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Another Infrastructure Is Possible: Grassroots Citizen Sensing and Environmental Data Justice in Colombia

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The world distribution of air pollution is deeply asymmetrical, disproportionately affecting cities in the Global South. One of the main obstacles to accessing environmental justice in Latin America is that citizens lack enough evidence in the form of environmental data. In addition, there is distrust in public data and the institutions that manage them. In this context, this article considers air quality–sensing infrastructures as objects of public deliberation and contestation. We follow a grassroots citizen sensing project in Colombia to analyze how through building alternative community infrastructures, and bringing together citizen science and proactive activism repertoires, people instigated public discussion on environmental governance and influenced change in air quality standards. The case shows the potential of mobilizing citizen-generated data for advancing environmental data justice in contexts characterized by deep structural inequalities, "data corruption," and precarious infrastructure.

Keywords: citizen science, data activism, citizen sensing, environmental data justice, critical data studies

Bogota is one of the most air-polluted capital cities in Latin America by its average yearly PM2.5[2] concentration (IQAir, 2018). The main causes of air pollution and high levels of particulate matter (PM) in the city are emissions from vehicles and factories, particularly the ones produced by diesel buses from *Transmilenio*, the local bus rapid transit (BRT) system. The city is considered one of the most traffic-congested urban areas in the world, with drivers on average losing about 191 hours—nearly eight days—each year in congestion (INRIX, 2018). High levels of PM in the air are a major environmental problem due

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[2] Fine inhalable particles that remain suspended in the air, with diameters of 2.5 micrometers or smaller. These fine particles can get into the lungs and the bloodstream, posing significant health risks such as respiratory and cardiovascular diseases, among other conditions.

to their negative effects on human health and quality of life. According to official reports, 10% of the total deaths in Bogota are attributable to urban air pollution (Departamento Nacional de Planeación, 2017). Although it affects the health and life quality of all the citizens, it has a greater impact on children, pregnant women, and the elder, and on the poor population that lives in the southern neighborhoods (García Aguirre, 2018; Mura et al., 2020; Rodríguez-Camargo, Sierra-Parada, & Blanco-Becerra, 2020).

Since 1997, the city governments have implemented several policies, initiatives, and programs, including the Bogota Air Quality Monitoring Network (RMCAB) and its own air quality index (IBOCA), to monitor, manage, and mitigate air pollution. However, these actions have been insufficient to tackle the problem, and they have failed to consolidate a robust environmental governance. For instance, the policies have not regulated the major sources of PM, particularly the diesel-powered public buses (BRT), private cargo trucks, and factory chimneys. In 2019, the increasing levels of air pollution in Bogota provoked a crisis that ended in the declaration of environmental emergencies (Barbosa, 2019). This happened in the context of the second term of the same mayor who, in the late nineties, promoted the creation of a BRT instead of a metro system and who continued advancing unpopular environmental policies such as the expansion of the bus fleet and the urbanization of wetlands. This political, historical, and environmental juncture placed the air quality problem at the center of the public debate during the environmental emergencies and helped make visible local environmental movements' long-term struggles.

Leveraging on recent jurisprudence developed in Colombia that recognizes environmental equity and the right to citizen participation on environmental issues, several local NGOs and activists have raised their voices, claimed for political inclusion, and demanded solutions to the air pollution problem. These activists have not only become engaged in the public debate but also developed projects and initiatives with the goals of educating citizens, influencing environmental governance, and improving how air quality is monitored, measured, evaluated, and communicated. The case of CanAirIO, a citizen air quality–monitoring network created in 2017, will serve to illustrate how the aims of environmental data justice materialize in concrete practices developed by local data activists and nonprofessional citizen-scientists.

This article draws on a 3-year ethnographic participatory research where we followed up a community of citizen-scientists/activists in Bogota, directly engaging in DIY sensor workshops, public talks, and community chat groups. We also drew on data collected from interviews, government documents and reports, news media, community blogs, and social media accounts. Our analysis focuses on how this community challenged government data infrastructures through prototyping alternatives, and how it leveraged citizen data to participate in the public debate on air pollution. For this purpose, we combine a discursive-material reading of data infrastructures (Barad, 2007)—to explore how different materializations of sensing apparatuses make a difference in the enactment of air pollution, privileging certain meanings, values, and politics, with an analysis of the media/data practices deployed by this community during a public controversy about the local air quality standard.

Before entering the case study, we discuss a theoretical framework we find useful for understanding the synergies between citizen science (CS) and proactive activism, as well as their convergence in the struggle for environmental data justice. Then we present the case study, which is divided into three parts. The first part explores the politics of public data infrastructures in Latin America by way of looking at Bogota's air quality–

monitoring system through the community lens. The second inquires how communities respond to public information infrastructure deficiencies by assembling their own alternatives through acts of "critical making" (Wylie, Jalbert, Dosemagen, & Ratto, 2014). In the last part, we delve into a public controversy on social media around the local air quality standard to show how community members mobilized environmental data to redefine the air quality problem and instigate public discussion on environmental governance. Finally, we close offering some concluding remarks on what we can draw from the struggles of environmental data activism in Colombia in terms of the means and the opportunities for civic participation in a datafied society.

The Convergence of Grassroots Citizen Science With Data and Environmental Activism

The term "citizen science" describes a range of research, making, and knowledge production activities developed by citizens (including professional and amateur scientists, laypeople, and volunteers) with different levels of participation and collaboration. Although there is no consensus about its definition (Haklay et al., 2021; Irwin, 2015; Strasser & Haklay, 2018), CS has become a popular label applied to a myriad of projects developed by universities, schools, government agencies, corporations, NGOs, and communities. To understand its diversity and polymorphous nature, scholars have developed typologies to conceptualize and categorize CS projects. Several classifications have sorted projects according to how power is distributed among participants, ranging from top-down initiatives started by universities and governments to bottom-up projects established by grassroots communities and lay people (Bonney et al., 2009; Haklay, 2013; Shirk et al., 2012). Others have classified projects according to the five epistemic activities that participants develop: "calculating," "sensing," "self-reporting," "analyzing," and "making" (Strasser & Haklay, 2018).

Despite the diverse possibilities of CS, most projects have a top-down approach, led by professional scientists, and tend to focus on conservation, education, and crowdsourcing (Haklay, 2013; Haklay et al., 2021; Irwin, 2015; Strasser & Haklay, 2018). Given power imbalances between scientists and amateurs, most initiatives tend to privilege professional scientific expertise and knowledge over the capacity of laypeople to formulate and address research in their own terms. Even in the Global South, the projects and initiatives that are gaining public recognition are those tied to academic and government institutions (Chandler et al., 2012; Invernizzi, 2004). However, researchers have documented grassroots CS projects and discussed their potential for enabling political action and civic participation. Ottinger (2010) and Wylie et al. (2014), for example, analyzed how community-based monitoring of air toxics (using plastic buckets) in Diamond, Louisiana, enabled local activists to engage in environmental justice campaigns and to confront polluting corporations. Kullenberg (2015) discussed how nonexpert citizens used diffusion tubes to measure levels of nitrogen dioxide in the London air and leveraged their evidence to oppose the construction of a tunnel, raising public awareness of its potential environmental impact on local communities. Analyzing the practices of several grassroots organizations in Japan that measure radioactivity levels, Kenens, Van Oudheusden, Yoshizawa, and Van Hoyweghen (2020) documented how activists leveraged science as a tool for generating environmental data that local communities could use for addressing their own needs. Community-based participatory research monitoring water, air, and noise pollution using low-cost instruments (e.g., lightweight buckets, kites, diffusion tubes, and sensors) have deployed CS epistemic practices in struggles against governments and industries, mobilizing them toward political and

environmental causes (see Berti Suman, 2018, 2022; Kenens, Van Oudheusden, Yoshizawa, & Van Hoyweghen, 2020; Kullenberg, 2015; Ottinger, 2010; Wylie et al., 2014).

In all these instances, citizens outside scientific and governmental institutions carry out research projects addressing issues of environmental injustice and explicitly seeking political, cultural, and technical changes. They hold control of research questions and objectives, and they develop their own epistemic practices while remaining action-oriented, promoting political empowerment, public inquiry, and engagement. However, CS projects also face political limitations. Research has shown how the focus on data in the pursuit of science may preempt political demands and actions that cannot be expressed as quantitative data, limiting the reach of environmental activism while foreclosing more effective modes of action (Jalbert & Kinchy, 2016; Shapiro, Zakariya, & Roberts, 2017).

Given their political commitment and their recourse to reappropriating scientific data practices and infrastructure (Beraldo & Millan, 2019), grassroots CS projects intersect with environmental and data activism (Kullenberg, 2015; Strasser & Haklay, 2018; Walker, Nost, Lemelin, Lave, & Dillon, 2018). Bridging the aims of the environmental movement with the ones of data activists, these grassroots CS projects enact what some researchers and practitioners have called "environmental data justice" (EDJ). EDJ can be understood as a reflexive framework and a set of practices oriented toward justice that integrates values common to both the environmental and data justice movements: participatory knowledge making, accessibility, anti-oppression, intersectionality, democratic governance, and transparency (Dillon et al., 2017; Vera et al., 2019; Walker et al., 2018). According to Dillon et al. (2017), EDJ aspires toward "the public accessibility and continuity of environmental data and research, supported by networked open-source data infrastructure that can be modified, adapted, and supported by local communities" (p. 186). By questioning what counts as data, thinking through data stewardship, and imagining new data infrastructures, EDJ upholds a tradition of activism and scholarship that challenges extractive logics and democratizes knowledge production (Dillon et al., 2017; Vera et al., 2019). Thus, EDJ promotes participatory research processes that generate socially contextualized knowledge, "incorporating historically marginalized perspectives into the production, stewardship, and dissemination of environmental data" (Vera et al., 2019, p. 1024).

In the context of a datafied society, the cases of grassroots CS projects show a tactical approach to navigate the politics of knowledge. By combining CS epistemic frameworks (investigating) with advocacy activities (instigating), participants of these projects have been able to influence environmental governance through a more democratic and contextualized production and circulation of knowledge, evidence, and data. By studying the different repertoires of practices that grassroots projects develop in their struggle for EDJ, we can illuminate current transformations in civic participation.

Case Study

Members of the CanAirIO community describe their initiative as a CS project that builds an air quality–monitoring network with DIY low-cost open-source sensors. They aim for popular adoption of sensing technology, so they run workshops, produce open documentation and manuals, and give online

support for people interested in building sensors and joining the network.[3] Since 2017, the community has gathered a heterogeneous set of actors (approximately 50 people) and interests: open data/software/hardware technologists/hackers, environmental activists, human rights activists, academics, and citizens affected by air pollution who all volunteer work to a self-financed endeavor.

Public Infrastructure Politics From the South

Born out of the members' dissatisfaction with the city's government management of the air pollution problem and attempts to politically obfuscate it through a nontransparent handling of air quality data, the CanAirIO community voiced a citizens' mistrust with government's unreliable and nonauditable environmental data, its choice of misleading indicators to assess health risk and communicate it publicly, and recurring blackouts in the public sensing infrastructure that allegedly hide critical pollution events. To them, the sensing network lacked sufficient city coverage. Out of the 32 monitoring stations that were originally planned in 1996, just 13 were set in operation, and some decayed in warehouses long awaiting for installation. Coverage particularly lacks in densely populated deprived zones in the south, where pollution is critical due to the concentration of factories, mining quarries, and cargo trucks and public transport powered by diesel. Besides, the stations were placed high above the street level and far from main transport routes where higher exposure to air pollutants is experienced—a sensing from above strategy. That was a design rationale that aimed at modeling so-called background pollution: measuring pollution away from sources to produce low-level stable averages generalizable to large areas.

Another important issue was the lack of reliability of the network and its data. They noted the public information system was frequently down, and some stations reported no data for long periods of time or, worryingly, during peak pollution events. Thus, configuring data voids that raised indignation and suspicion toward the environmental authorities. For instance, in Bogota's 2016 annual public report on air quality (Observatorio Ambiental de Bogota, 2016), captured PM2.5 data accounted for a 13% annual data loss. CanAirIO's members pointed out how, in that report, the stations closer to the poor and polluted south were not even counted for the annual averages because they failed to register data above the standard norm minimal threshold (75%)—making a rather convenient picture of the state of air quality for local authorities. Not being counted—or improperly counted—in public databases may constitute acts of marginalization productive of inequalities (see Barreneche, Lombana-Bermudez, & Ramos-Martín, 2021; Liboiron, 2015). Officials dismissed data blackouts on those reports as merely technical issues: recurrent failures in sensor equipment, data communication failures, stations during extensive maintenance periods, and so on. It is worth stressing that in the Latin American context, working infrastructures are far from being the norm. "On the contrary, most of the time they exist and function in a state of partial disrepair and partial functionality" (Velho & Ureta, 2019, p. 433). Consequently, in Colombia, public infrastructures malfunction has not only been naturalized due to decades of neoliberal state disinvestment and tolerated through institutional channels and regulatory frameworks (Acevedo-Guerrero, 2019), but it is also politically operationalized to obfuscate public perception of air quality and deter accountability and political action.

[3] See https://canair.io for sensors' technical specifications, code, and documentation.

Fueling further distrust, the normative apparatus also establishes that data reporting from the local monitoring networks to the air quality national database (SISAIRE)—used to inform state environmental public policy and interventions—should be done on a weekly basis instead of automatically reported minute by minute. So data are submitted to a human validation process—before reaching the national open data repository—to filter out "errors": peak concentrations and sudden increases in pollutants that fall outside the normal air quality parameters in a given area, as well as data that might be attributed to the diffuse category of "special events" (from "fires" to "public demonstrations"; Ministerio de Ambiente, 2010, p. 77). Here, the practice of checking for error highlights the fact that official data are not direct measures of air pollution but are always framed in advance (Garnett, 2016). Somewhere else, we showed how, within Latin American organizational cultures permeated by corruption, the delaying of data flows in the interface between different public information systems configures loopholes where political interference on data—"data corruption"—might take place (Barreneche, 2019).

As to the software layer that interfaces data and citizens, the CanAirIO community regarded the information system as inaccessible for the general public and poorly implemented. Critically, it does not provide direct access to open data, whereas key services such as map data visualizations are reachable only through numerical IP addresses, rendering the public information system virtually nonauditable. Moreover, because some of its components work only for Windows environments and there is no backup operational mode (failover), users commonly face "page not found" errors. Operationally, though, faulty system design acts here as instances of "data friction"—the "socio-material counter forces . . . that slow and restrict data movements" (Bates, 2018, p. 425)—preventing citizens of effective access to public data.

Finally, the community focused part of its activism online on the critique of the air quality index (IBOCA). This is a unique standard devised for Bogota, diverging not only from international standards but also from the national one. Criticism surrounds its misleading color semantics for PM concentrations attenuating perceived health risk. The local standard calculates risks from the concentration of pollutants registered by sensing stations using averages of the last 24 hours, masking pollution-peak events in the process. Those averages also translate into longer time exposures to unhealthy air before a risk alert may be triggered.

Community (Counter)Infrastructures

CanAirIO's project is a citizen response to the deep distrust toward the public monitoring network and its technical deficiencies. From the outset, they set out to build a so-called "parallel network" that could keep the public informed about the state of air pollution when the official one fails, while enabling permanent citizens' oversight over its data through alternative measurements (A. Vanegas, personal communication, April 5, 2019). To achieve the latter, they opted for developing and deploying DIY open-source, low-cost sensors to democratize environmental data production. Equally important, they wanted their sensing network design to expose in itself the official's infrastructure transparency issues. In their vision, they hoped to become a "success case"—a "persuasive prototype" (Schrock, 2018)—that would prove how a public data infrastructure could be made otherwise.

The initial moments of formation were animated sites of mutual constitution between the community and its infrastructure. The aforementioned heterogeneous composition of CanAirIO's group played out in these moments as a conflictual field of making and unmaking in an open-ended process of infrastructure building (Piattoeva & Saari, 2020), contingent on the political values, material resources, skills and technical repertoires available to the community. Theoretically, through infrastructure design, the community practices the design of itself (Escobar, 2019; Luna-Cárdenas, 2019). Moreover, in the building process, its members deployed also exercises of "infrastructural imagination" (Bowker, 2014) through the prototyping of conceptual artifacts that may or may not be functional and further incorporated (e.g., social media bots posting health-risk alerts or issuing automatic alerts when an official station stops transmitting data).

Technological choices in infrastructure building are important because they are always sociomaterial arrangements indicative of values. CanAirIO's community network opted for a decentralized control architecture and openness for its different layers (open data/software/hardware). Decentralization guarantees autonomy over data for every node, and each citizen sensor is autonomous over whether it shares data (and when) with the network or reports to another server—decentralization and self-determination are common tenets shared by civic hacking and EDJ projects (Walker et al., 2018). On the one hand, this makes the community network less subject to manipulation by a central control agent, hence adding transparency. On the other hand, this autonomy demands constant practices of care (recalibration, maintenance, and repair) of citizen sensors "that are not just technical but also political engagements" (Pritchard, Gabrys, & Houston, 2018, p. 4549). As well as affective engagements, because those investing effort and money in building their sensors, or those directly affected by pollution (e.g., concerned citizens living near emission sources), are the people most likely to carry out the necessary work that keeps the network running. As for openness, the community infrastructure comprises an open data cloud platform accessible via a public API (hosted on a local activist server) providing real-time data, as well as visualization tools to give people more insight into collected data. Technical-mediated transparency plays out as a "short route" to social accountability (Berti Suman, 2018): the API, one member states, "gives us technical and operational credibility, that is, what the public information system lacks . . . besides, providing total transparency, so there's no suspicion as in the official one" (G. Guevara, personal communication, April 5, 2019). Finally, technical openness has also been generative of CS practices, data activism interventions, and infrastructure bifurcation (CanAirIO-based citizen sensing networks have sprung up in Peru, Ecuador, and Brazil).

Another salient characteristic of CanAirIO's project is its commitment to diversify environmental data. The citizen network comprises both fixed and mobile sensors, making for a more dynamic mapping of air quality. Sensors linked to CanAirIO's mobile app produce real-time, location-specific, pollution data—so-called tracks. In contrast with "smoothed" estimated averages for large areas (the "background pollution" frame), tracks add granularity and contextual specificity to data (Walker et al., 2018). CanAirIO has also incorporated into their sensor design the capability of estimating the potential number of people affected by pollution (by tracking surrounding mobile phones' radio signals), further enriching their data with socially relevant metadata. Most important, community alternative measurements document pollution where people are exposed the most: on the street level and commuting on BRT buses. Therefore, different measuring practices reconfigure how air pollution is framed and valued. In Barad's (2007) performative account of apparatuses, they "are not mere observing instruments but boundary-drawing practices" (p. 140). By

including/excluding what properties of air pollution are observed, the citizen sensing apparatus enables then certain ways of knowing and practices of meaning-making—which bring into being another reality of air.

By 2019, CanAirIO's network comprised more monitoring stations (26 fixed and 20 mobile carried by people) than the official one (13), and it extended air quality sensing to serve urban areas—critically in the deprived south—where no official data have been produced (15 of 26 fixed stations were monitoring this zone). Community fixed stations do not claim to emulate the official's background pollution framework because some cannot be set at the standard height or without airflow obstacles, and some are deliberately placed nearby pollution sources. Instead, they measure locally situated manifestations of pollution. Hence, the community network is not intended to replace but to contest and mitigate the social effects of an infrastructure that does not serve the public interest. Rather than being "parallel" to the official sensing network, it is entangled in a relation of counteraction and dispute over environmental data. And as a "persuasive prototype," it materializes its critique of embedded injustice in public infrastructure by coding within it different political values. In this sense, CanAirIO could be read as a case of "counter-infrastructure" (Cowen, 2017), not only antagonizing but also prefiguring—through its community's infrastructural imagination—the sensing network Bogota should have.

¡Alerta Bogota!: Environmental Emergencies and the IBOCA Controversy

On February 14, 2019, the local government declared an environmental emergency in the entire city due to the high levels of PM concentrations. Since January, academics, environmental activists, and members of the CanAirIO community reported the critical levels of air pollution on social media platforms, pressing the local government to address the problem as a public health issue, to declare the environmental alerts on time, and to take actions that could help to reduce emissions. The main measure taken by the government consisted of extending a vehicle and motorcycle driving restriction policy to longer periods of time. One month later, the local government announced a second environmental emergency and accompanied it by the same measure.

The air pollution crisis created a political juncture that put air quality in the public imagination while evidencing its governance failure. Notably, the crisis revealed the lack of political commitment to take effective actions that could help mitigate the problem. The temporary measure taken during the emergency was palliative at best because it did not tackle its root causes.

Although they have been carrying out their activism since 2017, the emergency context allowed CanAirIO community members to gain more public recognition as citizen voices with the authority and capacity to shape the public debate. The crisis placed them in a position to embrace "adversarial forms of evidence-making"—that is, to use the citizen data to settle (or unsettle) scientific controversies, and to provide evidence and insights that mobilize multiple actors to act, including civil society organizations, lay citizens, policymakers, and academics (Van Oudheusden & Abe, 2021).

Through 2019 and 2020, several CanAirIO members participated in the controversy about the air quality standard and advocated for changes in air quality governance across all its dimensions: monitoring, managing, researching, and controlling. This controversy focused on the standard's technical problems, its

lack of transparency, and its impact on how the measures of air pollution were being used for making decisions at both the level of government (alerts) and the individual level of citizens. Although the mainstream media reported on the controversy, the more active discussion and debate took place on the social media platform Twitter, where citizens confronted the government, shared knowledge and evidence to redefine the air quality problem, and raised their voices to demand actions. As one of the CanAirIO members stated, "Twitter provided a space to put these topics and problems in the language of the people."

In 2019, the public discussion gained momentum during the first trimester of the year (declaration of environmental emergencies), and the months before the local elections (August–October). Despite the election of a new city mayor (2020–2022) that promised to make changes in the environmental governance, the controversy continued on Twitter during 2020 until the local government announced the transformation of the standard (the new one incorporated AQI's color-code standard for health risk), the expansion of the official sensing network (7 new stations), and the creation of a permanent roundtable for environmental civic participation in January 2021.

Our analysis of the controversy on Twitter reveals how CanAirIO community members deployed two kinds of media practices while participating in the public debate, composing and circulating multimodal messages that reported on their CS investigations and instigated policy change. The first practice leverages international standards for creating a chain of reference to validate evidence, questions, and claims, through the alleged neutral value of universal science. The second practice mobilizes local knowledge for contextualizing data within the everyday experiences of ordinary people. By tactically positioning their claims and research findings, moving between global and local scales perspectives, CanAirIO members were able to provoke civic inquiry, raise public awareness on pollution, and invite apprehension of the environment (Shapiro et al., 2017). These two modes of operation allowed them to not only capture mainstream media attention but also engage in network building with human rights NGOs, environmental activists, and professional scientists.[4] Particularly, these media practices were championed by those members with longer trajectories in the environmental movement and stronger relationships with environmental local groups, NGOs, and university researchers. They used hashtags related to the controversy (#CalidadDelAire, #IBOCA, #AireLimpioYa) and tagged and mentioned (calling up) multiple actors (government, NGOs, academics, politicians, activists) as part of their public media interventions.

Strategic Universalism: Leveraging Global Scientific Standards

As aforementioned, Bogota's air quality data are not easily accessible through the public information system. However, activists managed to circumvent this obstacle in their auditing efforts via a third party. The official sensing network reports data to AQIcn, an open platform managed by the Chinese-based World Air Quality Index project. This platform aggregates air quality data feeds from over 70

[4] CanAirIO environmental activists made appearances in local and national media outlets and participated in public events, workshops, conferences, and the meetings of a civic organization that clustered stakeholders interested in Bogota's air quality (Mesa Técnica Ciudadana y Académica por la Calidad del Aire de Bogotá).

countries, providing real-time pollution maps computed according to the AQI widespread standard.[5] CanAirIO activists exploited then AQIcn visualizations of Bogota's real-time pollution data to advance their criticism of the local standard's color-code health-risk alerts and measuring methodology (averaging 24 hours) to publicly ground their demands for a better public information system.

For instance, on a thread of tweets published on March 8, 2019, one activist provided an explanation of why the local standard (IBOCA) fails in communicating PM critical levels, and its effects on delaying government response and action (Figure 1). The thread starts with the following tweet:

> One of the reasons why alerts in Bogota are not so frequent even in times of high levels of particulate matter is that in Bogota the @Ambientebogota uses the IBOCA index (Bogota Air Quality Index) and not the international AQI index. (Arttesano, 2019)

Several images accompany the tweets from this thread. Some are screenshots of the local sensing network website visualizing air quality according to the IBOCA colors (displaying big areas of the city in green, yellow, and orange). Others are graphs and tables describing the differences between both indexes IBOCA and AQI, which help to illustrate the questions and criticism against the local standard (Figure 1). Another tweet from the thread, for instance, advances the criticism stating that,

> Although the stations measure high concentrations of particulate matter, IBOCA "smooths out" the results in such a way that it is displayed in a different way. And while in the AQI the value is red, in IBOCA the color is yellow. (Arttesano, 2019)

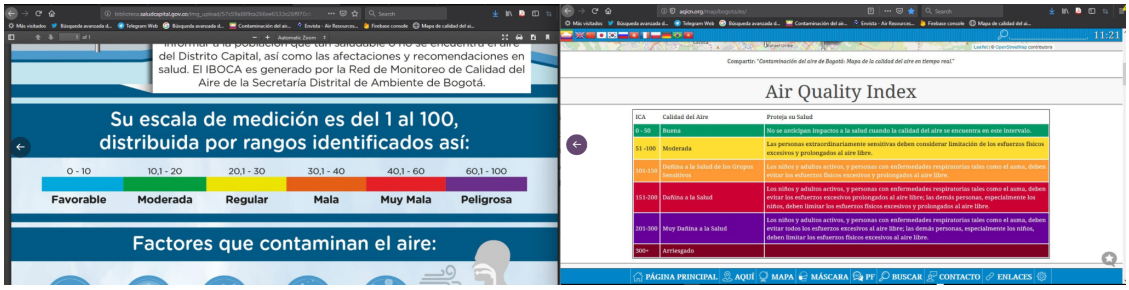

Figure 1. Color-code scales of IBOCA (left) and AQI (right) from March 8, 2019, Twitter thread (Arttesano, 2019).

Similar posts raised public awareness about the air pollution problem and the inadequacy of the public infrastructure, sharing knowledge and evidence that was validated appealing to an international

[5] There is no internationally accepted methodology for calculating an air-quality index, so some countries have designed their own frameworks according to their needs. Because there is no international standard consensus, AQIcn computes air quality from world air-quality data points using the U.S. Environmental Protection Agency's Air Quality Index (AQI) standard, and more precisely, the "Instant AQI" (U.S. EPA Instant-Cast), so as to display them in real time. It is worth stressing, once again, that Colombia has adopted AQI as the national standard, but Bogota still devised its own standard.

standard. The openness of the AQIcn website enabled them to provide both visual and numeric evidence to expose how the local standard misleading reading of air pollution disguises health risk (Figure 2). Such mode of operation shows how citizens exploit standards to contest official data as a resource for re-defining a local issue (Ottinger, 2010). According to Kullenberg (2015), grassroots CS communities embrace "strategic universalism" when they mobilize the "neutral empiricism" of science in their political struggles. In this case, activists created a chain of reference to the AQI standard to undermine the local one and demand changes.

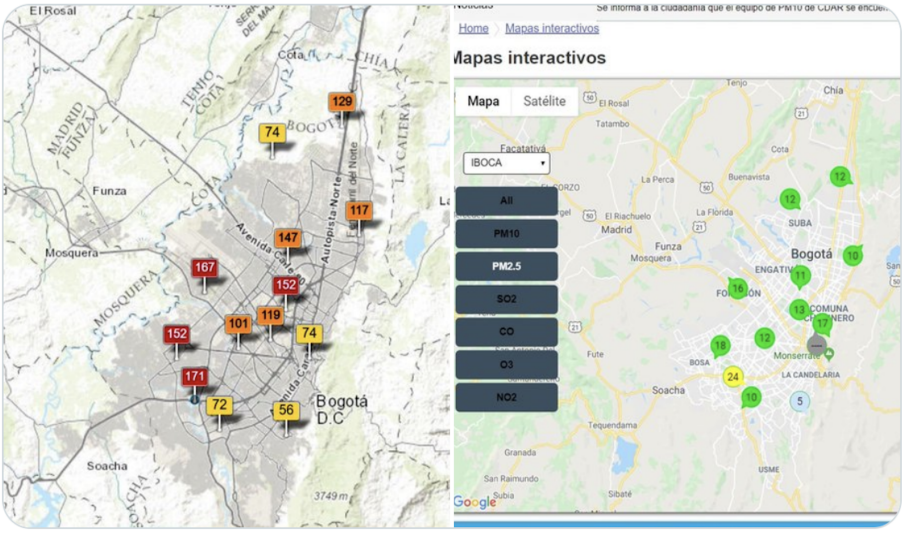

Figure 2. Twitter screenshot (November 29, 2019). On the left, AQIcn (AQI) air quality visualization; on the right, RMCAB (IBOCA) air quality visualization (Bernal, 2019d).

Moreover, these kinds of tweets encouraged citizens to further question the local standard, engage in auditing the sensing network, and share their expertise on the subject. For instance, some citizens contributed their legal knowledge on national environmental regulation, pointing out that the AQI international standard was indeed the one recognized by the Colombian environmental agency. Some others circulated links to policy documents and screenshots of specific parts of the regulation. Altogether, it was an exercise on public deliberation over data infrastructures that would otherwise remain within the closed domains of technical experts.

Tactical Localism: Mobilizing Situated Knowledges

Another mode of operation deployed by CanAirIO comprised the mobilization of local knowledges for the creation of short multimodal data narratives about the impact of air pollution on specific bodies and from specific places, producing embodied and socially contextualized accounts of pollution through the inclusion of local perspectives and the experiences of the most affected. This practice embraced what we call "tactical localism," that is, the practice of appropriating low-tech ("weapons of the weak") to produce alternative local accounts to high-tech and its supposedly universal protocols. In CanAirIO, this materializes as an effort to

thicken environmental data with local context and embodied experience to produce knowledge in a more democratic way. Such data practice is also tactical in the sense that it seeks to subvert "the view from nowhere" (Haraway, 1988; Harding, 2004) of "data universalism" (Milan & Treré, 2019)—in this case, destabilizing the "background pollution" framework by grounding data on the street (Taylor, Lindley, Regan, & Sweeney, 2014).

Instead of leveraging "universal knowledge," in this mode of action, CanAirIO activists used a "sensing from below" perspective to question the official network and its underlying injustices, particularly those configured as data voids of the uncounted. For example, on March 28, 2019, Bernal published several tweets reporting on dangerous air quality levels in different parts of the city. In some, he demanded the declaration of an environmental alert and called on the government to take "radical serious measures." Then, he offered advice to lay citizens, inviting them to wear facemasks and use streets with low traffic given the health risks. In all of them, the activist integrated different kinds of evidence to communicate knowledge: data tracks visualizations from CanAirIO's app (graphs), street-level photographs, and personal testimonies. In a following tweet, he built a narrative that combined a statement from the perspective of an urban cyclist, a visualization of the high PM measures captured with a citizen sensor (with a peak concentration over 150 PM that is dangerous to human health), and a self-portrait photograph (selfie) wearing a facemask:

> With this lousy #CalidadDelAire in Bogota there is no choice but to use masks with minimum N95 filter, go slow on the bike and take the cleanest and least traffic route. The particulate matter is sky high and you can really feel it in the air. (Bernal, 2019a)

In other instances, they focused on reporting citizen data from public transportation. For example, on April 26, 2019, an activist published a Twitter thread featuring the results of a sensing experiment on a BRT route. The thread presents sensor data along the specific trajectory completed by the bus (tracks), accompanied by evidence of children exposure to high concentrations (Figure 3):

> When I measure these very high levels of Particulate Matter PM2.5 in @TransMilenio and I see a baby car, I understand the hard work that needs to be done to improve our #CalidadDelAire. Infants and third age highly exposed, PM2.5 peaks of 300ug/m3 (mask-wearing emoji). (Bernal, 2019b)

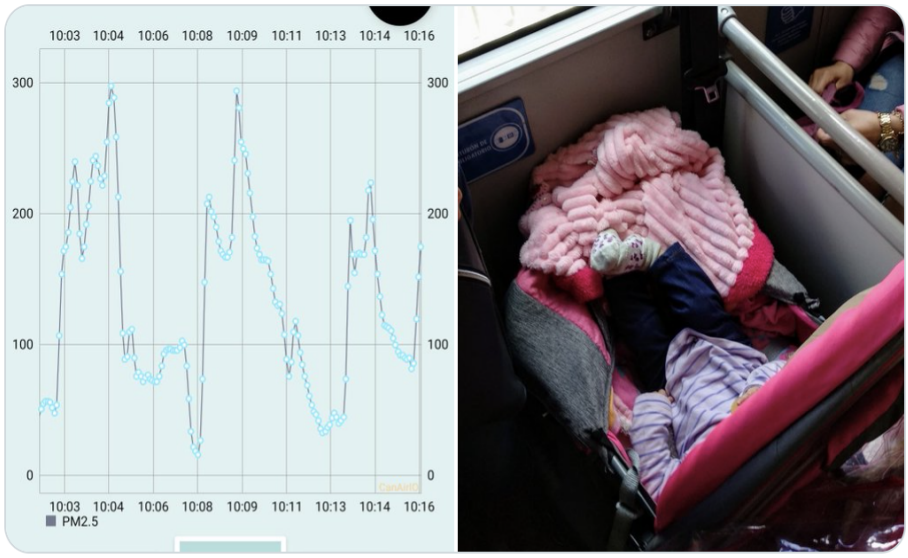

Figure 3. Twitter screenshot (April 26, 2019). CanAirIO app air quality visualization (*left*); photography of a baby stroller commuting on a BRT bus (*right*; Bernal, 2019b).

Similarly, activists created short narratives on air quality in southern localities—out of the official network coverage—bridging sensing data with the embodied knowledges and situated experiences of marginalized citizens. On May 29, 2019, for example, Bernal published a thread reporting on a sensing experiment he conducted in collaboration with a southern neighborhood leader worried about the impact of air pollution on respiratory illness within his community (Figure 4):

> I was visiting a community leader in Ciudad Bolivar - Barrio Mexico highly concerned with the lousy #CalidadDelAire they breathe. The sensor on several occasions marked outrageous values, look at that 900 of PM2.5, not even in @TransMilenio I have measured those levels (mask-wearing emoji). (Bernal, 2019c)

The other three publications from this thread complement the narrative with statements and photographs that summarize three hours of air quality sensing, including images that show dust accumulated in the windows of a neighborhood house. Interestingly, they also integrate bodily accounts of air sensing (Calvillo Gonz les, 2014): "I left with a sore throat, red eyes, dry skin, I felt very sick on several occasions (mask-wearing emoji)" (Bernal, 2019c). Moreover, one of the tweets denounces the harms faced by those living under these environmental conditions: "they live this drama all day long without stopping. There are seriously ill people in the sector" (Bernal, 2019c).

Figure 4. Twitter screenshot (May 29, 2019). **Left:** ***street-level photograph of cargo trucks.*** **Right:** ***CanAirIO sensor displaying hazardous air quality values (Bernal, 2019c).***

This way, CanAirIO activists anchored air pollution in everyday life through the articulation of data captured in-situ and people's experiences of exposure, not only contributing to enhance public understanding of the issue but also addressing citizen's preoccupations about its impacts on their health. As Allen (2003) has argued, this kind of articulation has the potential to transform local knowledge into a problem that scientific and government institutions can respond to and further analyze, in the process legitimizing the voices of marginalized communities.

These narratives also helped redefine air pollution in new terms because they contextualized environmental data, making it more accessible to people. According to the activist who championed the in-situ sensing experiments and reports, the tweets were effective because they communicated environmental data "speaking a common language" that was easier to understand:

> I am an ordinary citizen who gets on a bus, who sees a nice wetland and takes pictures with a cellphone, and this is warmer, and easier to assimilate by someone because we both belong to almost the same level of knowledge only that I have some advanced tools. (D. Bernal, personal communication, October 1, 2021)

It is precisely the proximity to lived experience of pollution that makes CanAirIO data narratives so powerful. Furthermore, it allows for a more democratic dissemination of scientific knowledge. As the activist explained to us, "laypeople think they don´t know about air pollution until someone comes along with a

number" (D. Bernal, personal communication, October 1, 2021). Hence, when citizens measure air quality and "openly communicate that number using common language" (D. Bernal, personal communication, October 1, 2021), others can relate to it and recognize the value of their own experience for defining and understanding environmental issues.

Ultimately, CanAiIO configured a space where multiple actors could intersect and join forces in their struggle for environmental justice. Thanks to its heterogeneous composition, CanAirIO assembled a rich mixed repertoire of practices, knowledges, and infrastructure, which helped them enact the goals of EDJ. That is, they challenged environmental injustice through "practices that are participatory and embody equitable, transparent data care" (Vera et al., 2019, p. 1012). As we have seen, through the deployment of "strategic universalism" and "tactical localism," they mobilized both universal and local knowledges to raise public awareness. At the core of this repertoire, we find a creative approach for legitimating and democratizing environmental citizen-generated data. In this case, this convergence of CS epistemic activities (calculating, sensing, self-reporting, analyzing, and making) and activist media practices empowered lay citizens to not only redefine the air quality problem from a citizen standpoint but also influence policy transformations. The subsequent changes in the local air quality standard and the public sensing infrastructure introduced by the new government in January 2021 are a testament to that.

Conclusions

One of the main obstacles to accessing environmental justice in the Global South is that citizens do not have enough evidence in the form of environmental data. In addition, available data are usually discredited due to an ingrained public distrust in the institutions that produce and manage them. In this context, the case showed how citizens contest the constructed political nature of official environmental data, as well as how such construction publicly frames air quality. By pointing to state infrastructure absence, malfunctioning, and design choices as enablers of social injustice, CanAirIO's activism exposed their performative effects: invisibilization of public health risk, of the most affected communities, of main pollution sources, and of public environmental data themselves. Inasmuch as "the information systems of public institutions play a crucial role in how we collectively look at and act in the world" (Gray, Lämmerhirt, & Bounegru, 2016, p. 7), these infrastructural arrangements are not simply a case of state failure. On the contrary, they are a form of state intervention on their own (Acevedo-Guerrero, 2019): allowing the local government to evade political accountability, while postponing the necessary actions to address the underlying causes of pollution and caring for people's health.

Despite this context, however, and countering the actions of precarious exclusionary infrastructures, communities all over Latin America are building their own to serve their interests in the absence of the state (see Acevedo-Guerrero, 2019; Ficek, 2018; Meehan, 2014). The case showed then how citizens' display of counter-infrastructure and alternative data/media practices challenged the government's environmental data monopoly and its measurement premises. Even though technological autonomy and self-determination are at the center of such projects, their politics remain entangled in relations of resistance-negotiation with the state, seeking to participate both as independent auditors and as recognized actors in public environmental surveillance and governance.

Moreover, the study illustrated how the politics of knowledge and evidence are changing in a datafied society—particularly here, due to the democratization of the means of sensing—allowing citizens to actively participate in public knowledge making. The air quality data generated through DIY low-cost sensors, despite being diverse and inconsistent, are "just good enough," as Gabrys, Pritchard, and Barratt (2016) point out, "to create different accounts and different forms of evidence for engaging with environmental problems" (p. 2). Where broader knowledge frames redistribute visibility—what counts—and hence power relations between citizens and government: making visible injustices, filling absences in official databases, enabling (data-mediated) arguments in the public debate, and as a means for demanding political accountability.

Furthermore, although diverse—and even incommensurable—environmental data apparently make the understanding of air pollution messier, citizen-generated data do have intrinsic public value inasmuch as they actually could complement official data and even grant them validity and legitimacy. Equally important, citizen-generated data also point to public environmental data deficiencies, making apparent to people how numerical differences matter for their health. Citizen sensing and community data infrastructures, in themselves, might also push public information systems development toward the direction of technological mediated transparency and accountability—if government data want to regain public trust.

Lastly, supposedly universal and situated modes of measurement may appear contradictory, however, they are not mutually exclusive. Indeed, they could coexist in a state of productive tension and partial integration (see Anderson, Naujokas, & Suk, 2015) to know and intervene in the world within epistemic complexity while expanding people's agency. As long as air pollution will likely remain a contested political—and onto-epistemological—issue, embracing data diversity has potential to orient a more democratic environmental governance. Despite their public good orientation, however, community-led tech projects from the South are short-lived, dependent for subsistence and scaling up on fragile economies of care and temporary international funding. Thus, as a society, we should find ways to nurture them as commons, because from there, people prefigure other sociotechnical arrangements that may help materialize the needed transition toward a more just and ecologically sustainable world.

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