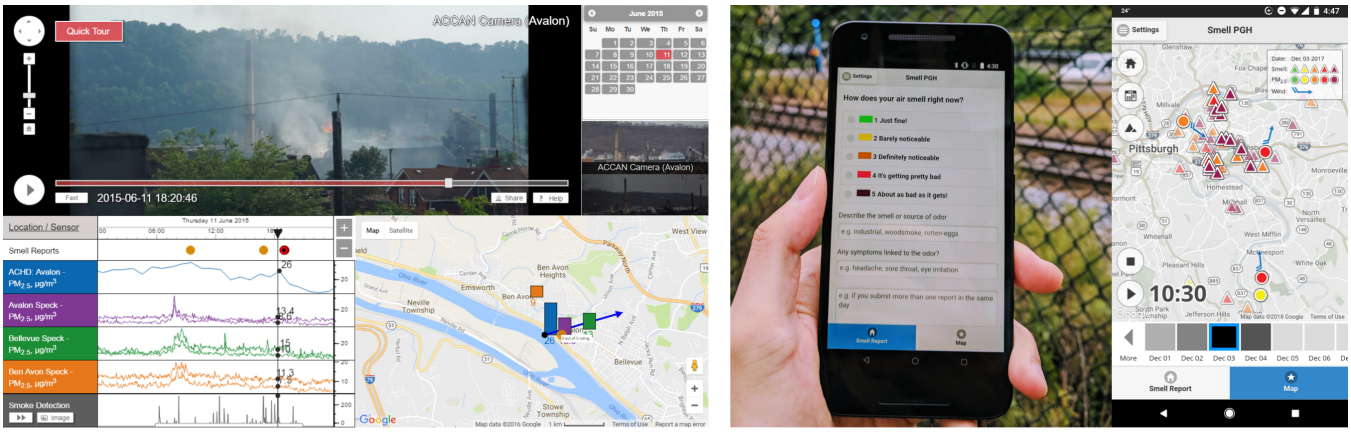


(a) (b)

Figure 1: (a): Community-empowered air quality monitoring system [4]. (b): Smell Pittsburgh [3].

I design, implement, deploy, and evaluate interactive systems that support community empowerment, especially for sustainability issues. Recently, scientists and decision-makers have applied Human-Computer Interaction (HCI) to lead research activities that engage lay people in addressing sustainability concerns, such as air quality. However, such top-down approaches usually pursue technology interventions that treat local participants as experimental subjects, which may cause adverse impacts to communities. I have proposed an alternative, **Community Citizen Science (CCS)**, to closely connect research and social issues by empowering everyday citizens to produce scientific knowledge, represent their needs, address their concerns, and advocate for impact [5]. In this way, I integrate sustainable HCI and CCS to advance the current science-oriented method by emphasizing continued community engagement after technology interventions.

My works emphasize going from research to practice to impact and have been featured in more than 50 media articles. I have collaborated in developing an air quality monitoring system that urged US EPA (United States Environmental Protection Agency) regulators to respond to the air pollution caused by a petroleum coke refinery during a public meeting [2, 4]. Also, one month after the meeting, the parent company of the refinery announced its closure, which was the ultimate goal that the community had tried to achieve for decades. In certain ways, this air quality monitoring system indirectly caused a social impact that **improved the living quality of over 70,000 residents**. Based on the experiences learned from the air quality monitoring system, I also collaborated in developing a mobile smell reporting system, which has **attracted more than 6,500 users who contributed over 25,000 reports** in 32 months since its release [3]. The system enabled community activists to debate air quality issues with scientific evidence, which urged the local health department regulators to enact rigorous rules for coke plants [1]. Currently, I am developing a system that enables citizens to label smoke emissions from air quality monitoring videos, which can be used for training a computer vision model for automatic smoke detection. In the future, I plan to establish Community Citizen Science as a formal research field with the goal of empowering communities and scientists to represent their voices, reveal local concerns, and shape more equitable power relationships.

What is Community Citizen Science?

Citizen science refers to the framework that empowers amateurs and professionals to form partnerships and produce scientific knowledge jointly. A major science-oriented strand aims to facilitate scientific research and address large-scale problems that are infeasible for experts to tackle alone. One example is Galaxy Zoo[1], which invites volunteers to classify a large number of galaxies online. On the other hand, Community Citizen Science, the main framework of my research, aims to democratize science by equipping citizens with technology to directly target concerns that are raised by communities [5]. CCS is a particular case of citizen science that:

[1] `https://www.zooniverse.org/projects/zookeeper/galaxy-zoo/`

- **Embraces participatory democracy** through scientific research to influence policy-making and address local concerns that community members wish to advocate for themselves
- **Adopts community co-design** to develop interactive systems with advocacy groups, who are deeply grounded in local cultures and can bring diverse expertise to inform the design and use of computational tools
- **Rebalances power relationships** by disseminating critical data-driven evidence from the bottom-up to inform and convince decision-makers about the perceptions of community concerns

CCS is highly related to sustainable HCI, which studies the intervention of information technology for increasing the awareness of sustainability, changing user behaviors, and influencing attitudes of stakeholders. CCS seeks to generate scientific knowledge from community data to support exploration, understanding, and dissemination of local environmental, social, and ethical concerns. CCS extends sustainable HCI by exploring: *(i)* how technology can strengthen the link between science and civil society, *(ii)* how researchers can take on the role of supporters that facilitate utilizing and disseminating technology, and *(iii)* how technology can empower citizens to produce scientific evidence and rebalance power relationships.

Community-Empowered Air Quality Monitoring System[2]

Air pollution has been identified by the World Health Organization as a top ten threat to global health in 2019 and causes millions of deaths globally every year[3]. In our case, 70,000 residents near Pittsburgh suffered from hazardous smoke emissions with fine particulates from a petroleum coke refinery. Although regulators and scientists in the local health department conducted air pollution studies, the result was rarely disseminated in an understandable form to the public. Over time, this non-transparent approach exacerbated a lack of trust between citizens and regulators. Unlike this traditional agency-led approach that leaves citizens out of the loop during decision making, we adopted Community Citizen Science to empower residents in advocating for better air quality.

Although residents organized a community to gather evidence about how air pollution affected the local region, the data that they collected manually was often held in low regard due to the lack of scientific validity. As technological supporters, we aided the community in setting up outdoor air quality sensors and monitoring cameras. We also distributed Google Forms to capture odor complaints. To visualize the collected hybrid data (sensor readings, odor complaints, and monitoring videos), we developed a web-based interactive system (Figure 1, left) [4]. Residents could use the system to search for and create videos with smoke emissions manually. Because this manual approach required considerable human efforts, we implemented a computer vision tool to automatically detect smoke and produce corresponding videos, which could then be curated and shared. With the system, residents could tell stories with concrete scientific evidence about what happened and how these events affected the local neighborhood.

Co-designing and deploying this system has offered insights for CCS and led to social impacts. From the analysis of server logs, we recommend combining manual and automatic approaches when gathering evidence. The manual approach encouraged communities to generate videos with smoke emissions. The automatic approach with computer vision reduced the workload by expediting the process of finding smoke videos, which sustained long-term participation. From a survey study, we found statistically significant increases in self-efficacy and a sense of belonging among users. Open responses in the survey showed that the system promoted critical discussions with policy-makers and empowered citizens to take community actions. Moreover, the smoke videos provided by the system, combined with affected residents' stories, have enabled effective communication of air pollution between citizens and regulators at a public meeting [2]. The acting director of the EPA from the Region III Air Protection Division in Philadelphia pointed at the videos projected on a screen and said: "But what I see in the video, is totally unacceptable." This impact shows the value of evidence-based visualization. In December 2015, the refinery was closed by its parent company, which was the ultimate goal that the community had tried to achieve for decades.

[2] `http://shenangochannel.org/`

[3] `https://www.who.int/emergencies/ten-threats-to-global-health-in-2019`

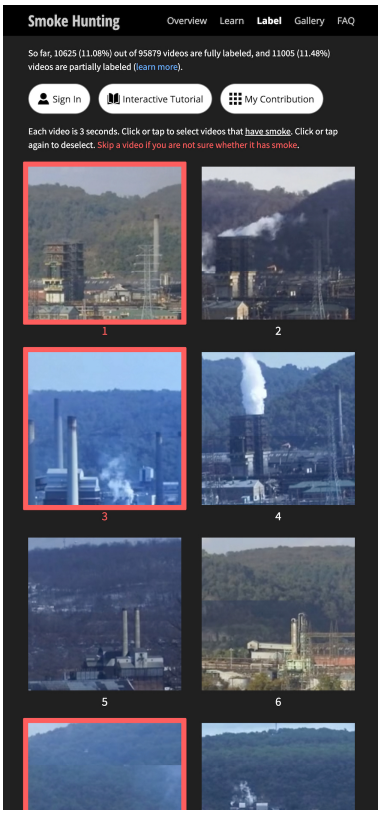
Smell Pittsburgh: Community-Empowered Mobile Smell Reporting System[4]

Cities like Pittsburgh deployed expensive monitoring stations sparsely to measure the impact of air pollution. However, in this way, it is difficult to understand how residents experience air pollution at the neighborhood level. Based on lessons learned from developing the air quality monitoring system, residents linked odor experiences with living quality. Although Pittsburgh citizens can report industrial odors to the local health department via its phone line or website, the quality of the data is doubtful. Citizens may not remember the exact time and location that pollution odors occurred, which results in missing data that can affect the statistical analysis of identifying pollution sources. Furthermore, the reporting process is not transparent. There is no real-time feedback or ways of sharing experiences, which makes it hard to know if air pollution is at a neighborhood or city-wide scale.

Smell Pittsburgh is an interactive system for citizens to report pollution odors with time and location data via mobile devices (Figure 1, right) [3]. The system visualizes odor reports in real-time, which enables residents to view if others also share similar experiences. Moreover, by forwarding the reports to regulators, the system adds more weight to these reports, and regulators can access the data to address potential pollution sources. Also, we used the reports and air quality measurements to train a machine learning model that predicts upcoming pollution odors and send push notifications to users. We also statistically explained relationships between smell reports and air quality measurements. Our survey study found that motivations for citizens to use Smell Pittsburgh came mainly from internal factors, including the desire to contribute evidence, altruism, and the ability to validate personal experiences.

Although stakeholders typically view odor reports as subjective and noisy, this work shows that smell data can help identify air pollution patterns and empower communities to pursue better air quality. The data were presented by advocates at the Board of Health meeting, which shows that the system encouraged citizens to communicate local issues with regulators [1]. The regulators later announced that they would enact rigorous rules for petroleum coke plants, which shows that this CCS approach can also benefit agencies in effective decision-making [1]. Such impacts can hardly be achieved by applying traditional methods that only involve researchers and regulators.

Community-Powered Industrial Smoke Labeling System[5]



Our prior work on the air quality monitoring system shows that visual evidence of pollution sources can influence regulators and empower citizens in pursuing environmental justice. However, the smoke detection model that we developed in the prior work was based on heuristic approaches that were highly tuned for one specific camera. To detect smoke emissions in multiple cameras, we plan to apply deep neural networks due to current promising results in its applications of video action recognition. Nevertheless, training the network requires a large number of manually labeled videos that are laborious to obtain. Also, the size of existing datasets for industrial smoke detection is insufficient. In order to overcome this problem, we are co-designing and deploying a system with air quality activists to invite broader communities in labeling videos that contain smoke emissions. These videos are obtained from cameras in our air quality monitoring network. Multiple videos with known answers are randomly placed in the labeling batch to control quality. We will compare the agreement among labels contributed by researchers and citizens to determine the labeling quality. With sufficiently labeled videos, we aim to train a deep neural network that can robustly detect smoke emissions on multiple cameras with different views. In the meantime, we will design visualizations of industrial pollution events for air quality advocacy.

[4] https://smellpgh.org
[5] https://smoke.createlab.org

Research Agenda

Although citizen science has been identified as an important field on a national scale, we are still investigating how to develop interactive systems to empower communities on a hyper-local neighborhood scale. The US EPA and National Institutes of Health have adopted citizen science to engage the public in addressing environmental[6] and community health[7] concerns. Also, the US Congress has established an act to encourage federal agencies to use citizen science to advance research, literacy, and diplomacy[8]. Despite all these significant efforts on the national scale, my prior works in Community Citizen Science have demonstrated that pursuing sustainability relies heavily on the understanding of local concerns. The implications of designing interactive systems to support CCS may depend on local context and can be difficult to generalize or replicate. In the future, I plan to establish CCS as a field that **emphasizes going from research to practice to impact**. Specifically, I am excited to explore the application of extending sustainable HCI with CCS. The formal training that I have received in both computer science and architectural design makes me very well suited for integrating computational and design thinking in developing interactive systems for CCS. Possible future research topics are outlined below.

- **Community-Empowered Smart City:** I am interested in applying both cyber and physical technology to address issues in local communities, especially but not limited to those related to sustainability (e.g., air quality, housing inequality, food safety, energy conservation). I believe that it is essential to co-design and deploy technology with communities. In this way, we treat technology as urban infrastructure, just like how architects and urban planners co-design buildings and open spaces.
- **Evidence-Based Visualization:** I believe visualizing sustainability issues with data-driven evidence is critical in influencing decision-makers and bringing about common discourse. Visualizations can raise public awareness and pave the road of building solutions around community concerns. I am interested in exploring both tangible and intangible interaction techniques to visualize multiple types of quantitative and qualitative data.
- **Human-Algorithm Interaction:** Modern Artificial Intelligence (AI) techniques, such as machine learning and computer vision, have the potential to help communities make sense of complex data and identify critical evidence. I am interested in exploring methodologies for citizen scientists to collaborate with AI in CCS research. Based on the results from my prior works, I believe that such collaboration can create meaningful social impact and raise communities' confidence in addressing sustainability issues.

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[6] https://www.epa.gov/citizen-science

[7] https://www.niehs.nih.gov/research/supported/translational/community/index.cfm

[8] https://www.congress.gov/bill/114th-congress/house-bill/6414