the climate system has grown, so too has the complexity of the scenarios upon which climate models—and the futures they project—depend.

By 2005 the IPCC was beginning to produce a new generation of emissions scenarios to replace those of SRES. These new scenarios would require time to develop and that would delay the advance of climate modeling research. To provide the information necessary to continue climate model development without waiting for updated scenarios, the IPCC simply selected a set of four radiative forcing pathways to the year 2100 for use by the research community. Called Representative Concentration Pathways, or RCPs, these were drawn from the many hundreds of existing emissions scenarios to represent one high, one low, and two middle projections. Modelers could then immediately apply the four RCPs to produce a range of updated projections of future climate behavior. In parallel, scenario developers would simultaneously start with this same set of radiative forcing pathways and work backward to develop socioeconomically plausible emissions scenarios that would produce the four RCPs.

Although the IPCC selected the four radiative forcing pathways to provide a range of projected futures to 2100, it did not consider the plausibility of the socioeconomic assumptions used to generate them. Indeed, in 2008 the IPCC noted, "It is an open research question as to how wide a range of socioeconomic conditions could be consistent with a given [RCP] pathway of forcing, including its ultimate level, its pathway over time, and its spatial pattern." The online guidance for the RCP database similarly warned, "The differences between the RCPs can therefore not directly be interpreted as a result of climate policy or particular socioeconomic developments."

The IPCC had cut the link between the socioeconomic characteristics underlying the scenarios (population change, economic growth, and so on), the emissions scenarios they provided for climate models, and the climate futures those models would predict. The effect of the separation was to save time while abandoning any commitment to evaluating the scenarios and pathways for plausibility or probability.

And yet the IPCC ignored its own guidance. It associated the RCP scenarios with not just plausibility but also likelihoods when it labeled the scenario leading to the greatest amount of climate change, called RCP8.5 (indicating a radiative forcing of 8.5 W/m^2 in 2100), as the single business-as-usual scenario of the set. In so doing, the IPCC identified RCP8.5 as the most likely future in the absence of further policy intervention, which gave it special status among not only the RCPs but among the hundreds of baseline scenarios of the broader IPCC scenario database.

What's good for science

Why does this matter? Because RCP8.5—the most commonly used RCP scenario and the one said to best represent what the world would look like if no climate policies were enacted—represents not just an implausible future in 2100, but a present that already deviates significantly from reality. We know this because we have studied RCP8.5 (as well as other climate scenarios) for years and have evaluated many of its inputs and assumptions against how the world has actually developed since 2005, where RCP8.5 begins. We have also evaluated hundreds of IPCC scenarios against near-term projections of global energy assessments. Our work (including collaborations with Matthew Burgess and other colleagues), as well as studies by other researchers published in many papers, clearly shows that most IPCC scenarios are already off track and some, like RCP8.5, significantly so. As summarized by two scenario experts in a January 2020 commentary in *Nature*, "the world imagined in RCP8.5 is one that, in our view, becomes increasingly implausible with every passing year."

For instance, RCP8.5 projects to 2100 a six-fold growth in global coal consumption per capita, while the International Energy Agency and other energy forecasting groups collectively agree that coal consumption has already or will soon peak. Also, RCP8.5 foresees carbon dioxide emissions growing rapidly to at least the year 2300 when Earth reaches more than 2,000 ppm of atmospheric carbon dioxide concentrations. But again, according to the IEA and other groups, fossil energy emissions have likely plateaued, and it is plausible to achieve net-zero emissions before the end of the century, if not much sooner. Today, projections that carbon dioxide emissions from fossil fuels will increase dramatically for the next 50, 100, or 300 years are simply implausible.

Why, then, did the IPCC choose RCP8.5 as its only business-as-usual baseline? Not because it explicitly judged it the world's most likely or even plausible future, although the designation implies both. Rather, it selected RCP8.5 in part to facilitate continuity with scenarios of past IPCC reports, both SRES and earlier baseline scenarios, so that results of climate modeling research across decades could be comparable. It also chose RCP8.5 to help climate modelers explore the differences between climate behavior under hypothesized extreme conditions of human-caused climate forcing and natural variability. The difference between the high (8.5 W/m^2) and low (2.6 W/m^2) RCP forcing pathways created, as scenario developers explained, "a good signal-to-noise ratio for evaluating the climate response in AOGCM [atmospheric-oceanic general circulation model] simulations." The technical requirements of climate modeling, and not climate policy, drove the design of IPCC scenarios.

These decisions might be justifiable if climate models were simply scientific tools aimed at exploring a variety of conditions as a way to test hypotheses and researchers' understanding of the climate system. But scientists, policymakers, the media, environmentalists, and the public now widely justify and interpret climate models as providing predictive information about plausible futures. By choosing RCP8.5 as one of only four forcing scenarios to be used by modelers, and compounding this choice by labeling it as the business-as-usual scenario, the IPCC promoted a scenario useful for scientific exploration but highly misleading when applied to projecting the future to inform decision-making.

In our research on the plausibility of IPCC scenarios, we have discovered it is not just RCP8.5 that is implausible, but the entire set of baseline scenarios used by the IPCC. In some ways this is unsurprising. As events unfold in a complex world, even the near-term futures anticipated by scenarios will drift away from reality. As a matter of scientific integrity, however, the reputation of science as a source of uniquely

LINDA TROELLER *Radon Waterfall, Bad Gastein, Austria,* 2015. Photograph, 16 x 20 inches.

Linda Troeller is interested in water as a healing power. Bad Gastein, Austria's thermal waterfall, was first referred to in writing in 1327 as "medicinal drinking water." According to Troeller, "It is very fresh, crystal-clear—the droplets contain radon that can be absorbed by the skin or through inhalation or from drinking from fountains around the town."

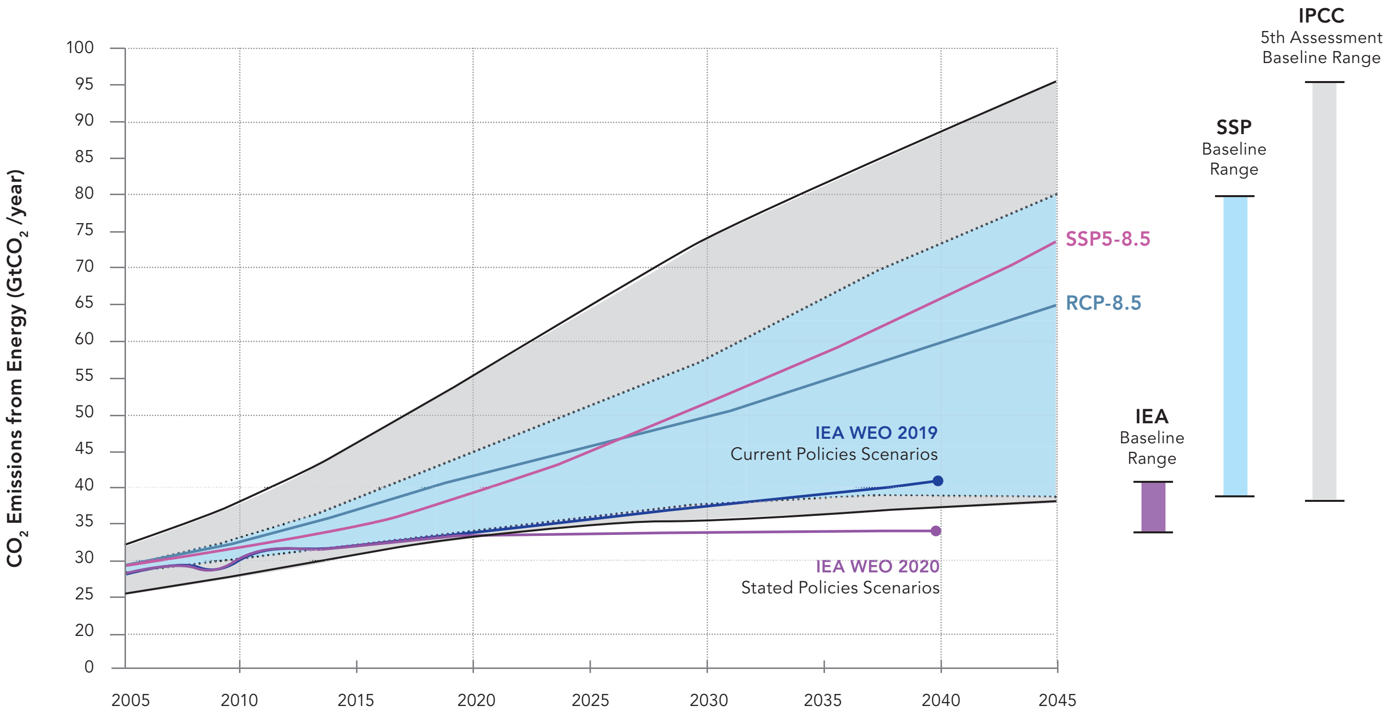
reliable knowledge depends on its internal capacity for self-correction. In the case of the RCPs (as with the example of breast cancer research after 2007), what we are seeing instead amounts to a stubborn commitment to error. This wouldn't matter if climate scenarios had no implications for the world outside of science. But they lie at the heart of scientific efforts to understand the future of climate change and society's decisions about how to respond.

A Rube Goldberg future

The RCPs are far from the end of this story. Originally, the IPCC intended them to serve as a stopgap, while it developed a more fully integrated set of scenarios that reunited socioeconomics with elements of radiative forcing. It took more than a decade to develop the Shared Socioeconomic Pathway (SSP) scenarios, which in principle would supersede the RCPs. In practice, our research shows that people continue to widely use the RCPs along with the SSPs as input into climate models and as the basis for assessments, projections of climate impacts, and policy evaluation.

The SSPs represent a massive effort and are themselves the focus of a growing literature that explores the futures that they envision. But the SSPs have repeated many mistakes of the RCPs, most notably in supporting the designation of two extreme, implausible futures, with future emissions that emulate RCP8.5—again not for reasons of plausibility, but for purposes of continuity and to meet the technical constraints of climate modeling. Indeed, the creators of the SSPs have noted that its most extreme scenario (SSP5-RCP8.5) can only emerge in a limited number of models under a restricted set of assumptions. Even with this indication of implausibility, the IPCC designated it as the highest priority reference scenario for purposes of the climate modeling studies supporting the next IPCC assessment.

Figure 2. **IPCC BASELINE EMISSIONS SCENARIOS FROM 2005 TO 2040**



The range of fossil fuel baseline emissions projected by the International Energy Agency in 2019 and 2020 lie almost entirely outside the full range of baseline scenarios for the IPCC Fifth Assessment Report and the SSP scenarios shaping the IPCC Sixth Assessment Report.

As with the RCPs, the IPCC chose the SSPs to represent a wide range in radiative forcing pathways. Yet all of the RCPs and SSPs share some important assumptions. One of the most significant is the projected growth of coal consumption. The single RCP and two SSP baseline scenarios prioritized in climate modelling studies envision that coal will outcompete virtually all other energy technologies this century. In the latest version of the RCP8.5 scenario (SSP5-8.5), coal would even surpass oil and electric vehicles to become the dominant fuel for the world's cars. One can trace the vision of a global energy system utterly dependent for the rest of the century on increased burning of coal to the beginning of the IPCC assessment process in the late 1980s and the influence on its early energy-use projections of flawed reports of virtually unlimited, very inexpensive coal in China and Siberia. The IPCC carried the error forward, freezing it into emissions scenarios to support the extreme energy outlooks adopted as baselines for climate science. It's as if the profound changes in the world's mix of energy resources and technologies in the past three decades, from the rise of natural gas to the growth of renewable energy, had never happened.

While RCP8.5 and its progeny SSP5-8.5 represent an obsolete and extreme vision of a coal-dominant future, the specter of coal superabundance introduces error into all other baselines, as well as the policy scenarios that derive from those baselines. For example, even in the lower-emission SSP baseline that depicts a globally coordinated effort to achieve sustainability through green growth (SSP1), the world's coal use doesn't fall below current levels until after the year 2080. The common assumption of coal as the most desirable global fuel source—independent of all other social, technological, and economic factors—results in a single point of failure across the scenarios.

To compensate for this shared error, IPCC policy scenarios have had to invent a Rube Goldberg kind of future. This is an imagined future where massive amounts of coal that will never be burned necessitate massive amounts of so-called "negative emissions" technologies (dominated by highly speculative bioenergy plus carbon capture and storage) in order to generate policy pathways to a low-carbon future. Yet, even though researchers are now more likely to recognize problems with the RCPs and SSPs, these scenarios continue to be the basis for dozens of climate research papers published *every week*. According to Google Scholar, from the beginning of 2020 until mid-June 2021, authors published more than 8,500 papers using the implausible baseline scenarios, of which almost 7,200 use RCP8.5 and nearly 1,500 use SSP5-8.5. Neither the IPCC nor the broader climate modeling community has sought to counter or reverse this proliferating source of error in projections of future climate change.

Restoring integrity in climate science

The consequences of pervasive, implausible climate scenarios extend far beyond the IPCC process and the academic literature these scenarios have enabled. A continued focus on implausible emissions scenarios in climate research is a failure of science's supposed internal quality assurance mechanisms and thus a failure of scientific integrity. The persistent use of implausible scenarios introduces error and bias widely across climate research. They are now woven through the climate science literature in ways that will be very difficult to untangle.

Many of these thousands of published papers project future impacts of climate change on people, the economy, and the environment that are considerably more extreme than an actual understanding of emissions and forcing pathways would suggest is likely. As scientists' understanding of climate change continues to improve, perhaps scientists will someday conclude that the most extreme impacts are also plausible under lower emissions trajectories. But that is not the consensus at present. And so, with any attempts at scientific nuance lost in technical language, these implausible projections of apocalyptic impacts decades hence are converted by press releases, media coverage, and advocates—as in an extended game of telephone—into assertions that climate change is now catalyzing dramatic increases in extreme events such as hurricanes, droughts, and floods, events that foreshadow imminent global catastrophe.

At the same time, and unsurprisingly, some opponents of climate policies are politically exploiting problems with the IPCC emissions scenarios. Groups such as the Global Warming Policy Foundation in London and the Competitiveness Enterprise Institute in Washington, DC, are highlighting the misuse of RCP8.5 to call into question the quality and legitimacy of climate science and assessments as a whole. But unlike many attacks on climate science, in this case these organizations have a good point.

Implausible climate scenarios are also introducing error and bias into actual policy and business decisions today. For example, the US government derives its social cost of carbon estimates, which it uses for cost-benefit analysis of federal regulations, from the IPCC scenarios. The financial sector also customizes IPCC scenarios for its use. The emerging market for climate scenario products has led to a $40 billion "climate intelligence" industry, involving familiar companies such as Swiss Re and McKinsey, and start-ups such as Jupiter Intelligence and Cervest. These companies are using implausible RCP scenarios to develop various predictive products that they sell to governments and industry, who will depend on these products to help guide policy and business decisions in the future.

Good science works to bring society the best possible images of the real world. The emissions scenarios of today's climate science are delivering distorted pictures that compromise both understanding and well-informed policymaking. Until the climate science community addresses this fundamental problem of scientific integrity, its potential to contribute to pragmatic solutions for the vexing, extraordinarily difficult challenge of climate change will be unnecessarily compromised. Climate change has been solved countless times in fanciful models, but it is the real world that matters.

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RECOMMENDED READING

Matthew G. Burgess, Justin Ritchie, John Shapland, and Roger Pielke Jr., "IPCC baseline scenarios have over-projected CO_2 emissions and economic growth," *Environmental Research Letters* 16, no. 1 (2020): 014016.

Brian C. O'Neill, Timothy R. Carter, Kristie Ebi, Paula A. Harrison, Eric Kemp-Benedict, Kasper Kok, Elmar Kriegler, Benjamin L. Preston, Keywan Riahi, Jana Sillmann, Bas J. van Ruijven, Detlef van Vuuren, David Carlisle, Celia Conde, Jan Fuglestvedt, Carole Green, Tomoko Hasegawa, Julia Leininger, Seth Monteith, and Ramon Pichs-Madruga, "Achievements and needs for the climate change scenario framework," *Nature Climate Change* 10 (2020): 1074–1084.

Roger Pielke Jr. and Justin Ritchie, "Distorting the view of our climate future: The misuse and abuse of climate pathways and scenarios," *Energy Research & Social Science* 72 (2021): 101890.

Justin Ritchie and Hadi Dowlatabadi, "Why do climate change scenarios return to coal?" *Energy* 140, no. 1 (2017): 1276–1291.

Detlef Stammer, Anita Engels, Jochem Marotzke, Eduardo Gresse, Christopher Hedemann, and Jan Petzold, eds., *Hamburg Climate Futures Outlook 2021: Assessing the Plausibility of Deep Decarbonization by 2050* (Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society, 2021).