# 16 Citizen science with small sensor networks. Collaboration between a Dutch EPA (RIVM) and local initiatives

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## *16.1 From ad hoc citizen science to innovating our national measurement networks*

The involvement in citizen science of the RIVM, the Dutch National Institute for Public Health and the Environment, started more than five years ago with its ad hoc participation in a number of air quality citizen science projects. The projects were of various nature, and it took a while before enough momentum was build up within the institute to acknowledge the significance of the citizen science movement. We decided to take part in more citizen science projects with local partners and listen to what citizens need from us and what they want us to do. In 2016, RIVM and the Dutch ministry for Infrastructure and the Environment (responsible for air quality in the Netherlands) agreed to start a program aiming at the innovation of its national air quality measurement network (LML). The project should enable small sensors and citizen science to become an integral part of the monitoring procedures. The innovation program has a timeframe of 5 years (2016-2020).

Below, we describe a number of the citizen science projects RIVM took part in. We give some examples of the lessons learned and the experiences gained. We provide a brief description of the planned innovations of the environmental monitoring, and how these innovations will help to ensure the continuity and effectiveness of citizen science measurements. The initial focus will be on air quality, but we expect that application is possible with other environmental parameters such as noise and water quality, light, vibration, radiation and meteorological parameters. These applications will follow in a later phase of the program. The final goal is to have a hybrid, flexible (air quality) network using different types of sensors, consisting of reference instruments, sensors of intermediate cost and quality, low cost sensors, and satellite observations. The data of this network may be provided by different parties, including citizens groups, cities, NGOs and official measurement institutes.

In short, our ambition is to make citizen science data an integral part of standard procedures and models for determining air quality. We feel that this is a way not only to motivate people to participate in citizen science, since it is more fun to measure if your measurements are actually used, but also a way to make citizen science sustainable and give it the steady basis and continuity which is very often lacking.

But why do we participate in citizen science? From the perspective of RIVM, an important factor that drives the innovation of the air quality monitoring network, is that such a network is expensive and therefore it is always good to look for better and more cost efficient solutions. In addition, thanks to the omnipresence of the Internet, advances in micro technology (especially sensor technology) and ubiquitous smartphones, the ability to perform air quality measurements has been 'democratized'. This means that practically all stakeholders and citizens can do air quality measurements if they want to. Often stakeholders and citizens want to do these kinds of measurements because the model-based data by the authorities is not trusted, or because data for their specific location are not available. For Environmental Protection Agencies (EPAs) this presents an opportunity as well as a challenge. They can profit from high spatial and temporal resolutions observations in the urbanized environment, if they find a way to assimilate these data in air quality and meteorological models to provide forecasts to the public. The involvement of citizens carries the prospect of having a denser coverage of observations that are needed for this purpose.

## *16.2 Citizen science is something you do - collaboration with stakeholders & local initiatives*

### 16.2.1 Measurement network Ammonia in Nature areas

Since 2005 the Measuring Ammonia in Nature (MAN) network monitors atmospheric ammonia concentrations in nature reserve areas in the Netherlands (http://man.rivm.nl). The monitoring network is an example of citizen science *avant la lettre*. Measurements are performed with commercial passive samplers, calibrated monthly against ammonia measurements of active sampling devices. The sampling is performed by an extensive group of local volunteers, mostly rangers, which minimizes the cost and enables the use of local knowledge (Lolkema et al., 2015).

**Figure 1: A ranger exchanging a passive ammonia sampler**

Without the unpaid help of the rangers, a monitoring network like this would not be affordable. The network provides a countrywide coverage, crucial input for policy, and a community of rangers happy to contribute to measurements they have great interest in.

Lesson learned: including the voluntary help of societal partners may be a very cost-efficient way to build a monitoring network on a scale that simply would not be feasible without trusting the measurement devices into the hands of non-experts.

### 16.2.2 $NO_2$ measurements by Friends of the Earth Netherlands

One of the first projects with citizens RIVM had a small role in, was a citizen science project by Friends of the Earth Netherlands. Since 2012 Friends of the Earth and local community groups have been measuring nitrogen dioxide ($NO_2$) concentrations with Palmes tubes, a rather simple but well-established method to obtain monthly averages, at about 100 locations in the Netherlands. Friends of the Earth wanted to get an impression of local air quality and subsequently ask local authorities to take their responsibility to guarantee good air quality. RIVM contributed in two ways. First, the Palmes tubes measurements were calibrated by mounting them next to official measurement stations of the RIVM, GGD Amsterdam and DCMR (Rotterdam). Expertise from RIVM was used in the quality control of the measurements and subsequent calibration. Second, by providing standardized procedures to calculate the air quality at the different measurement locations. These model results were compared to the results of the measurements to independently assess the quality of the models used in the Netherlands.

The measurements show that $NO_2$ concentrations are still quite high in several locations in large cities, and sometimes exceed the legal limit for yearly averages. The nitrogen dioxide concentrations measurements in the citizen science project are compared with the values calculated by RIVM using the official Dutch modeling system. The measurements and the calculations correspond rather well (Knol & Wesseling, 2014).

Friends of the Earth and RIVM deal differently with these results, each from their own role and position in society. The RIVM does research for the government and advises about the effects of policies to improve air quality. It is up to policy makers to decide about what policies to adopt. The citizen science measurements are used in RIVM analyses and reports. Friends of the Earth has a role as opinion maker, and tries to influence policy makers. They propose measures to improve air quality and are prepared to go to court to make their point if needed.

Despite their different roles, both parties benefit from this collaboration. By addressing the quality of the measurements together and beforehand, sorting out differences in methodology and other potentially confusing issues, the final discussion is about the values measured, and the *quality* of the measurements is without further debate.

Lesson learned: Even if citizens, NGOs and EPAs have different roles, they all want reliable data. A good reason to work together.

### 16.2.3 Measuring air pollution with your iPhone - iSPEX

#### *16.2.3.1 iSPEX: The project*

The iSPEX project, initiated in 2012, played a decisive role in changing the views on the way that citizen science is able to contribute to environmental science. The project makes use of state of the art new technology and employed citizen science on a – for environmental monitoring - unprecedented scale. More than 3000 people participated.

In the iSPEX project the properties of particulate matter (aerosols) are measured with iPhones that are supplemented with a small add-on for the camera. Together with a special iSPEX app that explains and guides the measurement process and sends the data to the servers of the researchers, this add-on transforms the iPhone into an advanced measurement device. Amongst smartphones, only the iPhone was used because of the uniform position of the camera and the calibration of the add-on. The iSPEX technology is based on that of an instrument based on astronomical technology, the Spectropolarimeter for Planetary EXploration (SPEX), which technology was adapted to a low-cost smartphone camera add-on to allow as many people as possible to use the instrument. The iSPEX add-on and app perform an analysis (in terms of spectrum and polarization) of the sunlight that is scattered by aerosol particles, which, in turn, can be interpreted in terms of the total aerosol load and microphysical properties of the particles. The measurements by the public are compared with and complemented by the aerosol measurements of scientific equipment. One of the primary goals of the iSPEX experiment was to find out how accurate the massive iSPEX-measurements were, and what kind of additional information about aerosols the measurements can provide. The experiment was very successful and the scientific results have been published by Snik et al. (2014). Moreover, the iSPEX project constituted a large-scale experiment in mobilizing thousands of participants to carry out complex measurements throughout the country. With more than 10,000 contributed measurements, this also proved very successful.

This citizen science project has been made possible because in 2012, the iSPEX-team (Leiden University, NOVA, SRON, KNMI and RIVM) won a €100.000 grant for translating scientific research to the general public. This money was invested in the development and production of 10,000 iSPEX iPhone add-ons and the development of a smartphone app. Apart from the scientific project partners, there was an important role for the societal partners of the project: Lung Fund, CNG Net, Sanoma and Avantes. In particular the Lung Fund (a patient organization for lung diseases) was an important partner for publicity, distribution of iSPEX add-ons and societal support of the project.

#### *16.2.3.2 iSPEX: The participant study*

The iSPEX project propagated a relatively new type of citizen science, where a large group of participants turn their smartphones into measurement device. Within this innovative type of citizen science, iSPEX distinguishes itself by collecting and transmitting data to a central database. In the Netherlands, the data collection was organized in two large-scale, nationwide measurement campaigns (and a scaling up in 2015 to 11 major European cities). Little is known about the participants of such projects. Consequently, a study among the Dutch participants was conducted in close collaboration with the department of science communication of Leiden University (Land-Zandstra et al., 2016). The study aimed to examine: (1) the motives and conditions of citizens for (continued) participation in the iSPEX project and (2) the impact of participation on citizens' understanding of both science and aerosols.

An online survey among participants showed that the project had attracted an older, male, well-educated audience, typical for many citizen science projects. However, the project did attract people with limited previous experience with science and scientific research. There are two dominant reasons for participants to join the iSPEX project: because participants want to contribute to scientific research, the environment or health and because of an interest in science or more specifically in aerosols and their impact on health and the environment. This resembles the findings in other citizen science projects where participants are excited to contribute to some greater good.

The respondents in this study self-reported that their participation in the iSPEX project taught them how citizens can contribute to science. This makes sense as for many respondents iSPEX was the first time they joined a citizen science project. Although there was some agreement that they learned something about aerosols and their impact on health, understanding of the science behind the project was rather low. Most importantly, people seem to expect immediate feedback on the aerosol load at ground level. Clearly, this is what they ideally want to have. However, the iSPEX measurements are indirect, remote-sensing measurements. This implies that organizers should find ways to improve the understanding of the science behind the project among participants. On the other hand, not completely understanding the science and technology behind the project did not decrease participants' enthusiasm about the project and their contributions.

**Figure 2: The iSPEX add-on on the left, instruction for taking measurements on the right**


From the participant study we learned that citizen science projects that use smartphones as measurement devices have the potential to attract a new audience for citizen science. The participants in this audience are primarily motivated by the prospect of contributing to a larger goal – science, environment or health. This suited the goals of the iSPEX project (to engage people and to improve the knowledge on environment and health) perfectly. Participants like the fact that the measurements take a limited amount of time and can be done individually. The participants wanted to keep informed about the project and results of the citizen science studies. Most importantly, the participants are highly motivated to frequently contribute measurements, also for longer projects.

The limited amount of self-reported learning and the limited understanding of the project imply that projects with citizen science measurements based on complex science face a challenge. This is to find ways to ensure that their participants understand what their measurements actually mean. The iSPEX project shows however that less than perfect understanding did not prevent that people contributed and enjoyed their participation.

*16.2.3.3 iSPEX – how to continue?*

The iSPEX project clearly demonstrated that in principle it is feasible to have a large group of citizens performing measurements, and that the results are scientifically valuable and complement professional measurements (mostly in terms of spatio-temporal resolution). The project was repeated in a European context with thirteen cities in eleven countries, see http://ispex-eu.org/. It was not difficult to find enthusiasm for the iSPEX measurements in a large number of European cities in 2015. However, to continue the iSPEX measurements on a more regular basis a significant investment would be needed in the technical development of the add-ons. The add-ons ideally would have to be designed in such a way that they become independent of or easily adaptable to any type of smartphone to be able to keep up with the latest models. In addition, a considerable investment would be needed to further develop a system for data retrieval so that all the information that is potentially stored in the data is indeed extracted. In addition, the data handling, visualization and storage in a database would need to be secured. Moreover, the operational costs for running such a project on the long run are significant. For all these aspects, additional funding is necessary and inbedding in a monitoring network to secure a stable support for the iSPEX observations.

### 16.2.4 Waag society Amsterdam Smart Citizens Lab

To experiment with more bottom-up citizen science approaches the Dutch National Institute for Public Health and the Environment (RIVM) participated in the 'Amsterdam Smart Citizen Lab' initiated by Waag Society in 2015 (Henriquez, 2016). Key idea of the project was that citizens developed tools and instruments that enabled them to register, measure and understand aspects of their direct living environment. Which type of environmental measurement to focus on was decided by the participants themselves. Waag Society supported this process by providing the facilities to build the tools in its Fablab. Typical Fablab (maker movement) facilities are a laser cutters and 3D printers. Waag Society collaborated in this project with a large number of partners, amongst others RIVM, Wageningen University and the municipality of Amsterdam.

Waag Society and its partners developed a 7-step research methodology called the Amsterdam Smart Citizens Lab Approach (Table 1).

**Table 1: The Amsterdam Smart Citizens Approach**

| | | |
|---|---|---|
| Step 1 | Meet | Citizens meet and get introduced to the topic |
| Step 2 | Match | Form groups on the basis of shared interests |
| Step 3 | Map | Elaborate, structure the problem |
| Step 4 | Make | Make the hard- and software |
| Step 5 | Measure | Collect data |
| Step 6 | Master | Analyze and visualize data |
| Step 7 | Mobilize | Create impact on other citizens and stakeholders |

Over the course of 7 months, between May until December 2015, citizens were free to participate in six workshops hosted at Waag's Makers Guild and Fablab. A Meetup page was set up to complement workshop lectures and open design days with an interactive digital space for facilitating group communication, announcing meetings and sharing member experiences. The next workshop functioned as a technical analysis, where researchers from Waag Society and RIVM gave in-depth lectures concerning the large number of affordable DIY sensors and measuring kits available on the market and their differences compared to professional sensors. Participants were introduced to successful online citizen science platforms like Zooniverse, New York Public Lab, various middleware technologies like Arduino boards, Wi-Fi, Bluetooth, and GSM modules, and additive manufacturing techniques that together make DIY sensing networks possible.

Researchers decided to drop the exclusive use of the Smart Citizen Kit(see: https://smartcitizen.me/), used in previous projects, in favor of a more open innovation model that gave the groups free use of the various fabrication tools found in Waag's Fablab after lectures. On open design days (hosted weekly) participants could ideate, design and build their own sensor assemblies with the hands-on assistance and mentorship of Waag Society's experts. Three teams were formed that focused on wind energy, air quality and noise pollution.

The outdoor air quality group, that included air quality scientists from RIVM and Wageningen University, developed five Arduino-based sensors and a sensing platform. Group members individually tested their sensors at home and convened in the Fablab to compare results and properly calibrate their sensing hardware. They originally wanted to gather data wirelessly but finally opted to use onboard SD cards due to time constraints.

The $NO_2$ sensor developed was drastically cheaper than those currently installed at official air quality measuring stations. Despite the air quality group's considerable progress, they still hadn't quite worked out all the hardware and software kinks. The sensors were in fact quite sensitive to moisture, humidity, sunlight and ozone. Because there are so many cross sensitivities, it appeared almost impossible to correct for all of them, and it was unclear which sensitivity was causing the sensor to gather data incorrectly. In the end, the group was successfully able to gather reasonable readings from over 27 locations around the city, store it on a Github-based server and generate a $NO_2$ map that showed that high-traffic areas had significantly higher levels of $NO_2$ while lower traffic areas had nominal levels. The groups' job was made a lot easier because it was a combination of both ordinary people and air quality sensor professionals (Jiang et al., 2016; Henriquez, 2016). An upgraded version of the same sensor was used in another citizen science project, Urban AirQ (see http://waag.org/en/project/urban-airq).

Lessons learned: when the project started the experts of the RIVM intended to take up a modest role as observers. However, they soon found themselves taking up a role as motivator and trusted source of information. Simply being present gave the participants the message that they were part of something that was scientifically meaningful. It increased the confidence in the project and participants were more motivated. The fact that experts could directly assess project ideas was also a great help to the participants. We learned that taking citizen science seriously is a self-fulfilling prophecy: if experts take citizen science seriously by providing support and information the chances of success increase. The support of experts was welcomed: "Finally an expert who listens". Timing is crucial, citizen scientists need *enough* information at an *early* stage, at the beginning of a project when the plans can still be adapted and improved. Nevertheless, too much information limits their freedom. Citizen scientists have different goals than EPAs and may want to measure with new technologies that are not yet established, or measure other pollutants for which there is not (yet) legislation.

### 16.2.5 Nijmegen Smart Emission project

Another project in which RIVM is a partner, is the Smart Emission project in the city of Nijmegen. This project has been initiated as a pilot project by Radboud University and the municipality. The project has its origin in the fields of Geographic Information Systems (GIS), Participatory Mapping and Planning, outside the disciplines involved in air quality. It started by a scientific research call called "Maps for Society", in which universities were asked to come up with creative ideas to innovate and study the available spatial data infrastructure and geo-information in the Netherlands.

The proposal was to create and test the proof of concept of a "citizen sensor network", with the creation of a 'feedback loop' of information, from interested participants to sensors and back. This would be realized with help of student work in analyzing data, ICT companies providing the new sensor technology (hardware and software) and help of (geo-) professionals in creating the necessary spatial data infrastructure. When the proposal had been granted, the project leaders formulated an approach that would enable measurement on a high spatial resolution in the city. At the time that a first sensor prototype showed that the technology for both batteries and long range data transmission would require significant Research & Development time, it was decided to work pragmatically with existing features of the city. This was necessary, as the pilot had to be conducted within a 2 years' time frame.

While the project took shape, the experts of the environmental department within the municipality became more involved and more enthusiastic. The Alderman of the municipality responsible for Environment affairs also turned out to be positive and supportive about the pilot experiment. When the first sensors developed by SME companies "Intemo" and "CityGIS", were ready, the consortium called for volunteers to accommodate a sensor (offer a power-supply and WIFI) in a local door-to-door magazine. Shortly after that, the first reactions came in. Currently there are 34 sensors in gardens, balconies or other suitable private outdoor spaces. The sensors do not only register air quality, but also noise, light intensity, low frequency vibrations, temperature, air pressure and relative humidity.

Apart from the municipality and the university, the project has several partners, amongst others RIVM and Geonovum. RIVM has two measurement stations of its air quality monitoring network in Nijmegen. The goals of the Smart Emission project are complementary to those of RIVM. The project wants to study how local data with small and cheap sensors relate to the data of the RIVM air quality measurement network (see: [http://smartemission.ruhosting.nl/wordpress/wp-content/uploads/2016/05/Poster-Explaining-Smart-Emission-project-Geonovum-ENG.pdf](http://smartemission.ruhosting.nl/wordpress/wp-content/uploads/2016/05/Poster-Explaining-Smart-Emission-project-Geonovum-ENG.pdf)).

The sensors that have been installed in May 2016 are measuring 24/7 and are still in operation at the time this chapter is being written. A network of small sensors asks for a different approach than that of an expensive monitoring network, for instance, the dataflow and data algorithms need to be able to work with downtime of individual sensors, which may shut off temporarily, for instance when the interior gets too moist.

During the project a clear decision was made to be open and transparent. The research team shared the information portal and "raw measurements" to citizen participants and other researchers as soon as they were available, and asked for direct feedback. In this way, the citizens were taken on board as co-working citizen participants. For example, a digital forum for questions and answers was added to the portal, on the request of citizens, so that discussions between researchers and participating citizens could take place in between meetings. In the course of the project, the research team learned a lot about participants needs and wishes, and the participant learned about the the process of gathering raw data, the construction of a data infrastructure, etc. This approach contributed to an increased a level of mutual trust.

Lessons learned:

Important first result of the project is that it shows that it is possible to create a relatively low-cost network to monitor environmental parameters with citizens.

Open data and transparency in all aspects related to the project created trust and a better understanding for both citizen participants and experts. The citizens showed a lasting interest in the project.

Intriguing observations during the project were about the interdisciplinary dialogues and the cultural differences between disciplines and professions. It became clear over the course of the project that learning-in-action-while-measuring-and-processing was an important feature of the project for both the involved researchers and citizens. For instance, when the sensor developer contacted the RIVM professionals about a climate room test, a misunderstanding ensued because they thought a few hours would conclude the tests, whereas the RIVM professionals were thinking in terms of weeks.

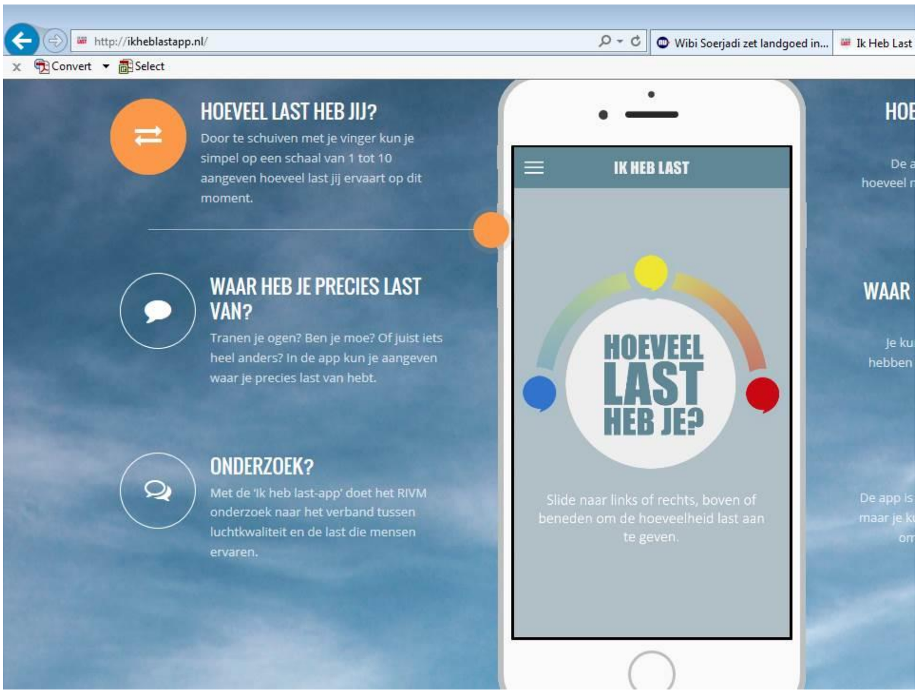
Another relevant finding is that there are large differences between citizens in their information needs. Graphs and pictures satisfy some citizens, but others prefer to have the figures, the data behind the visuals. This shows the importance of transparency and flexibility to present the resulting information in various ways.

16.2.8 Ik heb last app http://ikheblastapp.nl/ (I suffer now app)

The 'Ik heb last app' (I suffer now app) is innovative because it directly uses the health complaints of individuals as indicators for environmental issues. The air quality in the Netherlands is continuously improving. Nevertheless, there is a significant number of people that suffer from air pollution. Consequently, the society asks for tailor-made information: ‘Can you please indicate, preferably in advance whether I will suffer from air pollution? That would enable me to match my activities and medicine use with this situation.’ For the Dutch population as a whole we can make an estimate of the levels of pollution that will cause health issues. On the individual level this may mean something completely different. When will **I** suffer?

The purpose of the “I suffer now” app was that it would enable citizens to indicate that they have issues with their respiratory system. By matching this report with different air quality conditions, a pattern can be derived (by using ‘big data’), which enables a forecast of the sensitivity at the individual level. This forecast provides the user of the ‘I suffer now’ app the opportunity to plan activities and medicine intake. For RIVM and its' partners the data gathered with the app, would provide means to improve the identification of causes of (exacerbations) of respiratory symptoms. Moreover, the project is a test to investigate whether citizens are willing to participate and which incentives are important for their participation.

**Figure 3: Screen dump of the ‘Ik heb last app’ (I suffer now app)**




The user of the app can indicate: 1) the level of suffering and 2) the specific symptom((s). The feedback provided shows: 1) the level of suffering in the Netherlands and the level on a specific location and 2) the symptoms of other app users. RIVM collaborated in this project with Friends of the Earth Netherlands, Lung Fund, Utrecht University and Hogeschool Rotterdam.

Lessons learned: The project is innovative but complex, perhaps a bridge too far for now. As the information needed for feedback to the user is not real-time available users get disappointed. More and more direct feedback proves necessary. However, it is very attractive and a great way forward to measure the effect on health directly, and on an individual level. The coming years will show how this approach may best be deployed.

### *16.3 Innovation of the Dutch national EPA*

Considering everything we learned from the various citizen science projects we participated in, a number of recurring themes emerge that are relevant for an EPA and its societal partners:

1. Citizens are highly motivated to contribute air quality measurements that are complementary to the existing measurement networks because of their high spatio-temporal resolution;
2. There is a need for assimilation of data in e.g. models;
3. There is a need for the development of useful low-cost sensors;
4. There is a need for application calibration and validation of low-cost sensors;
5. There is a need for easily accessible expert information.

The second point, the assimilation of data in models, is perhaps the most challenging, and vital to ensure continuity of the measurements and motivation of citizen scientists. Applying the data asks for flexibility; this means coping with data that do not meet high quality standards of official monitoring networks. Data science may help dealing with cross-sensitivity or instability in measurements. Modelers may be able to include data with a lower accuracy or of a different nature than we are used to. At RIVM we have concluded that we should aim to make citizen science measurements an integral part of our existing national monitoring network and to employ the data in our real-time modeling procedures. The innovation of the monitoring network that we currently are working on is intended to provide a stable basis for the testing, calibration and use of citizen science data.

A natural role for the EPA as a reference institute is to assess the quality of the data. In practically all the citizen science projects we participated in, the quality of the data was a big issue. Although most relatively cheap sensors measure at least something, the relationship with official air quality measurements is often not very good and sometimes completely absent. It is clear that the measurements by national EPAs can serve as a reference to aid calibration of cheap sensors that are used in citizen science projects.

Sensors for, among others, air quality and Internet of Things applications are developing in a rapid pace. Hence, at RIVM we expect that within five years our network for measuring air quality can evolve from a network with a limited number of high quality (reference) measurement stations to a hybrid system that uses a much larger number of sensors that are cheaper and have a lower quality. Where possible, satellite data will also be integrated. A limited number of high quality measurement stations forms the reference base of this system. By combining all these data of varying quality and levels of uncertainty with models, a cost efficient way of monitoring will be realized. This results in a ‘crowdsourcing’ system that provides local communities with trusted local environmental data and at the same time enriches the national system for air quality monitoring. In this evolution different phases are distinguished. At RIVM we developed a roadmap for innovation of environmental monitoring, as illustrated in Figure 4. The different steps are defined in a lenient manner and timelines are not strict but help us to target our innovation program in the coming 5 years.

<u>Phase 1</u>
In the first phase, started in2016, we implement efficiency actions (e.g. automate some steps in the validation process) and make a plan to decrease the number of measurements (stations), which will create the capacity for innovation, while still complying to the requirements laid down in the EU directive. This requires that difficult decisions will have to be made about what measurements or measurement stations may be discontinued. Our innovation program aims at balancing the effects of the foreseen reduction of the monitoring effort on monitoring quality by introducing new lower-cost sensor technology into the network. The goal is to keep or even increase the quality level of our

monitoring program in this way. In the same period six of the official measurement stations (four of RIVM, one of GGD Amsterdam and one of DCMR, our monitoring partners) will be equipped with a facility to test small sensors. The facilities are open to citizen science communities and sensor builders to test and calibrate their sensors. The locations of the small sensor test stations are chosen to represent a broad range of measurement situations. There will be a rural site, an urban traffic station, two highway sites (one urban, one rural) and an industrial site. In addition, we will make a start with devising a test facility for small sensors in a climate chamber. The small sensor test stations will also be used to try out sensors employed by RIVM itself or by partner institutes. An example medium-cost sensor platform for air quality monitoring which is tested is the AirSensEUR (see box 1).

Phase 2

In the second phase, around 2018, advanced yet relatively cheap (still expensive for use by citizen science projects) sensors will be included in the national air quality monitoring system. The use of satellite data is included, where possible. Extensive tests will have to be performed to see how these sensors behave over longer periods, like a year. The practical effect of trading a limited number of reference measurements for (much) more cheap sensors on the uncertainty of the air quality monitoring will be determined.

**Box 1: AirSensEUR**

An example of a medium-cost sensor kit is the AirSensEUR developed by a consortium led by the Joint Research Centre (JRC). Together with partners like NILU and AirParif we will test the medium-cost sensor kit for air quality monitoring, two AirSensEUR kits on each small sensor test station. As the AirSensEUR aims to be used in several countries within the EU, the interfacing to users, expert as well as non-expert, faces the same challenges as we are addressing at RIVM.

AirSensEUR is an open framework focused on air quality monitoring using low cost sensors. AirSensEUR aims to implement a low cost, battery operating, accurate air quality monitoring system to:

- Sample a set of chemical sensors like, for example, $O_3$, NO, $NO_2$, CO and $SO_2$ from several manufacturers including Alphasense, City Technology, Membrapor and SGX Sensortech
- Sample a set of auxiliary sensors for temperature, air pressure and relative humidity
- Aggregate samples with optional GPS localized information
- Store aggregated samples in a local database
- Periodically update an external server through WiFi or GPRS channels

The air quality monitoring host board is the heart of the system and is able to connect with several sensor shields. The host board aggregates measurements, generated by sensor shields, with geographical coordinates. The resulting dataset is stored locally and periodically sent to a public database.

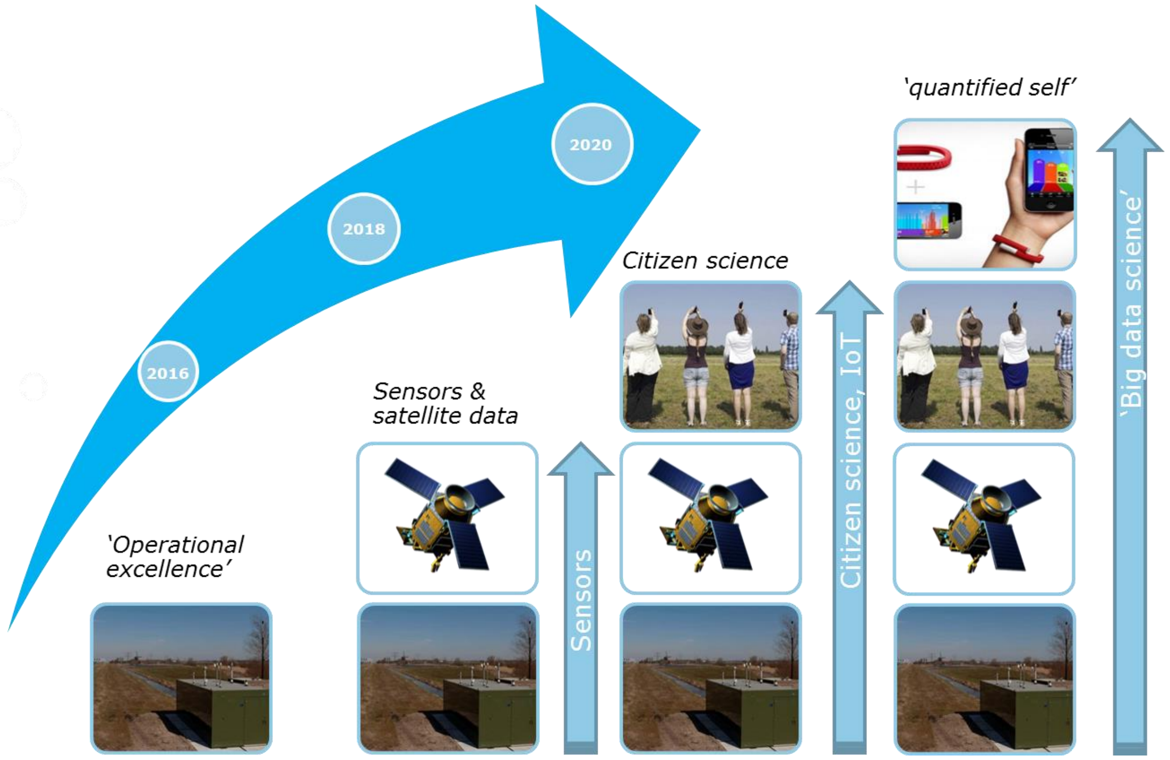
Phase 3

In the third phase, envisioned to be fully implemented around 2020, RIVM gradually develops a ‘crowdsourcing’ platform, which enables citizen science projects with low-cost sensors to participate in the national monitoring. The second and third phase will ask for creative solutions that enable the simultaneous use of data with different quality levels (data science). In order to achieve the ‘crowd souring’ platform in 2020, we will start new pilot projects with different degrees of citizen involvement along the way. A limited number of reference measurement methods will act as the backbone of the national monitoring but will be supplemented with a flexible layer of alternative, low cost sensor devices. Continuous validation cycles of these ‘low cost’ sensors with reference data will result in the gradual improvement of available sensor technologies.

Beyond phase 3

While environmental monitoring technologies are evolving, so do technologies for health monitoring. For health, technologies related to mobile healthcare (mhealth, “quantified self”) are rapidly maturing, e.g. GIS tracking to support individual exposure modeling, personal health measurements like heart rate or spatiotemporal tracking of medication use. They provide an excellent opportunity for environmental health research to become a key innovation partner in health transition technologies. Integrating environmental with health monitoring will give huge possibilities for follow-up innovation. Beyond phase 3, we foresee to combine our static air quality monitoring network with personal exposure and health monitoring. This is an important focal point of our roadmap that stretches beyond 2020 and is beyond the scope of this chapter.

**Figure 4: Innovating a traditional measurement network towards a hybrid 'crowd sourcing' platform**




## 16.4 *National EPAs firmly embedded in society*

An important reason to support and participate in citizen science is that RIVM as a knowledge institute wants to get out of the well-known scientific 'ivory tower' tower'. Citizen science is one of the approaches to shape science-society interactions in a more interactive and reflexive way. With reflexive, we mean that scientists are aware of the potential societal effects of their research and take these into account in their choice of research objects, methods and approaches. It is assumed that the reorganization of governmental scientific advising, along the lines proposed by reflexive scholars, will increase the accountability, quality, effectiveness and legitimacy of scientific expertise in society (Functowicz and Ravetz, 1993; Nowotny et al., 2001; Jasanoff, 2003).

Citizen science is not only beneficial for its' organizers. For citizens, the participants, it provides the possibility to democratize science, to learn about air quality measurements. In a relatively recent literature review Haywood (2014) collects the claims about the benefits of citizen science for its participants (Table A.1 in the appendix). We are aware that in the hybrid 'crowdsourcing' platform we will include citizens only at the basic level and ask them to operate as "sensors" (Haklay, 2012). Nevertheless, an evaluation of the iSPEX project (Land-Zandstra et al., 2016. See 16.2.3.2) shows that even on these low engagement levels citizens are able to learn significantly. Much of the benefits mentioned in this section are dependent upon the interactions at the local level and the way that the data is returned in e.g. maps and is being explained.

Important for the success of a hybrid 'crowdsourcing' measurement system are the motives of those who take the local initiative. Quite often, the initiative for an air quality citizen science project is (at least partly) taken by a municipality. For municipalities, citizen science provides the opportunity to improve the connection between citizens and their living environments; the environmental conditions of their direct local vicinity. This implies that municipalities usually prefer 'local' citizens in their environmental sensing projects, although there is the possibility to exclude them. Excluding citizens means e.g. that sensors are mounted to lampposts or bus shelters and are directly connected to Internet using a global WiFi network or LoRa. In fact, such an approach is by definition not citizen science.

## ***16.5 Fostering the connection with society and way ahead***

### 16.5.1 Fostering relationships with society

One of the most important lessons about the involvement of EPAs in citizens science with small sensors is that this meets a lot of enthusiasm by local partners, as we can really help them to obtain better data. However, a lot of learning on several aspects is needed. E.g. about the governance of long term data collection, about the dissemination of results, about the use of platforms with open data and about clever techniques that help to drive this development further.

Another lesson from participating in the several citizen science projects is that the need for information and data among citizens is very diverse. In the Smart Emission project in Nijmegen both a demand for more information and detailed insight in the underlying raw data was noted, but also explicitly a demand for less information by other participants: "I just want to know if it is good or bad". We note that although some people wanted to have the data in a very simplified form (simple color code or smileys), the fact that the underlying "complicated" data was available did give them more confidence in the data and the project. The project was not "holding back data". It is therefore crucial that the data is open and available at a very basic level. And it is crucial that the data is presented at different levels of complexity and in different forms (numbers, graphs, color codes, etc.).

A worrying observation is that the 'soft-side' (organization, motivation, learning, democratization of science) does not always gets the attention it deserves. Often a project starts from groups of passionate researchers and engineers. The result is that a lot of time and effort is invested in sensor development, calibration etc., while the development of a 'local sensing community' remains a relatively small activity. This was also the case in the EU Citi-SENSE project (EU Citi-SENSE, 2016). One of the challenges of projects based on complex science is to find ways to make sure participants (who may invest only a small amount of time) receive information about the underlying science and have some understanding of what their measurements actually mean.

### 16.5.2 Way ahead

An interactive knowledge and data portal for citizen science related to air quality monitoring is currently developed at RIVM within the roadmap 'Innovation of Environmental Monitoring'. This portal will be made in open collaboration with citizens. It aims at making the tools to connect to the citizen by supplying knowledge and data in a way that is understandable to the interested public, and that has been adapted to their needs. We would like to become an important source of information for air quality related citizen science in the Netherlands. Plans are to experiment with short (20 to 40 seconds) easy-smartphone-made videos, for example to answer frequently asked questions: "What is ozone? What is PM10?". Because these videos are made with simple devices we should be able to react fast to questions and have them ready in a couple of days at most. Moreover, we intend to make series of short videos to introduce or explain different types of innovative measuring devices, or explain background information: What is fine dust composed of? What are the health effects of air pollution? Finally, we will make slightly larger tutorials for people who want to know more about how to build their own sensor kit or about how to download data (see e.g. Hoe doe ik een iSPEX meting? (How do I do an iSPEX measurement?) on https://www.youtube.com/watch?v=vF0Hd4v1I8Y). We focus on air quality because of a strong interest of citizens, technological innovations and the authority role of RIVM in monitoring air quality. However, generic knowledge and experience gained may be used for other environmental domains like noise, light, radiation, soil and water. By providing a knowledge and data portal we encourage and support long lasting data collection by citizen science projects. Consequently, citizen science will be an essential element of Dutch national monitoring networks.

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Appendix A

**Table A.1 : Claims about Citizen Science Participants Benefits (source: Haywood (2014))**

| Citizen Science Participant Benefit | Citation |
|---|---|
| *Enhanced science knowledge and literacy* (e.g. knowledge of science content, science applications, risks and benefits of science, and familiarity with scientific technology) | Braschler et al. (2010), *Brewer (2002), *Danielsen et al. (2005), Devictor et al. (2010), *Evans et al. (2005), *Fernandez-Giminez, Ballard & Sturtevant (2008), *Jordan et al. (2011), Krasney and Bonney (2005), Sullivan et al. (2009) |
| *Enhanced understanding of the scientific process and method* | Bonney (2004), Bonney and Dhondt (1997), Braschler et al. (2010), Devictor et al. (2010), Sullivan et al. (2009), *Trumbull, Bonney and Grudens-Schuck (2005) |
| *Improved access to science information* (e.g. one-on-one interaction with scientists, access to real-time information about local scientific variables) | *Fernadez-Giminez et al. (2008), Sullivan et al. (2009) |
| *Increases in scientific thinking* (e.g. ability to formulate a problem bases on observation, develop hypotheses, design a study, and interpret findings) | *Kountoupes and Oberhauser (2008), *Trumbull et al. (2000) |
| *Improved ability to interpret scientific information* (e.g. critical thinking skills, understanding basic analytic measurements) | Bonney (2007), Braschler et al. (2010) |
| *Strengthened connections between people, nature, and place* (e.g. place attachment and concern, establishment of community monitoring networks or advocacy groups) | *Devictor et al. (2010). *Evans et al. (2005), *Fernandez-Giminez et al. (2008), *Overdevest et al. (2004) |
| *Science demystified* (e.g. reducing the 'intimidation factor' of science, correcting perceptions of science as too complex or complicated, enhancing comfort and appreciation for science) | Devictor et al. (2010), *Kountoupes and Oberhauser (2008) |
| *Empowering participants and increasing self-efficacy* (e.g. belief in one's ability to tackle scientific problems and questions, reach valid conclusions, and devise appropriate solutions) | *Danielsen et al. (2005), Lawrence (2006), Wilderman, Barron and Imgrund (2004) |
| *Increases in community-building, social capital, social learning and trust* (e.g. science as a tool to enhance networks, strengthen mutual learning, and increase social capital among diverse groups) | Bell et al. (2009), *Danielsen et al. (2005), *Fernandez-Giminez et al. (2008), *Overdevest et al. (2004), *Roth and Lee (2002), Wilderman et al. (2004) |
| *Changes in attitudes, norms and* values (e.g. about the environment, about science, about institutions) | *Danielsen et al. (2005), *Ellis and Waterton (2004), *Fernadez-Giminez et al. (2008), *Jordan et al. (2011), *Melchior and Bailis (2003) |

Studies that have empirically tested outcome hypotheses and reported results are noted with an asterix.