FILLING THE FEEDBACK GAP OF PLACE-RELATED 'EXTERNALITIES' IN SMART CITIES: Empowering citizen-sensor-networks for participatory monitoring and planning for a responsible distribution of urban air quality

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Abstract

With this paper, we present the set-up of the pilot experiment in project "Smart Emission", constructing an experimental citizen-sensor-network in the city of Nijmegen. This project, as part of research program 'Maps 4 Society,' is one of the currently running Smart City projects in the Netherlands. A number of social, technical and governmental innovations are put together in this project: (1) innovative sensing method: new, low-cost sensors are being designed and built in the project and tested in practice, using small sensing-modules that measure air quality indicators, amongst others NO2, CO2, ozone, temperature and noise load. (2) big data: the measured data forms a refined data-flow from sensing points at places where people live and work: thus forming a 'big picture' to build a real-time, in-depth understanding of the local distribution of urban air quality (3) empowering citizens by making visible the 'externality' of urban air quality and feeding this into a bottom-up planning process: the community in the target area get the co-decision-making control over where the sensors are placed, co-interpret the mapped feedback data, discuss and collectively explore possible options for improvement (supported by a Maptable instrument) to get a fair and 'better' distribution of air pollution in the city, balanced against other spatial qualities. The approach is based on the philosophy of 'bottom up urban planning,' from local places to city-government levels. With this pilot project we analyse how planning practice can benefit from seizing the opportunity of enabling technologic capacities and advancements of small and low-cost sensors, sensor data, Spatial Data Infrastructures and dispersed Geographic Information Flows. In our view, focusing these technological innovations on what economists call 'externalities', brings these externalities on the table and puts them in the spotlights for the eyes of citizens and city-planners. Being measured and counted transforms externalities as air quality from 'unaccounted for, invisible side-effects', treated separately from economic choices, into traceable 'feedback' about the state of our cities, and our own role in it.

We aim to present the first intermediate empirical experiences while executing the pilot project at the Aesop 2015 conference, as the first few sensors are rolled out in the pilot area at the end of June 2015. At Aesop, we seek a dialogue about these types of new ways of planning practice and planning support (for instance using many low-cost sensor measurements as input), and using Open data for processing real-time analyses for sustainable cities in smart, affordable and democratic manners.

1. Introduction

This paper describes the set-up of a citizen-sensor network measuring air quality in the urban built environment. The municipality Nijmegen and Radboud University have taken up the challenge to experiment with new, low-cost sensor technologies in combination with a participatory approach with citizens living in the city, building on previous knowledge of citizen-sensor-networks.

Planning for externalities; the case of air quality pollution in cities
The assumption is, that so-called 'externalities', e.g. those effects of activities that are not incorporated in peoples and businesses their internal assessments, are accumulating in cities, with air pollution as prime example. In economics, an externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit (Buchanan and Tubblebine, 1962). Air quality in the city typically is not chosen by the residents; they have no choice in breathing other air (besides wearing a personal filter outdoors, and install private filter machines indoors). In economic terms the outdoor air quality is generally seen as a public good. However, one may argue, if too many people interfere with the public 'good' lowering its overall quality, the collective air quality gets the character of a common pool resource,[1] because enjoying places where relative clean air can be breathed then may become rivalrous, with better and worse places in the city.

Moreover, the choice to pollute air quality is not an effect of conscious choice and direct intentions; industry manufacturers and car drivers do not pursue their activities with the prime intention to pollute the air, instead, it is a 'collateral damage' inherently included in present day's (fossil based) energy providing technologies, as 'unfortunate consequence' if someone chooses to drive somewhere, or to manufacture something. Because these externalities are treated 'outside' the defined economic system, for example treated as "pm-posts" in cost-benefit analyses of urban development decisions, there is no accountancy system that represents the growing negative effects in terms of costs of a gradually growing level of air pollution. In our current economic system, since there is *no price on pollution*, this collateral damage is not economically assessed in trade-offs and daily decisions, not accounted for in economic business performance, and thus may be seen as present-day *accumulated externalities of the city as urban system*.
Legal environmental norms are often in place to deal with these externality issues. But these norms only signal when a certain upper level has been met, it does not attribute financial costs to a growing accumulation of the externality itself; thus below the norm, no trigger exists to counterbalance growing externalities. However, in the long term, ever growing levels of air pollution in places where people live, breath and sleep, have a noticeable negative effect on people's health. This, in turn, may evolve over time into a decreasing attractiveness of cities for its citizens. In Chinese cities, we already see the effect of high levels of air pollution in cities, caused by traffic, energy plants and industries running on fossil fuels (coal, oil, gas), which all impact air quality negatively.

According to more classical theories on urban dynamics, f.e. Forrester (1969), balancing of relative *attractiveness* of a city has a '*feedback*' effect on its residents, which over long periods of time may decrease the level of city-inward migration. If citizens will respond to spatially differentiated levels of air quality, treating it as a common good instead of a public good, then high-income classes may leave the city centres to live in suburbs with higher air quality, increasing their living standards in relation to those that cannot afford to leave the high-density, highly polluted city areas where the air quality is relatively bad. From a spatial justice point of view, this is an undesirable scenario. Because the expectation of living in an environment with a healthy level of air quality should not be a matter of social class, but a matter of dignity and civilized practice, and thus of good city governance. Therefore, managing air quality (and other 'externalities') to achieve sustainable levels of pollution across the whole city, is a responsibility of city government and city planners.

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[1] For a short explanation of the characteristics of common pool resources, public goods, private goods and club goods in Economics, see: https://en.wikipedia.org/wiki/Common-pool_resource

Objective of this paper
This paper argues, that in order to plan consciously for a healthy city on the long-term, the 'externality effects' of decisions like new infrastructure plans, zonal plans and permits for air polluting activities, should be taken into account. For that purpose, effects on air quality should be an integral part of these urban planning processes. It would help, in our view, if the effects of planning decisions could be better quantified in terms of its effects on local air quality. For this purpose, we envision installing a *citizen-sensor-network* that serves as 'information feedback loop' informing city government and citizens of the day-to-day state of affairs in the city (on the topic of externalities, in this case air quality). The hypothesis is that this information feedback loop helps in increasing insight in the sources and spatial behaviour of local accumulations, that it *raises awareness of the level and spatial spread* of the phenomenon of externalities like 'air pollution clouds' in urban areas. As real-time feedback provider, citizen-sensor-networks can serve as direct 'test-bed' for testing local interventions to improve the level of air quality.

Main argument, expressed in the title of this paper:
Currently, in many cities there is no direct feedback information what particular (local) urban planning decisions mean for the urban air quality. Collectively however, such decisions, including the daily decisions of citizens (for instance, do they commute to work by electric or fossil-fuel powered car, bus, or bike) do have an impact on the cities air quality, which in turn may have a longer term impact on the city's health and attractiveness. By establishing a fine-grained network of monitoring sensors, in places where people actually live and breathe the air on a daily basis, this 'feedback gap' may be filled. With this monitoring information on the table, city planners, and citizens making daily choices in life and work, are better equipped to make rules, regulations and planning decisions with inclusion of trade-offs regarding the effects on urban air quality; not only for the city as a whole, but also on sub-city scale, for specific spaces and areas where 'air pollution clouds' may accumulate.

Project goal:
The project aims to establish an innovative citizen-sensor-network in a real-life 'urban lab' setting, building further on the knowledge of technical and social innovation in implementing such a new citizen-sensor-network, and reflect on the feedback provided by the new information, and its potential consequences for citizens and government to explore new venues and options to further improve local, urban air quality in dedicated places.
Today's technical advancements enable such innovations of citizen-sensor-networks, because more and more low-cost sensors are being invented, wireless communication infrastructures provide the means for information loops to be established over longer distances against relatively low costs, and big data tools are becoming available that make the handling of massive amounts of data-flows affordable and doable.

Research questions implementing a citizen-sensor-network:

1. Do low-cost sensors add to the fine-grained picture of air quality indicators? Can we trace an 'air pollution cloud' accumulating in certain places in the built environment?

2. Can we combine these measurements with other (modelling) information for informed citizens and government?

3. Does sense-making with citizens work? What is the citizen-science contribution?

4. If the concept works, does this open up opportunities for bottom-up spatial/traffic/urban planning to further improve quality of living and health?

5. Reflective: (How) do roles of government and citizen change?

Central element in the research questions are the notion of 'fine-grained' constellation, tracing 'pollution clouds', and 'sense-making'. The fine-grained constellation and tracing of pollution clouds will be discussed in the setup of the pilot project. Sense-making is seen here as a process of continued

redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data and is more resilient in the face of criticism or competing narratives (based on Weick, Sutcliffe and Obstfeld, 2005). Klein, Moon, and Hoffman (2006) define sense-making as "a motivated, continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively".

Research approach

The research conducted is shaped by the ideas of *action research*, constructing a pilot-version of a citizen sensor network in practice in the real city, with the aim to become and remain operational during the research project. The research project takes place from January 2015 until December 2016.

In order to establish a pilot citizen-sensor-network in the city of Nijmegen, a consortium was formed among (1) technology providers; two small-medium enterprises in innovative IT application areas, hardware and software in the area of geo-information services –with experience in applications in the field of safety, who develop the new, low-cost sensor that can sense air quality indicators (Intemo), and set up the information infrastructure making use of cutting-edge standards for data exchange and visualization (CityGIS), (2) the municipality government, Nijmegen, (3) the university, Radboud University (4) a national knowledge institute on geodata and standards, Geonovum (5) the national institute for health and environment, RIVM, who operates the national air monitoring system, (6) citizens living or working in the pilot area.

Citizens are involved according to theories and literature about *learning in communities of practice*. Knowledge creation is considered not a linear process of experts discovering new knowledge, disconnected from its context, and then transferring it to others in a production-consumption type of action. Rather the construction of knowledge is considered a social process among various social worlds and among various groups, including the eventual 'stakeholders' who are attached to their place of living and working, and because of this place-attachment, are subjected to daily breathing the air in the pilot area for considerable periods of time.

Together the consortium implements the project 'Smart Emission' (see Figure 1), a project in the context of national research program "Maps 4 Society" and executing projects in so-called Living Labs, to learn about smart city concepts and applications enabled by IoT (Internet of Things).

Figure 1 The Smart Emission consortium.

Scientific relevance
The project incorporates several research issues in the Internet of Things (and People) and (big) data sphere, incorporated in the national research program "Maps 4 Society."

Big Data research issues:
- Innovative small, low-cost sensor technology and data infrastructure
- Combining expert equipment and low-cost citizen sensors
- Data and communication standard (sensorThings API)
- Visualisation and sensemaking of data and information: 'piping' information through small and large information cycles)
- Big data, use, data sharing, information exchange, issues like data ownership and privacy

Bottom-up/co-creation planning research issues:
Furthermore, the project aims to address the issue of the role of citizens in such citizen-sensor-networks, and the relation between citizens and city-government in the monitoring and governance of their neighbourhood and quality of public space. Similar to the way Portugali (2006) sketches the conception of place and space in geography as two faces of the same coin, as two forms of information compression, it is possible to understand bottom-up citizen networks and top-down governance regimes as two faces of the same information compression process of a planning problem. The sensor network sits in-between those two worlds, or actually different sensor networks work in parallel for both sides. The sensor networks may be seen as *boundary objects* that mediate between the different social and institutional worlds: lay versus expert; experience versus quantitative model; local-scale needs versus national interests; human-environment interactions versus human-human interactions. As such, citizen sensor networks provide a language that unifies actions and strategies of allied actors in communities and citizen movements. In this sense, they have the potential to change or bring forward the policy-making social-institutional infrastructure on top of, or rather as a result, the technical sensor network itself. As a hypothesis or question, resulting from our findings, we suggest to speak of a co-evolution process.

Societal relevance
In the city of Nijmegen (see Figure 2), a policy debate has been going on for years, about the air quality in the Western part of the city, where industry, road traffic and river traffic come together. Heavy international inland shipping is crossing the city through the Waal river –the river branch of the Rhine between cities Nijmegen and Rotterdam is called the 'Waal' in the Netherlands– . Since a new bridge is being opened over the Waal river, giving the city a second bridge for road traffic in November 2013, more car-traffic is entering the city, contributing to more air pollution. The municipality is measuring this air pollution with two highly advanced permanent monitoring systems installed in the city, which belong to the national air quality monitoring net which serves to report about air quality according to norms institutionalized in legal regulations (for the Dutch and EU government). Next to these permanent, large, advanced air quality measurement stations, several other measurement campaigns have been conducted in the city. The maintenance and the hiring costs of such temporary measurement campaigns make it a costly endeavour. This project looks if small, low-cost electronic sensors can form an alternative for expensive measurement campaigns. If so, the city could extend this low-cost, small sensor network and maintain its operational function, and remain in constant dialogue with its citizens about local air quality. The project thus has a clear societal dimension.

Structure of the paper
In section 2, the background of this pilot project is summarized, as this project is a follow-up of an earlier project conducted last year. The main lessons of the previous research projects are outlined, as these are inputs for the project Smart Emission.
In section 3, the theoretical literature is briefly discussed, followed by an inventory of comparable projects in practice, in various cities, concerning citizen sensing in the field of air quality monitoring.

In section 4, the setup of the pilot project Smart Emission is explained. Especially the fine-grained constellation of the measurement network, the sensor specifications, and the level of citizen participation are discussed. Also, the use of small and long information cycles is explained, as these information cycles provide the multiple forms of feedback to citizens that this paper wants to address.

In section 5, a closure and conclusion is drawn. Because the project has just begun, no concluding results can be provided at this stage. With the outline of the project setup, we aim to exchange knowledge on our intermediate trade-offs and choices how to go about in achieving a citizen-sensor-network that lives up to expectations, and can fill the noticed feedback gap in city planning, for a better considerations of these 'externalities' in future planning decisions.

Pilot project in the city of Nijmegen

Figure 2. Location of the city Nijmegen in the Netherlands, near the border
with Germany and along the river Rhine (locally called the Waal).
Source of map: http://ds-lands.com/data_images/countries/netherlands/netherlands-02.jpg

2. Background

In a previous paper of Aesop 2014, we presented the results of an analysis of two citizen-sensor-networks, that were initiated by citizens. Those were the Groningen Earthquake monitoring network[2] and the Schiphol Airport noise monitor[3] (Carton and Ache, 2014).

Both cases tell the story of a region where capital-intensive economic activities, with national importance in terms of revenues for the State's treasury, have large impact on the local spatial environment and livelihood of local communities. The economic activities of large scale gas extraction in Groningen, and an intensively used airport at Schiphol (Amsterdam airport), have large impacts on their spatial surroundings, in a wider area than the immediate territory of the economic sites themselves, being it an airport or gas-pumping site. Many of these 'shadow effects' on neighbouring communities are valuated negatively for the vast majority of the local community, most notable noise and sleep-disturbance around Schiphol, and earthquakes –with related safety risks and damage to houses and other built-up constructions, such as century old churches, monuments and dikes, due to large-scale gas extraction in the region of North-East Groningen. As these effects are currently not represented in the economic system, rather than as un-priced 'externalities,' the appearance of these

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[2] 'Bevingskaart' of Gasbevingen portal of the GBB, a non-gouvernmental organization
[3] Google Earth vliegtuig monitor, part of Platform Vlieghinder Castricum

local impacts remains rather 'intangible' or 'invisible', until groups of (affected) people bring a discourse to the forefront that something is wrong, and governments should intervene.

We have studied the emergence of citizen-sensor-networks in these two cases; initiated as citizen initiatives outside the realm of government. In both cases an entrepreneurial pioneer with ICT skills took up the idea to build a monitor and map the extent, frequency and intensity of the particular 'externality,' earthquakes (Groningen) or noise (Schiphol) themselves, with help of a growing community. In both cases, a social network formed and was adopted by (or formalized into) an official organisation (foundation, non-governmental organisation). In the case of Schiphol, the monitoring network, institutionalized into a foundation, was adopted by a network of municipalities. In Groningen, there are debates that an information platform should be erected at the Province, the regional government body. Currently, the official information about gas extraction is in the hands of the gas-extraction company NAM (Netherlands Gas Enterprise), a fossil fuel company owned by Shell and Exxon Mobile who are primary co-owner (60%) of the gas field as part of the 'Groningen Maatschap,' together with the State as secondary co-owner (40%) of the fossil fuel reserve. The firm NAM is deeply mistrusted by the local community.

With building an own information base, the local citizen communities formed a 'fence' against hegemonic State practice. The fence, in both cases, delivered an information bases which served as resource of power for the local community, in their fight against the national government regime. The State's ethical stance in relation to the low-scale, local community interests may be questioned, as initially, despite signals of nuisance and risks for local communities, in the name of (neoliberal) economic objectives and "State interests", in both cases a 'card blanche' was given to profit-making activities (airport operations and gas extraction) without proper consideration of the side-effects and the resulting 'externalities' that fell on the shoulders of the local communities. In both cases, gradually the hegemonic discourse and its associated power balance and social order shifted, but only after considerable local resistance, and after the resistant groups brought measured evidence to the table (or more precisely; to the media) that backed their alternative narrative with verifiable knowledge.

We learned from these case studies the following lessons:

1. **Citizen-sensor-networks attributed to collective sense-making and worked to find common ground**

   - Combining the various collected measurements, over time and over space through a multitude of sensors, the citizen-sensor-networks bring about a kind of *'bigger picture,'* especially with simple map images that visualize an overall picture of the territory;
   - The web maps of the studied citizen-initiated monitoring tools represent the affected communities' live worlds in *understandable format* that lay-people can understand (in contrast to thick government reports);
   - *Sensors work as inter-subjectively agreed standards*: Sensors, measuring local features (vibrations, noise) in a commonly agreed dimension (levels in decibels, or on the Richter scale), help in creating awareness and a common 'overview picture' of the severity and justice of the situation, that are trusted and accepted by many local citizens; the web monitor instruments are seen as legitimizing the view of affected communities: the measured figures are accepted as factual evidence, as trustworthy information;
   - Citizen-sensor-networks help to connect and bridge the *physical world and social worlds* by creating a shared language and understanding: the 'embodiment' of pollution dynamics; The bigger picture, in combination with 'objectivized' factual measurements, helps creating a story and relating the emotional understandings of place with the quantitative, physical dimensions of the spatial phenomena under study; This leads to a process of *sense-making* within the community, and also in their dialogue with 'external' parties, such as national government or the media;
   - The information generated by the monitors, especially the real-time Internet Map Monitors, raises attention in the societal discourse about weighing of pro's and con's of

national policy regarding the economic, social and environmental developments in the region, and catalyzes media attention and political debate.

2. (Big) data played an important role
- The sensor networks measured the (yet) un-measurable (intangibles), and thus made invisible thresholds explicit;
- The data was combined with people;
- The measurements and figures were open data, available through Internet, open for verification by others;
- The data generated with the system created local information power that served as *countervailing force* against the then dominant narratives of the large business enterprises (Schiphol, NAM) and the State's Economic Ministry, in the analysed cases. The raw data empowered local citizens in their motivations and the validity of their perspective. By generating a measured overview of data with 'counter-evidence', the national-economic narratives where more heavily criticised, destabilizing the dominant discourse and offering a transitional perspective;

3. Social innovation
- Factual: New, not-existing information services were provided;
- The cases showed a type of 'living laboratory' setting to test new environmental monitoring technologies, using intelligence and involvement of the crowd.

We attribute the emergence of sense-making among the participants, and the informative strength it brings in their arguments and storytelling, partly to the social or participatory aspect of the citizen-sensor-networks: in both cases, the networks where constructed from *'within the community'*, by people affected by environmental 'externalities' enforced by 'outsider parties' coming from State and business enterprises.

Follow-up: Experiments in the pilot project Smart Emission
Learning from the above cases, and mixing these experiences with state-of-the-art knowledge on sensor technology, data & citizen science, and governance & planning, we have translated these lessons into a number of social, technical and governmental innovations that form the central aims in this new pilot project:

1. *Innovative sensing method:* connect new, low-cost sensors with a wireless network (wifi/mesh) for communicating real-time data

2. *Big data with citizens:* the measured data forms a refined data-flow from sensing points at places where people live and work: forming a 'big picture understanding' to build a shared, real-time, accepted 'diagnosis' of the local distribution of the specific 'externality', in this case urban air quality

3. *Governance with government embracing bottom-up practice:* Informed dialogue with citizens, empowering "citizen-scientists" by making visible the externality of urban air quality and feeding this into a bottom-up planning process.

3. Theories and practices on citizen sensing in the field of air quality monitoring

The approach and underlying philosophy of the project are based on three pillars:

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1. Inclusive Citizen Sensing:

- Transparency and democracy of pollution monitoring

- Citizen-sensor-networks for fine-grained measurements

- Assess fine-grained measurements & large-scale models in mutual relation

- Cost-effective environmental monitoring, Open Data

2. Towards Sustainable Cities:

- Value human health in the city

- Support change of daily behavior, shift car traffic to bicycle and electric transport

3. Smart Governance:

- Tracing phenomenon of "pollution clouds": Visualize urban environmental footprint

- Connect small cycles (feedback data) and large cycles (info piping through models)

Literature on Citizen science and air quality monitoring
On each of these three pillars, extensive scientific literature is available. However, dedicated articles on the combination of the three is yet scarce. For this project, we have based ourselves on articles on participatory sensing of noise or air quality sensing of Maisonneuve et all (2009) and Dutta at all (2009). We have made use of the recent citizen science literature review provided by Johnson et all (2014), and the literature on citizen science for measuring air quality by Snik et all (2014) and Austen (2015) specifically. We conceived this citizen participation or citizen science phenomenon as a bottom-up type of planning, that builds further on the steadily established body of knowledge on participatory planning.

Literature on GIS, PGIS, Geodesign and Geo-data standards was not particularly used as a reference, but the knowhow was available in the project consortium as multiple team members have a background in GIS and many years of experience in working with geo-data. How learning can be enhanced using PSS by Pelzer and Geertman (2014) may be a representative reference for further reading in this field.

The recent stream of literature on sustainable cities and smart governance is growing fast, but we postpone it to a later paper to filter, analyze and discuss the articles on these topics. The topics are yet fuzzy and broadly defined, to such an extent that we mention here no specific articles on smart governance, smart cities, or sustainable cities. While many articles discuss the advances in planning theory and planning approaches in general, so far, we found no article addressing a similar case of a pilot experiment on smart or sustainable cities relevant for participatory planning and discussing monitoring for improvement of urban air quality. Closest related is an article with an analysis of literature on the intersection between crowdsourcing and the governance of urban sustainability by Certomà, Sorsini and Rizzi (2014).
Multiple recent articles on planning theory emphasize the nature of planning processes as places where co-creation of knowledge takes place, and where conflicts are part of the strategic constellation of planning, which is, in the end, inherently political. We agree with the general criticism against an

overly market-oriented, economic (neoliberal) perspective on planning. As Albrechts (2015) argues, [strategic planning] 'aims to check government and corporate power, guarantee the use of local knowledge, and ensure that planning processes are responsive and democratic. It is directed at change by means of specific outputs (strategies, plans, policies, projects) framed through spaces of deliberative opportunities. These outcomes must be well informed, just, and fair.'

Learning through action research: exchanging knowledge among smart cities' communities of practice

The pilot project Smart Emissions takes place from the start of 2015 until December 2016. As we present this paper, the project is still in its first half year. The pilot starts with the enabling factor of new, low-cost sensor technology. Many ideas are refined and improved underway, as part of the action research. In order to align with current state of the art in the field of air pollution monitoring, we made a quickscan of related projects and experiences in other cities:

In **Barcelona**, the Fablab[4] has created the Smart Citizen Kit[5] based on open source technology (Arduino board.) Barcelona is also participating in the EU-funded the project Citi-sense, a project aiming at the development of sensor-based citizens'observatory community for improving quality of life in cities. Mark Nieuwenhuijsen, of the Center for Research in Environmental Epidemiology in Barcelona, uses wearable sensors to measure and map air pollution with citizens while they travel through the city, using new sensing devices like the TZO[6], in combination with people's smartphones.

In **London**, the Mapping for Change laboratory of Muki Haklay[7] has supported the citizen science project 'London Citizen Science 2014 - Network for Clean Air'[8]. This project uses analogue NO_2 tubes. A downside of this approach is the labour intensiveness of the work, involving mailing of tubes and lab analysis per tube on a monthly basis. The measurements are accurate, but only a monthly average value can be determined, as the tube is collecting accumulative NO2 pollution over the time-period of one month.

In **Amsterdam**, a similar project with the Barcelona Smart Citizen Kit has been carried out in 2014, with partners Waag Society[9] and Amsterdam Smart City[10], funded by the Amsterdam Economic Board. One of the findings was, that the accuracy of the sensor, particularly the NO_2 indicator that was used in the pilot, would need improvement in measurement range and accuracy.

In **Eindhoven**, specially designed 'Air Boxes' are used to measure different types of fine dust, ultra-fine particles and ozone in the project Aireas[11], an initiative started by Jean-Paul Close en Marco van Lochem. The boxes used in this project are in a higher-priced category than the project Smart Emission, above consumer price levels.

In **Chicago**, the 'Array of Things' project[12] starts in September 2015 with dedicated sensor hardware and software developed by Argonne Lab scientists Charlie Catlett, Pete Beckman and Rajesh Sankaran. This sensor is in a price range comparable with project Smart Emission, the top-end level of consumer price levels. In the city of Chicago, these sensor will be built into 'BigBelly bins' on street corners and along street lights. The project Smart Emission links up with the city network of the Array of Things. It is planned to exchange a sensor with the Array of Things project.

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[4] Fablab: http://spain-lab.net/project/smart-citizen-fab-lab-barcelonaiaachangar/

[5] Smart Citizen Kit (SCK): https://smartcitizen.me/pages/sck

[6] TZOA wearable sensors: http://www.smithsonianmag.com/innovation/with-wearable-devices-that-monitor-air-quality-scientists-can-crowdsource-pollution-maps-180954556/#SAC5yuQv6JXpjXqQ.99

[7] Mapping for Change Air Quality Monitor:
http://www.communitymaps.org.uk/version6_1/includes/MiniSite.php?minisitename=Air Quality Monitoring&minisite_group= , http://mappingforchange.org.uk/projects/citizen-science-used-to-map-community-air-quality/

[8] London, see for instance: http://www.cleanairuk.org/London-Greenwich-Deptford-citizen-science-2014.html, http://www.cleanairuk.org/clean-air.html

[9] Waag Society, Amsterdam SCK: https://waag.org/en/project/smart-citizen-kit

[10] http://amsterdamsmartcity.com/projects/detail/id/69/slug/smart-citizen-kit?lang=nl

[11] Aireas project Eindhoven: http://www.aireas.com/

[12] Array of Things project Chicago: https://arrayofthings.github.io/

All these projects have in common their presentation of measured air quality data over the web, on Internet Maps. In our project, we have linked up with the activities and project members of the cities Amsterdam, Eindhoven and Chicago so far, and have indirect contact with the activities in the cities London and Barcelona through involvement of chain-linked experts who share their particular expertise (air quality scientists, ICT/ citizen science experts or mapping / geo-information scientists).

4. Pilot setup Smart Emission

Based on the lessons learned in the cases described in the previous section and in our paper of Aesop 2014 (Carton and Ache, 2014), in this paper, we describe how we are developing a new citizen-sensor-network on the topic of measuring air quality with new, small, low-cost sensors in a participatory setting in the city of Nijmegen.

Fine-grained constellation of measurement network
Based on sharing experiences among cities, we decided to measure on a very local scale and set out the sensor locations along a busy junction in the city, as well as alongside a spatial gradient from the busy traffic junction towards an existing 'background level' measurement station of the national air quality measurement network. In this way, our initial idea of measuring very locally, on sub-city scale, aiming to trace local accumulations, is best concretized.
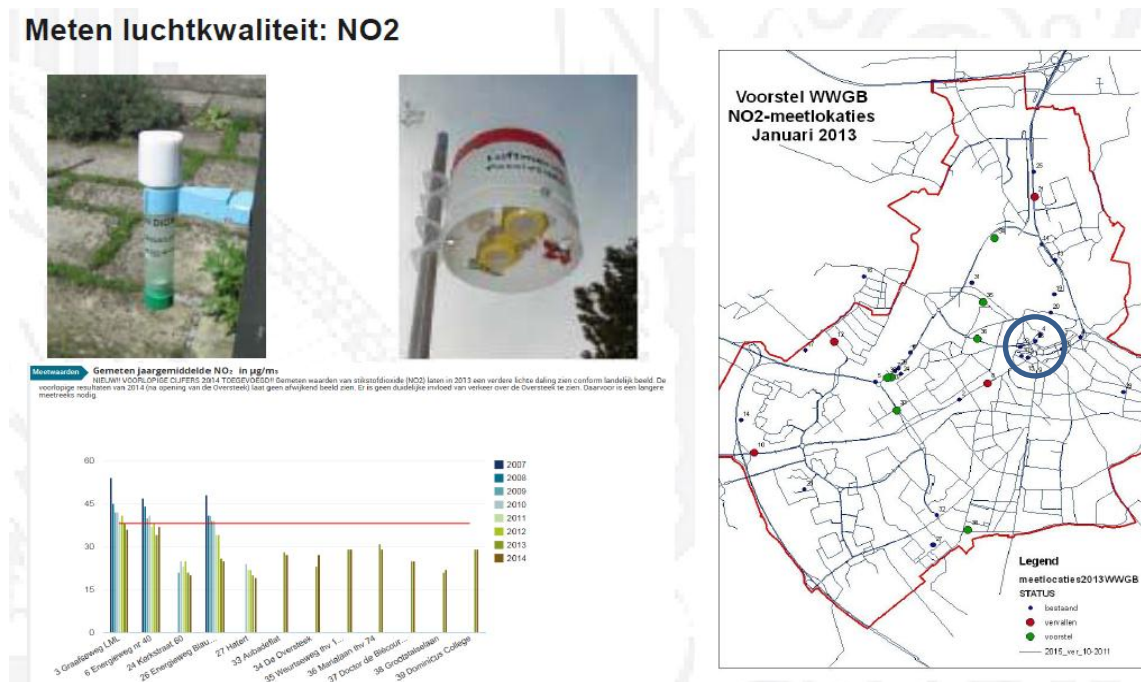The measurement net that is conceived is sketched in two maps, see figure 3 and 4.

Figure 3: Measurement set-up (here current professional devices from RIVM and municipality for measuring NO₂), showing the combination of measurement locations with high-end accurate equipment, involving high maintenance costs, and low-end equipment using analogous Palmes tubes. NO₂ is seen as representative proxy for traffic-related pollution, with an effect on citizens' health. In this pilot, Jose small sensors will be added within the area *enclosed by the circle* on the map at the right. Source pictures: Henk Nijhuis, air quality specialist city-government Nijmegen.

City of Nijmegen, 1st setup measurement strategy with low-cost sensors in a gradient (from traffic to background station)
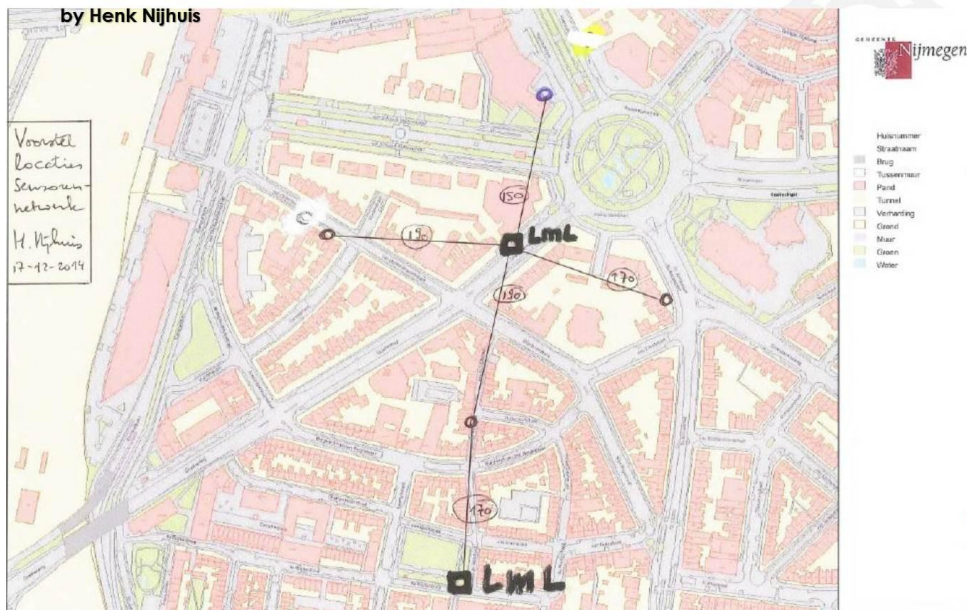

Figure 4. A rough sketch of the measurement net with the first set of 6 sensors, in a constellation limited to distances smaller than 200 metres between every sensor.

A central idea in the pilot project is, that with 24/7 measurements on many points in the urban built environment, we believe it becomes possible to *'trace pollution clouds,' making the levels of quality visible on a fine-grained scale*. With measured values over time, this could enhance insight in where and when levels of noise load, vibrations or bad air quality do concentrate within the morphology of the urban built environment, and where in other streets and places, the level of the indicator reads as if it is relatively good. (For air quality, this could mean that in the local landscape, for instance a windy street or hill-side, 'the streets are blown clean of emissions').

The idea of making a fine-grained constellation and the combination with existing air monitoring systems by defining a 'gradient' of measurement systems (see Figure 5), from professional, costly and accurate, via smaller equipment towards the cheaper end with small sensors, is derived in practice when starting the pilot and surrounding consortium. It is hypothesized that a combination of air quality measurement data from various sources, including small low-cost sensors and Open Data Standards, can add to the understanding of local accumulation of air pollution. The local, continuous measurements from the new sensors (measuring 24/7 in high frequency, logging every second) could validate the national air quality model on a sub-city level, and analyse dynamics in space-time.

If this concept would prove to work, and offer sufficient accuracy for use by citizens and government to *gain a more encompassing, detailed insight in where air pollution comes and goes*, then this concept of a low-cost citizen-sensor-network measuring air quality could form a cost-efficient addition to current practice.
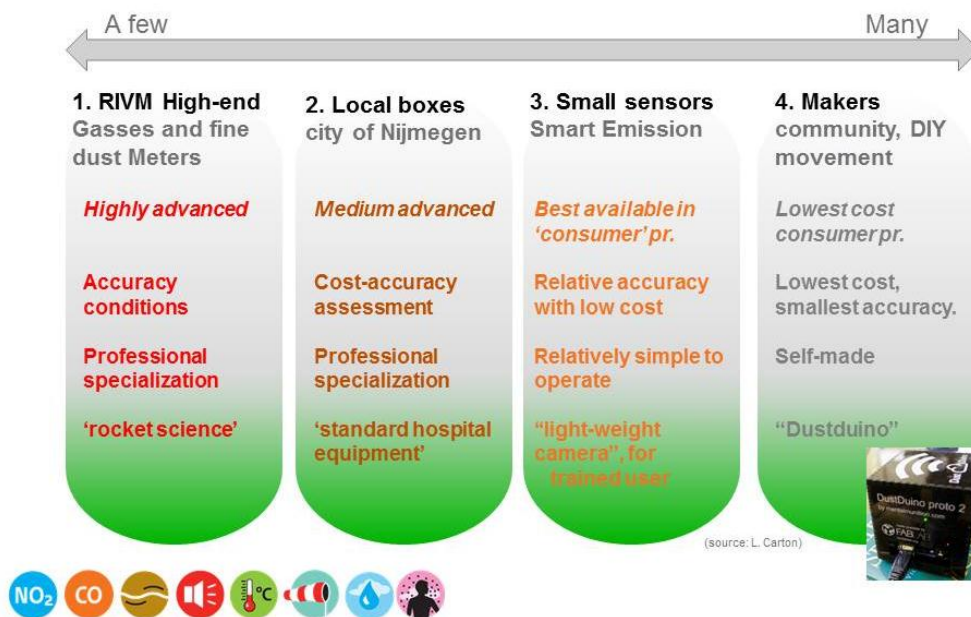
Figure 5. A gradient of type of measurement equipment. Sensor Jose, used in this pilot project, is classified as a 'type 3 spall sensor': it is a best available quality in the range of consumer products. The overall costs of a Jose sensor must remain around the level of circa 300 - 450 Euros per sensor unit.

Small sensor technology
The sensor that is being developed by Intemo, sensor Jose, has the following specifications:

> *Jose base unit for ßeta-test outdoor air quality*
> 1. Light intensity
> 2. Light reflection
> 3. Light (air) color
> 4. Earth vibration
> 5. Carbon monoxide
> 6. Nitric oxide
> 7. Ozone
> 8. hydrogen
> 9. Carbon dioxide
> 10. Pressure
> 11. Temperature (Unit / environment)
> 12. Humidity
> 13. Noise load dBm / Laeq (per 500Hz linof log.)
> 14. Time / Date
> 15. Location (GPS), latitude, longitude
> 16. Communications (WiFi / USB)
> 17. Memory + Multi Color Display Ring
> 18. Electricity, USB phone adapter

A photo and test-reading of the outdoor sensor is shown in Figure 6. The places where the sensors are being mounted on-site, near the city's busiest traffic junction, are sketched in the set of photo's in Figure 7.
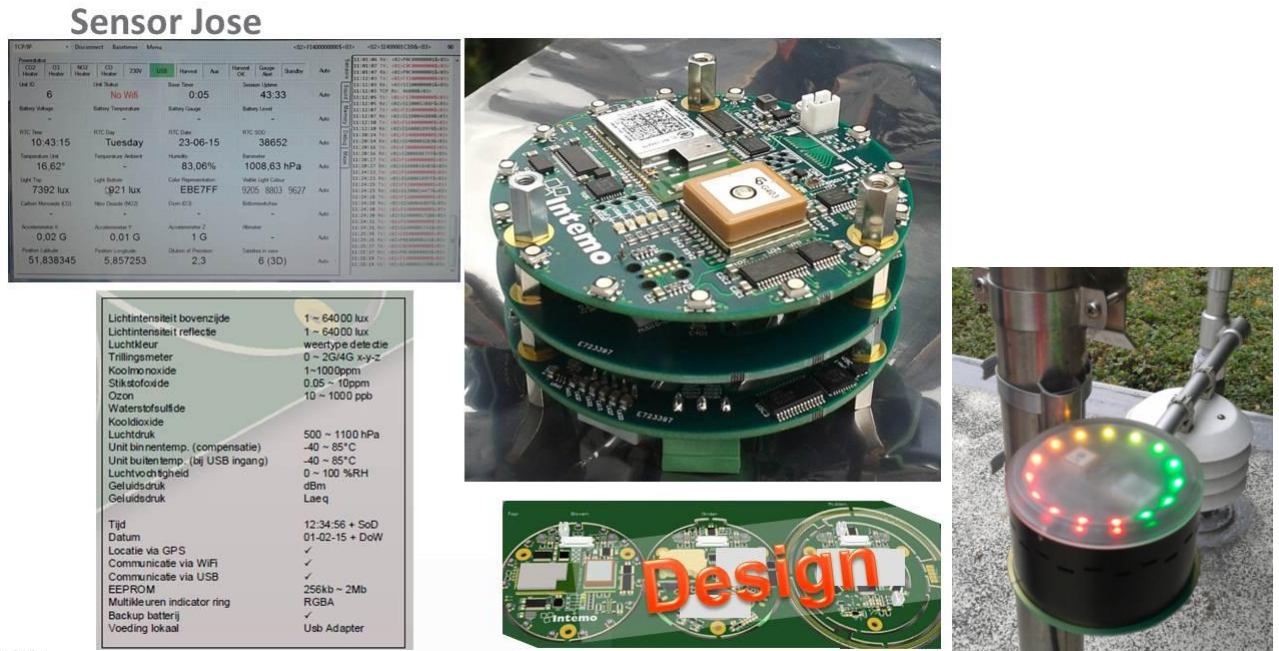
Figure 6: Sensor Jose, designed and developed by Intemo, specifications and photo of the first operational sensor, mounted on the roof of a national RIVM measurement station in Nijmegen.

Figure 7. Set of 4 photos/movies of the place near roundabout Keizer Karelplein: Site locations of sensors, in front of apartments (top left), outside of fast-food restaurant (top right), along the rain pipe of the dentist (bottom left, sensor installed), and participant of Guarded bicycle parking facility, mr Ronnie Heimans (bottom right, sensor installed).

Participation of citizens in the pilot project

Currently, in the Netherlands a national monitoring and measurement network is operational, based on a limited amount of permanent professional, large-scale measurement stations. Many cities have no measurement station within their city boundaries. In those cities, most air quality analysis is performed by modelling the air quality based on traffic counts, and calibrated on a limited set of measurements. This project starts with the philosophy to start 'bottom-up': beginning with local measurement in cities, at a focal place(s) and area, together with citizens who are interested to measure and see the raw data first, and then aggregating these measurements into a broader overall picture.

With a focus on measuring first, instead of modelling first, this approach of participatory sensing is different from legal norm setting. Currently, air quality regulations are built on a system of legal norm setting. This use of a legal norm imposes a 'bottom line', for instance on air quality indicators such as NO_2, and when reporting cycles provide feedback information that yearly average doses, averaged over a certain region (with governmental borders and division in spatial territories) are sufficient, then the norm is met. No further action or pricing or consideration is necessary. With a measuring focus, there is no red line between 'good and bad concentrations' of air pollution. All air pollution doses are considered bad for health. As more and more medical research indicates that air pollution has a negative effect on health, all above-zero emission is undesirable.

The idea is to do this measurement in close cooperation with citizens; at local places where citizens live and work, and thus breath the air in relatively long duration. For this purpose, the sensors are given in loan to citizens who live, or have their work place, in the pilot area. The citizens do not pay financially for having the sensor in loan, but they sign a letter of intention that they will care for its condition and will try to return it at the end of the project in good shape to the university.

In turn for their cooperation, the citizens can see the raw data of their sensor on a tablet, pc or smartphone through an internet app, and they can deliberate in participatory neighbourhood sessions organized by the project consortium, during the pilot. In these neighbourhood sessions, the analyses made by students and researchers are presented back to the citizens (filling the feedback gap that makes up the title of this paper!), using an interactive Maptable, a kind of 'very large tablet' (see Figure 8 and 9). The students and researchers will report on their analysis and experiments with visualizing parts of the large data set, with the extensive amount of measurement points in time and space. It is conceived that researchers will present a kind of 'weather presentations', similar with weather presentations in news channels on television, with using images preferably as well-understandable as the dynamic cloud formations that can be found on the Dutch 'Rain radar' (www.buienradar.nl).

Figure 8. Project Smart Emission in a nutshell. Illustration: Anke Nobel.

Feedback to participants with Maptable

Figure 9. The digital Maptable showing (modelled) air quality levels in the pilot area of the central traffic junction 'Keizer Karelplein roundabout.'

After some thinking of pro's and cons of various levels of citizen participation, it was decided not to execute the highest level of the 'participation ladder', which is citizen control, or self-organization. In order to get the best available knowledge of citizens and of the involved air quality experts, it was chosen to 'empower' the project team as a 'cockpit area' where the course of the pilot project was set-out, and then deliberate with the involved citizens in a partnership constellation (level 6 on the citizen participation ladder of Arnstein, see Figure 10).
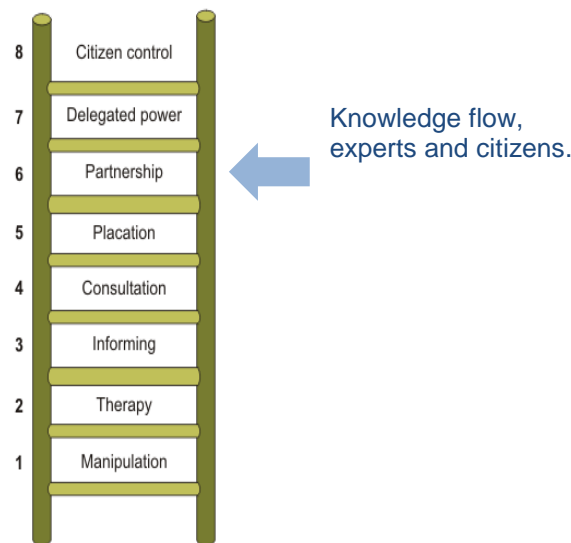
Citizen Participation Ladder

Figure 10. Arnstein, S.R. (1971) 'Eight Rungs on the Ladder of Citizen Participation', in Cahn, E.S. & Passett, B.A. (eds), Citizen Participation: Effecting Community Change, Praeger, New York. Image: www.dlsweb.rmit.edu.au/conenv/envi1128/focus3/f3_t9_q44.htm.

This should prevent the citizens re-inventing the wheel or making choices underutilizing the available experience and knowledge of the 'behaviour' of air pollution. Also, total citizen control can slow down the process and may give some citizens the idea of an adrift project, while the citizen expects to see 'an experienced pilot' when (s)he takes a figurative 'look in the cockpit'.

Therefore, we envisage the project consortium and the core project team members as 'the people occupying the cockpit and flying the plane', but citizens involved can enter the cockpit, ask questions and then they need to be treated as a partner who is in charge of (one of) the sensors. The university is chosen as the mediator who will be in charge of inviting citizens and handing over sensors, as the university is generally conceived as an independent body, separated from the city government in their role and responsibility. The consortium core team members form an interdisciplinary team that sets the stages and makes the design choices during the pilot phase, while capitalizing as much as possible on the instinct of involved experts with their years of experience, adopt wisdom of the crowds by involving the citizens of the location on occasion, as well as exchanging knowledge in Living Labs with other cities, and combine this knowledge with the latest know-how on developments in sensing, ICT and (geo) data processing technologies and standards. This is visualized in Figure 11.

Processes of power and conflict in social interactions
Off course, power issues may become apparent during the pilot. The philosophy of the project is, that also in evaluating data and discussing proposals for improvement, the citizens are seen as partners in the project. When conflicts appear, democratic-style of decision-making mechanisms should be put in place; like voting by majority or by handing over decision-making power to each of the groups' own 'constituency' or group. In the end, one can fall back on the formal institutionalized practices of democratic decision-making of the city of Nijmegen, following legal and political, democratic rules for making formal planning decisions. However, before the formal stages are entered, much is possible in an open setting that can be characterizes as "neighbourhood town-hall meetings" or in Dutch 'buurt-en stadsgesprekken'.
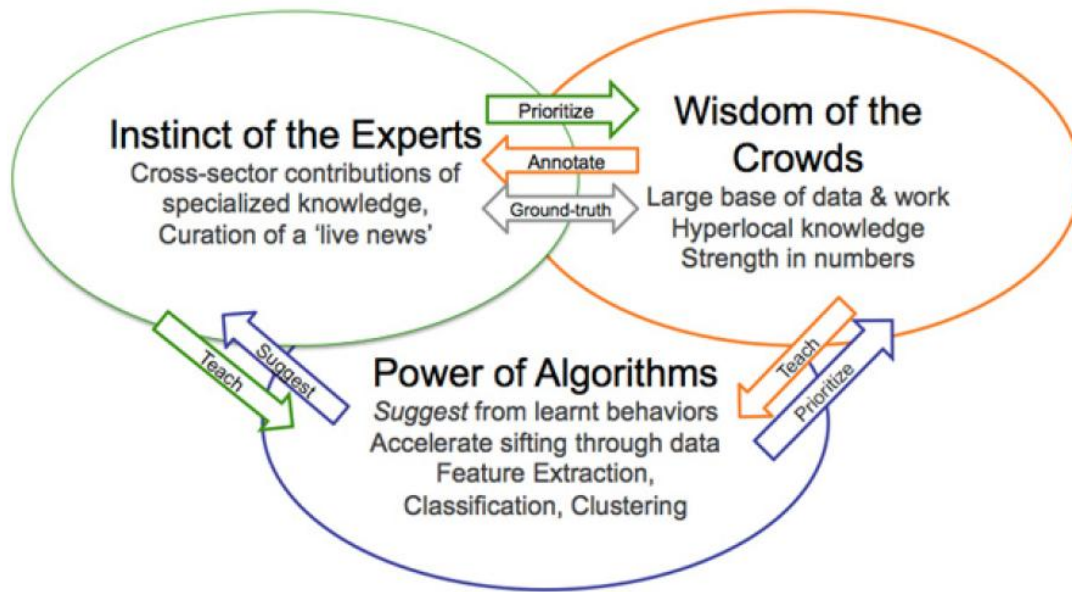
17

Figure 11. Aiming to bring together the best of experts, crowds, and systems/algorithms, for learning, transacting, teaching, and prioritizing knowledge and deciding on priorities. Source: Boulos et all (2011) Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. In: Int Journal of Health Geographics, 10:67.

In Figure 12, an overview of the project is presented in an information graphic. This information graphic has been given, and verbally explained, to the people who were invited to adopt a sensor to be installed outdoor at or near their home or workplace environment. As the sensors are limited in number, with a first set of 6 sensors being developed in spring 2015 and then a series of ca. 20 - 25 sensors to be produced in summer 2015, the first citizens are invited by the project team members thinking of considerations concerning the sensor technology, air quality characteristics and the citizen participation aspect.
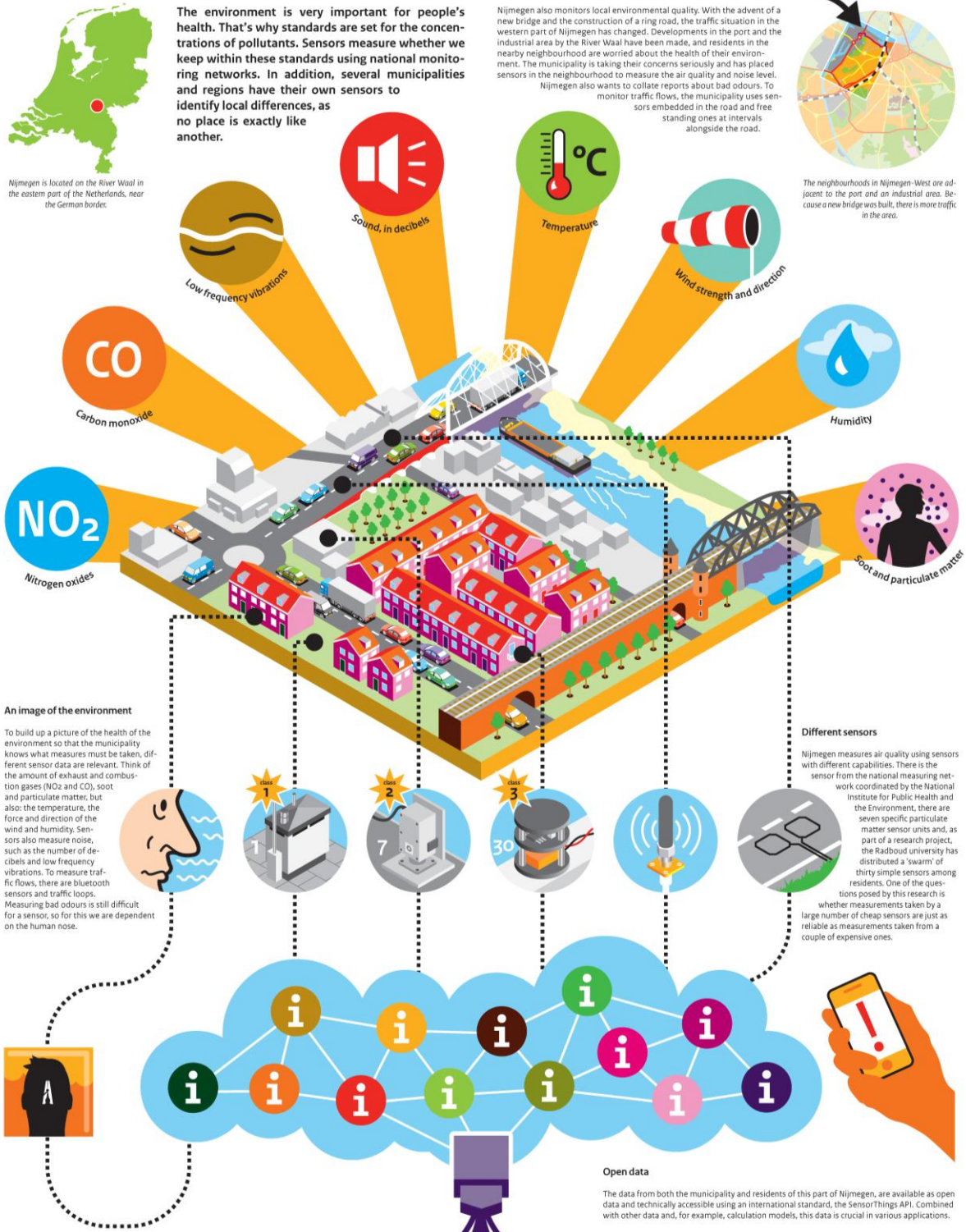
Figure 12. Overview of project Smart Emission, sensor network combining various degrees of sensing data. Illustration: Anke Nobel.

Small and long information cycles, providing multiple forms of feedback to citizens
When the measurement network is in place, the sensors can monitor and upload their data to the website server set-up by CityGIS. From there, the data will follow multiple feedback cycles: a 'small feedback cycle', bringing the data in its raw form back to the citizens who 'own' the sensors. But the Open data will also follow longer feedback cycles. One information cycle is planned to be executed by RIVM, who will import the data and confront the values with their advanced air quality model (RIO). Geonovum will assist in developing the plug-inn for facilitating the data flow into this model, according to EU standards for European geo-information exchange like the Sensor Observation Service (SOS-client), in line with their expert role in advising on the implementation and use of the EU Inspire guideline. Another information cycle is going through the city governments traffic models. Traffic flows can be redirected according to specific information about smog formation (see Figure 13).

Figure 13. From citizen sensing to a smart city; project Smart
Emission in a nutshell. Illustration: Anke Nobel.

Conclusions

The main question is, whether the proof of concept turns out positive: does the sensor-network function technically as envisaged, does it deliver measurement values in the desired ranges of pollution or cleanliness, and can we trace accumulations? As the project is just a few month underway, the results yet remain to be seen.
In this pilot, researchers are curious to see whether the measured data give deviating values with regard to the national model information that is available. After the pilot project, the sensor network could be extended with more sensors and a wider area, or replaced in a next area.
We hope that some of the various urban citizen-sensor-networks referred to in section 3 will succeed and deliver according to expectations. Then, the step towards filling the noticed feedback gap in city planning is brought within closer reach. The next step should then become trying to bridge measurement and quantification of physical pollution on one hand, with financial valuation and accounting in planning practice on the other hand; in order to achieve a better considerations of these 'externalities' in future planning decisions. However, as valuation of physical material 'externalities' and its translation into a certain financial balance sheet involves a power shift in the status quo, this might be another societal challenge.
But as in multiple cities we already see the health effect of high levels of air pollution, and smog becomes more and more persistent due to ongoing climate change and ongoing consumption of fossil fuels, it might also become more and more important to get a good picture of what is going on exactly with our urban air, the air we breathe day in, day out.
As for planning, we plea for attention to the use of ever more advancing ICT technologies in managing our cities and acting in our daily routines. These ICT technologies and data can be used for the benefit of all, or the benefit of just a happy few. Planners have a responsibility to bend the use of these enabling tools into directions of sustainable and just governance. In this paper, we have discussed one such a direction of applying ICT: the visualization of 'externalities' of the present-day urban system, in order to put the so-called 'economic externalities' in the spotlights for

the eyes of citizens and city-planners. Being measured and counted transforms externalities as air quality from 'unaccounted for, invisible side-effects', disconnected from economic choices, into traceable and quantifiable 'feedback' about the state of our cities. This ultimately provides us with feedback about our own role in this current and future state of our cities[13].

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[13] In our personal view, the very term 'externality' is typically invented in the realm of economics and thus a social (or subjective) concept, although the term sounds rational and material as if it stemmed from physical sciences. Responsible government economics should focus on internalizing 'externality' costs in economic transactions made in and between their societies, instead of copying business-style behaviour of externalizing and transferring 'unfortunate consequences' of its own behaviour onto others, de-facto acting as free-rider. If the State government is free-riding, then where is the legitimate, justified, 'right thing to do' example for citizens to follow?

Urls:

- http://ds-lands.com/data_images/countries/netherlands/netherlands-02.jpg
- Fablab: http://spain-lab.net/project/smart-citizen-fab-lab-barcelonaiaachangar/
- Smart Citizen Kit (SCK): https://smartcitizen.me/pages/sck
- TZOA wearable sensors: http://www.smithsonianmag.com/innovation/with-wearable-devices-that-monitor-air-quality-scientists-can-crowdsource-pollution-maps-180954556/#SAC5yuQv6JXpjXqQ.99
- Mapping for Change Air Quality Monitor: http://www.communitymaps.org.uk/version6_1/includes/MiniSite.php?minisitename=Air Quality Monitoring&minisite_group= , http://mappingforchange.org.uk/projects/citizen-science-used-to-map-community-air-quality/
- London, see for instance: http://www.cleanairuk.org/London-Greenwich-Deptford-citizen-science-2014.html, http://www.cleanairuk.org/clean-air.html
- Waag Society, Amsterdam SCK: https://waag.org/en/project/smart-citizen-kit
- http://amsterdamsmartcity.com/projects/detail/id/69/slug/smart-citizen-kit?lang=nl
- Aireas project Eindhoven: http://www.aireas.com/
- Array of Things project Chicago: https://arrayofthings.github.io/