Engaging Science, Technology, and Society

The Empowering Virtues of Citizen Science: Claiming Clean Air in Brussels *(Les vertus émancipatrices de la science citoyenne dans les revendications pour un air plus pur à Bruxelles)*

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Abstract

The governance and monitoring of environmental hazards—and of air pollution in particular—is often dominated by technical expertise and scientific knowledge. Approaches of this kind remove the issue from the public debate and democratic deliberation: citizens are de facto excluded from related decision-making and their knowledge about the problem is barely taken into account. This article explores the potential and limits of citizen science to challenge unfair frameworks of environmental monitoring and governance, inasmuch as it empowers citizens, by enabling three critical processes: gaining knowledge, gaining epistemic recognition, and building transdisciplinary coalitions. Empirically, this study is based on AirCasting Brussels, a Citizen Science project that unrolled in Brussels in the context of a mobilization for cleaner air to which it contributed. The analysis shows that citizen science has increased the ability of participating communities to scrutinize air pollution policy and to contribute to and influence public discussion about it, albeit with certain limits. Overall, as a counterpart to their fundamental right to participate in democracy, Citizen Science proves effective to strengthen citizens' capabilities to do so in a meaningful manner.

Résumé

La gouvernance et la surveillance des risques environnementaux—et de la pollution atmosphérique en particulier—sont souvent dominées par l'expertise technique et les connaissances scientifiques. Les approches de ce type empêchent que ces questions fassent l'objet d'un débat public et de délibérations démocratiques: les citoyens sont de facto exclus de la prise de décision en la matière et leur connaissance du problème est à peine prise en compte. Cet article explore le potentiel et les limites de la science citoyenne pour remettre en cause des approches inéquitables à la surveillance et à la gouvernance environnementales, dans la mesure où elle donne du pouvoir aux citoyens, en permettant trois processus cruciaux: l'acquisition de connaissances, la reconnaissance épistémique et la construction de coalitions transdisciplinaires. Cette étude se base, empiriquement, sur AirCasting Brussels, un projet de science citoyenne qui s'est déroulé à Bruxelles dans le cadre d'une mobilisation pour un air plus pur à laquelle il a contribué. L'analyse montre que la science citoyenne a accru la capacité des communautés qui ont participé au projet à évaluer la politique en matière de pollution atmosphérique, ainsi qu'à contribuer au débat public à ce sujet et à l'influencer, bien qu'avec certaines limites. Globalement, en tant que pendant de leur droit fondamental à participer à la démocratie, la science citoyenne s'avère efficace pour renforcer les capacités des citoyens à exercer ce droit de manière significative.

To cite this article: da Schio, Nicola. 2022. "The Empowering Virtues of Citizen Science: Claiming Clean Air in Brussels." *Engaging Science, Technology, and Society* 8(1): 29–52. https://doi.org/10.17351/ests2022.795.

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Keywords
environmental governance; citizen science; empowerment; air pollution; Brussels

Taking Air Pollution Out of the Labs

The governance of environmental matters—and of air pollution in particular—is typically dominated by technical expertise and scientific knowledge. More than in any other field, calls for evidence-based policy are ubiquitous and the boundaries between the scientific and the government apparatus are blurred (Ascher, Steelman, and Healy 2010; Whitehead 2009). Allowing decision-making to be led by those who have the relevant expertise might appear a commonsense and desirable approach, especially in the context of complex and urgent environmental issues. At the same time, leaving it just to the experts is problematic for different reasons. The post-political scholarly tradition has long highlighted the risks of depoliticizing the environmental agenda, underrating the dimensions of value, conflict, and inequality that are inherent in socio-ecological issues (Kenis and Lievens 2014). Additionally, notwithstanding the tremendous progress in techniques to monitor and model environmental phenomena, considerable, and often non-remedial, uncertainties remain (Walker 2012; Callon, Lascoumes, and Barthe 2001).

First and foremost, however, a purely technical approach to the governance and monitoring of air pollution is problematic because it conceals it in the labs of universities and government institutions, thereby removing it from the public debate and democratic deliberation. This phenomenon has an epistemic and a procedural question: citizens, in their capacity as members of a democratic society and bearers of given environmental burdens, are *de facto* excluded both from the exercise of making sense of such burdens and from the effort to address them. These issues become especially compelling when state science does not resonate with the lived experience of citizens, and formal compliance with regulations falls short in responding to the claim for a clean environment (Allen 2018).

In this context, opening the monitoring and governance of air pollution goes beyond just challenging the functioning of existing processes and institutions, but is strictly connected to the empowerment of those who are hitherto excluded and disenfranchised. Because of its elements of scientific inquiry and of citizen participation, Citizen Science (CS) appears to be a promising approach to realize both the epistemic and procedural aspects. This article aims precisely at exploring whether and how this potential is fulfilled by analyzing the experience of AirCasting Brussels (ACB), a CS project that ran in Brussels, Belgium, between 2016 and 2019 in the context of a mobilization for cleaner air; to which it significantly contributed. At a time of proliferation of CS projects focused on air pollution (see for example European Environment Agency 2019), this project is illustrative of ones that go beyond monitoring, and test epistemic and procedural innovations to change the framework in which air pollution is tackled. Building on the lessons learned from the project, in particular, I discuss whether and how practicing citizen science empowered the participants and allowed them to open up the public discussion about air pollution in Brussels, as well as the limits of the approach in bringing about change.

Empowerment and Inclusion

The notion of empowerment is multifaceted and its definition in a given context reflects how power is conceptualized. Understanding the concept of power in terms of *power to* (vs. *power over*), in particular, opens it up to generative forms of empowerment, such as one "concerned with the processes by which

people become aware of their own interests and how those relate to those of others, in order both to participate from a position of greater strength in decision-making and actually to influence such decisions." (Rowlands 1995, 102).

This understanding of empowerment places emphasis on an element that is particularly important when questioning the exclusionary nature of technocracy, i.e. the process of self-emancipation and awareness as preconditions to act. Two aspects are critical. First, it is about the procedural aspect of the governance of air pollution and about who can influence policy-making: simplifying, we can speak of the "ability to decide." On the other hand, the epistemic aspect of empowerment (i.e. the "ability to make sense of the world") is also critical, both because a thorough knowledge of the problem is necessary for meaningful participation (Ottinger 2013), and because of the fundamental place that knowledge has specifically in the governance of air pollution (Whitehead 2009).

At one level, as highlighted in the environmental justice literature, empowering groups that are excluded from air pollution governance—and in particular the most vulnerable communities—can be instrumental to challenge the structural determinants of vulnerability and to mitigate unfair distribution of environmental burdens (Walker 2012; Nadal 2008). At the same time, it is more than this—a meaningful engagement in environmental governance can be seen as a normative claim on its own. More adaptive, flexible and inclusive forms of governance, it is argued, can better address the increasingly complex modern environmental and sustainability problems (Newig and Kvarda 2012; Bäckstrand 2011; Callon, Lascoumes, and Barthe 2001). In these terms, empowerment can take many different forms, including formal participation in decision-making, but also opportunities to broaden the foundations of decision-making by contributing to social learning, or advocating specific values (Nadal 2008).

A distinct aspect of the issue is epistemic in nature, and concerns citizens in their capacity as "knowers." In this context, the theoretical and empirical reflections around the notion of epistemic injustice are illustrative, in that they put emphasis on the testimonial dimensions (i.e. on the knower of a given issue) and the hermeneutic dimensions (i.e. on the frames used to make sense of the issue) (Fricker 2007). STS research, also, has widely documented how the quest for a healthy sound environment has always been confronted with asymmetries experienced by communities in terms of access to the tools and resources to make sense of environmental pollution, but also in terms of what knowledge best represents it and what evidence counts: 'hard data' vs. embodied experience, qualitative vs. quantitative research, etc. (see for instance Ottinger 2010a; ibid., 2017a; Walker 2012 especially Ch. 3).

Citizen Science and Collective Learning

The expression "citizens science" (CS) has different meanings and interpretations, including: research approaches involving the active participation of citizens in data collection, analysis, and/or dissemination during a scientific project (Haklay 2013); research in which scientists "intertwine their work and their citizenship, doing science differently, working with different people, drawing new connections and helping to redefine what it means to be a scientist" (Stilgoe 2009, 11); and research where communities step forward and look for evidence about environmental burdens that they suffer from (Ottinger 2016). These different understandings of CS are not necessarily contradictory, and they sometimes overlap. For the current article, I propose an operational definition of the concept that encompasses the three perspectives, and takes CS as:

> an exercise where citizens—typically but not necessarily in collaboration with professional researchers—collectively engage in a rigorous and systematic effort to generate knowledge that helps to address an issue relevant to them and to society.

This conceptualization of CS is coherent with the understanding of empowerment introduced above, in which power is not something that can be bestowed but comes from within (Rowlands 1995). It also encompasses two key dimensions of CS, specifically *who* is engaged in generating knowledge and *what form of knowledge* is generated, offering the potential to address respectively procedural and epistemic environmental exclusion.

CS has potential benefits at different levels, ranging from its contribution to generating and spreading knowledge, to its capacity to change the people who participate and the context in which it takes place (Kimura and Kinchy 2016; Science Communication Unit-University of West England 2013 and references therein). In addition, CS has the recognized potential to influence democratic change (Bäckstrand 2011) and policymaking (Certomà, Corsini, and Rizzi 2015) and can be used as a tool for communities' struggle against different forms of environmental injustice (Dhillon 2017). Mobilizing scientific arguments in the context of an activist campaign is relatively common, both to prove the existence of environmental contamination and its harmful effects, and to reveal and make these effects manifest (see for instance Boudia and Jas 2014, Pt. 2; and Matz, Wylie, and Kriesky 2017). In some cases, CS is at the very heart of a movement (see for example the concept of evidence-based activism in Rabeharisoa, Moreira, and Akrich 2014).

Nevertheless, making use of CS means something more than simply backing citizen mobilization with scientific arguments: with CS, the "victims" of a particular risk become agents in the processes of generating the knowledge to address it (Haklay and Francis 2017). Regardless of how rigorous and shared the knowledge generated is, unveiling an environmental issue is nevertheless rarely sufficient to produce change (Davies and Mah 2020). Accordingly, my research explores the processes through which CS can alter and reshape social relations, by empowering the citizens that participate, and thus enabling them to realize change.

Citizen Science as an Empowering Device?

Citizen Science should not be uncritically ascribed as the silver bullet that inherently empowers all those who engage with it, not the least because of the sheer variety of projects and initiatives that are casted under this rubric and the several modes of social epistemologies it can enact (Kasperowski and Kullenberg 2019). Notwithstanding the good intentions and the determination of those who practice it to try changing the status quo, existing power structures unavoidably predefine CS activities (Liboiron 2017). In some cases, there are uneasy tensions and dilemmas between (sometimes conflicting) priorities such as delivering scientific rigorous information and broadening public participation in environmental science and politics, and how to pursue them (Jalbert and Kinchy 2016). Whether and how a CS exercise actually fulfils its empowering potential, depends on a wide range of elements characterizing individual projects, the context in which they take place, and the dynamic interface between projects and contexts. In particular, CS enables three processes through which participants can be empowered, i.e. gaining knowledge, gaining epistemic recognition, and building relationships. The extent to which these processes take place, I contend, is illustrative of whether CS exercises are truly empowering.

The potential of CS to enable the acquisition of (new or old) knowledge about an issue and how this translates into empowerment needs to be understood broadly, for the learning dynamics are different. While looking at the experience of participatory environmental monitoring in the vicinity of shale gas facilities, Jacob Robert Matz and others, for instance observe how citizen scientists used the sensing devices in different ways, and this was also thanks to the devices' user-friendliness (Matz et al. 2017). It also happens that the equipment is a trigger of participants' curiosity and pushes them to go further and seek knowledge beyond the immediate scope of the study, especially when a CS project provides opportunities for participants to become acquainted to scientific literature, and exchange with credentialed scientists, allowing the articulation of different forms of knowledge and expertise (Rabeharisoa et al. 2014).

There are different ways in which this greater knowledge is activated and used. CS can be instrumental in exploring areas of "undone science" (Frickel et al. 2010, 444), for example, collecting evidence about socio-ecological phenomena that are not monitored. In the context of bottom-up campaigns for a cleaner environment, it can also be instrumental to provide greater legitimacy to communities' claims and effectiveness in the quest for environmental justice (Ottinger 2010a; ibid., 2010b, Paddon et al. 2013).

CS does more than just make new evidence available. Apart from the most basic forms of crowdsourcing where citizens are mere carriers of sensors (and for which the label "citizen science" is arguably misused), CS can empower participants by increasing their legitimacy as "knowers" of air pollution. First of all, CS can help to offset the uneven distribution of privileges and recognition that characterizes the traditional policy-science-society interface, due to existing biases based on gender, class, ethnicity, or education. In addition, while similar biases also exist in CS (Haklay 2013), the lower thresholds to take part in a CS project vis-à-vis becoming a credentialed scientist still make it a powerful tool. More importantly, however, Ottinger highlights that "because of the structural authority afforded to science and scientists in environmental politics, it is useful to think of 'layperson' or 'non-scientist' as a marginalized identity category." (2017a, 42). In this context, CS can empower citizens—understood as the bearers of an environmental burden—by making them able to actively define this burden. Research has shown how this not only takes place when citizens collect data that are comparable and complementary to institutional monitoring, but also and especially when they engage in more speculative forms of environmental sensing and open up to new practices to make sense of lived experiences and measurements even when this is "just good enough," thereby articulating alternative forms of harm and expand the scope of what count as evidence (Gabrys 2017; Gabrys, Pritchard, and Barratt 2016).

In addition to allowing them to gain greater knowledge about air pollution and recognition as legitimate "knowers," CS (or more specifically CS projects) can empower citizens as it provides opportunities to engage in transdisciplinary dialogue among individuals and groups sharing the same concerns. Albeit obviously not unique to it, the potential to bring people and groups together is a critical part of CS, both because it helps to frame air pollution as a collective problem and not merely as the experience of individuals, and because it increases the political leverage of those who claim the right to cleaner air (Whitehead 2009, Ch. 9). Networking processes take place at different levels. A particularly relevant exchange that CS can energize is between credentialed scientists and lay people, or as Michel Callon and others acutely put it, between "confined" and "open air" researchers (Callon et al. 2001). Liévanos and others (2011) speak of "citizen-science alliances" as powerful tools to bring together the everyday lived experience of environmental victims and the knowledge of technical experts. These exchanges include a

better appreciation of the worth and limits of each other's perspectives, as well as concrete opportunities to work together around the same problem.[1]

The AirCasting Brussels Project

Empirically, this article focuses on the AirCasting Brussels project (ACB), a CS project focusing on air pollution issues that was conducted between 2016 and 2019 in Brussels. Although in the last years it has received significant attention, air pollution is not a new phenomenon. Since the early 1990s motorized traffic is the main culprit in Brussels, and—albeit with differences across the pollutants—today it remains among the largest contributors to local emissions (61% of total NOx emissions, 35% of PM_{10} total emissions and, and 29% of $PM_{2.5}$ total emissions (Bruxelles Environnement 2020). At the time the project was designed, in 2015, the theme of air pollution was rather marginal in the public debate. Beside the network of stations to monitor air pollution, the only policy directly targeting air pollution was the "Pollution Peak Emergency Plan," which aimed to reduce polluting emissions at critical times, but that was explicitly designed to be triggered only under extraordinary condition (Region De Bruxelles-Capitale 2008). The situation started to change precisely in 2016, with air pollution emerging in the public discussion because of the awareness raising, advocacy campaign and science communication work of two citizen collectives, namely Clean Air Brussels and Bruxsel'air. Some members of Clean Air Brussels, also, had joined hands with the lawyers NGO Client Earth to sue the regional government on air pollution issues.[2] These collectives, however, where an exception in a landscape where air pollution was barely a matter of concern for the organized civil society and was not included in any of the traditional channels of consultation between the government and the civil society.

ACB was run by a local university (the Vrije Universiteit Brussel (VUB)), a community-based organization working on issues of urban democracy, empowerment and sustainable urban development (BRAL Citizens Action Brussels), and various groups of citizens. The overall objectives were to test a collaborative approach to generating knowledge about air pollution, and to work together for cleaner air. The project was funded by the main public funding agency for research and innovation of the Brussels region (Innoviris), within a three-year scheme focused on questions of participation, and could count on the volunteer work of numerous citizens. This model had two critical impacts: first, the fact that I was not a project with the explicit aim to study the urban environment allowed a certain flexibility in designing the protocols for data collection, analysis and dissemination, as illustrated in detail below; second, the project's financial scheme allowed participants to take a critical stand—often very outspoken—vis-à-vis the

[1] For the current article, it is relevant to focus on the potential of CS to establish cooperation between scientists and lay people. At the same time, it should be acknowledged that in many cases, citizen science methods have been used to criticize "official" science and contest its methods and findings. (Kimura and Kinchy 2016, Ottinger 2016, Brown 2007).
[2] In January 2021, after a five year legal battle and well beyond the end of the project treated in this research, the judge ruled that the Brussels regional government has breached EU law and has failed to correctly monitor and protect its citizens against harmful levels of air pollution (ClientEarth 2021).

environmental protection agency (Brussels Environment) and the regional minister for environment, without fearing direct financial consequences.

The project methodology, developed together by the community-based organization and the university, in fact, explicitly reflected this ambition. BRAL and the VUB, in particular, proposed the idea to interested citizens of assembling in groups and participating in a series of workshops for six-to-eight months, and engage in different elements, including: #1 a scientific inquiry (to get to know), #2 activities of awareness raising and mobilization (to let others know), and #3 a reflection on the process.

The calls for participants, did not follow a narrow top-down approach but built on existing opportunities and responded to bottom-up demands for collaboration from existing groups or individuals who wanted to establish a thematic group on air pollution within their communities. Participants came from different backgrounds: one group was already campaigning for cleaner air, and its members wanted to engage in a scientific exercise. The other communities, in turn, had never directly focused on air pollution before. These included parents' committees of different local schools, a medical center, a trade union, an association of cyclists, and various neighborhood committees. For them, air pollution was just one of the elements related to their main issues of concern, which included children wellbeing, health, mobility, quality of the local environment. This approach resulted in a mosaic of collaboration of different kinds, with groups engaging fully or only partially with proposed activities. In this article, I focus on the trajectory of eight of the groups which participated in all three components of the project.

For the pollution monitoring part, the project used the AirCasting infrastructure. This consisted of wearable monitors for $PM_{2.5}$ pollution (AirBeams 1, see figure 1), the participants' smartphones (or smartphones made available through the project), and the AirCasting website and app (Aircasting). Also known as fine particulate matter, $PM_{2.5}$ are particles of suspended matter with a diameter of 2.5 microns or less. They are harmful for human health even at very low concentration, and—as such—they are commonly used as a proxy indicator for outdoor air pollution and to set minimum standards for clean air (WHO 2016). To start the measurement, users need to open the app and start a "session." Approximately once per second, the recordings are communicated via Bluetooth to the AirCasting Android app, which combines the recordings with GPS and time data from the phone. At the end of each session, the user can add a session name, multiple tag (e.g. by bike, in the office, with kids, work . . .) and a short description. The data is then uploaded to the AirCasting server where it is used to feed an online crowd-map online (see figures 2 and 3). Through the map interface, it is possible for everyone to visualize and download data from individual sessions, or groups of sessions filtered by tag, time, and user (for the technical specification and performance details, see Heimbinder and Besser 2014; US EPA [undated]).

Figure 1. One of the AirBeams 1 device used for ACB (Source F. Corbiau, May 3, 2018).

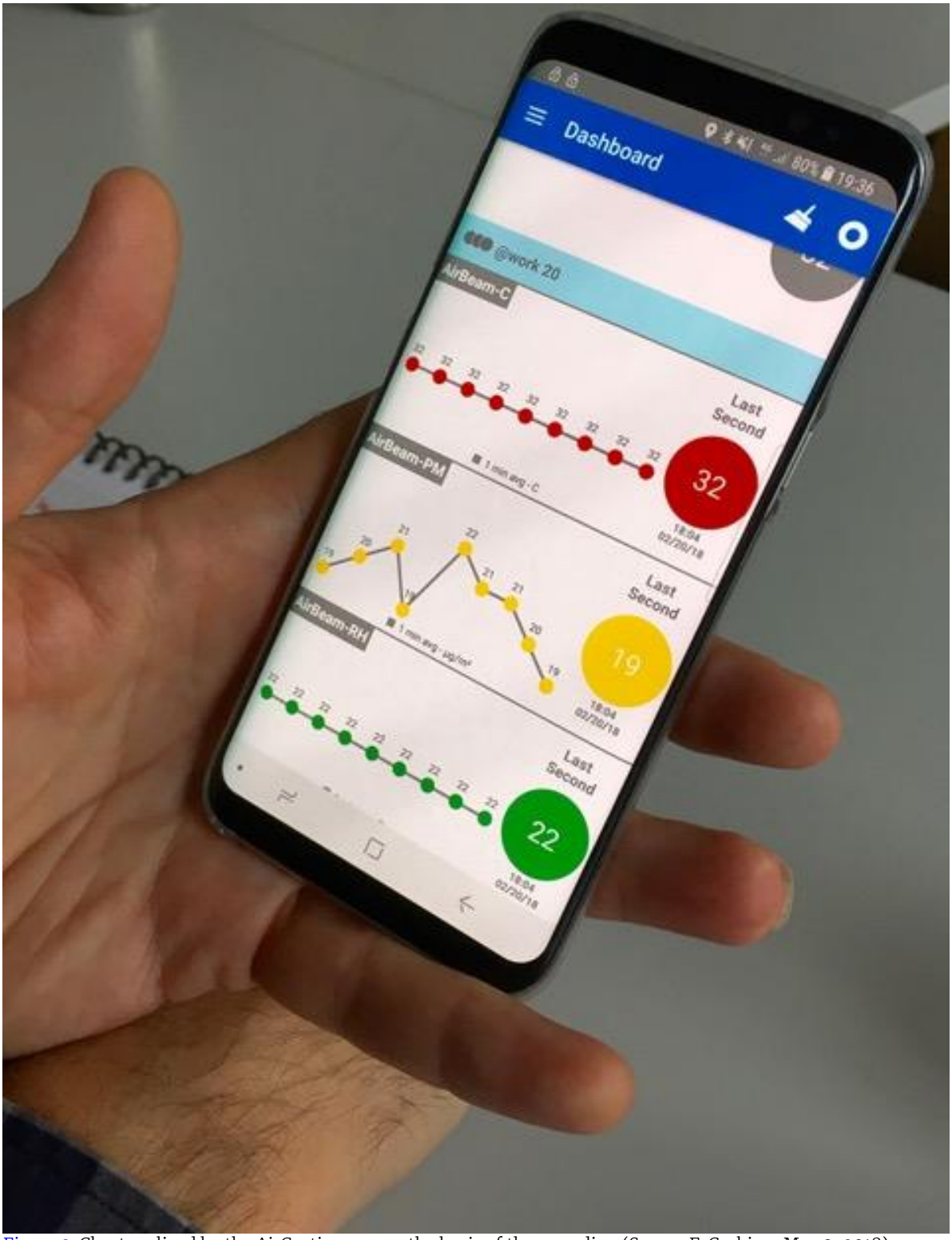

Figure 2. Chart realized by the AirCasting app on the basis of the recording (Source F. Corbiau, May 3, 2018).

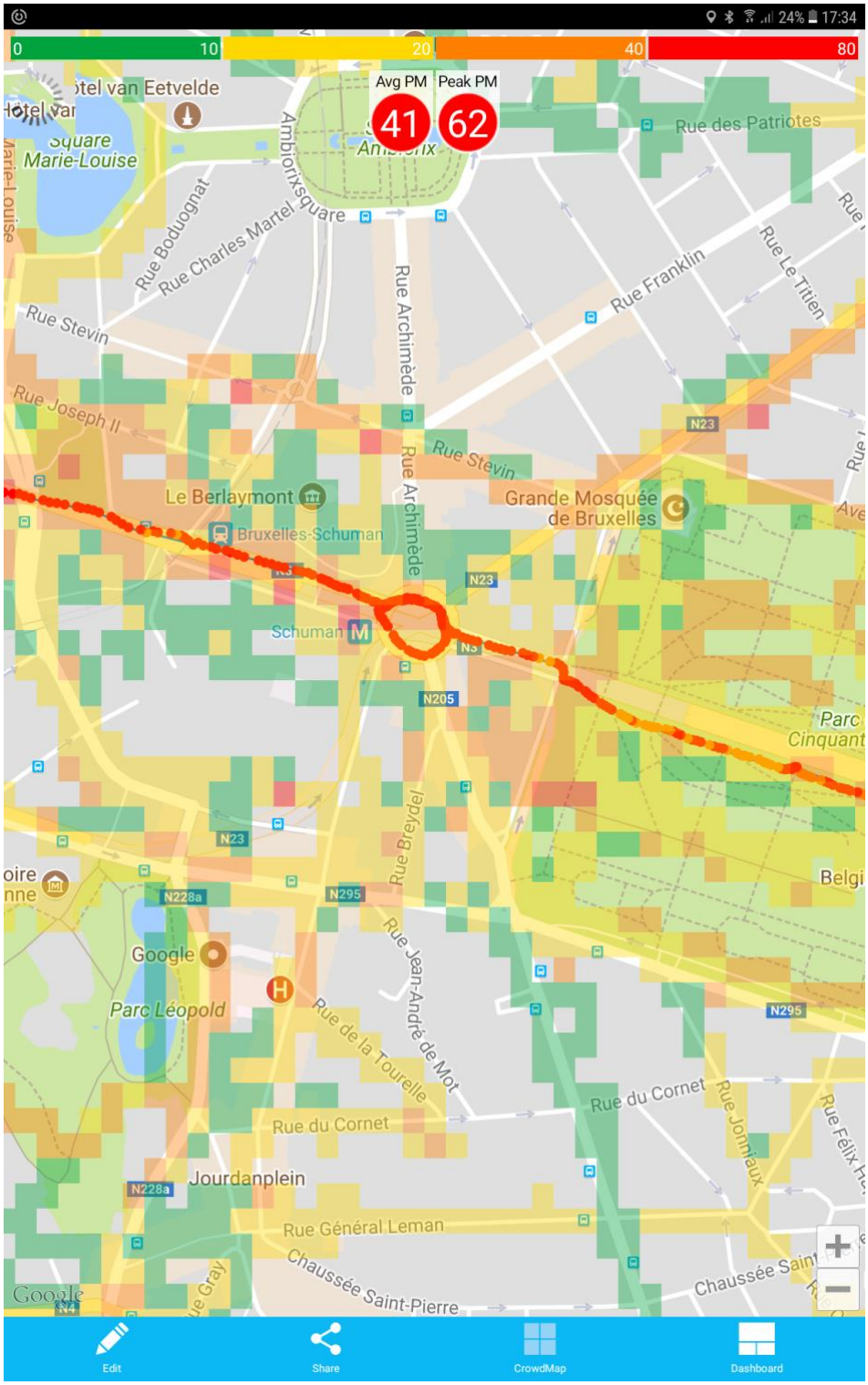

Figure 3. The AirCasting map as shown on the Aircasting app. The screenshot shows both the data from a recording taken by the user, and the crowdsourced data (Source HabitatMap, November 8, 2017).

During the workshops, participants were encouraged to share their experiences and interests, ask questions, and try to respond jointly to them. The research was driven from the bottom up, and was given a different weight (and time) by the various groups, developing less or more specific inquiries. As part of element #2, the groups designed and organized different types of campaigns, such as public events to share experiences and raise awareness, creative dissemination of the results through the media, discussion with policymakers, and pedagogical activities. Element #3 consisted of a joint reflection on the process and on the methods. This article is one of the results of this element in the project (for an extensive account of all groups and activities see Chemin, da Schio, and Cassiers 2019, 24–30).

Within the project, I acted as the focal person for the VUB and as a coordinator together with two staff members of BRAL. I was also directly involved in the activities of some of the groups, by facilitating the workshops and by supporting the setting up of the scientific inquiry and the analysis of the data. Lastly, I led the reflexive component of the project by conducting and analyzing the interviews. My background in urban studies and my training in qualitative methods meant that I was only rarely considered as an "air pollution scientist" by BRAL staff and other project participants. While this is indicative of a somewhat limited understanding of (air pollution) science, it possibly had the advantage of at least partially mitigating expert versus lay person imbalances that often characterize CS projects.

Within the extensive empirical material that the project allowed to collect (including data on $PM_{2.5}$ concentration, mobility practices, air pollution representation, and more), this article focuses on three categories. The first consists of the narrated experiences of the participants in the project, which I documented via five in-depth interviews with representatives of participating groups, four focus group interviews, and two workshops involving members of all groups together. The second category concerns the outreach efforts of BRAL and the participating groups, and includes blog posts, traditional and social media articles, brochures, flyers, and video transcripts. I collected this material systematically during the project duration, and eventually asked groups members to review it and share with me any more material I might have missed. The third category consists of the ethnographic notes I compiled while participating in the project, including a journal which I updated regularly throughout the project, the notes of all meetings I took part in, and various project documents (e.g. funding application, project reporting, and text in the project website). These data were analyzed with the aid of NVIVO, a qualitative data management and analysis program. After combining all texts into a single project file, I coded them thematically, and analyzed exiting patterns and relations. Codes include both deductive ones informed by the theory and the literature review, as well as inductive ones that emerged from the data.

The Empowering Virtues of Citizen Science

During the three years of operating, the ACB project produced a broad range of direct and indirect effects. In this article I analyze whether and how the ACB project enabled three empowering processes introduced above, namely (1) gaining knowledge, (2) gaining epistemic recognition, and (3) building relations; and I reflect on the conditions that allowed and deterred dynamics of empowerment of participating citizens.

Greater Knowledge About Air Pollution

In multilingual Brussels, two slogans were often cited when speaking about CS: *meten is weten* (in Dutch, measuring is knowing) and *savoir c'est pouvoir* (in French, knowledge is power). The quest for more

knowledge about air pollution, expressed either as personal curiosity or as a desire to contribute to the greater good, was acknowledged both during the first meetings, and in the interviews as one of the main motivations for participants to join the AirCasting Brussels project. In practical terms, AirCasting Brussels participants were involved in several hundred measuring sessions to monitor air pollution levels during their commute, at home, in front of their children's school, etc. Measurements were carried out with different degrees of systematicity and rigor, and delivered data ranging from impressionistic evidence about pollution levels in a given place at a given time, through collective measurements in a specific hotspot, to rigorous and systematic collections of empirical data for a scientific article. Overall, however, the experience of directly measuring the concentration of pollutants, and the possibility offered by the device to "see" air pollution in real time appear to represent added value to the data collected, making it more vivid and concrete.

> Even though normally I would think that a study carried out by a university has a higher seal of reliability . . . I still feel that for myself, and also engaging with others around me, it is something more convincing to say "*I saw it myself, with my own device.*" (Julius, 16 April 2018, focus group)

Different complementary processes can be clearly observed, although the degree of participation in each of them was not the same for all. Firstly, participants learn about pollution through the lenses of their own experience, are surprised about individual measurements, validate or invalidate the inferences they had made on the basis of what they could see, smell, or hear. Second, they share their experience with fellow citizen scientists, transforming their measurements in a collective effort of making sense of their polluted routines. And finally participation in the project was sometimes a trigger for exploring air pollution further, by engaging with academic and policy literature on the topic. Precisely to respond to this newly developed interest and curiosity, BRAL cooperated with researchers in different universities to produce scientific publications (published as da Schio, de Geus, and Bouland 2017; Paumard et al. 2017), organized around questions from the activists and designed to be accessible and easy to consult. In addition, one of the groups invited an expert to a public meeting and asked her to discuss the CS findings in relation to her research. The event, in the same vein of the scientific publications, was not designed as a science-communication lecture where an expert teaches to laypeople. Rather, it was co-constructed by the group's members, the experts and me, around the findings and the interrogatives that had emerged from the measurement campaign, with the objectives of discussing them, interpreting them, and linking them to the broader research on air pollution.

A note of caution needs to be added regarding the knowledge that was produced and on the scope of the learning that took place. While CS methods are sometimes used to produce knowledge largely comparable with professional science, in the case of AirCasting Brussels the approach was different. In particular, the choice was made to let participants experiment with the measuring devices and find ways to articulate their experiential knowledge of the city, with the $PM_{2.5}$ concentration data provided by the monitoring devices, and with other forms of knowledge. In some cases, rigorous protocols for data collection and analysis were followed, but in most cases they were not. Overall, this means the results of the measurement campaigns are not directly comparable with, for example, those conducted by the governmental environmental agency. Most participants were aware of this difference and of the indicative nature of the data produced by the device they were using.

In the context of empowering citizen scientists this lack of comparability is double edged. On one hand, the approach contributed to develop different—more experiential—knowledge claims, with their own legitimacy to make sense of air pollution in Brussels. Although STS research has clearly illustrated why this knowledge should not be seen as "amatorial" science, hierarchically inferior to "real" science (see for instance Ottinger 2017b), this view is not always shared in policy circles, and the potential of CS to generate knowledge readily "usable" for advocacy actions is therefore reduced (see also next section).

Indeed, while most participants agreed that "having facts" would make a claim more credible and legitimate, I rarely observed the direct use of these facts in the context of their advocacy. If the exercise of measuring air pollution was possibly useful for participants to realize that air pollution is present in their daily routine, the data collected in a specific location was not used for a specific demand for cleaner air in that location, nor to contest existing measurements. A notable exception was the case of school-based groups. During a whole week in February 2018, for instance, all the participants decided to measure daily averages and morning peaks of pollution levels at the school gate to strengthen the specific demand for traffic calming measures at children's drop-off time. One of the schools, moreover, was offered the opportunity to pilot test a "school street" and was asked by the municipality to take the air quality measurements that would be used in the evaluation.

No assessment was made to evaluate how much AirCasting Brussels participants actually learned about air pollution. Nevertheless, the self-evaluation was relatively positive, as indicated by the words of Carolien, below.

> So, indeed you feel more confident in those discussions. it is not just something I read in the news [pause] it's something I actually experienced myself [pause] so I feel—that's true—I feel more confident and less emotional, but more factual, and more fact based. And it happens to you; you really say: ah now, we have measured it. (Carolien, 16 April 2018, focus group)

In addition to the new knowledge, one of the project coordinators from BRAL put particular emphasis on the pride that participants came to develop from having learned and from the knowledge they developed themselves.

> [Citizen scientists] are proud of this knowledge, which they understand by themselves . . . And they will be able to discuss it with other people, talk about it at work . . . but also, sometimes, to express what they want for their neighborhood. (Liévin, 6 April 2018, media dissemination, translated from French by the author)

The analysis of discourses about the project, also, offers an unambiguously positive picture in terms of the benefits of greater knowledge for achieving activists' objectives. This appears, for instance, in the media representation of the project, and in the reflections of participants. "Those who measure fine dust have an influence" was the title in the newspaper *De Standaard* for an article about the AirCasting Brussels project (De Standaard 2018, translated from Dutch by the author). As illustrated by Olivier, below.

> When you can measure something, you can defend something: you can discourage people from going by car, you have arguments to take to politicians and say: hey, air quality is bad! You should do something about that! I think that if you don't measure it, you won't know it . . . . Otherwise you can smell it, but it is not enough to convince . . . . It is only when you come with facts. (Olivier, 3 October 2018, interview)

In practice, citizens mobilized the newly acquired knowledge to address local government workers and elected officials to lobby for a healthier environment. The frame of ACB was itself an opportunity to stage public discussions on the topic, and having participated in a CS project was used as a form of credential to prove one's legitimacy to discuss air pollution.

The government, however, was not the only addressee of the citizen scientists' advocacy. Through sometimes creative forms of disseminating information, different groups actively reached out to the general public to raise awareness about the air pollution problem, with the objective of achieving behavioral change and support for ambitious policies. In this context, the way participants referred to themselves—that is, not as the targets of an awareness-raising exercise, but as the agents of a campaign targeting other, yet-to-be-made-aware citizens—can be interpreted as a manifestation of empowerment.

Overall, if the project was useful to respond to citizens' "desire to know," (and in some cases as an awareness raising device) its main contribution to advancing their claims was not to build scientific backing for their advocacy. By contrast, the user-friendliness of the monitoring device, the space the project provided to raise questions and learn about air pollution, and the self-confidence it generated allowed them to develop a better appreciation of the air pollution issue, and thus make them more capable of engaging in the societal debate regarding cleaner air.

Epistemic Recognition

Analysis of empirical material, and in particular of the ethnographic observations, on how CS has changed citizens' role in the public debate over air pollution offers a mixed picture, with epistemic recognition remaining contested. An interesting example of empowerment can be seen in the process of interaction between politicians and citizen scientists facilitated by BRAL and the VUB. On different occasions and in varying formats, decision-makers discussed and presented their program to a jury composed of citizens. During the meetings, the experience and the expertise of so-called lay people allowed—at least partially—the power imbalance vis-à-vis the elected officials to be overturned; to the great surprise of those on both sides of the table.

> Everybody has learned a lot: on the variation of air pollution too, on the climate, the geography, the street canyons . . . . Well, they know more than the members of the parliament whom we met, it is true . . . we saw that during the meeting in the parliament building. (Josette, 20 September 2018, interview, translated from French by the author)

Another example showing how—albeit empowering—CS does not automatically translate into uncontested recognition comes from a statement from the regional ministry for the environment about the results of a CS project conducted by a local section of the opposition Green Party. This was dismissed as dangerous witchcraft, even though it used a widely acknowledged pollution monitoring technique.

> This deserves better than going into the neighborhoods to collect air samples with small plastic tubes like sorcerer's apprentices! (Mme. Céline Fremault, minister 22 May 2018, Parliament of the Brussels Capital Region. Full report of interpellations and questions, Committee on the Environment and Energy, translated from French by the author)

The domination of the governmental scientific apparatus over air pollution knowledge not only materializes when assumptions are made that the data collected by the government outranks any other source of knowledge (that is, *who* is to make claims about the air). A more subtle process is also in place, which concerns the definition of the most appropriate representation of air pollution. For example, the government uses concepts such as "year" and "24-hours-based concentration averages" or "characteristic values," as provided by law (Irceline [undated]). If the question involves the best method to monitor these specific indicators, the government infrastructure might well offer the highest degree of sophistication. However, the point is that other representations of air pollution are also relevant, and for those, CS methodologies might be better suited. Albeit possibly appropriate to meet legal provisions,[3] the concepts used by the government rarely resonate with the experience of people who live in Brussels and bear the air pollution burden; and further have different space-time trajectories, housing and working conditions, levels of vulnerability, and resources to cope with it.

> Do we know enough about the air we breathe? We can study the figures from the monitoring network at the regional level. But is that enough to estimate our daily exposure to polluted air? A regional, averaged alarm value does not show that in the street where we live or where our children go to school, the pollutants accumulate locally. That is why we, as citizens, want to be able to measure for ourselves the state of the air in our neighborhoods. (BRAL blog 28 November 2016, media dissemination, translated from Dutch by the author)

Two alternative frames emerge from the analysis of the empirical material. The first concerns the focus on personal exposure during particular moments in people's daily life; made possible to measure by the portable monitoring devices. While exposure monitoring techniques are not new as such, the ACB project still provided some elements of epistemic innovation. One of the groups, for instance, made a comprehensive comparison between quick and direct journeys and various "clean" alternatives. The same group also reflected on the suitability of a person's residence, not only based on whether the location was polluted or not, but also on the basis of the total exposure measured on the daily commute. Another group analyzed exposure by looking into participants' weekly routines and the sociological explanation of how they came about, in addition to the average exposure characterizing the different activities (da Schio 2020).

The second innovative aspect of the AirCasting Brussels project concerns the fundamental embeddedness of the air pollution measurements in the daily experiences of the project participants and their acquaintances. The CS research was not about comparing the exposure of an average cyclist with that of an average car driver, or between a typical daily pattern for full-time workers and homemakers. It was about looking at exposure characterizing a person's own meaningful activities, a colleague's commute to work, or a child's school or free time.

> It makes things more concrete . . . and also to speak about it from your own point of view, you have a much more concrete basis . . . you can speak about the pollution peak in Brussels being this or that, but it is

[3] Even the appropriateness to meet legal provision has been challenged, as noted.

> something else to say that we are here at the daycare center with our baby, and here is what we are breathing just now. (Cecile, 3 June 2018, focus group, translated from French by the author)

The work of school-based groups, moreover, is particularly emblematic of this way of framing air pollution as a problem that is concretely present in citizens' everyday life. Their attention to pollution levels at the school gate produces a shift in how pollution is framed from a problem "up in the air" to one that is "here and now," affecting a specific—and particularly vulnerable—segment of the population, in specific parts of the cityscape, at the specific time children are dropped off.

These novel frames of the air pollution problem around more reduced and more specific temporal and spatial scales proved to be a winning strategy for project participants and their discourse to gain at least some epistemic recognition. While they were not directly relevant to make claims against existing clean air standards, these frames brought the air pollution question on a ground where citizens knowledge could not be easily dismissed, precisely because there does not exist any widely acknowledged standard, and thus barely any institutional measurements and anyway no straightforward manner to conduct such measurements.

Opportunities for Dialogue and Coalition Building

The ACB project brought together a wide range of people and groups, establishing new relations, or strengthening and transforming existing ones, ranging from countless discussions between friends, family, and passers-by, to long standing friendships and professional relations. At the most basic level, the project was useful to bring people together and to provide opportunities for interaction over an issue of shared concern. These networking opportunities, and how they were instrumental in empowering participants, did not just happen as welcome side-effects of the project. On the contrary, the time and the energy that was dedicated to them by the project coordinators and by the participants throughout the lifetime of ACB were critical conditions for them to take place.

> Coming together to pool measurements and knowledge was the key to success. It greatly accelerated the collective knowledge, the sense of responsibility towards the group, and the empowerment and eagerness of the action researchers to mobilize. (BRAL blog, 5 June 2019, media dissemination, translated from Dutch by the author)

Social interaction was also indicated as one of the reasons why people joined the project and remained involved throughout. Further, learning to work together and the inspiration from other participants were indicated as key benefits they had gained from the project:

> I think there is a positive indirect effect. That is the possibility to speak to people [with similar concerns]. Sometimes I speak to people around me [about my concerns for air pollution] . . . and they take me as a [fool]. But after I joined here . . . this "self-help group," [laugh]: I really feel I am better understood. (Katia, 6 March 2018, focus group, translated from French by the author)

The extent to which the ACB activities contributed to strengthening community bonds differed from group to group is a consequence of the character of the participants and of the activities that were conducted. If in some cases a certain homogeneity across the groups and anyway the presence of a shared sense of

community helped to maintain the momentum and the motivation of the participants, in other the CS project was useful (and welcome) precisely to establish completely new connections. In many of the schools where the project was picked up, for instance, the monitoring campaign took place within existing activities of the parents' committees, which it contributed to continuing and expanding. The group created at the medical center, in turn, provided additional opportunities for the staff and the patients to get together and exchange information, beyond the individual doctor-patient relationships confined to the surgery.

> Yes, for them [the patients] it's extraordinary what happened. It woke them up and allowed us to improve our relationship. They are very optimistic . . . But for the medical house . . . . These are people who don't know each other that we brought together. It's very enriching, because you find people who would never have met. (Josette, 20 September 2018, interview, translated from French by the author)

The AirCasting Brussels project did not simply help develop friendly relations between neighbors and friends—it helped in establishing and developing groups of citizens tied by the shared awareness of being bearers of the burden of air pollution. Moreover, some "institutional" transdisciplinary relations were also created as a consequence of the project; that is, between organized civil-society groups and the research community. These relations, it should be noted, did not emerge by themselves, but resulted from active outreach work. Indeed, from very early on, both the VUB and BRAL engaged in an open dialogue with all stakeholders active on the topic. This outreach was useful to establish both a platform for discussion for all civic movements active for better air, in the form of mailing lists, social media groups, and regular meetings, and a multidisciplinary network of researchers working on air quality and CS, meeting biannually. The actual existence of the civil society platform and of the researchers' network, instead of a mixed venue for exchange, is proof of the challenges that were encountered in bringing together the two audiences; for example, the different schedules (working hours vs. evening), preferred location (university room vs. community center or NGO premises), and suitable format (academic presentation vs. interactive roundtable). Nevertheless, they both offered occasions for encounters and mutual learning, at least for individuals participating in the two networks.

The closing event of the ACB project, the *États Généraux de l'Air de Bruxelles*, also provided a snapshot of how this relationship was articulated. This was an event organized by a range of partners from civil society, academia, and administration, encompassing three pillars: an international scientific symposium, a hackers' gathering, and a series of events of different types dedicated to Brussels' citizens. For three days, people from different worlds and sometimes with radically different approaches to dealing with air pollution came together to discuss visions and solutions for working toward a healthier city, but also to listen to and learn from each other. The event concluded with a public debate in which top-level party candidates for the forthcoming regional elections (some of whom later became ministers) were questioned by representatives from the civil society and academia, standing together in the quest for cleaner air.

> During the États Généraux, the academic community, and citizens responded to the call and we would like to renew our commitment to work together for a more livable Brussels. The alliance between scientific research and the citizens' movement has shown its full potential, and we will continue to develop it. (27 April 2019, concluding speech, translated from French by the author)

While the cooperation between experts and citizens around cleaner air in Brussels is far from being institutionalized at the time of writing, this may change in the future, also as a result of the ACB project. In a meeting between Brussels' minister for environment and civil society advocates for cleaner air, one of the key priorities expressed by the latter was precisely the establishment of structural cooperation between ministries, governmental agencies, researchers, organized civil society, and citizen movements (March 5th, 2020, Meeting of Minister Maron with AIR Network).

Realizing the Potential of Citizen Science "Beyond Science"

In Brussels and in many other cities, citizen science has been re-discovered as a versatile approach to support governments and citizens in addressing the air pollution problem. By establishing a conceptual and methodological shift in the way science is understood and conducted, CS clearly offers the possibility to empower them and thereby address the shortcomings of a technocratic approach to air pollution. In this article I analyzed the extent to which and the ways in which the CS approach empowered the participants in the ACB project in Brussels, by looking at the sets of processes that CS can enable and through which it can realize its empowering promises, i.e. gaining knowledge, gaining epistemic recognition, and building relationships.

First, citizen science worked as a learning device at the level of those who participated in ACB, but also at a broader level in that more knowledge came to be generated and circulated throughout society. The generation and dissemination of knowledge happened in multiple ways including direct measuring, experience sharing, exchange between citizens and academia. The fact that Brussels is polluted has been known for a long time, and the project did not produce ground-breaking results in that respect. Ostensibly, however, citizen science made visible what was hidden in labs and mathematical models, and contributed to making it part of the public debate. Moreover, by showing how air pollution was not only an issue for white-coated scientists but also part of everybody's life, the CS approach helped to reveal its inherent complexity and socio-political nature.

While similar results might have been achieved through science communication activities, AirCasting Brussels CS methods went further: they contributed—albeit with limits—to legitimizing citizens' perspectives on the problem. This was not just a question of giving credit to their propositions through scientific arguments. It was about legitimizing their role as "knowers" of the problem, expanding the pool of people and groups whose voice needs to be heard in the air pollution debate, as well as the ways in which air pollution needs to be represented. In this respect, mixed results can be observed. The project led to a certain degree of epistemic innovation, allowing citizens' perspective to be articulated and voiced and bring the debate on a ground where the epistemic imbalances between institutions and communities were less prominent. At the same time, their role as a knower remains far from being consensual.

In relation to both processes of gaining knowledge and gaining epistemic recognition, the choice of tool (AirBeam) and of a methodological approach that are user-centered but outside of the strictest scientific standards for air pollution monitoring proved to be ambivalent. While the project did not produce knowledge about air pollution comparable with the institutional monitoring, and directly "usable" to contest it, it allowed participants to experiment, to articulate their individual and collective experience of air pollution, to bring the controversy in unexplored grounds, and eventually destabilize the government's reliance on the institutional monitoring. These aspects of the project probably challenge the definition of CS as *rigorous and*

systematic effort as indicated above, and highlight an area of tension in relation to the practice and the ambitions of CS project, which deserves further research.

Regardless of how it is generated and disseminated, nonetheless, knowledge alone is rarely sufficient to bring about change. AirCasting Brussels was part of and contributed to developing networks of interaction between individuals and institutions. Among other things, it contributed to weaving together relations between research and activist communities, which may be a game-changer in the context of future air-pollution monitoring and decision-making processes. In that context the explicit inclusion of elements of networking and community development in the project design and in the conduct of the activities proved to be critical conditions of success.

The processes of empowerment that have characterized the ACB project were enabled by the fertile ground of mobilization for cleaner air in which the project took place, but also by the particular setup of the project. This is just one among different possible setups. When seen against the broader landscape of citizen science exercises, in fact, the ACB project—and the lessons deriving from it—need to be situated in a middle ground between more top-down and rather bottom-up examples of citizen science exercises. Similarly to the former, ACB was initiated under a publicly funded project, with a core team of staff paid to conduct the project, and with research and engagement objectives originating from—and anyway compatible with—the existing policy and research agenda (see for instance the projects discussed by Dons et al. 2020). Similarly to the latter, in turn, the funding scheme and approach of the project staff allowed responding to involved communities' concerns and ambitions, stimulating and accompanying grassroots mobilization, which brings ACB in the direction of the experience of fenceline communities (e.g. Ottinger 2010a; Wylie et al. 2017b). If this hybrid nature of ACB allowed to have some of the advantages of both top-down and bottom-up approaches to CS, it also made it inherit some of their weaknesses and limits in bringing about change (Wylie et al. 2017a).

At the time of writing, it is premature to determine whether the AirCasting Brussels project and the broader movement it was part of will lead to the formalized right of citizens to meaningfully participate in air pollution monitoring and decision-making processes, or even whether this is necessarily the most desirable outcome. What seems clearer, however, is the extent to which citizen science has allowed citizens to take greater ownership of the air pollution issue. By allowing to gain knowledge about air pollution and epistemic recognition, and by facilitating new relationships, the citizen science approach increased participants' to scrutinize policy and to contribute to and influence public discussion on the topic (i.e. citizens science as a trigger of more participated political controversies). In this context, citizen science not only contributes in innovating in the way air pollution comes to be known, but also in the way it is dealt with. As a counterpart to their fundamental *right* to participate in democracy, citizen science allows the strengthening of citizens' *capabilities* to do so in a meaningful manner.

Acknowledgements

This research is part of a broader action research effort in which many people have contributed. I am thankful to all those who participated in the AirCasting Brussels project, as well as to Tim Cassiers and Liévin Chemin of BRAL whose efforts to change Brussels has been so inspiring for my work. This research has received funding from Innoviris (Brussels) under grant number 854919.

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References

Aircasting. [Undated]. http://aircasting.org/. App, November 2, 2019.

Allen, Barbara L. 2018. "Strongly Participatory Science and Knowledge Justice in an Environmentally Contested Region." *Science, Technology, & Human Values* 43(6): 947–71. https://doi.org/10.1177/0162243918758380.

Ascher, William, Toddi Steelman, and Robert Healy. 2010. "Knowledge and Environmental Policy: Re-Imagining the Boundaries of Science and Politics." Cambridge, MA: MIT Press.

Bäckstrand, Karin. 2011. "Civic Science for Sustainability: Reframing the Role of Experts, Policy-Makers and Citizens in Environmental Governance." In *The Postcolonial Science and Technology Studies Reader*, edited by Sandra Harding. [Electronic]: Duke University Press. https://doi.org/10.1215/9780822393849-030.

Boudia, Soraya, and Nathalie Jas. 2014. "The Greatness and Misery of Science in a Toxic World." In *Powerless Science?: Science and Politics in a Toxic World*. New York: Berghahn Books.

Brown, Phil. 2007. *Toxic Exposures: Contested Illnesses and the Environmental Health Movement.* New York: Columbia University Press. https://doi.org/10.7312/brow12948.

Bruxelles Environnement. 2020. *L'environnement: état des lieux—espaces verts et biodiversité. [The environment: state of play—green spaces and biodiversity].* Accessed July 22, 2020. http://environnement.brussels/lenvironnement-etat-des-lieux/en-detail/espaces-verts-et-biodiversite.

Callon, Michel, Pierre Lascoumes, and Yannick Barthe. 2001. *Agir dans un monde incertain—essai sur la démocratie technique. [Acting in an uncertain world—an essay on technical democracy].* La Couleur des Idées. Paris: Seuil.

Certomà, Chiara, Filippo Corsini, and Francesco Rizzi. 2015. "Crowdsourcing Urban Sustainability. Data, People and Technologies in Participatory Governance." *Futures* 74(November): 93–106. https://doi.org/10.1016/j.futures.2014.11.006.

Chemin, Lievin, Nicola da Schio, and Tim Cassiers. 2019. *Citizen Science: Collective Knowledge Empowers.* Brussels: BRAL & Cosmopolis. Accessed March 3, 2022. https://bral.brussels/nl/artikel/citizen-science-collective-knowledge-empowers.

Clientearth.org. 2021. *ClientEarth and Brussels Residents Win Five-Year Legal Battle for Clean Air*. Press release, 29 January 2021. Accessed March 2, 2022. https://www.clientearth.org/latest/press-office/press/clientearth-and-brussels-residents-win-five-year-legal-battle-for-clean-air/.

Da Schio, Nicola. 2020. "Self-Portraits of Personal Exposure to Air Pollution: On Where and When People Are Exposed, and On Why It Is Difficult to Avoid." *Human Ecology* 48: 465–479. https://doi.org/10.1007/s10745-020-00176-y.

——, Bas de Geus, and Catherine Bouland. 2017. "A Brief Guide to the Air of Brussels." *Brussels Centre Observatory Portfolio* #2, Accessed November 21, 2017. https://bsi-bco.brussels/nl/a-brief-guide-to-the-air-of-brussels/.

Davies, Thom, and Alice Mah, eds. 2020. *Toxic Truths: Environmental Justice and Citizen Science in a Post-Truth Age.* Manchester: Manchester University Press. https://doi.org/10.7765/9781526137005.

De Standaard. 2018. "Wie fijn stof meet, heeft invloed" [Those who measure fine dust have an influence]. *De Standaard.* February 28, 2018. Accessed March 2, 2022. https://www.standaard.be/cnt/dmf20180227_03381651.

Dhillon, Carla May. 2017. "Using Citizen Science in Environmental Justice: Participation and Decision-Making in a Southern California Waste Facility Siting Conflict." *Local Environment* 22(12): 1479–96. https://doi.org/10.1080/13549839.2017.1360263.

Dons, Evi, Sam De Craemer, Huib Huyse, Jordy Vercauteren, et al. 2020. "Measuring and Modelling Exposure to Air Pollution with Citizen Science: The CurieuzeNeuzen Project." *ISEE Conference Abstracts*: *Environmental Health Perspectives.* https://doi.org/10.1289/isee.2020.virtual.P-1016.

European Environment Agency. 2019. "Assessing Air Quality Through Citizen Science." *European Environment Agency Report* No. 19/2019. Accessed June 30, 2021. https://www.eea.europa.eu/publications/assessing-air-quality-through-citizen-science.

Frickel, Scott, Sahra Gibbon, Jeff Howard, Joanna Kempner, et al. 2010. "Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting." *Science, Technology, & Human Values* 35(4): 444–73. https://doi.org/10.1177/0162243909345836.

Fricker, Miranda. 2007. *Epistemic Injustice: Power and the Ethics of Knowing*. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198237907.001.0001.

Gabrys, Jennifer. 2017. "Citizen Sensing, Air Pollution and Fracking: From 'Caring about Your Air' to Speculative Practices of Evidencing Harm." *The Sociological Review* 65(2_suppl.): 172–92. https://doi.org/10.1177/0081176917710421.

——, Helen Pritchard, and Benjamin Barratt. 2016. "Just Good Enough Data: Figuring Data Citizenships through Air Pollution Sensing and Data Stories." *Big Data & Society* 3(2): 1-14. https://doi.org/10.1177/2053951716679677.

Haklay, Muki. 2013. "Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation." In *Crowdsourcing Geographic Knowledge*, edited by Daniel Sui, Sarah Elwood, and Michael Goodchild. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-4587-2_7.

——, and Louise Francis. 2017. "Participatory GIS and Community-Based Citizen Science for Environmental Justice Action." In *The Routledge Handbook of Environmental Justice*, edited by Ryan Holifield, Jayajit Chakraborty, and Gordon Walker. London: Routledge. 297–308. https://doi.org/10.4324/9781315678986-24.

Heimbinder, Michael, and Alex Besser. 2014. "AirBeam Technical Specifications, Operation & Performance." Accessed May 7, 2018. http://www.takingspace.org/airbeam-technical-specifications-operation-performance/.

Irceline.be Undated. Belgian Interregional Environment Agency (IRCEL—CELINE). Accessed March 2, 2022. https://www.irceline.be/en.

Jalbert, Kirk, and Abby J. Kinchy. 2016. "Sense and Influence: Environmental Monitoring Tools and the Power of Citizen Science." *Journal of Environmental Policy & Planning* 18(3): 379–97. https://doi.org/10.1080/1523908X.2015.1100985.

Kasperowski, Dick, and Christopher Kullenberg. 2019. "The Many Modes of Citizen Science." *Science & Technology Studies* 32(2): 2–7. https://doi.org/10.23987/sts.74404.

Kenis, Anneleen, and Matthias Lievens. 2014. "Searching for "the Political" in Environmental Politics." *Environmental Politics* 23(4): 531–48. https://doi.org/10.1080/09644016.2013.870067.

Kimura, Aya H., and Abby Kinchy. 2016. "Citizen Science: Probing the Virtues and Contexts of Participatory Research." *Engaging Science, Technology, and Society* 2: 331–61. https://doi.org/10.17351/ests2016.99.

Liboiron, Max. 2017. "Compromised Agency: The Case of BabyLegs." *Engaging Science, Technology, and Society* 3: 499–527. https://doi.org/10.17351/ests2017.126.

Liévanos, Raoul S., Jonathan K. London, and Julie Sze. 2011. "Uneven Transformations and Environmental Justice: Regulatory Science, Street Science, and Pesticide Regulation in California." In *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement.* The MIT Press Direct. https://doi.org/10.7551/mitpress/9780262015790.001.0001.

Matz, Jacob Robert, Sara Wylie, and Jill Kriesky. 2017. "Participatory Air Monitoring in the Midst of Uncertainty: Residents' Experiences with the Speck Sensor." *Engaging Science, Technology, and Society* 3: 464–98. https://doi.org/10.17351/ests2017.127.

Nadal, Carine. 2008. "Pursuing Substantive Environmental Justice: The Aarhus Convention as a Pillar of Empowerment." *Environmental Law Review* 10(1): 28–45. https://doi.org/10.1350/enlr.2008.10.1.003.

Newig, Jens, and Eva Kvarda. 2012. "Participation in Environmental Governance: Legitimate and Effective?" In *Environmental Governance: The Challenge of Legitimacy and Effectiveness*. Cheltenham, UK: Edward Elgar Publishing. https://doi.org/10.4337/9781849806077.

Ottinger, Gwen. 2010a. "Buckets of Resistance: Standards and the Effectiveness of Citizen Science." *Science, Technology, & Human Values* 35(2): 244–70. https://doi.org/10.1177/0162243909337121.

——. 2010b. "Constructing Empowerment through Interpretations of Environmental Surveillance Data." *Surveillance & Society* 8(2): 221–34. https://doi.org/10.24908/ss.v8i2.3487.

——. 2013. "Changing Knowledge, Local Knowledge, and Knowledge Gaps: STS Insights into Procedural Justice." *Science, Technology, & Human Values* 38(2): 250–70. https://doi.org/10.1177/0162243912469669.

——. 2016. "Social Movement-Based Citizen Science." In *The Rightful Place of Science: Citizen Science*, edited by Darlene Cavalier and Eric B. Kennedy. 89–103. Tempe, AZ and Washington, DC: Consortium for Science, Policy, & Outcomes.

——. 2017a. "Making Sense of Citizen Science: Stories as a Hermeneutic Resource." *Energy Research & Social Science*, 31(September): 41–49. https://doi.org/10.1016/j.erss.2017.06.014.

——. 2017b. "Opening Black Boxes." In The *Routledge Handbook of Environmental Justice*, edited by Ryan Holifield, Jayajit Chakraborty, and Gordon Walker. London: Routledge. 89–100. https://doi.org/10.4324/9781315678986-8.

Paddon, Natalie, Idil Mussa, Dalal Kheder, and Andrea Smith. 2013. *Can Citizen Science Activism Come to the Rescue?* 26 April 2013. Accessed October 28, 2019. http://rabble.ca/news/2013/04/can-citizen-science-activism-come-to-rescue.

Paumard, Leo, Catherine Bouland, Lievin Chemin, and Tim Cassiers. 2017. "Luchtkwaliteit. Weten Om Te Ageren." [Air Pollution, Knowing, in Order to Act] Accessed June 6, 2020. Brussels: BRAL & ULB. https://bral.brussels/nl/artikel/luchtkwaliteit-weten-om-te-ageren.

Rabeharisoa, Vololona, Tiago Moreira, and Madeleine Akrich. 2014. "Evidence-Based Activism: Patients', Users' and Activists' Groups in Knowledge Society." *BioSocieties* 9(2): 111–28. https://doi.org/10.1057/biosoc.2014.2.

Region De Bruxelles-Capitale. 2008. Arrêté du Gouvernement de la Région de Bruxelles-Capitale déterminant les mesures d'urgence en vue de prévenir les pics de pollution atmosphérique par les micro-particules et les dioxydes d'azote. [Decree of the Government of the Brussels-Capital Region determining the emergency measures to prevent air pollution peaks by micro-particles and nitrogen dioxides] November 27, 2008. Accessed March 3, 2022. *http://www.environnement.brussels/sites/default/files/user_files/20081127_agb_pic_pollution.pdf*.

Rowlands, Jo. 1995. "Empowerment Examined." *Development in Practice* 5(2): 101–7. https://doi.org/10.1080/0961452951000157074.

Science Communication Unit-University of West England. 2013. "In-Depth Report: Environmental Citizen Science." *Science for Environment Policy 9.* Report produced for the European Commission DG Environment. Accessed July 7, 2016. http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR9_en.pdf.

Stilgoe, Jack. 2009. *Citizen Scientists: Reconnecting Science with Civil Society*. London: Demos. Accessed March 3, 2022. http://creias.ipleiria.pt/files/2010/08/Citizen_Scientists_-_web.pdf.

US EPA, ORD. Undated. "Evaluation of Emerging Air Pollution Sensor Performance." US EPA. Accessed July 5, 2018. https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-pollution-sensor-performance.

Walker, Gordon. 2012. *Environmental Justice: Concepts, Evidence and Politics*. London: Routledge.

Whitehead, Mark. 2009. *State, Science and the Skies: Governmentalities of the British Atmosphere*. Chichester, UK; Malden, MA: Wiley-Blackwell.

World Health Organisation (WHO). 2016. *Ambient (Outdoor) Air Quality and Health.* Fact Sheet No. 313(September). Accessed May 26, 2017. http://www.who.int/mediacentre/factsheets/fs313/en/.

Wylie, Sara, Nick Shapiro, and Max Liboiron. 2017a. "Making and Doing Politics Through Grassroots Scientific Research on the Energy and Petrochemical Industries." *Engaging Science, Technology, and Society* 3: 393–425. https://doi.org/10.17351/ests2017.134.

——, Elisabeth Wilder, Lourdes Vera, Deborah Thomas, and Megan McLaughlin. 2017b. "Materializing Exposure: Developing an Indexical Method to Visualize Health Hazards Related to Fossil Fuel Extraction." *Engaging Science, Technology, and Society* 3: 426–63. https://doi.org/10.17351/ests2017.123.