East Asian Science, Technology and Society: An International Journal (2019) 13:1–21
DOI 10.1215/18752160-7267447

Combating Air Pollution through Data Generation and Reinterpretation: Community Air Monitoring in Taiwan

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Abstract Although cities in Taiwan are not as choked by smog as Beijing or Delhi, where people can hardly enjoy blue skies, air pollution is still a serious problem and has repeatedly aroused social concerns in central and southern Taiwan since 2010. Unsatisfied with the government's passive responses, the citizen groups in Taiwan have initiated several air monitoring projects to develop air-pollution claims and contest the deficiencies of the official air-pollution standard, data, and regulatory actions. Inspired by the concept of social movement–based citizen science, this article discusses how local community people have participated in knowledge production by integrating their observation and experiences into the scientific practices of air monitoring. The discussions particularly address citizens' data generation and interpretation efforts that signaled the alternative air quality information and triggered on-demand responses from the government to improve the air quality management measures. The analysis further highlights the characteristics of community air monitoring in Taiwan as well as its potentials and limitations.

Keywords citizen science · community air monitoring · social movement · data generation · data interpretation · Taiwan

Abstract 雖然台灣都會區的空氣不像中國北京或印度德里總是霧霾遮天那般的嚴重,但空污仍是一個嚴重的問題,自2010年之後,更引起台灣中南部居民不間斷的社會關注。不滿意政府被動的回應態度,一些台灣的民間團體發起了空氣監測的實驗計畫,為強調空

Acknowledgments I thank Shun-Ling Chen, Fa-Ti Fan (coeditors of this special issue), and two anonymous reviewers of *East Asian Science, Technology and Society* for their very valuable and insightful comments on earlier drafts of this article. I am thankful to my colleagues and assistants who have helped me develop the ideas and collect data presented here, especially Kuei-Tien Chou and Chia-Liang Shih, among many others. Finally, I am grateful to the Ministry of Science and Technology (Taiwan) for its financial support of my research on which this article is based.

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氣污染嚴重性的主張發聲,並挑戰官方空氣品質標準、資料生產與管制行動的缺失。立基在社會運動為主的公民科學觀點,本文討論地方社區團體如何將他們的觀察與經驗,結合系統性的空污監測實做,進而產生政策上的影響。本文特別著重於公民資料生產與詮釋的努力,因為其提供了理解地方空氣品質的替代性管道,並促成政府正視民間需求,從而尋求發展空氣品質管理監測的改善計畫。回應公民空污監測科學的既有文獻,分析中也特別強調台灣社區空氣監測的特色,及其發展的潛力與限制。

Keywords 關鍵字: 公民科學 · 社區空氣監測 · 社會運動 · 資料生產 · 資料詮釋 · 台灣

1 Introduction

Although cities in Taiwan are not as choked by smog as Beijing or Delhi, where people can hardly enjoy blue skies, air pollution has repeatedly aroused social concerns in Taiwan since 2010. The anti–air pollution protests that occurred mostly in central and southern Taiwan demonstrated the unequal distribution of air pollution among regions, with these regions often registering in the red zone—considered unhealthy on the air-quality index. Some research attributes this disparity to past industrial policies that spurred Kaohsiung (southern Taiwan) to host many polluting industries such as steel making, shipbuilding, petrochemical production, oil refinery, cement making, coal-fired power generating, and more, while Taipei (northern Taiwan) has transformed into a corporate, commercial, and political hub with an abundance of the less-polluting service industry (Hsiao 2015). Central Taiwan has also developed some heavy industry clusters, including the world's largest coal-fired power plant, the Taichung Power Plant (TPP), and Taiwan's largest petrochemical complex, the Sixth Naphtha- Cracking Plant (SNCP) of the Formosa Plastics Group.[1] Large-scale industrial development in Kaohsiung since 1970 and in central Taiwan since 1990 is considered to be the result of economic promotion of "neo-liberal developmentalism" (Chou 2015: 14582).

In Kaohsiung city, the country's second largest city and hub of the south, the smog is almost constantly present in winter months. Local residents complain about the bad air quality and are cautious about doing outdoor activities when the pollution is at its worst. However, no one seems to be responsible for the air pollution. While the government points the finger to the mobile source (e.g., motor vehicle) or lack of wind to disperse atmospheric pollutants, local environmental activists blame the expansion of industrial pollution. Citizen of the Earth, Taiwan (CET), a well-known environmental justice advocacy organization based in Kaohsiung City, has fought hard against air-pollution problems since its inception in 2010.[2] In addition to the traditional social movement tactics that involve protest events, CET conducted several experimental

[1] TPP consists of ten 550 megawatt coal-burning units, making it the world's largest coal-fired power plant, and also the world's largest emitter of carbon dioxide with approximately forty million tons annually. It provides 19 percent of Taiwan's electricity. Reference from the *Source Watch*, at www.sourcewatch.org/index.php/Taichung_power_station (accessed 3 July 2018).

The SNCP hosts sixty-six factories, including refineries, power plants, vinyl chloride monomer production, and harbors on its offshore 2,630-hectare marine reclamation land. Its annual production value was around US$53 billion in 2016, which is around 10 percent of Taiwan's GDP.

[2] For more information about CET, please refer to their official website at www.cet-taiwan.org/node/2190 (accessed 3 July 2018).

activities including the Kaohsiung Sky One-Hundred-Day Photo-Shooting (KS 100) Plan and Raising the "Air Pollution Flags," which signaled the alternative air-quality information and highlighted the deficiency of the regulatory standards and actions.

In central Taiwan, the air quality is also frequently rated "unhealthy" during the winter months. While the government blames the cross-border pollution from China, vehicular pollution, and the burning of paper money from religious rituals, citizen groups point to TPP and SNCP as the main sources of air pollution (*Formosa News* 2017). Due to the poor atmospheric dispersion, the central region, including Taichung City, Changhua County, Chiayi County, and Nantou County, are often blanketed in smog during the air-pollution seasons. Among them, Chiayi City and Puli, in Nantou, which used to be considered some of the cleanest towns with the least industrial development in the country, have detected high levels of $PM_{2.5,}$ fine suspended particles with a particle size of less than 2.5 microns. The bad air quality in the central region has driven residents to assert their right to breathe. A citizen group in Puli initiated the micro-air-monitoring program to prove the severity of air-pollution problems. Chiayi groups developed Air Raid Siren to rally the community around the cause of improving local air quality.

The experimental activities initiated by the citizen groups mentioned above can be considered a form of "social movement–based citizen science" that often takes place when communities are experiencing negative impacts and are unsatisfied by official responses. They "marshal information—monitoring data, health data, geographic information"—that can serve as evidences of the problem and compel authorities to recognize and address the issues (Ottinger 2017a: 352). In this study, I explore how these local community groups produced and reinterpreted the air-pollution data, and further analyze the concepts and methodologies behind the burgeoning community air-pollution-monitoring actions.

My argument draws on qualitative research conducted in several communities in central and southern Taiwan—Kaohsiung, Chiayi, and Nantou, where community air-pollution-monitoring initiatives have developed during the period of 2012–15, when tackling air pollution issues had yet to get attention on the political agenda. Information was gathered to plot the major events associated with citizens' air-quality data generation and interpretation, as well as their policy advocacies. Sources for data collection include media reports via electronic news archives and government documents on hearings, regulatory actions, and environmental inspections. The publications of the targeted groups, including their newsletters, campaign brochures, news releases, and information on websites related to the anti–air pollution campaigns also serve as important data sources for this research. From June 2015 to May 2016, my research team conducted one focus-group interview in Taipei and semi-structured interviews (topics on air monitoring and citizen science) in Nantou, Chiayi, and Kaohsiung with the members from the targeted groups. Thirteen people were interviewed in this study. Besides conducting formal interviews, we also traveled to Puli, in Nantou, to hold a group discussion with the members from the community group and the local university and observe their use of real-time monitoring technologies. We also attended several public meetings in Kaohsiung to observe and discuss the struggles over air-pollution interpretations and effective regulatory actions.

In the next section, I discuss the complexity of air-pollution problems and how citizen participation in air monitoring may contribute to better environmental governance. I will particularly review the citizen-science literature related to community air monitoring and connect the concept to my analysis in section 5. The citizen-science discussions serve as the initial point from which to evaluate the community air monitoring in Taiwan and provide some reflections for its future development.

2 Citizen Participation in Air Monitoring and Citizen Science

2.1 Complexity of Air Pollution Problems

Air-pollution problems are extremely complex and controversial. What is clean air or what makes air polluted? The different "scientific" rationales adopted by the various fields may provide different answers. The precise chemical and physical features of ambient air pollution, which comprise myriad individual chemical constituents, vary among the different locations, owing to differences in the sources of pollution, weather, and topography. Uneven distribution of environmental risks due to various geographic conditions and time scales that result in risk-exposure differences makes the effects of ambient air pollution difficult to measure (Hidy et al. 2011).

Although air-pollution assessment and developing abatement strategies require scientific evidence and data support, scientific knowledge is still contested in the field of air pollution research. Emma Garnett (2017: 902) reviewed emergent tension in the UK project Weather Health and Air Pollution, and analyzed "the modeled and monitored data problem" (using modeled data or data generated by monitors to study air-pollution impact on health). She found that monitoring and modeling are two different ways of defining air pollution and producing and analyzing relevant data. The different ontologies of air pollution were contested and the data were reworked in ways that made them valid for epidemiological research. The process of negotiating and facilitating multiplicity and difference enacted the new meaning of data and also shifted how air pollution could be identified.

John Bachmann (2007: 653) reviewed the history of the air quality management system in the United States over the last century and pointed out that the system requires an "extraordinary level of technical and scientific information needed to establish effects-based ambient targets, measure key pollutants, inventory sources and emissions, develop an estimate [of] costs for alternative control scenarios, and forecast and assess results." Each of the technical steps in the process is subject to large uncertainties. Some studies also indicate that existing scientific knowledge regarding the risk assessments of the synthetic effects of air pollutants are still limited. Our understanding of how exposure to multiple pollutants can damage human health and the ecosystems still progresses slowly (Hidy et al. 2011).

It is evidential that contemporary science is still unable to set the absolute safe-exposure standard, and regulatory control often involves numerous public-health and social-interest issues. In light of the complex air-pollution problems, we can hardly rely only on scientific laboratory simulations to eliminate the various changing factors and accurately assess the risks that air pollutions have on human health and the ecosystem. Focusing on the chemicals for which toxicity and exposure data are available is not enough to address the largest public health risks (Vandenberg 2013: 95). These features make it impossible for the policy or regulatory agencies to accurately predict or distinguish the exposure-concentration risks for individual pollutants, or to further determine the reasonable social costs for regulatory actions.

2.2 Citizen Participation in Air Governance

Understanding the complexity of air pollution, the limited scientific knowledge, and the importance of interdisciplinary interactions and negotiations, contemporary environmental governance has placed increasing emphasis on more diversified and inclusive decision-making models (Wynne 1992; Fischer 2009). Some studies have argued that public participation can contribute to better science and promote more trusted environmental policies in dealing with air pollution issues (Lidskog and Sundqvist 2011). Many studies contend that citizens interpret issues based on values, interests, experiences, and knowledge that differ from those of scientific experts and political representatives (Douglas 2005; Wynne 2007; Ascher, Steelman, and Healy 2010). Therefore, public inclusion is important for creating policies that are socially robust, politically legitimate, and trustworthy in the eyes of the public (Nowotny 2003; Renn 2008).

Rolf Lidskog and Håkan Pleijel (2011) explored the scientific uncertainties and governance problems of air pollution based on the historical experiences of ground-level ozone control efforts in the European regions. Their research indicated that air pollution control measurements are set based on the results of continual negotiations and interactions between the scientific, social, and environmental communities. The measurement development processes have gradually become the communication interfaces between the experts and other stakeholders, which result in the coproduction of policy-relevant science and science-based policy. In their studies, monitoring technologies and mapping activities play an important role not only in presenting environmental problems but also in shaping an understanding of the problems.

Steven Yearley (2006) studied air pollution and public participation assessment in England and found that public participation in mapping the local pollution hot spots can help to examine the hypotheses that were not tested under the traditional technology models. For example, models usually average vehicle-pollution emissions. But in reality, impoverished regions may have older vehicles with higher pollution-emission volumes and thus create pollution hot zones. Arguing the original technology models may have underestimated the pollution problems in the impoverished regions, Yearley demonstrated that developing novel techniques for allowing local citizens to express their knowledge of local geographies of air pollution can bridge the science-policy divide.

The research discussed above has demonstrated the importance of public participation in air governance to robust presentations and understandings of environmental health issues. It has shown that developing a new rationale and novel methods for involving citizens in the air monitoring can improve governance of complex air-pollution problems. These participatory approaches prompt the scientists to incorporate the citizens' perspectives into their modeling designs and introspect on the prejudices of technology-development and standard setting. However, putting citizen participation into governance seems to serve the needs of institutions rather than giving a voice to citizens' interests for their own sake. Such a reflection is especially critical in the developmental-state context, where the government intends to place economic growth over environmental concerns and has no intention or capacity to develop new forms of environmental governance for citizen engagement in a constructive way. Citizen participation in air-monitoring activities in such a context is not intended to build a partnership with the institutions but rather to challenge the government's inattention to the problems and to fight for the right-to-know and for clean air.

2.3 Social Movement–Based Citizen Science

While community air monitoring often involves scientific investigation and refers to citizen science projects, Gwen Ottinger (2017a) differentiated two approaches of public participation in scientific inquiry: "social movement–based citizen science" and "scientific authority driven citizen science." In her point of view, the social movement–based citizen science often refuses to separate inquiry from a vision for social change rooted in collective actions. This approach of citizen science criticizes standard scientific practices and tries to reconstruct the relations of power in a model more amenable to democratic participation. however, the scientific authority–driven citizen science grounds its claims to legitimacy in promises to uphold the standards of idealized science and tends to reproduce the power relations that surround science. The community air-monitoring projects, which were developed and enacted by the citizens to address the needs and concerns of communities and aimed at fostering collective action and political change, can be viewed as social movement–based citizen science.

The community participation in air monitoring was earlier documented by Dara O'Rourke and Gregg P. Macey's (2003) study on the "bucket brigades" projects of California and Louisiana. People in the community used easy-to-apply and low-cost air-collection containers made out of convenient materials to sample air emissions near industrial facilities. The projects involved developing community volunteer networks and small organization support systems that can instantly help the community residents and regulatory agencies to grasp more-detailed and accurate information that cannot otherwise be obtained by the traditional air-monitoring methods. They referred to these brigades as a new form of community environmental policing, in which "residents participate collecting, analyzing, and deploying environmental information in an array of public policy dialogues" (383). This form of community-based-action science has also been developed outside of the US. In Durban, South Africa, the citizen groups used science and lay-citizen knowledge to challenge the traditional authority on science and technology, redefine the pollution problems, and force the nation and the companies to take responsibility (Scotta and Barnett 2009).

These citizen-science projects establish a knowledge network for the community throughout the pollution dispute process. They construct another level of understanding of the air-pollution issues and provide opportunities for the local society to expand the knowledge base and scientific capacity. For example, some studies noticed that the monitor used to create regional estimates of air quality under the Clean Air Act are limited in number and provide only rough estimates over a large area. Lack of site-specific information and the asymmetry in information between factories and people in the community limits social mobilization for stricter enforcement. But citizen-science projects like the bucket brigades can empower communities for using self-collected data and building strong social networks to increase the accountability of polluters and the government (Overdesvest and Mayer 2008).

Citizen-science projects are powerful because the new evidence they produce challenges the absence of certain kinds of information in making good environmental health assessments and decisions, especially for the fence-line communities. Ottinger (2013) claims that the absence of environmental knowledge in the fence-line communities is simultaneously systemic and strategic. The topic is worthy of more research, but is left unfunded, incomplete, and generally ignored, resulting in "undone science" (Frickel et al. 2010; Hess 2007). Through collective air-sampling actions, the citizens create a new form of information to fill the gap of absent local knowledge and force more transparency of the factory air-emission data. This extension of the capacity of community knowledge also enables the environmental-monitoring policy debates to switch from the traditional technical-risk orientations to the health and quality-of-life discourses defined by the communities themselves.

However, the creation of new data does not mean the community can know more than before. Ottinger (2010) reminds us that environmental monitoring data alone may not necessarily lead to great community empowerment. Information generation involves issues such as complex data interpretation and problem definition. For example, which factor poses greater impact to health, and should the people adopt the long-term average exposure data or the short-term worst exposure data? The applications of law enforcement (promoting environmental-quality enforcement also includes challenges to unreasonable standards and judicial litigation strategies) and mobility options (the effects that pollution exposure have over economic autonomy, life choices, and freedom of relocation) are also related to community empowerment. In her point of view, the empowering potential of surveillance rests in large part on how to make data meaningful to enable community groups to act.

In fact, making sense of data the community collects is challenging due to fundamental disconnects between community and expert ways of knowing and different standards of proof. Ottinger (2017b: 41) argues that citizen-science efforts should take both data collection and sense making around publicly available data into account, as together they offer "alternatives to hegemonic scientific practices that do not adequately represent community experiences." She further suggests that the stories told by frontline communities (about harms to health, systemic danger, and disrespect) can serve as an essential hermeneutic resource for making sense of air-quality data. The discussions broaden our understandings of citizen science that involves not only data generation but also strategic interpretive capacity for social change.

The citizen-science projects for air pollution monitoring in the United States present the community-led innovation in response to imperfect regulations, deficiencies of monitoring standards, and epistemic injustice in marginalized communities (Ottinger 2016, 2017b). The projects are developed for community empowerment that enables the residents to present and interpret their problems, challenge the official standards, and make information more transparent. These understandings of citizen science serve the initial point to examine the community air monitoring in Taiwan. As I will present and analyze the cases in the following two sections, data generation and reinterpretation via innovative citizen actions can be potent for the regulatory improvement.

However, it is worth noting that many community air-monitoring projects in the US were initiated to fight against the specific polluting facilities and to hold the polluters and regulators accountable through litigation and advocacy. In Taiwan, the community air-monitoring projects often have difficulties in identifying the specific pollution sources due to the historical patterns of industrial development that tend to set up dense clusters of different factories in the industrial parks along the west coast (Liu 2012).[3] The agglomeration of polluting facilities complicates pollution identification that further creates significant knowledge gaps between the predicted emission, the actual emission, and the community sensory experiences throughout the policy process. This pattern of development has somehow constrained Taiwan community air monitoring to target the specific polluters.

In the following sections, I will begin with the discussions of air pollution issues in central and southern Taiwan and the actions in response by local groups. The cases will be elaborated to understand how citizen air-monitoring projects were initiated and with what purposes. With the social movement–based citizen-science perspective, I will then explore how the data was generated and reinterpreted for problem reframing, what the influences were made by the citizen air-monitoring projects, and whether the official standards are challenged and questioned. The analysis will highlight the characteristics of community air monitoring in Taiwan.

3 Air-Pollution Problems of Central and Southern Taiwan and the Grassroots Advocacy

3.1 Challenging the Official Air Pollution Indexes: Citizen of the Earth Taiwan

Due to the high ozone and aerosol concentrations, the air qualities in Kaohsiung City and the neighboring Pingtung County (Kao-Ping area) have been rated as the worst among the seven air-quality zones (Fig. 1) for a long time, and air pollution has become an unavoidable issue for the people of Kaohsiung.[4]

In light of the concern over the deteriorating air quality and air-pollution problems, Citizen of the Earth Taiwan (CET) has actively requested that the government enforce the emission cap regulations in order to adhere to the "Air Pollution Control Act" (APCT) amended in 1999. The APCT was promulgated in 1975 and was amended to add the "Air Pollutant Total Quantity Control (APTQC)" system,[5] which stipulated the Environmental Protection Agency (EPA) and the Ministry of Economic Affairs (MOEA) must announce the measures together. Once the APTQC system is enforced, the factories that are causing serious pollution in the designated air-quality zone would

[3] According to Liu (2012), there were 59 industrial parks developed in Taiwan since 1964; 44 of them are located in counties and cities along the west coast and 15 of them are located at coastal townships and districts.

[4] Based on geographical and meteorological conditions and the nature of air contaminants, the EPA has divided the nation into seven air-quality zones (see figure 1)—northern, Chu-Miao, central, Yun-Chia-Nan, Kao-Ping, Hua-Tung, and Yilan—and announced total quantity control zones accordingly.

[5] The APTQC system tasks include 1) establish air quality standards, 2) establish an effective air-quality-monitoring station network, 3) designate air-quality zones and phase-in proclamation of total quantity control zones, 4) draft and enforce total quantity control plans and air pollution control programs, 5) divide air-quality zones into compliance and noncompliance zones according to the status of air quality, 6) enforce total quantity reduction in those zones not in compliance with air-quality standards; allowable pollutant increase limits in those zones in compliance with air-quality standards, and 7) promote an emission saving, exchanging, and trading system with economic incentives.

Fig. 1. Map of seven air-quality zones in Taiwan. Sources: Taiwan Environmental Protection Administration, Air Quality Monitoring Network website (taqm.epa.gov.tw/taqm/en/PollutantMap.aspx).

have to reduce the amount of pollution they are emitting. However, the MOEA had refused to provide consent for the EPA to implement the APTQC measures due to the concerns that the stricter emission control would harm economic development. As a result, even though Kao-Ping area had been rated as a level-3 air-quality (the worst level) control zone and the EPA had proposed the "Kao-Ping Area Air Pollutant Total Quantity Control Plan Draft," the plan had not been announced nor implemented until 2015, sixteen years after the total quantity control system was added in the APCT.

In addition, CET found the long-time air pollution index used in Taiwan—pollutants standard index (PSI)[6]—inadequate to reflect a real air-quality situation at local. The PSI, which was based on averaging data of five pollutants collected for the previous twenty-four hours and did not take $PM_{2.5}$ concentration value into account, has been used since 1993 to provide a way to inform the public about air quality on a daily basis. The PSI was reported on the EPA's official website as a number on a scale of 0 to 500,[7] which is grouped by the index values and colors to indicate the general health effects (0–50/green: good; 51–100/yellow: moderate; 101–199/red: unhealthy; 200–299/purple: very unhealthy; 300–500/brown: hazardous). A general criticism has been that the level of pollution and health concerns based on the twenty-four–hour PSI value without considering $PM_{2.5}$ standards cannot match local sensory experiences to air pollution. However, the PSI was the air-pollution data officially recognized before the air quality index (AQI) was adopted in the end of 2016.[8]

6 The index was based on measurements of the concentrations of five pollutants: PM_{10}, SO_2, NO_2, CO, and O_3. Air-quality standards had been developed for each of these, and the highest of five numbers is reported as the PSI for the day. Information can be accessed at the Taiwan EPA website at www.epa.gov.tw/ct.asp?xItem=61145&CtNode=35719&mp=epaen (accessed 3 July 2018).

7 The EPA has replaced the PSI with the AQI on "Taiwan Air Quality Monitoring Network (TAQMN)" after the agency adopted the new index in 2016.

8 The AQI is based on monitoring data on the same day in the air (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, and O_3). The AQI is divided into six categories to indicate increasing levels of health concern. An AQI value below

To reflect the seriousness of air pollution problems and promote the APTQC in the region, in 2011 CET started to closely watch the official PSI data and post its analysis on its website to garner public support for the anti–air pollution campaign. During 2012, CET conducted the KS 100 Plan to document and demonstrate the problems of air pollution. In this plan, CET staff took pictures of the Tzaishan Mountain (the natural landmark of Kaohsiung City) and the sky every day at a fixed point and time through a window from the CET office from 2 February to 10 May 2012. At the same time, they also recorded the PSI values, the hourly $PM_{2.5}$ values, and the daily visibility levels. They posted the photo along with monitoring data from the EPA on CET's Facebook page and further explicated the air-quality situation day by day. The objective of the plan was to illustrate the persistence and the severity of the air pollution problem through visualized data, and address the necessity to implement the Kao-Ping Area APTQC Plan.

To raise public awareness of air pollution, CET initiated the Campus Air-Pollution Flag Program in November 2014, with Wenfu Elementary School and Ganghe Elementary School in Kaohsiung City agreeing to join (Lin 2014). The program asked the school faculties and students to wave red flags whenever the air pollution reaches an alert level (PSI "very unhealthy" level or $PM_{2.5}$ concentration of 35 ug/m^3 or higher) in order to remind people to take self-protection actions by wearing masks and avoiding outdoor activities. The program also called on teachers and students to maintain the record based on measurements taken at local air-quality survey stations each morning before the first class and kept the air-pollution diary to record the color of the sky, the visibility levels, and the smell of the air for each day. The program later was copied by some local governments and spread nationwide when the Ministry of Education (MOE) published the "Campus Air-Quality Flag Pilot Project," which asked schools to hang the flag with colors identical to the color of the air pollution indicator.

3.2 $PM_{2.5}$ Regulatory Campaign and Generating Local Pollution Evidence: Chiayi and Puli $PM_{2.5}$ Self-Help Groups

In central Taiwan, cities (Taichung, Chiayi) and counties (Changhua, Nantou, Yunlin, and Chiayi) have often been shrouded in haze during the winter seasons after the year of 2000. However, the people were not fully aware of the air-pollution problem in the region until the anti–Eighth Naphtha-Cracking Plant (No. 8 NCP, Kuokuang petrochemical industry) and antiexpansionof the SNCP campaigns took place in 2010. The construction of No. 8 NCP on the coastal wetland in Changhua County was one of Taiwan's most controversial projects in recent years. The project, supported by the MOEA, called for a petroleum refinery capable of producing 300,000 barrels of crude oil daily, a naphtha-cracking plant capable of producing 1.2 million metric tons of ethylene annually. It raised public concerns that the plan would exacerbate Taiwan's proportion of CO_2 emission worldwide, create air-pollution problems and health risks, damage the wetland ecosystem, and violate the sustainable route toward the green economy. During its environmental impact assessment review process from June 2009

fifty represents good quality, and a value over three hundred is considered to be hazardous. For more information, please refer to TAQMN at taqm.epa.gov.tw/taqm/en/ (accessed 3 July 2018).

to April 2011, the civil society had mobilized the large-scale movement and finally successfully stopped the project (Tu 2012).

Influenced by the anti–Kuokuang Petrochemical campaign and as smog problems worsened, the $PM_{2.5}$ pollution and its related health-risk issues surfaced onto the regulatory policy agenda and became widely known in the society. The medical community in central Taiwan claimed that the rising percentage of lung cancer cases proved the negative impacts of $PM_{2.5}$ pollution as the smoking population has continued to decline. The scientific community warned that the large pollution sources in the Central Region such as the TPP, Dragon Steel, and the SNCP emit large quantities of carbon dioxide, sulfur oxides, and other pollutants, causing severe air pollution damages.

Mobilized by the anti-Kuokuang Petrochemical campaign, Air Clean Taiwan was formed in response to the growing number of people suffering from air pollution–related illnesses in Taiwan. They disseminated air-pollution information and actively urged air-pollution laws be enacted to control $PM_{2.5}$. Groups from Taichung City (host to TPP) and Yunlin County (host to SNCP) have also actively promoted bills for the local government to ban the burning of bituminous coals and petroleum cokes during the local elections in 2014.[9]

The series of anti-pollution campaigns have driven residents in central Taiwan to be aware of the danger of $PM_{2.5}$. While it is understandable that cities and districts with large industries are badly affected by air pollution, cities without heavy industry such as Puli, Nantou, and Chiayi are also suffering serious air pollution problems. According to the EPA' s monitoring data, $PM_{2.5}$ levels in the two towns are more than double the average recommended by WHO (25 μg/m^3 twenty-four-hour mean) during over two-thirds of year (*Formosa News* 2017). In 2013, Puli had the highest annual average $PM_{2.5}$ value (33.3μg/m^3) among all towns in Taiwan.

In September 2014, a group of five women, unsatisfied with the fact that Puli had the worst $PM_{2.5}$ concentration in the nation, formed the Puli $PM_{2.5}$ Air Pollution Reduction Self-Help Group. The founders of the group were all concerned mothers who linked their children's respiratory irritation and asthma problems with poor air quality. Ironically, some of them moved back to Puli from the big cities just because they thought this small mountainous township with only eighty three thousand people could have offered the healthier environment for children. These active mothers hoped to channel social pressure through raising community awareness to improve the local air quality. Through storytelling in schools and community participation, they were able to recruit several hundred people into the volunteer network. They routinely held volunteering meetings, invited experts to give the lectures on air-pollution issues, and once organized the street protest attended by more than a thousand Puli residents. Their activism has discouraged the haphazard burning of farm waste, trash, and paper money, and also has reducedmobile source emissions.

Inspired by their active voluntary actions, Puli township chief and professors from the neighboring National Chi Nan University (NCNU) also joined their efforts to provide administrative and various professional assistance to expand the campaign network. In their joint effort against air pollution, NCNU professor of information

[9] For more information, please refer to "Since the SNCP came" website, fpccgoaway.blogspot.com/ (accessed 3 July 2018).

technology Rong-Fuh Day helped to develop low-cost mobile-$PM_{2.5}$ sensors and an app to monitor pollution at local levels. In consultation with self-help group members, Professor Day's team distributed the sensors to over thirty sites throughout Puli township to collect the real-time $PM_{2.5}$ data onto a Cloud information recording system.

In Chiayi, a group of medical and public health professionals established the Chiayi City Community Health Development Association (CCCHDA), which advocated the value of medical treatments for the practice of basic human rights. In February 2014, one of the founders of the CCCHDA, Dr. Shang-Ru Yu formed the Chiayi $PM_{2.5}$ Self-Help Group to educate people about the $PM_{2.5}$ problems because he discovered the increasing respiratory problems among his patients, and many citizens have no air pollution prevention and self-protection practices. The Chiayi $PM_{2.5}$ Self-Help Group used the network CCCHDA established earlier to disseminate the air-pollution information throughout the community. They developed the easy communication tools such as an air-pollution calendar and the mountain ridge observation technique, which were widely accepted and used by the laypeople and finally adopted by the local government as the municipal project.

4 Social Movement–Based Information Production and Citizen Science

In section 3, I have provided some background information about the citizens' experimental activities and discussed how they were initiated and with what purposes. In this section, I will focus on citizens' data generation and interpretation efforts for problem reframing and social advocacies, which have been widely discussed in the social movement–based citizen-science literature. The analysis will address the following inquiries: How did the citizen groups interpret the air-pollution information provided by the government? What types of information did they primarily produce in order to increase risk awareness in the society? What are the information gaps they intended to produce and fill? What information and knowledge are still unattainable as of now? What social change do they contribute to and with what limitation?

4.1 Reinterpreting Official Monitoring Data to Address Local Health Concerns and Regional Risk Disparity

The citizen groups found that the public generally lacks air-pollution risk awareness when they initiated the anti–air pollution movements. How to connect the people's physical experiences with the air-pollution problems and promote public awareness have become the primary goals for the citizen groups. In Chiayi City, many medical and public health professionals are involved in anti–air pollution campaigns. Their observations over the people's air pollution suffering experiences provided the perfect interpretation to the relationships between the people's health and the air-pollution problems. An interviewee with public health background told us that their primary work is to help the general citizens to recognize the dangers of $PM_{2.5}$: "It is very dangerous for those who are already suffering from chronic or severe diseases to be exposed in high concentrations of $PM_{2.5}$. . . . We have started from education. When the people have gradually become familiarized with the so-called $PM_{2.5}$ . . . , we can then transfer expert knowledge to the lay people" (Interviewee CYT, 17 November 2015).

While promoting the air-pollution-related knowledge, the citizen groups would gather the existing scientific studies and compare the official monitoring data with the generally recognized international health standards. After analyzing the contents of scientific studies, they are able to organize the information in a way making sense to the general public about the effects that air pollution has on health. They found communication particularly effective when the relevant comparison data are presented in table or graphical formats, which can clearly show the severity of the local air quality and the inadequacies of the current air-pollution control system in terms of health protection. For example, the CCCHDA made the "Air Raid Siren" flyer, which comprehensively organized the daily local $PM_{2.5}$ value (based on EPA's monitoring data) into an annual calendar chart. By comparing the local air-quality data to the international standards, the colors of data cell, ranging from green, yellow, orange, and red, demonstrated the different levels of air pollution. The review of the Chiayi City 365-day air-quality calendar of 2014 indicated that only 6 days (marked green) out of the whole year conformed to the "Healthy Air Quality" level defined by the US AQI. The chart highlighted the severity of the air-pollution problems.

Through the dissemination of the "Air Raid Siren" flyers, the CCCHDA was able to cooperate with the Chiayi municipal government, local medical institutions, NGOs, and small businesses such as coffee shops, restaurants, and even mask factories. The Environmental Protection Bureau of Chiayi City later sponsored the publication of the "Air Raid Siren" flyers. Local NGOs, such as Chiayi Astronomical Society, Chiayi Wild Bird Society, the Society of Wilderness, and local shops also cosponsored the lectures on the $PM_{2.5}$ pollution issues. The process of "Air Raid Siren" dissemination has contributed to professional and experience exchanges by the various groups on the issues such as how to correctly wear masks or promote health education knowledge (Interviewee CYT, 17 November 2015).

In Kaohsiung, CET also made good use of the EPA's limited information to compare theirs with other air-pollution data throughout the nation. They demonstrated that the average "suspended particle" and "ozone" concentrations in the air of the Kao-Ping area between 2007 and 2009 were among the highest in the nation. On CET's website, they presented the chart showing that the suspended particle annual average concentration value in the northern Taiwan air quality zone achieved 100 percent compliance of the national air-quality standard, while the conformity rates in both Kao-Ping and Yun-Chia-Nan air-quality zones were all below 15 percent.

In its KS 100 Plan, along with the low-threshold observation and documentation techniques, CET made a comparison chart that reorganized the official data to show Kaohsiung's air quality in the comparative context. They concluded that only twenty-three days were rated as good with the PSI value less than 50, while the number of the good air-quality days doubled (fifty-three days) in the Northern Taiwan air-quality zone. These comparisons indicated that Kaohsiung has the worst pollution in the entire nation.

These actions indicated that the citizen groups have primarily integrated the existing government information and put the data in the comparative context to show the uneven risk distribution and the severity of the air problems. They translated the data into charts, graphics, or calendars that became more communicable with the general public. They focused on the relations between air pollution and health and called on the public to take the precautionary measures when air pollution became severe. Through the information dissemination and communication education processes, these citizen groups have also connected with the various social and political sectors that they may not have been able to access in the past. These efforts enable them to generate more social capital and create more possibilities to leverage their air-pollution reduction campaigns.

4.2 Challenging the Deficiencies of the Official Air Pollution Indicators and Developing Sensory Data for Pollution Evidence

The official environmental monitoring data and air-quality indicators have numerous limitations. For regions with multiple pollution sources such as Kaohsiung City, values detected for a single pollutant often cannot reflect the air quality within the region. An interviewee told us that the old PSI calculation cannot present the actual air pollution status in Kaohsiung, host to a variety of heavy industries. In her opinion, the $PM_{2.5}$ and Volatile Organic Compounds (VOCs), which were not included in the PSI, were the bigger concern in this industrial city. "We checked the indicators, but we cannot see the severity of the pollution based on the PSI. The $PM_{2.5}$ problems were often severe. . . . However, the PSI index at the time showed moderate . . . The problem with the indicators was that they underestimated the risks in the Kao-Ping area and fooled a lot of people. Many people would say, 'See, Kaohsiung is okay, the indicator shows moderate!'" (Interviewee CML, 27 November 2015).

The same problem is also reflected in the air-pollution alert flag controversy. As mentioned, CET initiated the Campus Air-Pollution Flag Program in 2014 that prompted the MOE to propose the MOE Campus Air-Quality Flag Pilot Project in 2015. Different from CET's program that asked the school to wave the red flag when air quality reached the alert level, the MOE's project required the school to hang the different colored air quality flag based on the PSI and $PM_{2.5}$ air quality indicators posted online by the EPA. There were four different colored flags identical to the color of the air-pollution indicator "Green, Yellow, Red, and Purple," which served to notify the teachers and students whether to conduct normal activities or use preliminary protection, medium protection, or emergency protection, respectively (MOE 2015). However, the environmentalists have argued that the program failed to understand the complexities of the air-pollution problems and the limitations of the existing indicators. One CET member raised an example:

> There are numerous schools within the three kilometer parameters of the industrial zones in the southern regions. The $PM_{2.5}$ may be low for these places, but the VOCs may be severe. Do you think we can hang the green flag just because the $PM_{2.5}$ is low? The MOE said how could we have this problem? But that is the problem! So don't think that everything is OK just because the $PM_{2.5}$ is low! Our areas may still have odious odors when $PM_{2.5}$ is low! You tell the students that we're going to hang the green flag today, and the students would think you're crazy! It obviously smelled awful, why does the flag show great air quality? (Interviewee CML, 27 November 2015)

The limitation of the official data prompted the citizen groups to develop the alternative ways to document and interpret the local air quality. Based on our interview data, many environmental and health groups have invariably emphasized using the visual experiences of the common people to reflect the severity of local air pollution. As mentioned, CET had conducted the KS 100 Plan. Through photographing, they pointed out that the official PSI data cannot match their visual evidence. In many heavy smog days, the PSI values were showing as "moderate." The plan demonstrated the serious gaps between the visibility, the cleanliness of the sky, and the PSI values that legitimated CET's request of changing and improving the official air-quality index. The EPA finally adopted new AQI in 2016 that incorporated eight-hour ozone values and $PM_{2.5}$ values to present the levels of air quality.

In Chiayi City, the citizen groups addressed the visibility of the Jhu-Luo Mountain is an important indicator of air pollution: "It is simple for Chiayi City, just look east. Something is wrong if Jhu-Luo Mountain is not visible (covered by smog)" (Interviewee CYT, 17 November 2015).

Chiayi $PM_{2.5}$ Self-Help Association further convinced the Chiayi City government to use "Yushan observation" as an air quality indicator for Chiayi. In response, the Chiayi City government developed the "Chiayi City E-Environmental Protection" app and "Yushan Observation Webcam" website. The city government set the "Rewitness the Yushan Snow"[10] target to demonstrate its commitment to improve air quality, and invited the people to care about air pollution using this observation and web application method.

4.3 Developing Participatory Micro-Sensing Network and Mapping Local Pollution Problems

The EPA has seventy-six air-quality monitoring stations, which monitor for $PM_{2.5}$, PM_{10}, SO_2, NOx, CO, and O_3, and are distributed based on the pollution-emission sources, as well as the meteorological, topographic, geographic, urban-planning, population, and traffic conditions.[11] As the objectives of the monitoring stations are such things as to interpret legitimate air quality and monitor the long-term trends of air pollutants, the data collected by the monitoring stations present large regional air-quality conditions and cannot illustrate the air quality in a particular site or small region. Two environmental activists shared their concerns that there is a considerable gap for the general public to use the large-scale air pollutant information as the basis for health alert assessment or making polluters accountable.

> For the common people, they care about the data collected from the air quality monitoring stations because they are the only data that provided reference. However, the location of the station and its distances to my home may make big differences. (Interviewee CHH, 26 November 2015)
>
> The data we are seeing now are relatively universal. The monitoring station is set at a certain place, but not at the air exhausts of the factory. (We need) real-time

[10] "Yushan Snow" was painted in 1947 by the well-known Taiwanese painter Tan Ting-pho (en.wikipedia.org/wiki/Tan_Ting-pho, accessed 3 July 2018), who sacrificed his life as a result of the 2.28 incident in 1947. The painting was painted in Chiayi City from Tan's old home, and it clearly shows the snow on top of mountain with no signs of smog or pollution. It has become a luxury for the people to see such a clear sky in modern days.

[11] See figure 1 for the EPA air-quality monitoring stations distribution.

> monitoring at certain industrial complexes, not just in general regions. (Interviewee CSH, 17 November 2015)

The official air-quality data apparently cannot match people's experiences of pollution. To better protect health on a daily basis, the people need small-scale local real-time air-quality information. Thanks to the advances in sensing and computing technology, the information technicians in Taiwan have developed the low-cost sensors for small-scale air-quality sensing that have been largely applied in many cities in recent years. One remarkable example is a maker community of the Location Aware Sensor System (LASS), which partnered with the information scientists to develop the devices for participatory urban $PM_{2.5}$ monitoring (Chen et al. 2016).

Different from the LASS network that cooperated with many city governments and spread rapidly across the urban areas, the development of the air monitoring system supported by low-cost mobile-$PM_{2.5}$ sensors in Puli was triggered by the local anti-pollution campaigns. The motivation of developing the micro-sensing network was to make the pollution evidence more scientifically convincing and thus provide the legitimacy for local actions and policy advocacy. One of the local self-help group members claimed that with more scientific evidence, the "action plan can be more persuasive . . . and provides a more positive pressure to the government to take on policy actions" (Interviewee CHC, 17 November 2015).

However, air-quality data production is more than just simple measurements. Behind the air-quality information disclosure lies the different purposes and strategies and different advocacy groups' abilities to apply the tools. The information expert who collaborated with the self-help group mentioned that the small-scale monitoring instruments were affordable enough that these sensors can be distributed at numerous sites to form a local air-pollution monitoring network to obtain a more comprehensive and real-time overview of the area. He shared his thoughts on the R&D of this kind of air-pollution monitoring system as follows:

> The first step is environmental information transparency, and the second step is to use the power of the people and a low-cost strategy. . . . What I do now is another step further, i.e., real-time. Assume that we deploy ten sensing stations to certain places, and these sensing stations would transmit data to me in real time. I can then transmit the data to cell phones or websites so we can achieve information transparency. Once the entire environment has reached an initial transparency level, there are a lot of things we can follow up with. (Interviewee SD, 15 June 2015)

In his opinion, the EPA air-monitoring stations have high monitoring accuracy and can measure more items. But the instruments cost from NT$600,000 to NT$1 million each. Their operations must also be maintained by several technicians to ensure the data quality. Under the nation's limited budget, it is impossible to densely deploy such stations. The objectives of the small-scale simple monitoring sensors are not to replace the national-grade stations, but to serve as the preliminary alert tools to understand the air-pollution hot spots and help the government to identify the meaningful measurement locations.

Besides, how to select a measurement site illustrates the importance of collaboration between the local groups and technical experts. The local residents' living experiences and sensory perceptions are helpful in distinguishing the pollution hot spots for this air monitoring network. Examples include areas where the more sensitive population such as the elderly or the children converge for leisure activities, severe-traffic periods and locations, or places and seasons where open-air burning is common. A local self-help group member explains the relationship between understanding the social life patterns and arranging the air pollution detection sites: "We have a lot of questions to clarify. What does it mean for kindergartens, parks, and areas often visited by the elderly and children? What are the differences between high and low traffic volume areas for a same street? During different seasons . . . , maybe having three or four detection machines would be more desirable so that different places can be detected simultaneously and thus yield better results" (Interviewee CHC, 17 November 2015).

These local experiences and knowledge thus assisted the implementation team by providing more comprehensive considerations in determining the air-pollution monitoring sites. Therefore, the air quality information can be more accurate, consistent, and conform to the local experiences. The air-pollution computing simulations can also be triangulated.

The joint effort in developing the air-quality micro-monitoring system in Puli gained the EPA's attention. In 2015, the EPA commissioned NCNU to develop inexpensive sensors to be distributed across residential areas to detect nonindustrial emissions such as vehicle exhaust, cooking fumes, and burning incense and agricultural waste. Puli was designated as the first trial zone of this pilot monitoring project (EPA 2015). The improvement of air quality of a one-third annual average $PM_{2.5}$ concentration cut within three years (from 33.3μg/m^3 in 2013 to 21.3μg/m^3 in 2016) was also attributed to the monitoring system that effectively provides real-time data to remind people to act on pollution reduction at the personal level such as self-restriction on burning paper money or straws.[12]

Despite the air-quality improvement, the $PM_{2.5}$ concentration in Puli was still higher than 20 μg/m^3 and failed to meet the WHO guideline of 10μg/m^3 annual mean. The self-help group noted that Puli residents have made a lot of effort to reduce the local air pollution, but pollutants transferred from external sources and unfavorable meteorological and geographical conditions for pollution dispersion make this small town, located in a natural basin, vulnerable to air pollution (Interviewees CYC and CLY, 9 May 2016). It shows the limitation of the air-quality monitoring project: even if people know about the air-pollution conditions within a specific region, obtain real-time air-pollution hazard information, and master the atmospheric dispersion conditions; it can still be hard for the people to directly grasp what are the sources of the pollutions and the contribution ratio of each pollution source to fundamentally improve the air quality.

5 Conclusion

The degrading air pollution conditions and the government's out-of-focus responses have prompted the citizens to take urgent actions in order to make the severity of air

[12] Information from the Puli $PM_{2.5}$ Air Reduction Self-Help Group Facebook page, www.facebook.com/pulipm2.5/ (accessed 3 July 2018).

pollution problems visible. As demonstrated in this article, some citizen groups have actively transformed the official data into information that is easy to understand by the general public to mobilize the local awareness. They used charts and graphics to covey the air pollution issues and disseminated the flyers through community health network. They have also strived to use data collected via lower-cost and lower-technology-threshold methods to provide alternative versions of air pollution information. The experimental methods include systemic photo documentation to compare sky visibility with the air-pollution data and calculate the number and ratio of bad-air-quality days. It demonstrated intuitive yet evidence-based information that covers both the sensory observations and the official data reinterpretation.In addition, the affordable $PM_{2.5}$ sensors have been developed based on the need of the community to generate the firsthand environmental monitoring data and endeavor to master the local air quality status on a small scale.

These citizen groups used the systematic methods to create and reinterpret data to further contest the deficiencies of the official air-pollution index, information, and regulatory actions. Focusing on data reinterpretation and generation, they presented a way of reconstitution ad reintegration of science within everyday life (Irwin 1995) that set up an example of citizen science practice in Taiwan. Through these experimental activities, the citizen groups have joined forces with the diverse alliance that are not accessible in the past, such as the information scientists and technicians who can develop micro mobile sensors and apps for monitoring applications, interdisciplinary experts who can provide counter scientific arguments, small business owners who can contribute their space, time or products in support of campaign, and so on.

The citizen air-monitoring projects in Taiwan, like other similar projects discussed in the citizen-science studies, did create new forms of information that extend the community knowledge network and capacity for social change. However, Taiwan case studies present two distinctive features that somehow differ from the discussions in the existing literature. First, different from their counterparts in the US, where citizen science projects in community air monitoring are widely studied and found effective to hold polluters accountable (Ottinger 2010; 2013; 2016; O'Rourke and Macey 2003), Taiwan community air-monitoring projects currently developed are better at providing warning signals for self-prevention, but cannot clarify what compose the air pollutants or who is the main pollution contributor. In other words, the evidences that citizens collected and interpreted can prove the severity of air-pollution problems but have not been strong enough to hold the polluters accountable. Second, the current citizen-science experiments are more developed in the urban area where well-educated young people voluntarily organized themselves for advocacy, while the air monitoring in the US is often seen in the fence-line communities around the polluting factories.

These disparities may result from some factors related to Taiwan's social, political, economic, and technological development context. Taiwan's dense industrial agglomeration patterns, rapid urbanization, and mismanaged mixed land use have made it difficult for the community residents to identify the single specific pollution source. It may explain that the citizen groups often prioritize their demands for tightening regulations and overall pollutant quantity control rather than directly targeting the polluters. The hard battle to push forward the air pollution regulatory control also speaks to the characteristics of the developmental state that intends to relax environmental regulations to lower the compliance costs of the industry.

It is also worth noting that the support system for the citizen-science project in Taiwan is best at its technical development on computing data, the Internet of things, and sensor making. Such development is led by a phenomenal maker movement in Taiwan that emphasizes the creation of novel devices, network technology, and open-source data for promoting air pollution awareness. It explains the widespread use of $PM_{2.5}$ sensors in urban, well-educated areas with high environmental awareness. However, focusing on the computing technology and particle sensors only without grasping and triangulating other important information such as what pollution sources discharge what pollutants, the characteristics and toxicity levels of the pollutants, and so on, may in turn limit the understandings of the air pollution issues.

The existing literature on community air-monitoring projects has provided rich discussions on the new form of environmental knowledge production that highlights the reshaping of epistemic boundaries (Ottinger 2009) as well as struggles and breakthroughs of the fence-line communities (Ottinger 2010; 2017b). The US cases demonstrated a rather clear picture of negotiation process among community members, polluters, scientific communities, and state agencies. Constrained by the industrial agglomeration land use patterns and limited support from broader scientific communities for interdisciplinary scientific analysis, toxin analysis in the laboratories, and so on, the community air-monitoring projects in Taiwan cannot serve as a potent weapon at the negotiation table between communities, industries, and agencies. The instruments and techniques developed in the burgeoning community monitoring actions haven't melded the scientists with the citizen groups into an epistemic community. However, these experimental activities provide an evidential base to challenge the state's lax standards and regulations as well as its information-transparency policies, which may in turn allow more possibilities to engage a variety of community monitoring projects. In this sense, Taiwanese cases remind us that it is necessary to situate the citizen science actions in a broader social context to understand its development trajectory, limitations, and potentials.

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