SECURE

Use of low-cost sensor technology to monitor air quality & engage citizens

SECURE Workshop organised at COSLA, Edinburgh

31 March 2016

Executive summary

The workshop focused on the opportunities and challenges of using low-cost sensor technology to monitor air quality and how this emerging technological opportunity could help to engage citizens. With more than 50 individual expressions of interest, the workshop brought together 44 participants including researchers, local authorities & public bodies, sensor developers & consultancies and citizens & civil society groups. After an introductory session with three short presentations providing an overview of current sensor technologies and introducing two activities involving sensors and citizen science (the EU FP7 research project CITI-SENSE and the SEPA Teaching Pack & SE Web), the workshop addressed key questions in three parallel working groups. During the morning session, the groups considered questions related to the current capabilities and needs including *"Current sensor capabilities & applications"*, *"What data do citizens need/want?"* and *"Low-cost sensing for local authorities"*. After reporting back and lunch, the second group phase had a forward-looking focus, addressing *"Research needs for next-generation sensors"*, *"How to safeguard data quality from CS projects?"* and *"Stakeholder roles for next generation low-cost sensors"*.

As key findings, the workshop concluded that in order to overcome key barriers in the development and use of low-cost sensors, there is a clear need to improve sensor performance and implement standards. However, there is currently no clear funding model for this, and different stakeholders (government, regulatory agencies, academia and research institutes, private companies) could have a role to play. The emergence of "Big data" raises questions on how data is shared, analysed, modelled, by whom, and where? At this point in time, robust and comprehensive technical standards seem to be a few years away and GB/EU/global official quality standards maybe as much as five years or more. It was considered to be vital to identify viable ways forward in the meantime, with a focus on how we get 'the right information' to 'the right people' at 'the right time'.

Activities such as this workshop were viewed as important activities to facilitate and engage different groups and stakeholders, and to foster an ongoing dialogue. In addition to providing information, this dialogue can help to shape the policy and governance landscape, for instance creating platforms and initiatives where scientists, citizens and civil society groups, regulars and policy makers can co-produce solutions to improve public health and well-being in the cities of tomorrow.

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A joint activity of the
Scottish ResearcH partnership for Air Pollution health Effects (SHAPE)
and the EU FP7 project CITISENSE[1]
funded by the EPSRC network SECURE[2]

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[1] CITI-SENSE, www.citi-sense.eu, is a collaborative project co-funded by the European Union's Seventh Framework Programme for Research, Technological Development and Innovation, grant agreement no 308524.
[2] Statistics of Environmental Change, Resources and Ecosystems - http://www.gla.ac.uk/research/az/secure

1. Overview

Environmental change is a natural state, but increasingly there are concerns about the impact that anthropogenic activity has on exacerbating such change and, the implications this may have for a secure and sustainable future. Understanding and forecasting environmental changes are crucial to the development of strategies to mitigate against the impacts of future events. Communications and decision-making around environmental change are sometimes troubled by issues concerning the weight of evidence, the nature and size of uncertainties, and how both are described.

Evidence for environmental change comes from a number of sources, but key to the EPSRC funded network Statistics of Environmental Change, Resources and Ecosystems (SECURE) is the **optimal use of data** (from observational, regulatory monitoring, and Earth observations platforms – for example satellites and mobile sensors) and models (process and statistical). A robust and reliable evidence base is key in the decision-making process, informed by powerful statistical models and the best data.

The workshop therefore focused on the opportunities and challenges of using **low-cost sensor technology** to **monitor air quality** and how this emerging technological opportunity could help to **engage citizens**. With more than 50 individual expressions of interest, the workshop brought together 44 participants including Researchers, Local Authorities, Public Bodies, Sensor Developers and Consultancies, and Civil Society and Citizen Scientist Groups (Table 1). A full list of participants can be found in ANNEX A.

Composition of participants	
Researchers	28
Local Authorities	3
Public Bodies	3
Sensor Developers and Consultancy	7
Civil Society Groups and Citizen Scientists	3
Total	***44***

The workshop commenced with three short presentations providing an overview of current sensor technologies, and introducing two activities involving sensors and citizen science (the EU FP7 research project CITI-SENSE and the SEPA Teaching Pack & SE Web), the workshop addressed key questions in three parallel working groups. During the morning session, the groups considered questions related to the current capabilities and needs, e.g. "*Current sensor capabilities and applications*", "*What data do citizens need and want?*" and "*Low-cost sensing for local authorities*". After reporting back and lunch, the second group phase had a forward-looking focus, addressing i.e. *"Research needs for next-generation sensors"*, "How to safeguard data quality from CS projects?" and "*Stakeholder roles for next generation low-cost sensors*".

In addition, during the workshop breaks, participants had the opportunity to engage with sensor manufacturers including *AirMonitors Ltd*, the Centre of Excellence for Sensor and Imaging Systems (*CENSIS)* and the CITISENSE project.

The findings of the workshop have been summarised based on the group reports (ANNEX B) and are made available through the SECURE website http://www.gla.ac.uk/research/az/secure.

2. Workshop structure

2.1 Introductory talks

After a general introduction, three short presentations (see the SECURE website http://www.gla.ac.uk/research/az/secure for links) set the scene for the workshop and served as a preparation for the following breakout groups.

Dr. Christine Braban (NERC Centre for Ecology & Hydrology, CEH) elaborated on the need to assess the performance and data quality from low-cost sensors. In her presentation, she focused on types of sensors and known cross-sensitivities between different trace gases, as well as types of confounding atmospheric and environmental properties. Based on this, she discussed where science should be heading and identified potential practical ways to cope with current technology (and developing technologies). Finally, Dr. Braban provided an overview on which technologies in the future are likely to be most traceable.

Dr. Karen Galea (Institute of Occupational Medicine, IOM) introduced the European research project *Development of sensor-based Citizens' Observatory Community for improving quality of life in cities* (CITISENSE, http://www.citi-sense.eu/), which has the application and evaluation of low-cost sensors for air pollution, both stationary and for personal exposure assessment, at its core. CITISENSE is funded by the EU Directorate General for Research. The large, multi-centre, collaborative research project is led by NILU, the Norwegian Air Pollution Research Centre, and comprises 27 Partners across Europe. It started in October 2012 and will conclude in September 2016. The project develops "citizens' observatories" to empower citizens to contribute to and participate in environmental governance, to enable them to support and influence community and societal priorities and associated decision making. These observatories aim to create communities of users that will share technological solutions [sensors, software ...], information products and services [outputs of the measurement programmes], and community participatory methods, by using appropriate communication solutions. By achieving this, CITISENSE has the objective to complement established environmental data and information systems and improve local environmental decision making in cooperation with local policy decision makers.

Dr. Ian Wager (Scottish Environment Protection Agency, SEPA), finally, introduced the information services around Scotland's Environment Web (http://www.environment.scotland.gov.uk/). The website provides substantial resources and tools around Citizen Sciences and enables the general public to gain access to information, but as well getting involved in improving Scotland's environment.

Resources comprise a repository of existing citizen science projects and material to learn more about air quality. In addition, a national teaching package on air quality, using custom-built low-cost air pollution sensor units alongside extensive information resources supports teaching activities in primary and secondary schools across Scotland. For example, for Geography lessons, class and activity based teaching materials aim to engage the pupils with class-based challenges and collect real-time data, while for Science lessons, classroom based activities focus on teaching the underlying science and on conducting experiments designed by SSERC (http://www.sserc.org.uk/). Feedback from teachers and students has been very positive, and next steps will include development of more advanced teaching tools in partnership, including sensor technologies, the creation of national awards and collaboration with Science Centres across the countries to support the improvement of the curriculum for teaching in Science, Technology, Engineering and Mathematics (STEM).

2.2 Breakout group sessions

After the introductory talks, a first breakout group session commenced, with workshop participants split into similar sized groupings comprising representatives from a variety of backgrounds. These group discussions were facilitated by a chair, with a designated rapporteur responsible for capturing notes and reporting back key findings to a plenary session following the group discussion.

The individual groups focused on different topics related to the existing capabilities, needs and challenges of low-cost sensors for air quality. The individual group topics and guiding questions are listed below. Key findings and discussion points raised by the groups are compiled in the following section.

- ☐ Group M1: Current sensor capabilities & applications
  - *What can we measure with existing sensors?*
  - *Which are the key barriers & challenges for using low-cost sensors?*
  - *What lessons can we learn from existing sensor applications?*
- ☐ Group M2: What data do citizens need/want?
  - *What data/information on air quality is most useful to the general public?*
  - *How can vulnerable groups benefit from low-cost sensors?*
  - *What role can mobile/personal devices have?*
- ☐ Group M3: Low-cost sensing for local authorities
  - *Which capabilities do low-cost sensors offer for regulatory monitoring?*
  - *What are the primary concerns/barriers for the use of low-cost sensors?*
  - *How can low-cost and reference sensor datasets be integrated?*

During the lunch and coffee breaks, workshop participants had the opportunity as well to engage with sensor manufacturers including *AirMonitors Ltd* (http://www.airmonitors.co.uk/) and the centre of excellence for Sensor and Imaging Systems (*CENSIS*, http://censis.org.uk/). In addition, the CITISENSE project team enabled volunteers to contribute to the project's engagement activities through the Citizen's Observatory Portal (http://co.citi-sense.eu/).

After lunch, groups reported back in short presentations, with the opportunity to ask questions for clarification and have a brief discussion with members of different groups.

In a second breakout group phase, the focus was designed to be more forward looking.

- ☐ Group A1: Research needs for next-generation sensors
  - *What are the emerging technologies for low-cost sensing of air pollution?*
  - *Which knowledge and research gaps exist?*
  - *Which priorities for research funding can we identify?*
- ☐ Group A2: How to safeguard data quality from CS projects?
  - *What tools and methods do we need to develop for quality control of data?*
  - *Which skills and capabilities do citizen scientists and researchers need to build?*
  - *How can we communicate uncertainties in data?*
- ☐ Group A3: Stakeholder roles for next generation low-cost sensors
  - *Which roles (users, developers and funders) for low-cost sensors do stakeholders see?*
  - *How can stakeholders influence/support the development of next generation sensors?*
  - *What barriers and challenges do stakeholders identify for being involved in the process?*

After the session reporting back from the second breakout group discussions and a final discussion, the workshop was wrapped up with a general reflection on outcomes and potential follow-up activities.

3. Key findings and conclusions

The workshop was judged to be well received by participants on the basis of the feedback received (ANNEX C). During the workshop, it was also discussed if the outcomes may serve as the basis for the development of a peer-reviewed publication. While a final decision on this is pending a more detailed evaluation and discussion of the workshop findings, the following key points have emerged from the workshop and should be considered in order to further progress the use of low-cost air quality sensors.

With regard to existing capabilities, one key question to be addressed is what should be measured, rather than what is technically feasible to measure. In order to make low-cost sensors more robust and reliable for individual and public information, as well as compliance monitoring, extensive field testing and calibration, based on methodical laboratory experiments would be required. In addition, a comprehensive definition of *'low cost'* has yet to emerge, with current sensors and sensor packages ranging in costs from a few hundred to several thousand pounds. Distinguishing between sensors and sensor systems is essential in order to ensure that both types of applications are assessed adequately. At this point in time, focusing on regulated pollutants (e.g. nitrogen oxide/dioxide, fine particulate matter, ozone), alongside key meteorological parameters (temperature, rel. humidity, surface pressure), would be the best approach. Ideally, measuring pollutants with clear relevance for exposure and health impact assessments would be the focus of developing sensors.

Citizen needs need to be assessed with the range of target audiences in mind, e.g. pupils/students, older adults, professions (e.g. traffic wardens), with information provided needing to be in the appropriate format for each group. Providing live data in public spaces could aid awareness rising in the context of continuing exceedances of air quality limit values. A key issue identified was around the need to engage and support deprived communities, contributing to the alleviation of environmental inequalities and promoting environmental justice. The debate about precision and ratification of official data vs. data quality of low-cost (non-ratified) datasets needs to be addressed, and enhanced by the value of utility of providing information where it is relevant. The Aarhus convention (http://www.unece.org/env/pp/treatytext.html) on providing public access to pertinent environmental information was highlighted as a potential framework and driver to address this.

In the context of local authorities using low-cost sensors, it was concluded that current sensors did not yet provide robust datasets authorities could base decisions on or compliance assessments on. However, it was agreed that it could be useful to classify low-cost sensor data quality into three categories, e.g. "1" = *reference*, "2" = *indicative*, and "3" = *informative*, and to classify accuracy and variance of data from sensors into each of these groups. As a key question in relation to low-cost sensor use (no different from any type of measurement) is to determine *"what are the sensors, and the resultant data being used for"*. Defining the problem, resp. the scientific/regulatory question to be answered before determining that (which kind of?) sensors are the solution would be a useful first step.

Addressing research needs for next-generation sensors, cross-sensitivities between environmental contaminants present a key challenge, as well as persistent challenges for small, lightweight, yet accurate wearable devices. This requires investment and buy-in, which in the case of low-cost air quality sensors is in an early development stage. With air quality and health effects being an emotive subject, an important question would be to address if the objective is to assess compliance vs conducting research and development into transformative approaches. Having a plethora of indices and poor quality of existing information or maps in relation to uncertainties are barriers for a better uptake of new technologies. Finally, calibration certificates or quality approvals for sensors could be a way forward to increase trust in data.

Quality assurance and control of data from low-cost sensors, as well as the need for ongoing calibration and maintenance are key features needing to be managed in citizen science projects. However, to be most useful, data needs to be provided in (near) real-time, as citizens want to use data 'now', as soon as it is collected, in particular to respond to potential health risks (e.g. for individuals suffering from asthma, COPD). This provides a challenge for current QA/QC approaches, which require detailed processing and validation. In addition, a need to you engender caution in the interpretation of data in individuals, who may have limited expertise or knowledge was identified. There could be a role for government or regulatory organisations to set up facilities regionally where citizen scientists could bring their sensors in for testing, and to learn more about data quality and limitations. Ultimately, this could lead to e.g. a *British Standard*, which does not currently exist for sensors. All low-cost sensors are currently 'badged' as if they are the same, which not adequate when some are of reasonable quality and others are simply low quality. A reliable label to tell the consumer something about sensor performance and data quality, based on an independent evaluation carried out following such a standard would solve a lot of issues. A further develop step could be to integrated air quality sensors with other devices, perhaps linking with health gadgets. The core challenge will be to develop sensors which measure multiple parameters, while being small and inexpensive.

Finally, stakeholder roles in relation to low-cost air quality sensing are manifold: For instance, in health care, there is a lot of potential for the use of low-cost sensors for patients suffering from asthma, with potentially positive impacts on their life. However, current low-cost sensor technologies are not designed to measure air quality at this level of accuracy, and there are no standard methods for testing. This suggests that both legislation/regulation and standardization are areas that need to be addressed when developing the next generation of sensors. A role for stakeholders could be to ensure that decision making is driven forward, by sharing citizen data, and that British, European, or global quality standards are developed, implemented and followed. In addition, stakeholders can stimulate and create the potential to integrate more data, with close links to modelling being an integral part. At the same time, it is important to consider the end user, addressing questions such as "Who owns the data?" and enabling sharing of citizen data. Initiatives such as the OpenAQ movement (https://openaq.org/) could facilitate this. Overall, there is a clear role for low-cost air quality sensors in providing data to stakeholders to support the development of sustainable 'smart cities'.

To overcome key barriers in the development and use of low-cost sensors, there is a clear need to improve sensor performance and implement standards. However, there is currently no clear funding model for this, and different stakeholders (government, regulatory agencies, academia and research institutes, private companies) could have a role to play. The emergence of "Big data" raises questions on how data is shared, analysed, modelled, by whom, and where? At this point in time, robust and comprehensive technical standards seem to be a few years away and GB/EU/global official quality standards maybe as much as five years or more. It is vital to identify viable ways forward in the meantime, with a focus on how we get 'the right information' to 'the right people' at 'the right time'.

Activities such as this workshop were overall viewed as important activities to facilitate and engage different groups and stakeholders, and to foster an ongoing dialogue. In addition to providing information, this dialogue can help to shape the policy and governance landscape, for instance creating platforms and initiatives where scientists, citizens and civil society groups, regulars and policy makers can co-produce solutions to improve public health and well-being in the cities of tomorrow.

ANNEX A: Breakout session notes from rapporteurs

Group M1: Current sensor capabilities and applications

What can we measure with existing sensors? - In theory everything.
More pertinent question, what we **should** be measuring?
Concentrating on regulatory pollutants, including:

- NO_2
- (NO – no compliance requirements)
- O_3
- PM (Particulate Matter)
- Relative Humidity (RH)
- surface pressure
- Temperature
- (CO_2)
- BC (Black Carbon)

In parallel, where health outcome targets are identified they should be developed.

Distinguish between sensors and sensor systems - should be made clear. Two separate issues and potentially separate assessments. Working from the lab: need field calibration to make data useable. Types of environment to target:

- Personal exposure:
- Indoor air processes;
- Building sensors for indoor AQ: HVAC systems suck in air at different levels: T &RH (CO_2).
- Understand chemistry at a point;
- At the point of risk: what is the quality of the air where I live or where I am?
- Biological dose non-linear: high resolution

As a general principle, need a solid network with all sensors co-located to calibrate cross-sensitivities before you can do a wide area distributed network. Wide area distributed networks can overcome limitations of fixed site compliance/reference stations.

Group M2: What data do citizens need and want?

We were asked to think outside the box and to define who are the public?

- EDUCATION: that we engage with PUPILS (a mini traffic warden project) and OAPS (older adult person) and …
- further TARGET teachers, parents, lobbyists, policymakers, industry and commerce.
- We work with the PUBLIC SECTOR who have responsibilities and different needs in relation to providing information to the public, community councils and through to MSP's.
- And that this information needs to be in the CORRECT FORMAT for the END USER.

We then discussed the problems of continued exceedances of pollutant levels in the cities, traffic congestion charging, changing the modes of transport, links to street lighting and possible LIVE DATA ON OVERHEAD MOTORWAY GANTRIES and STREET LEVEL DISPLAY BOARDS.

It was strongly suggested and supported that we target the most DEPRIVED COMMUNITIES and we support a strategy of ENVIRONMENTAL JUSTICE and also better engagement with the NHS. That we address the problem of providing information to PUBLIC HEALTH campaigns as an AGENT OF CHANGE, and we support PUBLIC POLICY challenges to include PREVENTION and EARLY

INTERVENTION initiatives in relation to the developing links between poor air quality exposures and hospital admissions.

We further developed our thinking about the need for more and better quality information.

We looked at more SPECIFIC INFORMATION targeting for groups such as athletes, “Fitbit” users, cyclists, pedestrian, car and public transport users. We agreed that it was important to get the “CORRECT” INFORMATION TO USERS AS THE TECHNOLOGY EVOLVES, and to establish linkages to BIG DATA projects.

Existing small technology users are already doing some off this, through crowd sharing and mapping.

We need to settle the debate between the “CERTIFICATED” quality of data from the fixed networks versus the UTILITY (usefulness and low costs) of the data from the wearable sensors. Compliance with the Aarhus Convention[3] is essential. The two or more emerging networks should converge, be complementary to allow the creation of JOINT MAPS.

RESEARCHERS and LOBBYISTS need access to HISTORIC DATA, we all need more EXAMPLARS from other cities and countries. This then raised questions for future discussion about WHO HAS ACCESS to the DATA and WHO PAYS for it? And how was this data to be USED ETHICALLY? We concluded with the (rhetorical) statement that what was needed was (better) INFORMATION not (necessarily) more monitors.

Group M3: Low-cost sensing for local authorities

Which capabilities do low-cost sensors offer for regulatory monitoring?

- The Automatic Urban and Rural Network (AURN) and the 92 monitoring sites noted on the Scottish Air Quality Database provide a reference standard for air quality monitoring however they clearly only represent chosen spots within a spatial and temporal model. With this in mind it was agreed greater spatial and temporal data must surely add value.
- All believed low cost sensor data, at present, had little direct value as reference quality regulatory level monitoring.
- There were mixed views across the various professions (environmental, planning, policy, and transport) on the quality and value of low cost sensor data on their own. Some had early experience of poor quality and reliability, however others believed the data could be used, fused with other data (such as transport and reference data) to provide good evidence for decision making. Some applied research projects such as UTRAQ, CARBOTRAF, and work by Libelium have shown varied success in this area, and centres of excellence such as CENSIS are working hard to

[3] The Aarhus Convention (UNECE) is a multilateral environmental agreement through which the opportunities for citizens to access environmental information are increased and transparent and reliable regulation procedure is secured.[2][3] It is a way of enhancing the environmental governance network, introducing a reactive and trustworthy relationship between civil society and governments and adding the novelty of a mechanism created to empower the value of public participation in the decision making process and guarantee access to justice: a "governance-by-disclosure" that leads a shift toward an environmentally responsible society.[4] The Aarhus Convention was drafted by governments, with the highly required participation of NGOs, and is legally binding for all the States who ratified it becoming Parties. Among the latter is included the EC, who therefore has the task to ensure compliance not only within the member States but also for its institutions, all those bodies who carry out public administrative duties.[5] Each Party has the commitment to promote the principles contained in the convention and to fill out a national report, always embracing a consultative and transparent process[6]

demonstrate applied business models. Such projects need robust academic review, peer commentary, and wide dissemination of the findings.

- It was agreed it may be useful to classify the quality of data from low cost sensor into three groups of *1 reference, 2 indicative, and 3 informativ*e, and to classify the accuracy and variance of the data from sensors falling into each of these groups.
- A key question in relation to the use of low cost sensors (indeed any type of measurement) is "what are the sensors, and the resultant data being used for". We also perhaps need to define the problem before deciding sensors are the solution.
- Any management decisions must be based on robust defensible data.

What are the primary concerns/barriers for the use of low-cost sensors?

- Systems are currently presented as "black boxes", with little explanation of the method of working, the algorithms used to produce data, and the servicing and operational requirements. Accuracy, reliability, and lifespan, can all be variable.
- The equipment can go out of date very quickly, either through degradation of the sensors, or due to more accurate lower cost equipment becoming available as the technology develops. With this in mind it is important to maximise use, and share sensors with other organisations. For example schools could be encouraged to use equipment to raise awareness of air quality and the links to transport.
- There was a recognition much lower cost sensor may be available if they are produced in large enough number, however conversely there was also an understanding this would require a commitment from large organisation, or a major research project, to their use. Such a change requires significant funding and support
- There are also clear challenges for misrepresentation and misuse of the data.
- It is important to define low cost.

How can low-cost and reference sensor datasets be integrated?

- Perhaps the current $PM_{2.5}$ network in Scotland could be enhanced by using a grid of low cost sensors around the current PM_{10} reference stations.
- There is a lot of statistical experience on integrating the data across sensor networks to inform decision making algorithms. This could be deployed within a sensor network to inform modelling and real time decision making.
- It is import to provide metadata with outputs from low cost sensors. This should include data on dropouts, failures, and accuracy. The data should also be quality assured and audited. This quality based approach would help provide integrity to the integration process.
- Such systems need to be scalable, with exportable data, and with good links to other systems. Data can be integrated and fused with other datasets to improve decision making.
- All of the above can be challenging within a fast developing industry, with a range of providers (sensor manufacturers, box providers, systems designers, and retailers), and delivery sectors. It would be useful to produce a paper describing the shape of the industry, a vision for its future, and a series of required protocols for scalable architecture.

Group A1: Research needs for next-generation sensors

- Wearable sensors: still challenging
- Cross sensitivities: real life vs lab calibrations
- Algorithms: how to understand cross sensitivities: range of opinions about whether they should give away. Sufficient information so that user comfortable with offsets/slope. Range of opinions on sensor data and sensor algorithms.
- Barrier of investment and costs – low cost are in the development stages
- Difference between garbage in/garbage out: developing the statistics. Moving to higher R^2 so not garbage in/garbage out
- Hope is challenging: what can the citizen expect from it? How can that be matched.
- Characterise locally improves performances

What lessons can we learn from existing sensor application?

- Confidence building: "calibrations certificates"/Self-development of calibrations – some information sufficient; Standards and/or equivalents developed through CEN
- Emotive subject: compliance vs research into transformative approaches
- Engaging LA: Covering gaps in monitoring – case studies
- How to prove or disprove challenges? Won't use for compliance, but other applications.
- Targeted case studies
- Finding a way to get the next generation of "to use" technology.

Communication:

- AQ indexes – too many!
- Communicating information from this subject area is highly variable.
- Terminology of data quality needs to be developed
- Uncertainty through charts and maps is done poorly. They are all garbage!
- How to communicate in a correct enough way; How do we communicate the uncertainty through the system.

Funding

- Ownership of IPR for funding providers/government/charities/PR up that there is an issue. Can the private sector invest?
- Sensor systems: relatively high cost but research going on to lower costs.
- Academic research: push it through;
- Collaboration: for future data publication: archiving.
- INSPIRE compliance.

Data access

- Frequency DS4 Long term stability and quality ESPRC project. *(see as well paper by Ally Lewis et al. on Evaluating the performance of low cost chemical sensors for air pollution research, DOI: 10.1039/C5FD00201J)*
- Data repository
- Data confidence: be brave!

Group A2: How to safeguard data quality from Citizen Science projects?

What tools and methods do we need to develop for quality control of data?

- Can't just leave sensors, need for maintenance, check for drift, weird numbers
- Questions raised – do we have all the necessary QA/QC tools – the answer was no. Something is needed to get valid results
- Systems are maturing – do people buy a system and 'that's it', who would provide the tools and methods for QC?
- From LA perspective, QA/QC is outsourced on Scotland wide basis which is a good system as same uniform standards are applied throughout. Added bonus is that the data then becomes publically available. How this could be stretched beyond the ref monitoring stations is another matter / challenge.
- Discussion on real-time aspects – people want to use data 'now', as soon as it is collected. QC/QA may slow down that provision. Is this considered or are manufacturers thinking about incorporating/advancing QC elements within the sensors system design to help address this
- Need to consider the inherent 'nosiness' of the data and calibration
- Idea was put forward about having some mechanism where when a sensor passes within a certain distance of a reference monitor that it recalibrates itself in real-time. Caution was expressed as ideally would like sensors within 0.5 m of reference monitoring stations to allow for calibration
- Calibration of electrochemical sensors with certified gas cylinders was also mentioned.
- Time of life of the sensor, how much variation is there? If the lifespan of the sensor is 6-12 months is there value in repeat calibration, perhaps instead just replacing the sensor with a new (perhaps improved) one.
- Any merit is having three of the same sensor within a device so that it is clear if any issues are occurring?
- Raised that some sensor system manufacturers / developers are good – they can check the data being generated and alert users when things don't look correct.
- It was considered that it would be useful to have 1. Clear definition of the system architecture for particular decision making requirements. 2. Classification of the type of sensor (system) – reference, indicative and informative. 3. Performance characteristics for the system / sensor.
- Cross sensitivity – still an issue and how do you address this?
- Costs involved in servicing a network of 100s, potentially 1000s of sensors remotely.

Which skills and capabilities do citizen scientists and researchers need to build?

- How do you engender caution in the interpretation of data in an individual who may have limited knowledge?
- Potentially government, organisation sets up something regionally where people can bring their sensors in for testing, learn more about data limitations.
- It was highlighted that it can be confusing for experts to interpret peaks and troughs from data and understand why these are different from what may be expected. If this is the case how can those with little or no knowledge interpret information correctly? May also put people off from continuing to use the sensors if the data isn't in line with what they are expecting.
- 3 things important to citizen science – what data means? so what? What can I do about it?
- Considered that holding atmospheric chemistry workshops for interested people may help. 100s people buying devices without any real understanding of their capabilities or otherwise.
- Do you get what you pay for? People may become obsessed / sensitised by the data which may lead to over interpretation.
- Been moves to better inform decision makers and there is a need to help educate people who are then going to influence the decision makers.

How can we communicate uncertainties in data?

- Uncertainty means different things to different people.
- Some people experience was to avoid dealing with this – 'keep it black and white'.
- What's already out there is misunderstood, sometimes deliberately so and there is an increased danger of this. Example, use of unratified data, malfunction of reference NO_2 monitor which leads to journalists asking comments and time spent trying to address these. This could become an even more frequent issue.
- Not against data being out there but it needs to be robust. Concern is when things are incorrectly reported.
- Need buy in from public – won't get change until public believes there is a need and the evidence needed to support this needs to be there and robust.
- Colour maps – green, orange and red – how do you reflect that this isn't a hard barrier?
- Difficult to communicate and demonstrate what the sensors are actually measuring rather than what is stated on the packaging.

Three wishes….

1. Scope for British Standard – nothing there at the moment. All sensors are 'badged' under the same thing which isn't fair when some are reasonable quality and others are simply rubbish. Kite mark or something similar would at least tell the consumer something and that an independent evaluation has been carried out. Possible control outlets where they are being sold (Corgi certification) to ensure that appropriate information is given at the point of purchase. Highlighted that citizen science projects tend to use aggregated data and this would also need to be considered.
2. Integrated devices with other things, perhaps linking with health. Once AQ problem is solved, what can we measure next?
3. Like them to measure multiple things and to be small.

Group A3: Stakeholder roles for next generation low-cost sensors

Which roles for low-cost sensors do stakeholders see?

- We initially talked about the definition of stakeholders in this context and agreed on the following: all interested parties (users, developers, funders).
- We discussed big companies like Apple, Microsoft, Fitbit etc. and their roles and responsibilities.
- We talked about what the use of low-cost sensors, if used by 'the general public', can bring to society and agreed that the aim should be to enhance the capacity for people to make effective choices, and enable them to transform those choices into actions and outcomes. Furthermore, the use of low-cost sensors can empower people to contribute to and participate in environmental governance, and in that way enable people to support and influence public and social priorities and decision making.
- At lot of the discussion revolved around asthmatics and how the use of low-cost sensors potentially can have a positive impact on their life. However, the technology of low-cost sensor is not designed to measure air quality at this level of accuracy, there are no standard methods for testing, and legislation and standardization are therefore areas that should be addressed when developing the next generation of sensors.

How can stakeholders influence/support the development of next generation sensors?

- Meetings like this workshop is an ideal and necessary way to involve and empower stakeholders.
- Stakeholders should ensure that:
    - Decision making is driven forward, by sharing citizen data.
    - British, European, or World quality standards are developed, implemented and followed.
    - Create the potential to integrate more data; modelling will be/should be an important part.
- The density of sensors and measurements is insufficient and should be increased, to get rid of noise.
- We need more reference instruments, which we can calibrate the low cost sensors against
- Important to consider the end user:
    - Who owns the data?
    - Enabling sharing of citizen data.
- Stakeholders should support the development of sustainable 'smart cities'.

What barriers and challenges do stakeholders identify for being involved in the process?

- We need to improve sensor performance and implement a standard BUT who will pay; government, Universities, private companies? What part will they all play?
- Big data; how do we share, analyse, and model?
- Technical standard still a couple of years away and GB/EU/World standard maybe as much as five years away; what do we do until then?
- We need more focus on how we get 'the right information' to 'the right people' at 'the right time'.

ANNEX B: Workshop participants

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ANNEX C: Delegate feedback

SECURE Workshop
Use of low-cost sensor technology to monitor air quality & engage citizens
30 March 2016

20 returned forms with varying degrees of completion. Numbers in red below give number of responses recorded.

We hope you have enjoyed the workshop. We appreciate your feedback and would be grateful if you could take the time to complete and return this short questionnaire.

1. Please rate the following aspects of the meeting venue and facilities, from excellent to poor.

	Excellent	Good	Average	Poor
Venue location	16	4	☐	☐
Room size	16	4	☐	☐
Food & beverages	7	9	4	☐
General comfort	9	9	1	☐

Please provide any comments below (continue overleaf if necessary)

Need to open window, increase air con, decrease solar gain.
Coffee break too long
Thanks!
Egg free requested (food rated average)

2. Please rate the CONTENT of the workshop programme, from excellent to poor.
Note- several people responded to all breakout groups (even though they would have only been in one)

	Excellent	Good	Average	Poor	N/A
Introductory presentations	3	11	☐	☐	☐
Morning breakouts					
M1: Current sensor capabilities & applications	4	5	1	☐	☐
M2: What data do citizens need/want?	3	5	☐	☐	2
M3: Low-cost sensing for local authorities	4	9	1	☐	1
Reporting of morning sessions	5	8	☐	☐	☐
Afternoon breakouts					
A1: Research needs for next-generation sensors	3	5	1	☐	1
A2: How to safeguard data quality from CS projects?	2	7	☐	☐	1
A3: Stakeholder roles for next generation low-cost sensors	3	5	1	☐	☐
Reporting of afternoon sessions	3	10	1	☐	☐
Posters	3	4	1	☐	5
Exhibition	3	9	1	☐	1

Please provide any comments below (continue overleaf if necessary)

Please continue to develop these ideas and links to policy makers and agents of change e.g NHS.
Good event
Thank you
Presentation lengths too diverse, better if they were a uniform length
Need to combine experience in the room and possibly bid for funding to take forward ideas from this conference.

3. Are there any additional issues concerning low cost sensor technology that you think should have been included in the workshop? (Please continue overleaf if necessary)

Ownership and sharing of data collected from sensors
How to engage citizens as data gatherers