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What Kind of Information Does the Era of Climate Change Require?

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ABSTRACT
This article explores the promise of institutions and infrastructures associated with democracy to limit the worst consequences of climate change. The article highlights the apparent conflict between expert governance on the one hand, and, on the other hand, calls for democratization that reflect the diverse perspectives of groups whose rights and labor have been exploited over historical timescales. Drawing on the history of bureaucracy and governance, this article argues that the apparent contradiction between the two poles of discourse can be reconciled by a system of information infrastructure designed to create a robust, accountable system of environmental data-monitoring that also accounts for the work of inclusive community groups as stewards of landscapes. The article concludes by recommending a six-point "Outline of an Information Infrastructure for Responsive, Accountable Governance of the Environment," which includes the following recommendations: 1. Broadcast efforts to enlist communities - especially vulnerable communities on the front lines -- in efforts to document environmental degradation and the effects of climate change; 2. Equitable and sustainable solicitation of the voices of populations underrepresented in traditional science; 3. Centralized preservation of the data in an archive where it can be found, retrieved, revisited, and implemented for action; 4. Analysis of the data by both community participants and laboratory scientists; 5. The creation of accountability through the establishment of centralized, powerful organs of governance capable of holding polluters to account on the basis of data collected by both citizens and scientists; and 6. Transparent mechanisms for negotiation.

Keywords: democracy, participation, climate change, infrastructure, politics

Disclosures: none.

What Kind of Information Infrastructure Does Effective Climate Governance Require?[1]

In the year 2021, western science stands on the cusp of an apparent victory of data over politics, of scientific consensus over propaganda, and of precautionary thinking over the self-preservation of the fossil fuel industry. The renunciation of the Paris climate accords by President Trump was reversed by President Biden as one of his first new acts of office, and it seems possible that the U.S. will fund climate research and innovation under the aegis of a "Green New Deal." In a superficial view, the American return to support for climate governance represents an apparent victory for scientific consensus.

On a deeper level, however, it might be important not to miss the way that recent events have exposed the vulnerabilities of data-driven decision-making at national and international levels of government. We have observed that populist leaders are capable of enlisting ignorance of science towards the overhaul of the leadership of both national and international scientific institutions (for instance the EPA and CDC). We must not make the mistake of assuming that populism or emotional havoc will go away; indeed, every indication about the stresses put on agricultural, infrastructural, and economic systems by a changing climate indicates that national politics will become, if anything, more fraught in the future. In other words, recent events have made clear that no climate policy is safe – no matter how backed it is by research – unless its

[1] Thanks to Liz Barry of Public Lab for orienting me to community science over the course of the last decade, but also specifically in the context of preparing to write this article. Thanks to Deborah Coen and the other organizers of and participants in the "Actionable Climate Data" conference at Yale, November 2020, where this conversation came together. Thanks also to Rajesh Tandon and the staff of the Institute for Development Studies in Sussex for access to their archives.

implications are enshrined within a structure of information-driven governance where commitments to the common good are somehow made safe against the vagaries of local political turmoil.

There is a second challenge to climate governance that recent events have exposed as well, one about privilege and exclusion. In recent years, we have also learned to respect the divergent experiences of disease, climate, and economic fortune by race. We live in an age when the legacy of structural racism is increasingly recognized and taken as an issue in need of reform, as are the lasting harm and deep danger posed by contaminants of many kinds. The recognition of the environmental burden faced less privileged societies in an age of climate change is not, however, consistently recognized as the basis for political decision-making.

At first glance, the two challenges posed in recent debate cut in opposite ways. Some conjecture, given the vicissitudes of popular politics, that *less* popular influence on governance might be required for the sake of protecting the planet. Others contend that the world needs *more* popular oversight of how environmental harm is defined, analysed, and governed.

A seeming paradox emerges: do we need a world ruled by scientific philosopher kings, unharnessed from the ignorance of the masses? Or a world governed by direct democracy, where the terms of scientific research as well as economic allocation are dedicated from below ?

I believe that the apparent paradox is an illusion, easily dispelled by a deeper understanding of how both crises emerge. This article makes the argument that strategies for environmental reforms that would serve rich and poor alike depend on democratic mechanisms of data collection that put the tools of monitoring the environment into the hands of the poor and dispossessed. It makes the case that the failure of science to serve the many reflects the linkages between modern science and the "information infrastructures" associated with modern governance – including the many research institutions that serve modern democracies, and the way that their interests are fashioned to reflect a "public" which is itself the outcome of a long history wherein many communities were deliberately shut out from political power.

In the article that follows, I will briefly review challenges to data-driven decision-making from history of international governance at the UN and World Bank. I will then turn to review episodes from the history of e forts to decentralize data-driven decision-making in local and international governance since the 1930s. Both histories, I argue, o fer instruction about how information architecture has gone astray in the past that pushes past the "more science" and "more democracy" poles of current debate towards a precise vision of what it would mean to create accountable data-driven infrastructure where the documentation of concern from climate-impacted communities and the insights of laboratory science are institutionalized, made sustainable, defended against resistance, and rendered actionable.

This article makes the case that effective activities to protect populations vulnerable to climate change require not *merely* more science or more democracy, but also a fusion of the principles of popular democracy with the values of scientific data collection. It shows that examples of practices that provide for such a fusion have been gestating over recent decades, and could be drawn upon. It demonstrates that, with institutional support, governments could support a system of widespread data-collection along scientific principles that would ensure the protection of communities vulnerable to climate change. It calls upon scientists and

administrators involved in climate change to investigate how grants and research can be recalibrated with the principles of democratic participation, such that their research may be made more effective in terms of representing the interests of all.

In particular, this article reflects on (a) the nature of the vulnerabilities of science to politics, and (b) the traditional limits on diverse voices in the process of scientific collection of data, and the ways in which new technologies and movements have pushed against those limits. Leaning into those reflections, this article proceeds to construct eight criteria for sound climate governance, where both the diversity of affected populations and the reality of scientific consensus are reflected in a binding process of governance capable of addressing the urgency of the emergency that faces us. I will identify specific roles for science – both of the lab and community variety – within this proposed framework.

A Short History of the Politics of Information

The information of how institutions use science – and other forms of information – to serve the public has a long and contested history. In this story, information has almost never been neutral; it has been a tool with which to substantiate the interests of one party over another – to argue that one county deserves levees while the other deserves none. In earlier centuries, information represented, to its holders, the opportunity to seize land by mapping it. Science was neither innocent nor uninvolved in these machinations; science was the medium by which political innovations were executed.

Today, differentials in the life of *climate* information have a similar politics. Access to the methods of documenting environmental harm are unevenly distributed among communities worldwide. In order for environmental burdens to be identified and acted upon, communities need mechanisms not only for understanding but for holding local, national, and global bodies responsible for developing appropriate strategies and acting according to their promises.

Scholars are increasingly making a connection between the political access enjoyed by a community and its ability to transcend environmental harm. Researchers in public health and environmental history have exposed the fact that communities of color have disproportionately borne the toxic load produced by industrial pollutants in the U.S. (Camacho 1998, Bullard and Wright 2012, Lerner 2012, Taylor 2014, Bullard 2018). The differential experience of environmental contamination has a long history, dating back to how natural resources and physical labor have been exploited to the benefit of white elites in western nations, which have also disproportionately enjoyed the benefits of industrialization (Chakrabarty 2009, Jonsson 2015, Mikhail 2016, Malm 2016).

As scholars have long recognized, the facts of history have predictive power in explaining *who* will bear the burden of climate change, and *why* the experience of flooding, drought and displacement driven by climate change is unevenly distributed, with the he t of the experience falling upon indigenous groups, persons of color, and developing nations that face the brunt of disasters from climate change (Shue 1993). “Globally, Indigenous people will experience the impacts of climate change directly, forcefully, and well before more insulated, less rural, less northern *or* less southern centers of commerce and power,” writes Candace Callison. “Forest

fires, droughts, loods, sea-level rise, storms, permafrost melt, and other ecosystem changes have already impacted all aspects of human and nonhuman lives" (Callison 2020).

In another work, I have used the term "information infrastructures" to define the institutions that fund and accommodate science and that make data actionable in the policy world (Guldi 2022). Bureaucratic information infrastructures govern whose data is reviewed, and ultimately whose voices are heard, in questions of international policy. Understanding the history of information infrastructures can help us to shape a better architecture for climate governance -- one where the realities of environmental suffering driven by structural racism are recognized, where laboratory research has a role in making visible invisible connections, and where data-driven findings drive robust and accountable action to govern carbon emissions -- as well as other pollutants that affect the health of humans and the ecosystem as a whole. To embrace the challenge of information infrastructure is to open up one of the million-dollar questions of climate governance: how to make governments (and allied actors like corporations) responsive to climate-impacted communities. is article directly addresses the joint challenges of the vulnerability of international climate policy by looking to history for an account of the dangers implicit in building information infrastructures to serve the public good.

Information infrastructures, however ambitious their dreams, are vulnerable to the fate of larger political systems. Information infrastructures that are centralized at an international level are vulnerable for the same reasons that international governance is vulnerable in general: there are choke points, by design, that allow powerful nations to stop an initiative that threatens their interests. Consider the case of the UN's Food and Agriculture Organization (FAO), the branch of international government that was created in 1945 with the explicit task of supporting farmers in the developing world, a mandate that led to the FAO providing technical support for land redistribution schemes designed to reverse the sins of colonialism by turning the world's poorest agricultural laborers into landholders.When U.S. interests in multiple nations began to perceive these schemes as a threat, a U.S.-led World Bank under Robert McNamara pulled funding for the FAO's land reform programs in 1974. Programs that had been decades in the making were undermined, and developing-world nations that had previously looked to the UN for research support in agricultural development thus had to look elsewhere (Guldi 2022). Centralized, international governance has been extremely vulnerable to shifts in national leadership.

Historians of the UN argue that this vulnerability to choke-points was designed from the beginning. Thee UN council was denied binding power by representatives from the US and Europe, who wanted to maintain control over their former colonies. Ideas for creating a judicial branch of the UN – a world court, capable of hearing human rights pleas from the developing world, for instance – were similarly never enacted (Mazower 2009, 2012). The vulnerability to choke-points is not, in other words, an implicit feature of international governance; it is instead a precaution that was demanded by the U.S. at the end of the Second World War as a means of enforcing U.S. hegemony over a world where the Soviet Union was perceived as a threat. In an era when we are more cognizant of the long-term vulnerability of the developing world, single-nation power to "choke" international initiatives demanded by large numbers of nations from the developing world may no longer be appropriate.

Not every information infrastructure needs to be centralized, of course, and some of the most powerful examples of information infrastructure in the twentieth century have been radically decentralized. Scholars of information have also underlined the comparative resiliency of grassroots movements which share information. In Lisa Gitelman's review of how social movements share information, for example, she points to the role of the photocopier shops in Cambridge, Massachusetts in the 1960s in allowing the rapid copying and dissemination of the Pentagon Papers (Gitelman 2014). Similarly, participatory organizers in India and southeast Asia in the 1970s and 80s used mimeographs, dot-matrix printers, and photocopiers to disseminate case studies of best practices for community organizing (Guldi 2022). In general, cheapness, redundancy, and decentralization forfend against shifts of political will, allowing communities political independence to pursue the problems that directly address them.

Decentralized information structures have different vulnerabilities from centralized ones. Where centralized institutions governing with information are vulnerable to the machinations of powerful allies, decentralized activism is more likely to simply be ignored by authority. Decentralized meetings can also be "co-opted" by authority, as when, for example, the UN and World Bank promote decentralized "citizen science" within a platform that makes room for education but not for accountability.

Despite these aims of empowerment, however, community science groups face tremendous barriers to creating binding actions, reparations, or policies on the basis of the data they collect. Frequently, organization efforts are abandoned before they take actionable form. The data is collected and analyzed at a local level, but it rarely reaches the office of a lawyer or regulatory official with the power to ensure that justice is undertaken. Despite the willingness of regulatory officials to consider writing policies to protect minorities, only infrequently are the documented concerns of local communities translated into policy. Communities have few tools to monitor government representatives on ecological issues and hold them responsible (Harrison 2017).[2] The limited power of community science to create policy action is particularly pronounced where issues arise among poor communities, indigenous communities, and communities of color who are typically first to suffer direct threats to the quality of their land, air, and water. The barriers to ecological empowerment are, in many ways, familiar issues from the history of democratic reform, with new implications for scale and immediacy of response.

History supplies many examples of what can go wrong when national and international institutions enlist citizens for data-collection *without* accountability. From the 1980s forward, many urban authorities as well as international actors such as the World Bank adopted participatory mapping initiatives around the world, which provided easy metrics demonstrating on-the-ground impact, according to the writers of reports. Most of these initiatives did not, however, produce any actual control over natural resources on the part of communities. Instead, participatory meetings tapped local communities for the uncompensated volunteering of time

[2] Harrison writes: "Although [environmental justice] advocates and agencies' [environmental justice] staff have proposed many regulatory reforms that could protect poor, minority, and Native American communities from dangerous environmental hazards, agencies have implemented few of them." https://publiclab.org/notes/mlamadrid/12-05-2017/what-s-happening-with-government-agencies-environmental-justice-work

contributed to meetings facilitated by World Bank sta f. Seemingly "participatory" meetings provided a pretext for World Bank development schemes rolling forward unchecked – "consulting" with grassroots groups while refusing to give citizens directive authority over resources. Ultimately, these initiatives were denounced by journalists and scholars as a "swindle" (Guldi 2017).

Where community science lacks information infrastructures for holding wrongdoers accountable, it can actually become an impediment to empowerment. Some are characterized by a logic of "taming" civic dissent by channeling concern into education programs (Kinchy 2017, Fung 2003). Reformers, meanwhile, have called for solutions to this problem, with some highlighting the importance of making governments for earth's shifting planetary boundaries (Biermann et al 2012), and others advocating shifts to make governance responsible to poor people in every locality (Extinction Rebellion 2019).[3]

Accountability to local groups thus remains an important criterion for a working environmental governance architecture. An effective environmental governance regime would require not only the mechanisms for gathering and analyzing data, but also the mechanisms for holding polluters responsible for the harm they have caused, pursuing redistributive and reparative justice across national borders. This could be accomplished through national regulatory agencies, or through a world human rights court, but only if those agencies and that court are appropriately staffed and funded to pursue polluters and hold them responsible. e remedy for effective participation is thus about empowerment and accountability at every level of the process. Citizen time is not an infinite resource that can be contributed over years or decades without compensation; citizen observers need to be *paid* for their time; citizen data collectors need to be compensated as well. Citizen-collected data cannot simply be uploaded to a repository; there must be some mechanisms for holding accountable the wrong-doings documented by the data. There must be *binding agreements* and an arm of government tasked with pursuing the evidence of harm and appropriate remunerations, and there must be a permanent and independent arm of governance capable of pursuing polluters across national borders.

If we come to understand one of the fundamental problems of information infrastructure as empowerment, we can begin to imagine the steps that would be necessary to create an information infrastructure that enabled appropriate responses on the part of climate-impacted communities around the world.

[3] An example of thinking about democratic monitoring on the international level is Frank Biermann et al., "Navigating the Anthropocene: Improving Earth System Governance," *Science* 335, no. 6074 (2012): 1306–1307; for a proposal that integrates global environmental monitoring with local democratic supervision, see "Citizens' Assembly," *Extinction Rebellion* (blog), accessed October 2, 2019, https://rebellion.earth/act-now/resources/citizens-assembly/.

How Information Infrastructures Evolve

How do these vulnerabilities of information infrastructures inform our choices in the era of climate governance? One important fact about information infrastructures is that they also evolve over time. Max Weber famously traced the history of bureaucracy from the Khan's family — where intermarriage was a precondition of promotion — to the nineteenth-century civil service of Europe, finding in meritocracy the culmination of centuries of labor (Weber 1968). Over recent decades, information infrastructures have continued to evolve, motivated by concerns with the inclusion of voices of the working class (in Britain, for instance) and of previously-colonized people (in India, for instance). The structures built by societies do not follow some code of law of nature that is held static since the birth of the scientific method; those structures and institutions have evolved to serve new social and political needs, and they must keep evolving anew if new needs are likewise to be serviced..

Tracing the history of the evolution of information infrastructure over relatively recent time-spans can give us the courage to imagine the shape that contemporary information infrastructures would need to take in order to not be resilient to the dynamics of undermining by an antagonistic superpower or cooptation from above. e history of governance can supply perspective on the changing mechanisms for collecting data about the environment, which has never been static. Indigenous communities, communities of color, and working-class communities have been excluded from the process of governing land (and thus what we today call "the environment") in the Americas (and much of the previously-colonized world) at least since the foundations of modern democracy were laid in the eighteenth century (Greer 2018). Over the course of the twentieth century, demands for equal representation led to reforms of various kinds, including the removal of barriers to African-American and indigenous voting in the U.S. during the Civil Rights Era.

In the midst of these democratic revolutions, various reformers looked to change the information infrastructure around government so as to favor the inclusion of information collected by the many. Already in the 1930s, key theorists of the state imagined how systematic investment in infrastructure for the many to document their landscape that would make possible the fashioning of a more inclusive information infrastructure, where data gathered by schoolchildren across the nation would inform maps of economic blight and opportunity, with the end of enabling a new kind of policy-making where national decisions were informed by more democratic processes representative of the nation as a whole (Matless 1999; Rycro t and Cosgrove 1995). During the Second World War, Britain experimented with citizen intelligence initiatives such as the one known as Mass Observation, an e fort designed by its founders to apply the natural scientist's passion for collecting information to democratic experiments with self-knowledge (Hinton 2008). In the first decades of the twentieth century, theorists of information called for an expansion of card catalogues, microfiche document collections, and other information systems as means of access by the people directly to information (Gitelman 2014). In the early design of the World Wide Web in the 1970s and 1980s, programmers taken with utopian and communal ideology attempted to create an online world devoid of hierarchy and open to information exchange (Turner 2006). Idealistic programs for democratization

inspired geographers, librarians, and coders to enact experiments in democratizing the life of information, sometimes played out at the level of community, and sometimes on a planetary scale.

The need for democratic reform was often felt the strongest in places where democracy had been the most scarce. In the world after the Second World War, Europe's former colonies began to demand independence and to look to national programs for literacy and economic development to raise their citizens out of poverty (Getachew 2020). In those parts of the world that were in the process of rejecting the political and economic relics of European colonization, intellectuals and government ministers strove to imagine a world where the interests of disenfranchised communities did not merely inform but also actually shaped national and international policies around land. Some of their ideas explicitly took on ideas about designing an information infrastructure where the experience of the many would inform policies for the nation at large.

In the 1960s and 70s, the problem of how poor people could advise their governments became the subject of intense experimentation and sharing by activists from the developing world. Across Latin America and in many parts of the global south, the followers of Paolo Friere argued for literacy and regular citizens' meetings to debate what kind of economic policies, state infrastructure, and educational institutions would best serve local communities (Freire 1968; Bhasin 1976; Tandon 1981; Shrivastava and Tandon 1982). From these conversations a new imaginary appeared about how modern democracies might become truly "participatory," or directly responsive to citizen demand. By the 1970s, the global followers of Paolo Friere were organizing "participatory research" networks around the world, where local organizers trained in leading community discussions about local conditions, frequently involving questions about the maintenance of local waterways and ecological future of local townships (Guldi 2022).

In *The Long Land War* (2022), I documented some of the strategies used by citizen groups to organize information about land and water use by these movements. Many of those experiments and strategies took the form of data-gathering techniques and facilitation techniques to document poor peoples' knowledge about their immediate environment — that is, about the land and water that surrounded them, including contested claims of landownership, or toxic pollution in the water. In the 1970s, the first participatory maps appeared in Canada, used by the Beaver and Cree people to defend their historical property rights against timber and mineral interests. Another famous case involved a suit against a local tannery by villagers for polluting the waters used for fishing by local populations. Using techniques such as participatory map-making, participatory facilitators invite villagers to join together in documenting environmental grievances, the evidence of harm, and the best strategy for repair. Formerly colonized people had devised a toolkit to allow them to collect and analyze data about the environment and to propose appropriate policy around it (Guldi 2017, Guldi 2022).

In the 1980s and 1990s, the techniques of participatory mapping were formalized. They were taught at community colleges in India and were promoted by development specialists at western universities like the University of Sussex. They were embraced at the UN and World

Bank as a tool for incorporating the voices of the dispossessed into international development policy.

Early experiments in participatory governance demonstrate that grassroots data gathering is one avenue for documenting and correcting the exploitation of vulnerable communities, which includes those communities' disproportionate exposure to toxic pollutants. In general, the participatory mapping experiments of the 1970s and 80s offer an early precursor to today's community science movement, where facilitators meet with members of a neighborhood, village, or region, and present tools and strategies for documenting local experience of an environmental crisis.

e Evolution of Information Infrastructure as an Opportunity for Environmental Justice

Modern information infrastructures -- from the nineteenth-century civil service to participatory mapping — evolved as societies came to recognize needs for representation and equity that had formerly been suppressed. Today, in the movement known as "community science," citizens from diverse backgrounds have banded together for the purposes of collecting and analyzing data that describes, in detail, the embodied experience of ecological toxicity, in such ways as to document and validate the existence, nature, and origins of harm (Dosemagen 2020). The modern movement for community science dates from roughly 2005-10, a moment when multiple activist and academic spaces were exploring the use of social media and information design to enhance civic participation.

One emblematic story of the rise of modern community science is the story of the founding of Public Lab. From 2009, students and activists were regularly convened by MIT's Center for Future Civic Media to invent opportunities for collaborative creation in the space of information design for the public good. In 2009, several of those individuals became involved in grassroots mapping initiatives, which eventually led to the founding, in 2010, of Public Lab, a nonprofit that has galvanized the documentation of environmental harm in communities, working principally in North America ("Public Lab History" 2012).

Many advocates of community science conceive of their work as an opportunity to empower previously dispossessed groups. In the words of one such initiative, that work means collaborating "with marginalized groups, such as indigenous peoples, to support them in combining scientifically sound methods with local knowledge so they can participate more e effectively in decision-making processes relating to pressing issues such as deforestation, biodiversity loss, and food security" (Stevens et al. 2014). Some observers have urged building "resiliency" into the governance process by creating systems where citizen science supports pre-disaster planning as well as post-disaster recovery (Paul et al. 2017). In the desire to correct the exploitation of disenfranchised communities by broadening access to the documentation of harm, community science today mirrors the techniques and values articulated by participatory researchers in the postcolonial era, who emphasized the importance of empowering formerly disenfranchised communities.

Much of community science explicitly targets problems of environmental governance, taking up the experience of environmental harm -- sensed, for example, through the human

sensation of seeing smoke, smelling or tasting chemicals, or feeling sick. Embodied observation offers a route to investigation that is radically open to non-scientists, thus putting the mechanisms of collecting data and writing policy into the hands of populations that were traditionally excluded from laboratory science (Shapiro 2015).

Opening science up to excluded populations represents, in itself, a major opportunity for righting the mechanisms of exclusion implicit to western scientific traditions. History tells us that, over significant timescales, western science and technology have been allied to projects involved in exploiting the natural resources of the former European colonies and developing world. While the world made by nineteenth-century professionals (such as doctors and lawyers) was more open than the kinship-based networks of Genghis Khan (Weber 1968), nineteenth-century professional advancement was scarcely open to everyone; women and ethnic populations were altogether excluded. The civil engineering projects in the developing world notoriously tilted the landscape in favor of the colonizer, for instance in the form of the Indian railways that charged one set of fees to (usually white) people exporting agricultural produce to the ports, and another set of higher fees to the (usually native) people importing production machinery inland (Goswami 2004).

Familiarity with the history of community science can teach us to regard grassroots e forts at collecting data about the environment not as some newly-arrived rival to scientific consensus, but the face of a new participatory and inclusive forms of governance and data practice that have been evolving over decades, and which could be improved further through a deeper dialogue with science. The broad emphasis on human sensation as an index of possible harm means that community science's standards for data are o ten more encompassing than those established decades ago by the EPA (Shapiro 2015). Including the perspective of vulnerable groups in climate assessment often means raising the bar for what counts as environmental harm.

Over the past two decades, community science has begun to evolve increasingly sophisticated mechanisms for gathering and reviewing data about the environment. In community science, citizens typically follow up on the information conveyed by human sensations with a phase of gathering supplemental information, for example through sensors designed to collect information about air or water quality. Using cheap sensors, citizens have measured air quality, in the process, establishing new standards that had been previously "overlooked by scientists," according to one scholarly review (van de Gevel 2020). Citizen groups also have monitored the public health crises related to the "fracking" boom of the northeastern U.S. (Kinchy 2017). Cheap sensors paired with cell-phones have enabled a boom in crowdsourced assessments of flooding (Paul et al 2017). Open-source tools for demarcating inhabitation and recording air and water quality have become readily available in recent years, offering a foundation for citizen monitoring of the local landscape (Woods et al. 2018). A diversity of tools for monitoring contamination of air, land, and water has been adopted for these undertakings, typically with the explicit intent of inaugurating the repair of landscapes or some kind of restitution in justice, based on, for instance, the polluter recognizing harm done to families that have contracted disease, and paying compensation accordingly. Decentralized movements have collected data about their environments – not merely for the sake of abstracted

scientific research, but more frequently to actively defend communities from disaster, pollution, and disease.

Community science offers to document the harm and to propose the shape of effective remedies. What we need next is a model for how the information of community science would reach governance and become actionable.

Laboratory Science in the Service of Accountability

Community science, of course, is not the only sector that has a role to play in the documentation of harm to the climate. Other important sectors of planetary and climatic modeling in the atmospheric sciences defy the powers of community science as it currently exists. Because of these limits, I propose that community science is best conceived of not as a replacement for environmental science, but rather as the beginning of a mechanism for restorative justice, capable of monitoring the harm to local communities that has transpired as a result of global capital and the mining, agriculture, petrochemical, and other extractive industries of the world.

Since the 1960s, when the first ice cores were drilled that documented the spiraling emissions of carbon in the Earth's atmosphere, climate scientists have compiled data and made recommendations, for instance of carbon taxation, that were designed to hold polluters responsible for their harm to the planet's atmosphere (Oreskes and Conway 2010, Oreskes 2011). In these e forts, climate scientists have routinely pursued datasets that would have been invisible at the community level in their time. Laboratory and research science have served the role of anticipating future harm by making visible the invisible evidence of contamination that is, as yet, below the threshold of detectability in some communities.

It is vital that scientists continue to collect data on a planetary scale, because the scale of planetary climate change defies the powers of any one community group, and community science is still too scattered and varied in its data-collection to create a truly global picture of planetary change as a whole. Social movements cannot act in relation to data about the landscape of which their community is unaware (whether because the harm is below the threshold of individual detection, or because the data is private, has been disappeared by the government, or is behind paywalls).

Another role for lab science is in the analysis and comparison of case-studies from a centralized archive of community science. An archive of community experience would make it possible for public health experts to turn their attention to generalize about the particular disasters, events, or contaminants, documented by community science. An international archive would make possible general comparisons about the scale of population affected by certain chemicals, industries, or individual polluters. In dialogue with a public, international archive of community experience, lab science initiatives might be funded to concentrate on the chemical pollutants that have been shown to result in the largest-scale exposure of human communities, together with the ecological pathways that result in exposure, and the biological consequences of that exposure.

In the past, a major role for laboratory science has been the investigation and theorizing of invisible interconnections between industry and ecological harm, enshrining these findings as *precautionary principles* to be upheld by regulatory agencies. In her book, *Toxic Bodies*, the historian of science Nancy Langston argued that, under pressure by the manufacturers of chemicals, the scientists leading U.S. regulatory agencies abandoned the precautionary principle, choosing instead to "green light" new chemicals before they had been thoroughly tested, in the name of fostering "innovation." The result of this choice, Langston argues, was the flooding of water and foodways with molecules that disrupt endocrine systems and lead to large-scale incidence of cancers (Langston 2010). STS scholars Wylie et al. (2017) update Langston by observing that "nearly 80,000 chemicals on the market have yet to be analyzed for their ability to disrupt hormonal signaling during [the early stages of human] development." ese facts indicate that renewed investment in the lab sciences and public health are sorely needed to formulate a new set of precautionary principles capable of stemming the tide of environmental and atmospheric contaminants – not only those that already exist, but also barring problematic contaminants that *might* exist in the future, creating appropriate guidelines for corporate manufacturers to abide by which are designed with planetary and community health in mind. Community science, in this vision, is not a rival to laboratory science – but rather an important supplement, collecting evidence of harm in the human world, which can be backed up and generalized by lab and research scientists.

Another possible threshold for an actionable climate science might be the creation of a science of observations tailored to holding polluters and institutions of governance accountable. Today, documenting and tracking atmospheric polluters on a global level could be accomplished through sensors as well as through satellite imagery, a domain in which departments of geography might collaborate with material sciences and engineering. The test of the fit between lab sciences and effective governance of climate science is the ability of research to result in accountability for polluters and the preservation of the atmosphere in the name of collective survival.

Laboratory Science Also Needs a More Robust Information Infrastructure to Be Effective in its Defense of the Environment

Our survey of history suggests that there are measures that would protect both community science and lab science in their work to document environmental harm. As Oreskes and Conway (2010) have shown, the work of climate and lab science has been hampered from creating durable policies in the U.S., despite clear reporting by the scientific community since the early 1970s, as a result of lobbying e forts by private industry.

Independence in regulation implies the need for an international authority, free from the influence of individual nations, that could create binding resolutions that are resilient to regime change among member nations. An international, independent archive supplies one criterion of permanence and independence. A political entity would need to be created to administer the archive and hold polluters accountable for wrongdoing on the basis of science. Such an entity would need to be resilient to the kind of attacks on funding that the World Bank leveled against

the FAO in 1974 (Guldi 2022). The creators of such an entity would therefore need to work to secure steps protecting the scientists and administrators of that entity against political vicissitudes, for example permanently funded from national and corporate contributions.

If this seems like an extreme step, history again offers instruction in the expansion of nineteenth-century bureaucracies that gave us our modern institutions of civil engineering -- a domain where, in developed nations, technical expertise continues to inform where and how roads, dams, and bridges are constructed and who pays for them. e creation of national bureaucracies capable of diverting funds from one region to another was no simple matter; like climate, civil engineering sometimes involved threatening private interests in order to serve a larger public good (Guldi 2012). The creation of independent bureaucracies with binding authority, protected from regime change and undue private interest, was essential to creating modern bureaucracies of civil engineering. In the nineteenth century, the expanding bureaucratic administrations of France and the U.S. that ran the post office, roads, bridges, and trains devised new strategies for sheltering their administrations from political negotiations over which region would secure the next nationally-funded development – and the economic promise that went with it. As historian Theodore M. Porter records, in the nineteenth century, French engineers were protected from negotiations by the prestige and *secrecy* – such that negotiations over allocations were made in a closed council whose deliberations were never reported to the public (Porter 1995 p. 116). e protections that engineers enjoyed -- including independence from political gamesmanship and centralization -- are appropriate for climate science today. Both Oreskes and Conway (2010) and Langston (2014) have shown that it was corporate influence that undermined U.S. regulatory agencies. The status of scientific data and research at U.S. regulatory agencies is vulnerable in ways that endanger the prospects of independent and actionable science. If we value the atmosphere, water system, and land as a commons that is a public good, we too must be willing to imagine government institutions that shelter science and data-backed decision-making from the vicissitudes of local government priorities.

Porter argues that information infrastructures in the past evolved to make transparent the trade-o fs involved in negotiations over the common good. In the 1940s, the administrators of the U.S. Army Corps of Engineers deliberately needed a strategy for working "in a context of suspicion and disagreement," adopting cost-benefit analysis as a common language for decision-making (Porter 1995 p. 149). Porter's work points to the fact that bureaucracies administering scarce resources will always be under pressure, and that formulas of objectivity in accounting o fer one way of formalizing the rules by which goods are allocated.

In the era of climate change, the decisions over which communities have climate observers funded or remediation funded are likely to remain intensely political. At the same time, the urgency of limiting carbon emissions to avert a climate disaster also requires stark re-assessments of how societies calculate cost-benefit assessments, raising questions. Those trade-o fs may be superficially framed as a cost-benefit analysis of treating di ferent *kinds* of pollution: for instance, whether water pollution (dangerous to humans and ecosystems but less directly linked to a planetary crisis driven by rising temperatures) is equally urgent as a crisis of atmospheric pollution. The issue also concerns with how "economic growth" and "scarcity" are measured and calculated, and how human health and safety and safe drinking water count in the

measurement of human achievements. Efforts at restorative justice show how previously oppressed populations have disproportionately borne the toxic loads of industrialization and continue to take the brunt of risk for climate change (Callison 2020). These observations suggest the need for a structural and rigorous engagement with how we value climate, and whose valuation matters -- an issue that must be taken up by any independent regulatory agency as one of the first matters of work.

Today, the mechanisms of negotiating climate change must revise models for valuing the climate unduly influenced by private lobbyists or models of national employment that implicitly privilege the well-being of certain citizens above the survival of all.

An Outline of an Information Infrastructure for Responsive, Accountable Governance of the Environment

The challenge is thus to design an information infrastructure where polluters can be held accountable, whether the harm they do is hyper-local and targets people of color, or whether the pollution is extremely widespread, yet so dilute in any single place that it escapes notice. e solution, in any case, should be built upon data-driven assessments of harm created both by community stewards whose work is broadly reflective of planetary diversity of incomes and privilege, and created and documented by research scientists whose task is to make visible the invisible connections between industrialization and ecological harm. In the service of imagining such an information infrastructure, let us list a number of qualifications of a modern system of data collection, analysis, and governance appropriate to contemporary trends in democracy and science.

1) *Broadcast* e forts to enlist communities -- especially vulnerable communities on the front lines -- in e forts to document environmental degradation and the effects of climate change

   As we have seen, part of the power of community science reflects the promise of integrating the observations, experience, and needs of communities that have previously been excluded from the benefits of capitalism. Indigenous communities, communities of color, and communities in the developing world are frequently exposed to higher levels of toxic pollution than affluent communities. By documenting the experience of vulnerable populations, the facilitators of community science e forts -- and the participants in these e forts -- are offering the rest of the world an important opportunity to right the exclusions that have traditionally defined who benefited from advances in science, healthcare, and the extraction of natural resources. One component of an effective environmental governance regime in the era of climate change would therefore be a system that expands efforts to integrate the voices of vulnerable populations.

Until the present, the forms of activism that coordinate and amplify the voices of non-privileged communities -- participatory research, community science, and citizen science -- have mainly operated in an ad-hoc manner, following the work of particular activists (John Gaventa, Robert Chambers, Rajesh Tandon), or the work of particular organizations (The Center for Participatory Research in Asia, the Institute for Development Studies, Public Lab).

Historic revolutions in information infrastructures can inspire us to rethink the kinds of information infrastructure that effective climate governance requires. A centralized, independent institution for supporting climate and environmental science would need to be designed, under whose aegis polluters would be held accountable, ensuring that the data gathered by both community scientists and lab and research scientists will be actionable.

2) *Equitable and sustainable* solicitation of the voices of populations underrepresented in traditional science

As the foregoing sections have explained, today's questions about race and equity in environmental governance stem from the long-lasting and uneven relationship of access to the benefits of science and economic development by privileged populations, and the exclusion of indigenous communities, communities of color, and communities in the developing world. It is therefore crucial to the ideals of both postcolonialism, participatory research, and community science that e forts to document environmental harm.

One of the most obvious ways that both laboratory science and community science initiatives already reinscribe a logic of exclusion is through the differential in salaries: one general expectation of most movements is that research scientists and regulatory officials working for the government will be compensated with professional wages, while ordinary citizens who work to document ecological harm in their locality will work on a voluntary basis.

Compensation of participants is not recognized by most proposals about centralized e forts, including the UN's Citizen Science Global Partnership. is is a dangerous profile for organizing, in that it recreates the exclusions typical of World Bank e forts to enlist participatory mechanisms in the 1980s, which led almost nowhere to the redistribution of resources, and which directly conflicted with Sherry Arnstein's measure of participation (Guldi 2017, Arnstein). As the critics of the "participation swindle" argued, the "participatory research" schemes of that era were frequently typified by uncompensated documentation of local grievances with few mechanisms of

accountability. Such systems take for granted the labor of community scientists; they are also not sustainable in a long-term sense, because people in vulnerable communities must choose how to allocate their labor -- whether for wages, food, rent, or activism -- and cannot dedicate their time to voluntary scientific observation of climate change on an unlimited basis. Such long-term commitments to documenting climate change such as are envisioned by the UN's Citizen Science Global Partnership are therefore not sustainable in any real sense.

The obvious solution for an equitable and sustainable climate science is compensation: citizen observers and collectors of data both need to be *paid* for their time. One could imagine a green citizen science network laid out on the scale of the Peace Corps or the New Deal, training and paying citizen scientists to monitor their communities, to research, recommend, and constructed needed forms of infrastructure such as environmental remediation schemes to deal with legacy industrial waste in the groundwater, recycling facilities to minimize future waste contamination, levees to deal with flood risks to endangered communities, and environmental monitoring stations and schools to carry out the future work of environmental monitoring. For the pattern of initiatives of this kind, we could look to the model of citizen councils in Ireland, where citizens are compensated for their time researching and writing policy around issues of civic concern.

One mechanism to ensure equity might be to attach requirements for equity to all science funding, creating a "community climate research" fund attached to all research initiatives from developed-world nations working in the developing world. In principle, such a fund would recognize the implicit labor of local persons as stewards of the environment. One might also imagine a law requiring all beneficiaries of government grants to employ an organizer with a certificate in participatory research to facilitate a community-science program. If a lab scientist working in Africa is paid $100,000 for a year of research, the same grant should provide for $100,000 to be paid annually for each full-time citizen data facilitator and collector, whose data is not required to be collected in tandem with the same aims as the science project in question, but should instead be governed by community aims. Another mechanism might be to fund local community science initiatives out of penalties paid by polluters, setting up a global fund to compensate community science groups for their activities.

3) *Centralized preservation* of the data in an archive where it can be found, retrieved, revisited, and implemented for action

The collection of data is merely the first step in a process of data management, retrieval, analysis, and policy-making where data collected by scientists must be consulted. Because the implications of data about environmental degradation and the local impact of climate change may be cumulative in their implications, it is vital that data collected by both community scientists and laboratory and research scientists be preserved under the conditions for long-term retrieval.

This implies a role for a national or international archive, which should be made responsible for providing the infrastructure to house the data collected by citizens in something like a historical archive where data collected by communities can be preserved, retrieved, and analyzed for legislative or judicial action. There is a role for the state to support community e forts at data-gathering by collecting and preserving the data of citizen science movements in a format where it can be retrieved and inspected as cases are reviewed by appropriate bodies of governance, including especially environmental regulatory agencies and the courts.

The data housed in such an archive should support inclusive studies of environmental harm that document the experience of underprivileged communities such as indigenous nations, persons in the developing world, and other ethnic groups that have historically been the subject of economic and environmental exploitation. The archive should be designed so as to enable timely decision-making responsive to an active democracy that is informed about local and global climate data. The point would be to render all such data accessible and actionable.

There would also be a role in such an archive for scientific data – as well as data about the political and economic networks of polluters.

The design of such an archive for the preservation of data may need to reflect a reality in which climate change predicts the disruption of normal weather and harvest patterns, and real-time data is needed in order to effectively describe and predict near-term emergencies. In cases of climate-produced disasters such as typhoons or hurricanes, it is the timely *retrieval* of community- data that is crucial to an effective response. Victor Marchezini and his collaborators have envisioned how a network of early warning systems could pave the way for reducing vulnerability to extreme weather events across the global south (Marchezini et al. 2017). The potential for the radical disruption of the experience of climate -- and the need for early warning systems like the one suggested by Marchezini and his collaborators -- should be taken into account in the design of such an archive.

4) *Analysis* of the data by both community participants and laboratory scientists

Community scientists who are exposed to the consequences of environmental degradation and climate change are o ten in the best place to interpret the data they collect and to articulate the implications for local governance, according to the experience of many community science facilitators. Where data about the environment is freely available, local communities have been quick to retool that information, alongside their own data, into a call for action. Citizen documentation often consists of the first step towards documenting an agenda for repair.

Through careful attention to minute, regional data about climate change, citizen scientists have become the architects of careful and responsive policies. For instance, in Nicaragua, Ethiopia, and India, citizen scientists developed crowdsourced approaches to helping farmers choose strains of crops suitable to climate-driven changes in precipitation and weather (Etten et al., 2019). In an institutionalized regional, national, or international program of community science, it would therefore make sense for regulatory agencies to recruit community participants as the authors of policies for repair.

As we have outlined above, there is also room in the analysis process for laboratory and research scientists, who may be able to make visible previously undetected connections between diverse sites of climate-driven disasters or pollution-driven disasters in public health.
Laboratory and research scientists, as well as community scientists, should therefore be recruited as analysts and authors of policy in a forum that is sheltered from corporate or political pressure.

5) e creation of accountability through the establishment of centralized, powerful organs of governance capable of holding polluters to account on the basis of data collected by both citizens and scientists.

Any effective information infrastructure for climate governance would require the existence of some regulatory office, at the national or international level, capable of taking binding action to penalize carbon emitters and other polluters.

Institutions for climate governance must be created that make it possible for ordinary citizens and scientists, working on the basis of data, to hold local and global bodies accountable for new mandates within frameworks designed for citizen sovereignty.

Citizen science is only meaningful, and only a solution for the lack of resources, if it is paired with actual redistributions of authority – for example, taxes upon polluters which go into medical support and flood-control infrastructure, scientific and historical literacy to help young people understand the roots and scale of the current crisis, and redistributions in the ownership and governance of land and water that put authority for future administration of natural resources into structures of common ownership. Van de Gevel et al (2020) have emphasized that most citizen science projects to date lack the permanence, infrastructure, or funding to pursue change on a broadcast scale that would routinely hold polluters and local authorities accountable to a higher standard of governance.

Penalties must be devised with the goal of making corporate polluters accountable for their actions, and of holding local, regional, and national authorities responsible for the safety of their populations. Penalties must be brought into alignment with the growing body of evidence from community and other scientists, whose observations have documented liability for harm.

Polluters must be held responsible in courts of law or by regulatory agencies for any area where community science can demonstrate cause of harm to humans or ecosystems. Reparations of the harm caused to these communities might take the form of payments to bereaved families, the cost of appropriate environmental remediations, the funding of hospitals or schools, or the funding of further community science endeavors.

6) *Transparent mechanisms for negotiation*

The details from the history of governance recounted above suggests the need for civil servants and scientists involved in accountability work to be sheltered from fluctuations in local and national politics and corporate pressures, while preserving the work for the common good that the institution was installed to oversee. Unless the norms of negotiation are revisited, there is a real risk that any institution of climate governance will recreate the norms of privilege from the twentieth century, where the richest communities (which can a ford the scientific documentation of their problems) will be the first to receive remediation, while other communities are le t behind.

As new forms of value come to be subject to abstraction and assessment, new priorities may come to structure how our societies are run. Lab scientists, public health experts, ethicists, social scientists, and community scientists all have a role to play in describing “value” and “scarcity,” conceptual work that will involve dismantling systems based on false or superficial

> conceptualizations of the trade-o fs at stake, and in devising new norms for the transparent and fair allocation of scarce resources to communities (Jonsson et al 2019).
>
> Broadcast data collection in itself does not ensure that the analysis made on the basis of data will contribute to the just allocation of resources. e designers of a new information infrastructure will likely be required to build a new cost-benefit analysis of contributions to the commons, capable of supporting the mechanisms of trust that would allow an information infrastructure to support the robust work of accountability in environmental governance. As the norms for resource allocation are debated, issues of equity must be factored in, and representatives from vulnerable communities must be recruited as consultants for every phase in the definition of norms and how they will be applied.
>
> Only through stringent consultation with representatives of the broad diversity of populations at risk from climate change can we devise norms for governance which result in vulnerable community's experiences resulting in appropriate action. Only with the existence of such norms can we imagine a world that will be equitable -- that is, will the benefits of scientific inquiry and liberal governance redound to all populations, regardless of their historical experience of capitalism.

What is at stake is not only our collective ability to make choices determinative of health and survival now – a task that depends on the harnessing of environmental information to inform international governance in a way that is both inclusive and resilient. Any acceptable regime of environmental governance in the age of climate change must therefore satisfy the qualities enumerated above: broadcast efforts to enlist communities, effective soliciting of the voices of underrepresented populations, compensation of participant labor, analysis of the data by community participants as well as (potentially) by scientists; centralized preservation of the data in an archive where it can be found, retrieved, revisited, and implemented for action; circulation of the data to regulatory offices mandated with the responsibility of taking action; the creation of accountability through the establishment of centralized, powerful organs of governance capable of holding polluters to account on the basis of data collected by both citizens and scientists, and transparent mechanisms for negotiation.

Solutions of this kind require that scientists, administrators, and members of the public learn to transcend the language of an apparent tradeoff between "scientific expertise" and "popular democracy" that has characterized climate debates in recent years. Instead of that sham debate, what we need is a radical reimagination of the life of information in society. We need a system of government that integrates information from the diversity of communities vulnerable to climate change – a challenge that involves recognizing the politics of information as well as reclaiming the capacity to design institutions around us in the service of the many.