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Behind the scenes of planning for public participation: planning for air-quality monitoring with low-cost sensors

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We report from an environmental monitoring project planning for public participation to evaluate low-cost air pollution sensors. With an ethnographic approach, we studied how challenges were expressed and negotiated in discussions among project members when planning to involve the public in monitoring with low-cost sensors. Data was collected through participant observation of project meetings. Our analysis shows that perceived challenges involve data quality (i.e. reliability and validity), support, creating a sense of ownership and trust, as well as how to handle a possible rearrangement of power between authorities and the public. In order for the project to have control over different parts of the process when planning for public participation, they cannot stay true to all of the goals. This study contributes to the understanding of factors that foster the use of community-based data, and on the barriers for engaging the public in policy issues.

Keywords: low-cost sensors; public participation; environmental monitoring; challenges; negotiations

1. Introduction

Collecting data from internet-enabled or automated low-cost sensors for environmental monitoring has become increasingly popular due to the technical development and reduction in size and prize (Balestrini *et al*. 2015; Conrad and Hilchey 2011; Jalbert and Kinchy 2016; Jiang *et al*. 2016; Muller *et al*. 2015). It is argued that these low-cost sensors can be used for real-time monitoring and management, decision making, and policy making in cities (Jiang *et al*. 2016; Muller *et al*. 2015; Perera *et al*. 2014). There is also a rapid expansion of monitoring initiatives by local communities (Carlson and Cohen 2018; Conrad and Hilchey 2011) to answer community-driven and locally motivated questions. This expansion is attributed to technical development as well as to the limited governmental and scientific capacity and scope of monitoring, and the growing health and environmental concerns of communities (Carlson and Cohen 2018; Conrad and Hilchey 2011). At the same time, there have been calls for more collaborative, participatory and democratic approaches in environmental management (UNECE 1998; Westberg and Waldenström 2017). The focus for air quality management to combat air pollution in the European Union has been the use of innovative methods for monitoring and modeling, capacity building and encouraging behavioral

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change (European Commission 2014). It is also suggested that there is a “clear need for crowdsourcing weather and climate data” due to the increasing “demand for real-time, high spatiotemporal resolution data” (Muller *et al*. 2015, 3197f).

These factors combined—the technical development, the need for innovative methods to monitor the air quality, and the expansion of local community initiatives—has led to an increasing number of initiatives involving the public in air quality monitoring. As a result, a growing body of research has focused on participatory sensing systems (for example Tian *et al.* 2016, and Kuznetsov *et al.* 2011), and the engagement of volunteers to participate (Balestrini *et al*. 2015; Rowe and Frewer 2005; Seymour and Haklay 2017). Benefits and potentials of policy implementation for engaging volunteers in participatory sensing and crowdsourcing are also identified (Haklay 2015; Couvet *et al*. 2008), and there are several examples of successful implementation and results from policy-related initiatives and participatory sensing (see examples in Haklay 2015). In participatory sensing and crowdsourcing, volunteers commit to a call for participation and are contributing to a common interest (Balestrini *et al*. 2015). Citizen sensing (CS) on the other hand, as defined by Balestrini *et al*. (2015, 2282), “is an approach that develops and uses lightweight technologies with local communities to collect, share and act upon data”. It is also described as lay people (acting in a non-professional role) organizing in grassroot-monitoring activities (Berti Suman and van Geenhuizen 2020).

There are questions raised about the quality of the data collected from low-cost sensors (Jiang *et al*. 2016; Watne *et al*. 2019), and the credibility and reliability of citizen-generated data (Brasier *et al*. 2017; Carlson and Cohen 2018). At the same time, policy makers will have to address the previously noted expansion of local community initiatives using these sensors. However, only minor attention in research has been devoted to these aspects (e.g. policy) of involving the public in environmental monitoring (Berti Suman and van Geenhuizen 2020; Jiang *et al*. 2016). There have also been calls for the need to explore the factors that foster or hinder the use of data collected by community-driven monitoring (Carlson and Cohen 2018), and on how local governments react to citizen sensing (Jiang *et al*. 2016). This indicates a need to understand the challenges involved using citizen-generated data in air quality monitoring. There is hence also a need to address these issues from more than one perspective; to combine the technical and data quality aspects of participatory sensing systems with the aspects of how to involve and engage the public in monitoring.

Our research focus is on an environmental monitoring and internet of things (IoT) project (from now on referred to as the IoT project) aiming at offering city inhabitants access to IoT-based environmental monitoring by supplementing existing environmental monitoring with passive sensors for monitoring air quality in cities. To do this, they invite volunteers to assemble IoT-enabled low-cost sensors to measure particulate matter (PM) and fine dust. The aim of this paper is to explore how the IoT project members are dealing with the aspects of public monitoring with low-cost sensors that follow with engaging volunteers to participate in monitoring activities. To do this, we have used an ethnographic approach that allows us to explore how the IoT project members are negotiating the challenges and uncertainties in the context of planning for environmental monitoring through public participation. The central questions underlying our analysis are: *what different challenges with involving the public in monitoring with low-cost sensors are addressed by the IoT project members,* and *how do the project members negotiate these perceived challenges and uncertainties in relation to benefits, project goals, and available resources?*

In the next sections, we will examine challenges and possibilities with involving volunteers and IoT-enabled sensors, as described by previous research on monitoring aspects, and how to motivate and engage volunteers. Then we present the IoT project and the CS initiative to which they are aligned for administrative benefits, before describing the use of participatory observations and inductive methods for data collection and analysis. We present the negotiations of perceived challenges and uncertainties in three dimensions related to the drivers of the IoT project. We show the negotiations around being a test-bed for sensors, obtaining more data by engaging people, and having an effect on people. We conclude by discussing how the traditional way of monitoring air quality is being challenged by low-cost sensors, and the possible social and political effect on different dimensions of the distribution of power.

2. Related work

In order to provide a better understanding of the challenges that project developers or researchers are facing when involving the public in monitoring with low-cost sensors we here present important aspects of monitoring and of engaging volunteers. We draw upon a growing body of research on the use of innovative air quality monitoring methods, community-based monitoring, and research on the engagement of the public in monitoring or research practices.

2.1. Monitoring aspects

IoT-enabled small and cheap sensors for air-quality monitoring can collect real-time data, exchange, and process information all day long (Cuff *et al.* 2008). However, both opportunities and questions of concern have been raised regarding the monitoring aspects for the smallest and cheapest versions.

The most evident opportunity is the possibilities that the smaller sensors are bringing about for obtaining more environmental data (Conrad and Hilchey 2011). More data nodes are also enabling monitoring other areas than before (Conrad and Hilchey 2011; Muller *et al*. 2015), and allows getting closer to the users of the data (Gubbi *et al*. 2013).

This paper focuses on the passive use of volunteers, where their only involvement in the process is to install the sensor and to ensure its continued operation where they are considered gatekeepers of their sensor (Haklay 2013; Muller *et al*. 2015). The fact that passive sensing does not require human interaction during data collection and data processing (Muller *et al*. 2015) removes the opportunity for the user to provide feedback on their experience, and the important knowledge on local or context-specific conditions that are important in people-centric, or active sensing, can be lost (Gubbi *et al*. 2013). Haklay (2015) argues that relying on the equipment that people are using removes some of the human errors that can influence the quality of the data collected. Also, when enough data is collected in an area, the data is as good as authoritative sources. But, when passive sensing is done using low-cost sensors researchers contest this, arguing that low-cost sensors need careful calibration and post-processing before the data from them can be used (Jiang *et al*. 2016; Muller *et al*. 2015; Watne *et al*. 2019).

Some of the limitations of active and people-centric sensing is also evident for passive sensing done by volunteers; not being able to control when and where data is collected, privacy, ownership, and appropriate participation incentives (Gubbi *et al*. 2013;

Santos *et al*. 2017). Other challenges are associated with the design and deployment of socio-technical systems for participatory sensing, in addressing e.g. lack of technical skills, data reliability and sensemaking (Balestrini *et al*. 2015). On the other hand, there are examples of when these issues were seen to be negotiated by volunteers and policy makers, and later used for improving environmental conditions and limiting pollution. This is described in the ethnographic work by Ottinger on the potential effects of community air monitoring using 'buckets', or easy-to-operate sampling devices (see e.g. Ottinger 2010a, Ottinger 2017; Ottinger and Sarantschin 2017; Ottinger 2010b). Ottinger particularly emphasizes the importance of the dual nature of standards and standardized procedures in both bridging and marginalizing stakeholders. The ethnographic work in her study also revealed that environmental regulators expressed concerns about the validity and reliability of the data from the buckets, and that this led to a hesitation to act upon possible problems that could be detected by the buckets (Ottinger 2010b).

There seems to be agreement that there are challenges with participatory sensing in motivating and engaging users (Balestrini *et al*. 2015; Conrad and Hilchey 2011; Gubbi *et al*. 2013; Santos *et al*. 2017).

2.2. Engaging and empowering volunteers

A huge potential in using volunteers in the scientific and monitoring processes is accounted for in research on public participation in scientific research. Participatory sensing, in particular, is described as having the potential to bridge the gap between different scientific fields and as a new way to engage the general public in collecting data (Muller *et al*. 2015). But some of the challenges in participatory sensing are related to the dependence on people volunteering.

One challenge is to recruit volunteers and to retain the services provided by them (Wright *et al*. 2015). A useful starting point for designing, implementing, and maintaining projects involving the public is, hence, to understand the motivations to participate. There are also different incentives for participation in different stakeholder groups to consider (Verbrugge *et al*. 2017). The most prominent motivations to participate seems to be an enthusiasm for the goals of the project (Brandeis and Carrera Zamanillo 2017; Church *et al*. 2019; Roy *et al*. 2012; Van Brussel and Huyse 2019; Wright *et al*. 2015), involvement in the scientific process and the mere joy of, or love for, nature (Roy *et al*. 2012; Wright *et al*. 2015). On the same notion, a study on participant behavior found that risk perception had a positive impact on participation intention and behavior (Xu *et al*. 2020). Research comparing two communities using IoT-enabled participatory sensing tools found that supporting meaningful participation by, for example, feeling responsible for the data, being able to envision collective action (i.e. to revise legislation), and making sense of the data could create a sense of empowerment that makes the volunteers more engaged (Balestrini *et al*. 2015).

Projects wanting to engage volunteers in passive sensing could, hence, need to consider how to empower the volunteers. In a literature review by Schneider *et al*. (2018) examining the relationship between citizen participation and empowerment, empowerment is defined as "a process by which individuals gain mastery or control over their own lives and democratic participation in the life of their community" (Zimmerman and Rappaport 1988, 726). Schneider *et al*. (2018) argue for addressing the notion of power when engaging in issues of empowerment with technology, since power can be seen both as imbalances in power between multiple parties as *power-over*, and also as giving parties abilities to act (without taking power away from others) as *power-to.* When wanting to empower participants through the use of technology, important categories to consider are related to the concept of power (power-to or power-over), how the empowerment is manifested (as feeling, knowing or doing), when it happens (during or beyond use), and the design mindset (participatory or expert) (Schneider *et al.* 2018). The authors also suggest that a participatory mindset, referring to the value of people as 'co-creators' instead of 'subjects' or 'users', could be necessary if wanting to empower people.

The co-created air quality measuring project CurieuzeNuezen, for example, claim their success on creating both internal and external values; contributing both to personal learning and development for the volunteers, as well as utilizing data for the decision-making process (Van Brussel and Huyse 2019). It is also argued that crowdsourcing is empowering in itself by moving "the centre of gravity of power equilibrium from the alliance of scientific and political institutions to the 'masses'" (482), since it gives credibility and power to the participants (Farah 2014). Other research has come to the opposite conclusion, especially when it comes to passive sensing (Balestrini *et al.* 2015; Jalbert and Kinchy 2016). When comparing two local communities involved in participatory sensing, Balestrini *et al.* (2015) for example, found that "funding and owning the technology does not necessarily translate into active participation" (9). In their study of the use of automated data loggers, Jalbert and Kinchy (2016) claim that the passive sensors used in their study "are reducing, or at the least neutralizing, capacities for local empowerment and influence, as compared to programs that encourage non-professionals to get involved in all levels of (…) [the] study designs" (Jalbert and Kinchy 2016, 393).

3. The context

In order to uncover what goes on behind the scenes of public monitoring we have studied one particular project, the IoT project, and how this aligns to a larger CS initiative. In the following, we give some necessary background information before moving on to describing our data collection.

3.1. The internet of things environmental monitoring project

The project is part of a strategic innovation program, funded by government research councils in Sweden. Altogether, the project has 15 partners, which include representatives from municipalities, research and innovation institutes, network/sensor/technology companies and a science center in Sweden. The goal of the project is to develop and evaluate IoT sensors, to make data on air- and water quality more available to the public by visualizing the data from the sensors available. In making data more available to the public, one of the goals is to make the inhabitants more aware of how to affect the air and water quality of their surroundings. This is to be achieved by citizen sensing inspired methods, allowing interested people in the city to measure the air quality using IoT-connected environmental sensors.

This study is based on the planning of an open workshop at a local science festival. At the workshop, small digital sensors measuring particulate matter (PM10 and PM2,5), and a sensor measuring temperature and humidity are to be connected to a

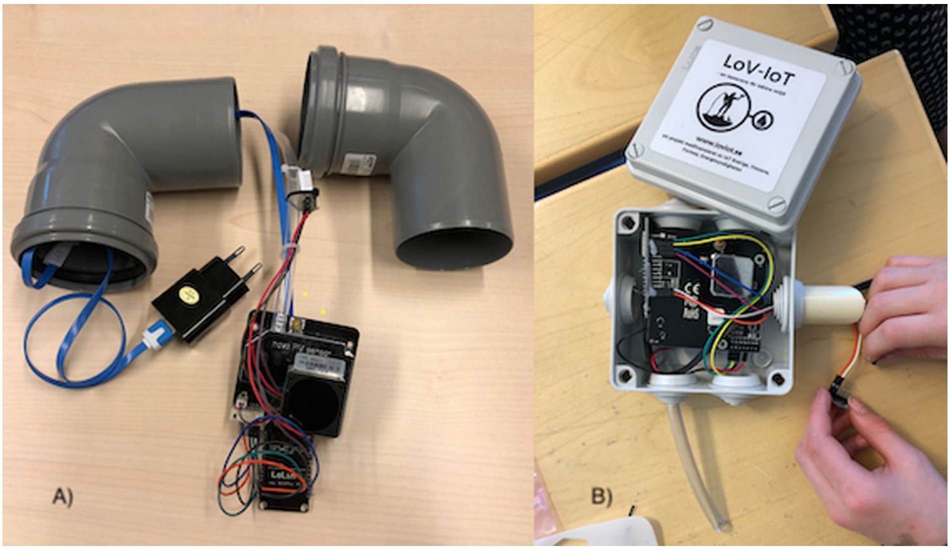

Figure 1. The low-cost sensor with Wi-Fi connection displaying the parts with different types of weather protection; a drainage pipe and a junction box.

low-cost microchip with Wi-Fi connection. They are also to be assembled with a usb power supply, some cables and a plastic tube into some sort of weather protection for the device[1] (see Figure 1).

3.2. The planning of public participation

The goal of this workshop was to engage the public in building sensors to measure particulate matter and to upload the data. The workshop is the first project encounter with future participants, and was planned by some of the members of the IoT project. For planning meetings were held on four occasions and each meeting lasted 1–2 h. In the first meeting, ideas for the workshop were scouted and the frames decided on. In the second meeting the communication around the workshop and scheduling of the workshop day were planned. In the third meeting, the schedule and the materials used for information were discussed in more detail, and the fourth meeting addressed last minute corrections before the workshop. The meetings were informal in structure but they all had a specific agenda. At the meetings, 5–8 people attended (including 1–2 via an internet link).

The meetings had representatives from the different stakeholders in the IoT project: the project managers, the city's environmental agency, technology institutes and companies, environmental monitoring experts, and a local university. The group had expert knowledge in several important areas.

3.3. Luftdata.se

The CS initiative involved in this paper is the Swedish (Luftdata), but the ideas behind the project come from the German-based 'Luftdaten Selber Messen' [measure air quality yourself], sometimes also referred to as Luftdaten.info. The idea of the initiative is to allow people to build their own particulate matter monitors (see Figure 1), and to later send data back for visualization of the measurements on an open world map, where you are able to zoom in to a particular node to see variations in particulate matter. The data is available for use through downloading the API by using Creative Commons Attribution Share Alike 4.0 (CC BY-SA 4.0) and Database Contents License (DbCL) v1.0[2] for its content.

Volunteers join Luftdata.se by following the instructions[1] at www.luftdata.se on how to build a fine dust sensor, configuring the sensor to connect to the configured WLAN access point, and by signing up for a user account and adding the sensor to the luftdaten.info network.

The Swedish and the German initiatives describe themselves as Citizen Science. In Citizen Science, volunteers are involved in scientific or monitoring processes by assisting with observations and classifications, or by creating data to e.g. tracking the diversity of organisms, monitoring species or air quality (Bonney *et al*. 2009; Kasperowski, Kullenberg, and Mäkitalo 2017). As a Citizen Science initiative, we describe them as aiming for civic mobilization (Kasperowski, Kullenberg, and Mäkitalo 2017). The Swedish and the German initiatives are here described as Citizen Sensing (Berti Suman and van Geenhuizen 2020), but could also be described as Community Based Monitoring (Carlson and Cohen 2018; Conrad and Hilchey 2011; Whitelaw *et al*. 2003).

4. Method

While most previous studies have been based on data on user experience through surveys and interviews, in this paper we want to understand the underlying negotiations that result in certain actions through the project perspective. For this purpose, and in order to explore how the IoT project is negotiating the challenges and uncertainties in the context of planning for environmental monitoring through public participation, we apply an ethnographic approach with participatory observation. The aspects of ethnography that we use, are the more active role of the researcher in "observing, watching, seeing, looking and scrutinizing" (Gobo 2011, 15). With participant observation, we are able to establish a relationship with the actors by interacting with them in the situations, and hence learn how and why they act like they do, in order to understand the meaning of their actions (Gobo 2011).

The ethnographic work upon which this paper is based was carried out by the first author. Data was collected from January through to April of 2018. As previously noted in section *3.2 Planning for public participation*, the informants in this paper were all part of an internet of things and environmental monitoring project. They were nine in total, six men and three women, in the age range of 25–50. The meetings were held in Swedish.

The first author participated in three (of four) meetings prior to the workshop at the Science Festival and the first author also participated at a workshop where sensors were built by the project members. Two of these meetings were recorded, while the rest of the meetings, including the workshops, were documented in field notes. Even though we did not attend all meetings, we have access to meeting notes and have access to web-pages and digital project documentation in the project. This is also well in line with Garcia *et al.* (2009), who argues that many organizations today cannot be understood without technologically mediated communication.

Data in this paper consists of transcribed audio recordings from meetings, fieldnotes from participatory observations, mail conversations, and other internal data (such

Table 1. Sources, type of data and their use in the analysis of the findings in this study.

Source of data	Type of data	Use in analysis
Participatory observations	Transcribed audio recordings from two meetings	Open coding and iterative coding for patterns.
	Field notes from five meetings (including the two transcribed meetings) and two workshops from January to April 2018.	To triangulate codes, patterns, and facts
Mail conversations and other Internal project data	Project goals, agendas for meetings, notes from meetings, project webpages	To triangulate codes, patterns, facts and observations regarding the project. IoT.

as project documentation, agendas and notes from meetings, and information on websites). The sources and types of data, as well as their use in analysis, can be seen in Table 1. Individuals involved in the audio recorded meetings have orally consented (on tape) to being recorded for research purposes. When citing a statement, we only refer to them as 'project members', ensuring that no-one can be identified.

The recordings were transcribed to enable analysis. We used an inductive approach, and undertook a thematic analysis (Braun and Clarke 2006) with an iterative coding process. After the open coding of the transcribed audio recordings in NVivo12, we identified several patterns evolving around the technological aspects of measuring particulate matter; e.g. the need for more nodes/sensors to model and visualize pollution. Several other emerging patterns evolved around the participants, such as how to motivate more people to engage in measuring particulate matter, what information and instruction to give to them, and how to address intended outcomes regarding behavior change. These patterns were then triangulated with other collected data: field notes, mail conversations, and social media observations (see Table 1). Mail conversations and project websites were also used to triangulate facts and observations, especially regarding related challenges and uncertainties to benefits and project goals.

From the emerging patterns presented above, and through an iterative analytic process, we ended up with three dimensions of challenges that are related to the main drivers for the IoT-project. These are; being a *testbed* for environmental sensors by obtaining *more data* on particulate matter by adding sensor nodes, and at the same time having an *effect* on people. These categories will be presented in more detail in the next section.

5. Behind the scenes of public participation

In the following sections we demonstrate the challenges involved in public monitoring with low-cost sensors that follow with engaging volunteers to participate in monitoring activities. Also, based on the empirical data presented below, our analysis will guide a discussion on how IoT project members negotiate perceived challenges and uncertainties in relation to benefits, project goals, and available resources.

5.1. Being a test-bed for environmental sensors

The IoT project members talk about the main project goal as being a 'test bed for sensors'; wanting to test the quality of different sensors, and to evaluate their accuracy.

The planning of workshops is an activity in the IoT project to achieve this goal and to obtain more sensor nodes. Also, they comment on a possibility of the city *using* data from these sensors in models on calculating and visualizing the geographical distribution of air pollution. These visualizations are to be published on official websites, with access for the public. In this category, we also found uncertainties, dilemmas and negotiations on issues regarding the quantity, accessibility, reliability, and validity of sensor data.

The IoT project members express a need for more nodes to deliver data. They argue for the need to increase the quantity of sensor data and reason about the information that can be extracted from them and to compare data from different sensors. They talk about possibilities with the increased quantity of open and accessible data, and what they can do with it along with the large amount of existing data from monitoring in the city. This is well in line with the opportunities presented by previous research (see e.g. Conrad and Hilchey 2011, and Cuff *et al.* 2008). The IoT project members address the possibilities in using the new sensor nodes to explore network effects of sensors and local variations in air quality. They also express that they view the data from the passive sensing as supplementing existing monitoring. The processing and understanding of data is being addressed as one of the challenges of using IoT-sensors (Muller *et al*. 2015; Perera 2017), but the IoT project members do not discuss it in detail when planning for the workshop. It is within the scope of the project, but not for the planning of the workshop. The IoT project members express possibilities with the increased quantity of open and accessible data, and what they can do with it, along with the large amount of existing data from monitoring in the city. This is well in line with the opportunities presented by previous research (see e.g. Conrad and Hilchey 2011, and Cuff *et al.* 2008).

On the topic of using the data, it is consensus in the IoT project that accessible data from the sensors will, or at least can, be used by the city in their models on calculating the geographical distribution of air pollution. As they discuss the modeling and the aim of the project, one of them says: "That the goal is to get better air through faster actions with primitive instruments. That you try to get knowledge out early on. This is still… The city could use this in the long run, to get better action programs, better follow-up on implemented monitoring". This indicates that there is an ongoing discussion on the validity of the low-cost sensors in the IoT project, as well as of the current environmental monitoring system of the involved city. Also, having a project where officials from the city's environmental agency are working with the data together with experts from environmental monitoring and technical research institutes is, indeed, a way to address the issues of quality and reliability raised in research (Bonney *et al*. 2014; Muller *et al*. 2015; Theobald *et al*. 2015). Having data open and available to stakeholders is, according to previous research, seen as a way to embrace opportunities for policy development (Brasier *et al*. 2017; Hecker *et al*. 2018).

Since some of the project members are experts on environmental monitoring, there are some concerns around the more technical aspects of measurements. This includes reasoning about the reliability of the temperature sensor and whether the often-rainy weather in Gothenburg will make the sensor parts corrode or not. The difference between professional monitoring and monitoring with small IoT sensors were addressed on more than one occasion. In the IoT project group, there seems to be consensus on the positive effects of having access to many, rather than just a few, measuring points, regardless of how reliable the collected data is. Yet, the topic of validity arises on several occasions, indicating that they have a need to convince themselves that they are on the right track. This can be seen in one of the dialogues where the issue is raised of having professional monitoring with high precision, but in very few locations. Here, an IoT project member addresses the reliability issues with the low-cost sensors and invokes the issue of the much higher costs of the professional sensors. One of them reflects on the hypothesis on having network effects with a large number of low-cost sensors; "if we can find the limit—this far from the official precise sensor, then the small, small cheap sensors are better". The IoT project members are thus well aware of the issues of reliability and validity suggested by e.g. Jiang *et al*. 2016, Balestrini *et al*. 2015, and Muller *et al*. 2015, and view the data from the passive sensing as supplementing existing monitoring, which is also in line with previous research (Muller *et al*. 2015).

5.2. Getting more data by adding sensor nodes

In order to be a 'test bed for sensors' the IoT project relies on the engagement of volunteers to monitor particulate matter with low-cost sensors built at the workshop at the local science festival. To obtain data for the test bed, the IoT project members also realize that they need to figure out how to make the volunteers have the sensors up and running for as long as possible. The issue of giving technical support is, hence, also addressed. In this category, we will also present how the IoT project members address issues regarding technical fluency, trust, data quality, and creating a sense of ownership.

The IoT project members talk about creating a relationship with the volunteers in order to establish a sense of trust. They express that they would like to make the participants feel responsible for their sensors, that they want them to feel like their actions matter, and that their specific measurements are needed. As one of the project members said; "It is super important to create a relationship that makes them think it exists. Not that they come and disturb you, but that they feel a certain responsibility. I think that you must have that". The building of a relationship is important for the IoT project, since the volunteers are to build sensors, connect them to the internet, register the sensors to Luftdata.se and then also have their sensors up and running.

The IoT project members realize that information about sensor assembly is crucial for the quality of sensor data, as well as for having the volunteers actually build sensors. In addition to this, the information needs to address different levels of technological fluency. The volunteers will have access to the instructions made by Luftdaten.info, but since the IoT project members assembled their own sensors on a previous occasion, they have some mutual experience and realize that they are not adjusted for people without specific technical knowledge. As one of the IoT project members put it; "It‘s the deal breaker—if someone comes home and fails—then we will not get an air pollution monitor. That‘s how it is". Two individuals are thus assigned to work on writing instructions in Swedish for the assembly of the digital sensors to be used at workshops. Since not knowing who will attend the workshop, they cannot predict their technical competence nor their digital fluency. The instructions on how to assemble the sensors are equivalent to the data protocols used in initiatives where data is collected or interpreted in scientific research. Since the sensors used by the IoT project are providing standardized and specific data, the data protocols are less complex than the ones where the participants are more actively involved in the data collection. But the protocols still need to be correct, and as Balestrini *et al*. (2015) concludes; "lack of technical skills […] can hinder sustained engagement" (p. 9).

To arrange a persistent flow of data, the IoT project members address the challenge of how to provide the necessary help and support. In the first meeting they discuss what to do with any expectations of support and administration after the workshop. Early on in the planning process they discuss the idea of having volunteers join 'Luftdata.se', where peer support is available and from where the IoT project will have access to the operational data portal set up by Luftdaten.info. They reason about the alternative not being manageable for them; to have someone assigned to assist and support the volunteers. They express a fear of becoming support people for the volunteers, for example, when talking about the volunteers taking the sensors home from the workshop (before they decide to align with Luftdata.se), one of them reacts: "Because that's exactly it, then we become the channel for them, they have got these things [the sensors], so then I don't know if they expect us to be these support people, the administrators. We cannot really be that". The IoT project members soon come to an agreement on the benefits of the existing community with access to support. They also reason about the role of the social media community in the CS initiative, and that the people in it are willing to help and are eager to grow by helping others. This is in line with Balestrini *et al*. (2015), who found that poor community building hindered engagement in participatory sensing. Letting the volunteers join an existing CS initiative is making some of the challenges in participatory sensing addressed by Santos *et al*. (2017) less challenging in the long run, since the IoT project doesn't have to manage the sensors by themselves. The CS initiative is thus acting as a service provider (Perera *et al*. 2014), at the same time as the IoT project is getting the administrative challenges solved, which is also saving them a lot of time and money (Conrad and Hilchey 2011). Also, by using the operational data portal set up by Luftdaten.info (the visualizations on the web-based open map), they do not have to develop a portal by themselves (or adjust existing portals to the data from Luftdaten.info), and are avoiding the technical challenges addressed by Haklay (2015).

Creating a sense of ownership by a written agreement is yet another example of how the IoT project members are addressing the challenge of getting more data by engaging and supporting the volunteers. The issue of ownership is raised several times during the planning process and the discussion also continues between the meetings. They argue that owning, or even having to pay for, the sensor will make the participants more engaged, and hence they will be more likely to use the sensors in line with the project's intentions. Another way, they reason, could be to let the participants borrow the sensor, or pay a deposit. As it turned out, the handling of money was the most important obstacle, and it was decided that the sensors will be lent at no cost, but with a written agreement. In the written agreement, they are not only engaging the participants to actually put the sensor up, and to take good care of it, they also talk about the agreement as a way of giving the IoT project access to the volunteers. This way, they will also gain information about the participants that will allow communication and interaction. The IoT project members realize that they need access to the participants throughout the project, for example to carry out surveys, as well as to the particular sensors built at the workshops.

Previous research has raised the issues of controlling when and where data is collected (Gubbi *et al*. 2013), and this is also addressed by the IoT project members. We could see that to control that data will be collected, they work on creating a sense of trust, as well as making the volunteers feel a bit obliged to actually commit the IoT-sensor by using a written agreement. For the IoT project members, controlling data collection also includes leaving the technical support issues to be solved by peers (which, in this case, are other engaged and tech savvy people) in the CS-community.

5.3. Having an effect on people

In the meetings, the IoT project members discuss how to affect the awareness of the public, to inform them about air pollution, sensors, internet of things and air pollution data. They talk about making films and slideshows about the project to recruit participants, but also express a hope that the passive sensing will have an effect on people. The IoT project aims to make people more aware of how to affect the air and water quality of their surroundings by taking action, e.g. cycling and commuting instead of taking the car. In this category, we found uncertainties, dilemmas and negotiations regarding awareness, empowerment and agency.

When discussing how to create awareness, the IoT project members see the workshop as being more than just a *hacking event*, since it's a science festival and because they wish to promote the project goals. They not only want to encourage an interest in IoT-technology, but also to promote knowledge about air-pollution monitoring. When discussing how to inform the visitors at the science fair on important aspects on air pollution and air quality monitoring (e.g. on slideshows), one of the project members puts forward an idea about displaying the open map of the sensors in Germany on New Year's Eve, with all the fireworks making the sensor map of the initiative turn all red (instead of the usual green and yellow); "things like that make an impression! You can, like, see things happening here". We interpret this as a way to motivate future participants to make them see what it could be like to be part of something larger, to be part of a community where each individual sensor contributes to a larger picture.

However, the IoT project members also discuss how the participants will react to, and act upon, the data they collect, especially if they get high levels of PM and contact the city's environmental agency. They reason about this perspective and are trying to grasp the challenges that might arise for the IoT project, and for the municipality, if volunteers are empowered to act upon their data. On three different occasions they express uncertainties about how the participants could (or would) act if the passive sensing makes them aware of local environmental issues. When discussing how to achieve the goal of making the inhabitants of the city more aware of how to affect the air quality of their surroundings, it becomes obvious that the behavioral outcomes are more distant to them than the technical outcomes. One of them asks whether "*to influence*" is within the framework of the project, and two of the other project members express ambiguously that "yes, actually. Well … not to influence, but we have talked about nudging and finding behavioral change … eh identification", and "[y]es, it is not strictly a technical project […] but we have not determined exactly where we draw the line".

This empowering of the volunteers to act is a dilemma for the IoT project members, since they would like to change behaviors of the people in the city, for instance by having students' campaign at schools for parents to stop driving when there are high levels of PM. At the same time, they also express a concern for a "potential political dimension" of using the data collected, in that it "may be used by different actors with different agendas". At the same time, they are aware that people in the city already are engaged in the CS initiative, and that people in the city could act upon data regardless of their project. They tackle these issues by discussing different scenarios on how people could act upon data. Especially the project members employed by the city are confused about their duality in roles. They talk about being the ones pushing for participation, but at the same time having to handle complaints from volunteers about potentially bad air quality due to construction work. One of the IoT project members says: "We do not know how to tackle this in relation to our reference instruments and in relation to our reference data. We do not know! We have just started thinking about it now and we need to tackle it somehow, but we do not know yet." The IoT project members identify a need to tackle the issue of being a project with specific goals at the same time as one of the partners being the environmental monitoring agency of the city. They also struggle with not having control over how to tackle this political dimension of community-based data. This is similar to the findings of Westberg and Waldenström (2017), suggesting that to enable participatory approaches in the work of environmental authorities, their practice needs to be reinterpreted and seen in their institutional contexts (including national and international levels). The IoT project members' way out of the dilemma of handling possible agency is to address the fact that the CS initiative is not theirs from the beginning and that the initiative gains new members regardless of their efforts. They do not follow through on activities to engage participants further. They do produce films that they publish on social media to make people come to the workshop at the science festival. At the workshop, the IoT project members talk to the people on their way in to the workshop, showing the map of sensors to engage them in the goals of the project. We interpret this wish to empower in terms of the framework provided by Schneider *et al*. (2018), as wanting to give power-to the volunteers manifested in an increased knowledge on air pollution monitoring and increased awareness of what to do to prevent further pollution.

Our analysis suggests that the focus on actions to make the volunteers collect data combined with the lack of activities to engage and empower the volunteers further, is due to an expert design mindset, where the volunteers are seen as users or consumers of data rather than co-creators (Schneider *et al*. 2018). Jalbert and Kinchy (2016) argue that grassroots environmentalists are treated as unpaid research assistants when data collection is automated, thus neglecting the citizenship with questions of political powers. Even though the IoT project members do not neglect the political power of the participants, we argue that they are focusing more on the science and technology part than on the citizenship, which is in line with Jalbert and Kinchy (2016) and Kullenberg (2015). Also, we interpret the discussions on these issues as a concern about a persistent empowerment manifested in potential action (Schneider *et al*. 2018) that the IoT project members do not know how to handle. We argue that this concern is important to consider in relation to calls for the use of more collaborative, participatory and democratic approaches in environmental management (UNECE 1998) as well as the focus of the European Union to use innovative methods for capacity building and encouraging behavior change when combating air pollution.

The way the IoT project members are facing the possibilities of having to tackle questions from the sensor owners in relation to reference instruments can also be seen as indications of a rearrangement of the distribution of power and responsibility (as described by e.g. Linders 2012; Harding *et al*. 2015; and Farah 2014). We interpret this as trying to adjust to the giving of power-to the public without losing power themselves (Schneider *et al*. 2018). We thereby argue that the IoT members are struggling with how to handle possible rearrangement of power and responsibility between authorities and the public. They find a way out of the dilemma of the political dimension by addressing the fact that the CS initiative is not theirs from the beginning; that the initiative will continue to engage new members and that probably will act regardless of their efforts. Nevertheless, we agree with the final conclusion of Schneider *et al*. (2018) on "the need to consciously reflect on the notions of power and empowerment" (9).

6. Conclusions

To understand the underlying negotiations that result in certain actions, an ethnographic approach was used to explore how project members were dealing with aspects of public monitoring with low-cost sensors that follows with engaging volunteers to participate in monitoring activities. This approach allowed us to answer questions on how project members address different challenges with involving the public in monitoring with low-cost sensors, and how they negotiate these perceived challenges and uncertainties in relation to benefits, project goals, and available resources. To answer these questions, we followed a project aiming to be a test-bed for IoT-enabled environmental sensors when planning for public participation to access more data. We have demonstrated that challenges are included in the three categories related to the goals of the project; being a test-bed for sensors and to use the data, obtaining more data by engaging and supporting volunteers, and having an effect on people.

In the first two categories, the challenges include the quality (reliability and validity) of data from the low-cost sensors, how to control when and where data is collected, and how to provide the necessary help and support. To manage these issues, the IoT project aligns with an existing CS-initiative that provides administrative benefits and helps with supportive aspects. This allows the project to work with the main goal, to be a test-bed for sensors. This goal was seen to be prioritized over the goal of having an effect on people, at least when it comes to planning for activities to achieve these goals; in contrast to the challenges on how to have an effect on people.

The findings also suggest that the traditional way of monitoring the air quality of a city is being challenged by small, low-cost sensors owned by the public. Challenges were seen in how to address the higher degree of empowerment the volunteers in the citizen sensing initiative are perceived to have. The social and/or political mobilization that might emerge from this could be a powerful way to further rearrange the dimensions of the distribution of power. Our analysis thus shows that issues of power and empowerment are important to consider when local governments come into contact with data collected by community-driven monitoring, or vice versa when local communities contact local governments with data from community-driven monitoring. Further research is needed to fully understand the implications of such a rearrangement of the power distribution.

We believe that this research contributes to the understanding of factors that foster the use of community-based data, and also on the barriers for engaging the public in policy issues. We cannot draw any generalizing conclusions from this single case, but we believe that this knowledge is important for others planning for public participation. The analysis pinpoints the struggle of having control of the process and in order to have control over the different parts of the process, the project members cannot stay true to all of the project goals when planning for public participation.

Notes

1. For a detailed description of the parts and the assembly, see https://luftdaten.info/en/construction-manual/
2. https://opendatacommons.org/licenses/dbcl/1-0/

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