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0.4 Code availability

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H.F.D. conceived of the article and conducted the analyses for Figure 1. H.F.D. and G.H. contributed equally to crafting the argument, reviewing the literature, and writing the manuscript.

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Abstract

Much of modern climate science is motivated by the problem of human-caused climate change or its potential solutions, and aims to be "usable" for relevant stakeholders. Sobel (2021) argues in this issue that the expectation for improved climate projections to drive mitigation of greenhouse gas emissions "can now be understood [as] naive about the role of politics, and the power of entrenched interests to inhibit climate action." While he criticizes this "linear model" of the science–policy interface, he does not elaborate on alternative avenues for scientific advances to spur mitigation. Instead, he encourages physical climate scientists who wish to produce usable results to orient their work towards informing adaptation. He argues that, relative to mitigation science, adaptation science is more likely to be used by stakeholders because the remaining scientific uncertainties are larger and the social barriers to implementation are lower.

We join Sobel in calling on physical climate scientists to reflect upon the pathways through which their research improves societal welfare. However, we argue that Sobel's argument overlooks an important theory of change, namely that mitigation science is politically usable through the non-linear dynamics of social mobilization. Social theories of policy change suggest that organized groups play an outsized role in setting the policy agenda. Grassroots activism on climate, however, has historically been hindered by the abstract nature of climate change, paling in comparison to the lobbying and misinformation campaigns funded by the vested fossil fuel interests. We describe how two recent advances in mitigation science, the Transient Climate Response to cumulative Emissions (TCRE) and Extreme Event Attribution (EEA), have provided social movements with information that allows them to re-frame the climate change problem in a way that attributes blame for the problem, motivates collective action across a diverse coalition of stakeholders, and could plausibly compel policymakers to prioritize the issue in the coming years. Given the utmost importance of mitigation in preventing climate change at the source, we thus advocate for a broader agenda of usable climate research that includes co-production of both mitigation and adaptation science.

1 Introduction: climate change, mitigation, and adaptation

The political challenge of addressing climate change has prompted calls to rethink the relationship between science and public policy. The traditional "linear model", in which scientific findings directly shape officials' decisions, has withered under the scorching heat of the global warming debate. In this issue, (Sobel, 2021) draws on this critique to argue that climate scientists seeking to produce usable findings should study adaptation rather than mitigation. In response, we contend that two recent advances demonstrate how scientific information can indeed be politically usable, even in the seemingly intractable realm of mitigation. We present a non-linear theory in which scientific information can strengthen social movements' ability to mobilize political constituencies, who in turn can pressure governments to make climate change a priority[1].

[1] This non-linear perspective stands in contrast to Jasanoff (2021), who argues in this issue that youth climate activism is just a reanimation of the "linear notion of the impact of knowledge on action".

To explain how political actors can use mitigation science to influence policy, we must briefly review the terms of the climate debate. The conventional narrative of anthropogenic climate change presents the worst-case scenario of fossil-fueled economic growth as a "business as usual" baseline, against which humans can intervene by reducing their emissions ("mitigation") and trying to adapt to any residual climate impacts. The scientific evidence is clear that continued emissions disproportionately harm the poor, vulnerable, and marginalized (Field et al., 2014); to what extent this problem should be addressed with mitigation or adaptation—or not at all—however, is a value judgement. The conventional neoliberal framing inherently favors only marginal mitigation (Nordhaus, 1992), with an implicit assumption that people will "optimally" adapt to the significant remaining impacts (e.g. de Bruin et al., 2009); by contrast, indigenous people's right to self-determination instead sets mitigation as the appropriate baseline, whereas the externally-imposed "adaptation strategy will prove genocidal" (Tsosie, 2007).

Virtually all national governments have now agreed that the climate impacts of conducting "business as usual" would be catastrophic and must be avoided. Concretely, they aim to limit global warming to well below 2 °C (hopefully 1.5 °C) above pre-industrial levels (United Nations Framework Convention on Climate Change, 2015), requiring net-zero emissions (full mitigation) by mid-century; we take these goals for granted throughout the article because we share these values. Problematically, both the actions and commitments of governments fall well short of these lofty goals, thus committing living and future generations to the catastrophic fallout of 2 °C to 4 °C of global warming[2] (Hausfather and Peters, 2020a). While far from enough, the modest mitigation to date would certainly have been even less in a counterfactual world without any basic climate science—and is demonstrably less than in a world without any unilateral climate policies (Bayer and Aklin, 2020; Lepissier and Mildenberger, 2021).

The failure of international climate negotiations and domestic policies to drive sufficient emissions reductions to date has caused some climate impacts to already emerge from the modest background of natural climate variations. Present and imminent impacts have motivated increasing interest in climate adaptation—and the adaptation-oriented climate science that supports it. We agree with Sobel (2021) that climate adaptation science is usable and necessary but not that it is the *only* usable climate science (the types of climate science and their usability are defined in detail in Section 3). Furthermore, evaluating adaptation science's utility requires contending with the possibility that—despite these efforts—future adaptation fails as spectacularly as mitigation has in the past, including for political reasons, or that its benefits are unjustly distributed. Most importantly, we argue that it is irresponsible to abandon the pursuit of usable climate mitigation science precisely when it is needed most—when emissions appear to finally be peaking and when near-term policy decisions will determine whether emissions can fall sufficiently fast for climate goals to remain achievable.

We specifically disagree with Sobel's assertion that the failures of the "linear model"—the idea that further incremental advances in climate mitigation science will directly drive commensurate changes in climate policy (Jasanoff and Wynne 1998, Pielke Jr. 2007, Beck 2011)—imply that there is *no model* through which mitigation

[2] Only slightly improved if the more ambitious commitments stated surrounding the COP26 summit are taken at face value (Hausfather and Forster, 2021).

science can influence climate policy. The core of our disagreement is exemplified by the caveats Sobel appends to his argument (emphasis ours):

> My argument here is that there is no productive avenue by which further advances in climate science can be incorporated in a dialog with those governments so as to influence mitigation policy in a pragmatic way—*at least, not until the governments, particularly in the USA but not only there—change very substantially, and perhaps not even then.*

While science might not have the desired *linear* impact on policy, we should not ignore its role in *non-linear* theories of social mobilization and policymaking. In particular, we argue that mitigation science can motivate participation in the climate movement, pressuring politicians to prioritize the issue.

2 Non-linear theories of social movements and policy-making

Policy theories suggest an indirect relationship between scientific information and policy (Weible, 2008). Kingdon (1984) argues that a policy alternative is more likely to arise on the agenda when lawmakers perceive it to address a commonly understood problem and align with their electoral incentives. Researchers can "use science to indicate the seriousness and causes of a problem" as well as "legitimize ideas" for addressing it (Weible, 2008). For a policy to align with electoral incentives, Kingdon (1984) argues that public opinion or interest groups must favor the given alternative.

Recent scholarship in the United States has challenged the notion that public opinion shapes policy, instead pointing to interest groups and politically active constituents as driving change (Gilens and Page, 2014). Representatives rely on interest groups and activists to signal policy problems that are salient to electorally influential constituencies and propose solutions (Henderson et al., 2021). These actors sometimes form social movements, which use tactics that rely on popular participation (Tilly, 1994) and can use scientific information to motivate such participation (Weible, 2008). For example, in the mid-2000s, the finding that open-loop liquefied natural gas terminals could impact fish populations inspired Gulf Coast fishing communities to pressure elected officials to oppose those projects (McAdam and Schaffer Boudet, 2012).

Synthesizing the literature, McAdam (2017) describes three factors that together allow a movement to emerge. First, prospective adherents must perceive a political opportunity to enact their agenda, owing to sympathetic elites or receptive institutions (Lipsky, 1970; Meyer and Minkoff, 2004). Second, leaders must have access to resourced organizations to coordinate strategy and activate supporters (McCarthy and Zald, 1977). Third, collective action frames—the products of repackaging complex issues to highlight, attribute blame for, and propose solutions to problems (Snow and Benford, 1988)—allow activists to interpret their conditions in ways that motivate and facilitate collective action. Of these factors, climate science is most likely to be usable in contributing to framing processes.

McAdam (2017) identifies four dimensions of climate discourse that have frustrated framing efforts (in the U.S.).

First, he contends that popular commentary tends to misleadingly portray climate change as affecting society in the distant future. Second, he argues that no identity group has claimed ownership of the issue—an argument belied by the concept of "frontline communities" and the recent upsurge of youth activism. Third, the distant prospect of climate impacts has failed to evoke the emotions (e.g., fear or anger) which motivate action. Fourth, communicators fail to connect extreme weather events to climate change, preventing "natural disasters" from catalyzing action. In Section 5 we discuss how usable climate mitigation science concepts—and especially the two concepts reviewed in Section 4—can help overcome each of these four framing obstacles and thus strengthen the global climate justice movement. First, however, we explain what we mean by "usable" "mitigation science".

3 Mitigation science, adaptation science, and usable climate science

We focus on narrow definitions of both science and usability to clarify our differences with Sobel (2021) but recognize that science may have value for many other reasons. We also acknowledge that the western conceptualization of science described here, rooted in white colonialism (Mayorga et al. 2019, Liboiron 2021) and shaped by the persistent dominance of white male scientists (Ranganathan et al. 2021), is not the only valuable form of knowledge—see for example Callison's 2021 comparison with indigenous knowing in this issue.

Following Sobel (2021), we focus on the subset of climate science that falls under the Intergovernmental Panel on Climate Change's Working Group I, i.e. the physical basis for climate change. We define mitigation science as the study of how climate change and its physical impacts vary with anthropogenic emissions, whereas adaptation science refers to the study of human-relevant climate impacts under a given climate change trajectory. Examples of recent advances in conventional mitigation science include the development of the newest generation of computerized climate models (Eyring et al., 2016) and of in-situ ocean observing platforms (e.g. Johnson et al., 2022). Examples of advances in adaptation science include the mapping of physical adaptability limits due to moist heat stress (Sherwood and Huber, 2010) and improved methods for computing and communicating forecasts of hurricane risk (Lin et al., 2020). Many climate impact studies could be reasonably classified as either mitigation or adaptation; here, we only discuss approaches that can be unambiguously categorized based on their underlying framing: is it about the impact of the climate on humans (adaptation) or of humans on the climate (mitigation)? For example, a study projecting changes in the frequency of heat waves by mid-century in a particular region would be classified as adaptation science, while a study attributing these same trends to anthropogenic emissions would instead be classified as mitigation science.

Following Sobel, we define "usable" climate science as science which is both 1) "oriented towards decision-making" and 2) "contributes to societal welfare in a [...] causally discernable way"; crucially, we drop Sobel's requirement that this causal relationship be "direct". In other words, a particular advance in climate science is usable only if the process by which it influences policy is both *intentional* and *effective*.

Most mitigation science, however, does not meet these usability conditions. As described by Sobel, for example, efforts to reduce uncertainty in Earth's Equilibrium Climate Sensitivity are *intended* to better inform "optimal" mitigation decisions (e.g. Hope, 2015; Sherwood et al., 2020), but have no effective causal pathway for driving policy change in our suboptimal reality (see Drake et al., 2021). Conversely, the possible collapse of the oceanic Atlantic Meridional Overturning Circulation due to global warming (the quintessential climate "tipping point"; Rahmstorf 1995) has been *effectively* used to build support for more ambitious climate action among both the public and academics (Broecker, 1987; Cai et al., 2015; Leiserowitz, 2004; Lenton et al., 2019), but took several decades to evolve from its original intended uses in physical oceanography (Stommel, 1961) and paleoclimatology (Rooth, 1982). While both of these advances are impressive contributions to climate science, the relatively rapid rise to prominence of the following concepts suggest that new scientific results are more likely to be *effectively used* if the *intended use pathways* that motivate them are well-developed and explicitly stated.

4 Recent examples of usable advances in mitigation science

Example A: The Transient Climate Response to cumulative CO_2 Emissions (TCRE)

Early global climate negotiations aimed to stabilize atmospheric CO_2 concentrations (UNFCCC; Wigley et al. 1996); however, no target concentration was ever decided upon and thus no emissions constraints were ever imposed (Matthews et al., 2012). Even if a target concentration were decided (e.g. 350 ppm; Hansen et al. 2008 and 350.org), "stabiliz[ing] greenhouse gas concentrations" would not stabilize global climate, which would continue to evolve for centuries (Figure 1b,c, dashed lines; Matthews et al. 2012).

The alternative framing of stabilizing global warming below a fixed *temperature* threshold eventually gained favor (see Randalls's 2010 historical account on the 2 °C goal) because temperature is more closely related to both the fundamental issue of Earth's energy imbalance and the prospect of dangerous climate impacts (many of which are thermally-driven, e.g. sea level rise, extreme heat waves, and rainfall). Warming depends on both the carbon response to emissions and the energetic (radiative and thermal) response to carbon, however, introducing additional geophysical complexity and uncertainty to the climate stabilization problem. Although the time-dependent dynamics of the carbon cycle and energy balance are independently complex, a remarkably simple empirical relation emerges when the two are combined (Figure 1b,c; Matthews and Caldeira 2008, Solomon et al. 2009, Matthews et al. 2009): every additional ton of emitted CO_2 increases peak global warming by the same fixed amount (Figure 1d). In their ground-breaking article in the scientific journal *Geophysical Research Letters*, Matthews and Caldeira (2008) explain the intended use of this basic research in their concluding sentence: "This means that avoiding future human-induced climate warming may require policies that seek not only to decrease CO_2 emissions, but to eliminate them entirely". Within just a few years of this discovery, many of the same authors re-packaged their scientific results into a novel framework to effectively guide international climate policy: the Transient Climate Response to cumulative CO_2 Emissions (TCRE; Zickfeld et al. 2009, Matthews et al. 2012, Allen et al. 2009).

Several implications of the TCRE have revolutionized climate thinking:

1. it directly attributes global warming to cumulative emitters (Figure 1d), making it exceedingly clear that

burning known fossil fuel reserves would cause a catastrophic overshoot of temperature goals (McKibben, 2012; Welsby et al., 2021);

2. coupled with a temperature goal, it implies a "Remaining Carbon Budget" (RCB; Figure 1d);

3. elementary geometry allows the RCB to be translated into a zero-emission-year (Figure 1a).

For example, consider a goal of having a 2/3 chance of limiting global warming to 1.5 °C or less, relative to preindustrial levels. Since we are already at roughly 1.2 °C of warming, the TCRE implies a RCB of only 510 $GtCO_2e$ (Figure 1d). If emissions decrease linearly from the present rate of $E_0 = 35$ $GtCO_2$ per year (Hausfather and Peters, 2020b), then this RCB implies that we have only roughly $\Delta t = 2\,\mathrm{RCB}/E_0 = 28$ years– or until about 2050– to reach zero emissions (Figure 1a). Running these TCRE-inferred emissions back through a simple climate model, we indeed find that warming peaks and stabilizes just below 1.5 °C (Figure 1a).

It would only take a few more years after the framework's conception for it to be ingrained in the popular consciousness as "Global Warming's Terrifying New Math" (McKibben, 2012) and formalized via an internationally-agreed commitment to limit warming by reaching net-zero "greenhouse gases in the second half of this century" (United Nations Framework Convention on Climate Change, 2015).

Example B: Extreme Event Attribution (EEA)

While the TCRE framework attributes global-average warming directly to emitters, it represents only the first step in attributing blame for localized climate impact events, i.e. "end-to-end" attribution (Stone and Allen, 2005). In Allen (2003)'s groundbreaking and provocative article, he proposes a methodology for attributing a fraction of a specific climate change risk to greenhouse gas emitters. The method estimates changes in the likelihood-weighted risk of a class of extreme events (or a single event), based on either climate model simulations (with and without emissions) or observed changes (relative to an earlier period, implicitly attributing any differences to anthropogenic emissions). For example, Stott et al. (2004) apply the method in the wake of the 2003 European summer heat wave that killed tens of thousands; they estimate that by the 1990s, anthropogenic emissions had at least doubled the likelihood of similarly strong Europe-wide heat waves. Since then, many more EEA analyses have been conducted using a variety of frameworks and statistical methods for a variety of different types of impact events[3] (see Otto 2017, Naveau et al. 2020, and annual EEA reports from the Bulletin of the American Meteorological Society, e.g. Peterson et al. 2012). There are various equally-valid EEA approaches (Mann et al., 2017; Otto, 2017; Shepherd, 2016)—the best approach for a given problem depends on the type of event and the framing of the question (Stott et al., 2017).

To date, EEA has not yet[4] been successfully used to demonstrate emitters' liability in a court of law (Lloyd

[3] There remain some concerns about the correctness of the statistical methods underpinning several studies, but corrections have also been proposed (Bellprat et al., 2019; Sippel et al., 2015). Sippel et al. (2015) emphasizes that these corrections generally affect the magnitude of the effect but not its sign; e.g. the finding that anthropogenic global warming exacerbates heat waves still holds.

[4] Schiermeier (2021) argues that we may now finally be at an inflection point for climate suits, but conclude with the warning that "winning a lawsuit is one thing; getting rid of fossil fuels is another".

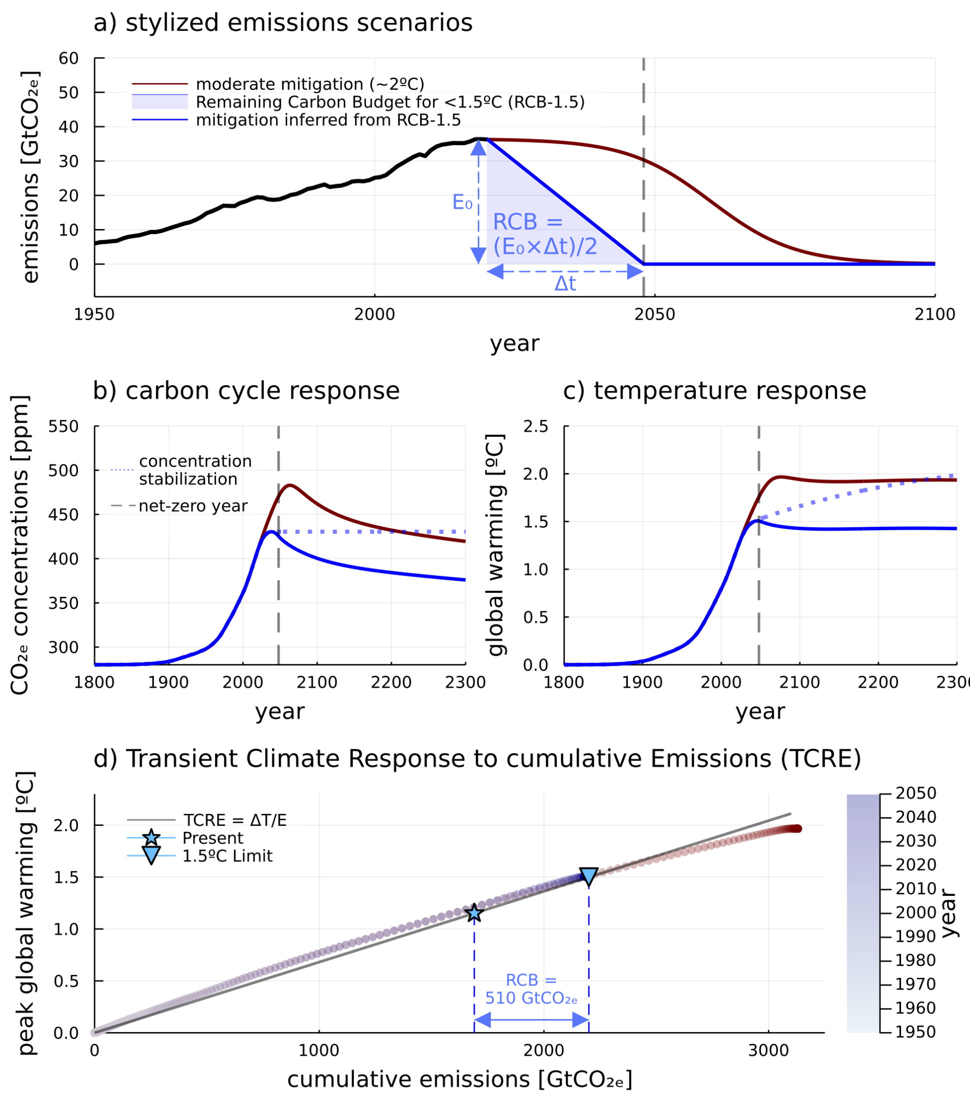

Figure 1: Carbon (b) and temperature (c) response to stylized CO_{2e} emissions scenarios (a). Despite the seemingly complicated temporal dynamics of climate changes in the moderate emissions scenario (red), the global warming response is a quasi-linear function of cumulative emissions (d)– the slope of which is the TCRE. Relative to present-day, this simple empirical relationship allows a temperature goal (e.g. 1.5 °C) to be translated into a Remaining Carbon Budget (RCB). Assuming emissions decrease linearly from present day E_0 to zero over Δt years, elementary geometry shows that the RCB directly specifies Δt (area of blue shaded triangle in panel a). The simple climate model used here combines CO_2 impulse response functions (Jöös et al., 2013) with a two-box energy balance model (Geoffroy et al., 2012); the climate feedback parameter is sampled according to the 2/3 quantile of climate sensitivities, the empirical distribution of which reflects improved climate feedback process knowledge (Sherwood et al., 2020). Historical emissions are from the Global Carbon Project (Friedlingstein et al., 2020) for CO_2. For simplicity, all non-CO_2 climate forcings are represented in terms of CO_2 equivalents (CO_{2e}) and assumed to roughly cancel out in the historical record—see Damon Matthews et al. (2021) for more accurate TCRE and RCB calculations.

et al., 2021) as originally intended by Allen (2003). However, EEA has succeeded in the 'court of public opinion', where it legitimizes popular claims attributing perceived increases in extreme events to anthropogenic climate change. The popular use of EEA science to support calls for mitigation is not a distortion by the media or activists—these groups are using the peer-reviewed science exactly as the scientists intended. The World Weather Attribution project team, for example, explicitly acknowledges that a key use of their research is to "increas[e] the 'immediacy' of climate change, thereby increasing support for mitigation" (van Oldenborgh et al., 2021).

5 Are we are on the brink of a pronounced global climate movement?

We now describe how these *intentional* developments in usable mitigation science have addressed each of McAdam's (2017) framing barriers, enabling activists to more *effectively* use climate science to strengthen the movement for global climate action and justice.

First, the TCRE has shortened the crisis' time horizon. The IPCC's (2018) projections have inspired a rallying cry among advocates, who often allude to the 2030 benchmark with the claim that "we have [X] years" to dramatically reduce emissions. Activists' ability to communicate the decarbonization required within a certain time frame to meet a global temperature goal gives policymakers a clear mandate for action.

Second, this shortened time horizon has contributed to a collective identity among a diverse coalition of young people (Nakate, 2021; Prakash and Girgenti, 2020). For example, the Sunrise Movement, invoking the IPCC's (2018) report, says inaction "will be a death sentence for our generation." Sunrise has exploded into the American consciousness since its 2018 sit-in in Rep. Nancy Pelosi's office, becoming the standard bearer for younger generations in the climate struggle. Sunrise has established over 400 grassroots groups across the country, and features regularly in policy debates. During just one week in 2019, teenage activist Greta Thunberg inspired 6 million people to take part in youth-led climate protests and strikes across the globe, including 5,000 in South Africa, 10,000 in Turkey and 30,000 in Chile (Barclay and Resnick, 2019; Penalver, 2019; Taylor et al., 2019). The growing youth climate movement now features prominently in policy debates, including the recent negotiations in the U.S. Congress over the Biden administration's budget proposal (Phillips, 2021). Although the Senate has to date come up one vote short of passing the Build Back Better Act, the bill's climate-related spending proved uniquely resilient as legislative bargaining whittled down the overall package (Prokop, 2021).

Third, the TCRE has attributed responsibility for climate change, evoking powerful emotions within potential activists. Drawing on the carbon budget concept, 350.org states that "the vast majority of fossil fuel reserves need to stay in the ground for us to stay below 1.5 degrees C." This attribution generates anger at governments and corporations responsible for emissions, and hope that we can address the crisis by holding these institutions accountable. The slogan "Keep it in the ground" has inspired mobilization across the Global North, from pipeline protests in North America to coal mine protests and occupations in Australia, Germany and Poland (Chernov and Jordans, 2020). These actions have increased the electoral costs that officials suffer from approving fossil fuel projects. For instance, upon assuming office President Biden quickly revoked the permit for the Keystone XL pipeline, which had been delayed after years of protests sparked by a sit-in at the White House and inspired by early and relentless opposition from Indigenous rights groups (Arvin, 2021; Gilio-Whitaker, 2019). Disaggregated equitably across the globe, TCRE-based cumulative carbon budgets also imply that industrialized countries, such as the U.S., China, and much of Europe, would already exceed their 2 °C quotas based on the emissions committed by infrastructure alone (Raupach et al., 2014), supporting activist calls on wealthy nations to retire fossil fuel infrastructure early (e.g. `https://fossilfueltreaty.org/`; Newell and Simms 2020).

Finally, impact studies have helped communicate climate change's human costs. "The difference between 1.5 °C and 2 °C of global temperature rise could mean well over 10 million more migrants from sea-level rise," warns `350.org` (citing the IPCC Special Report on 1.5 °C). EEA demonstrates that human-caused climate change is already having serious consequences, especially for communities on the front lines of the crisis. Various organizations now publish estimates of how much more likely and intense extreme weather events were due to global warming (Achenbach, 2017; Otto et al., 2018). These estimates are another arrow in frontline communities' rhetorical quiver, potentially building on vibrant environmental justice movements within and across the Global South and North (Bullard, 2005; Keck and Sikkink, 1998; Martinez-Alier et al., 2016).

Research documenting EEA's effects on climate attitudes, at this early stage, suggests two pathways through which EEA could increase participation in the movement. First, it could mobilize individuals to act. Scientific evidence "connecting the dots" between extreme weather events and climate change, as 350.org puts it, might reduce the psychological distance from the problem among people with strong place attachments. Experimental evidence from California suggests that news articles attributing extreme weather events to climate change can increase support for adaptation (Halperin and Walton, 2018). However, other work casts doubt on EEA's reception even among policymakers, reflecting unfamiliarity with the method (Osaka and Bellamy, 2020).

EEA's more powerful impact—and, in our view, its more likely one—would be to galvanize the climate justice movement on a collective scale. Prior research finds that EEA affects those who are concerned but not yet alarmed about climate change, nudging them toward a higher level of policy support (Halperin and Walton, 2018). While movements can convert and even mobilize their skeptics, that process requires deep interpersonal relationships in addition to an effective message (Munson, 2008); the "concerned" public therefore represents a more ready constituency. As the concerned public already knows that climate change exacerbates extreme weather, we doubt that greater awareness at the individual level accounts for their increased support. As Mildenberger and Tingley (2017) demonstrate, political behavior on climate change hinges not only on personal attitudes but also on perceptions of others' beliefs. Therefore, popular enthusiasm for climate policy may increase with the knowledge that a new kind of scientific information could strengthen claims to public officials that such measures could make a difference to their constituents. As we have seen, this collective feeling of efficacy is an integral ingredient of a social movement (McAdam and Schaffer Boudet, 2012).

To draw an analogy from the environmental justice movement's founding, Bullard (1983)'s groundbreaking study showing that waste disposal sites were disproportionately located in black communities confirmed community

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members' preexisting beliefs (McKeever Bullard and Cole, 1994). When Houston homeowners declared their opposition to a proposed landfill in 1979 on grounds of environmental racism, their lived experiences had already demonstrated to them the ways in which people of color were excluded from decision-making and targeted with polluting facilities. Yet Bullard's study nonetheless sparked a global movement, as it provided a blueprint for a message that resonated not only with marginalized communities but with allies in government and the broader public (Martinez-Alier et al., 2016). The possibility that frontline communities could similarly draw on EEA to advocate for policies to increase their resilience merits serious examination.

Of course, a movement's strategic capacity (Ganz, 2009) and context (Amenta et al., 2010) mediate between mobilization and policy enactment. Still, scholars generally agree that activism can shape the political agenda (Baumgartner and Mahoney, 2005; King et al., 2005; Olzak and Soule, 2009). For instance, the two American parties largely kept slavery off the agenda until the abolitionist movement entered electoral politics (Sundquist, 1983). While understanding movements' effects on policy is methodologically challenging (Giugni et al 1999; Amenta et al 2010), recent causal inference offers evidence that protest can influence lawmakers' actions, such as their public positions and legislative votes (Madestam et al., 2013; Wouters and Walgrave, 2017).

6 Looking forward: how can we make mitigation science more usable?

While the non-linearity of the science–policy relationship may have impeded climate action in the past, it also provides an opportunity for the rapid change required in the near future. Baumgartner and Jones (1993) show that rather than changing incrementally, as some have argued (Lindblom, 1959), public policy demonstrates long periods of stability punctuated by marked change. When political actors alter a policy's image, government officials "overcompensate for previous neglect of information" and respond by establishing policy venues that invite new actors into the debate (Baumgartner and Jones, 1993; Weible, 2008). As established images and venues create substantial inertia, shifts in images or venues can produce radical policy changes, which can become the new equilibrium if they benefit supporters and weaken opponents (Patashnik, 2008). One "theory of change", then, is for mitigation scientists to pursue research questions intended to trigger these climate policy tipping points. We thus encourage further research on usable mitigation science, including the TCRE and EEA frameworks, but also on more usable re-packaging of complex earth system dynamics such as the risk of climate "surprises" (Schneider, 2004).

Climate scientists often shy away from explicitly advocating for *anything*—let alone specific climate policies—out of a misplaced fear of losing their "objectivity" and thereby their scientific credibility[5] (Schmidt, 2015). The result is a feigned objectivity, which obscures authors' true intentions and ironically allows subjective values to propagate freely but unannounced. In the United States, for example, a small minority of elite "antigreenhouse" scientists—well-resourced by vested fossil fuel interests (Oreskes and Conway, 2011)—have deliberately misled the public with their non-peer-reviewed opinions and otherwise undermined the democratic policy negotiation

[5]This, on top of the very real fear of being attacked by opponents of climate action (e.g. Mann, 2012).

process (Franta, 2021a,b; Lahsen, 2005). By contrast, the responsible approach is to acknowledge the boundaries between scientific analysis and advocacy (as well as any conflicts of interest). Following Lahsen (2005), we advocate for a democratized climate science, which engages with other forms of knowledge and value, and responsibly serves the public (as opposed to the self-interested elite), yet still benefits from the rigor of scientific conventions (e.g. axiomatic principles) and the scrutiny of a diverse set of peers (Oreskes, 2021).

Community-driven and participatory models of climate mitigation science could be particularly promising avenues for designing usable research in the future. Levine's (2020) field experiment shows that practitioners are more likely to work with researchers if they believe the researchers will value practitioners' knowledge and share information efficiently. Although presently focused on usable adaptation science projects, such as "mapping heat vulnerability to protect community health" (McCarthy and Valdez, 2019), the American Geophysical Union's (AGU) Thriving Earth Exchange program helps researchers, community leaders, and sponsors work together to solve local climate and environmental challenges. The AGU, in collaboration with the Citizen Science Association and other professional societies, also recently announced a web-portal for values-driven and co-designed community climate science, featuring both a traditional peer-reviewed academic journal and various other multi-media platforms (AGU, 2021). We encourage climate scientists interested in the democratization of climate science to embrace these new transdisciplinary platforms and funding streams while also learning from past experiences (e.g. the Future Earth program; Lahsen 2016).

One corollary of our argument is that researchers could make their mitigation science more usable by specifically co-designing or co-producing it with climate activists. This does not necessarily involve a corruption of science—values are already present in science; activist-driven science just emphasizes a different set of values "than academic scientists would" (Ottinger, 2015). The Environmental Enforcement Watch project (`https://environmentalenforcementwatch.org`), for example, collaborates with partner organizations, such as the Sunrise Movement's Boston hub, to democratize the Environmental Protection Agency's Enforcement and Compliance History Online (ECHO) database through community oversight. We urge scientists to look beyond their disciplines and learn how to build caring partnerships (see Coen, 2021) with organizations effectively advocating for evidence-based policies (Gardner et al., 2021).

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