Smart Control of Air Pollution

Policy Briefs from the **iSCAPE** project funded by the European Union's Horizon 2020 Research and Innovation Programme

Air quality sensing and real time reporting in cities

Contents

Key Take-Aways

Low-cost sensor technology provides an opportunity to expand and advance the conventional air pollution monitoring.

Recent advancements in the field of sensors, digital electronics, and wireless communication technology have led to the emergence of a new paradigm for urban pollution assessment. This involves gathering highly granular, spatially and temporally located data by a ubiquitous network of low-cost sensor nodes that monitor urban climate parameters and near real-time concentrations of various pollutants. However, some challenges remain, and need to be addressed, notably with respect to ensuring and maintaining sensor performance (thus ultimately data quality and reliability) across time and installations.

This Policy Brief recognises a need for more practical guidance - although based on sound scientific and empirical evidence - to help urban decision-makers choose the most appropriate commercially available solutions based on their requirements and the specific parameters to be monitored. In particular, the iSCAPE project results yield a tested and detailed calibration procedure for new sensor installations, acting both in laboratory and in real life controlled conditions.

In terms of implementation, this Policy Brief provides evidence from the action research carried out during iSCAPE, including two different options of air quality sensing and real time reporting stations. These solutions are based on the principle of directly involving citizens in the collection and interpretation of gathered data according to the Living Lab approach, that has been actively and

The iSCAPE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689954.

successfully implemented in six European pilot cities during the project's lifetime (Bologna-IT, Bottrop-DE, Dublin-IE, Guildford-UK, Hasselt-BE and Vantaa-FI).

"It encourages a shared responsibility for science"

A member of one of the city pilots.

What Is Available

Find more online at
https://smartcitizen.me/kits/

The overall objective of iSCAPE was to develop an integrated and replicable strategy for urban air pollution monitoring and control, that is grounded on evidence and actively involves the population in experiments of Citizen Science. In fact, the project has developed and successfully deployed two distinct air pollution sensing solutions for city managers willing to experiment with novel, non-conventional and people-centred approaches:

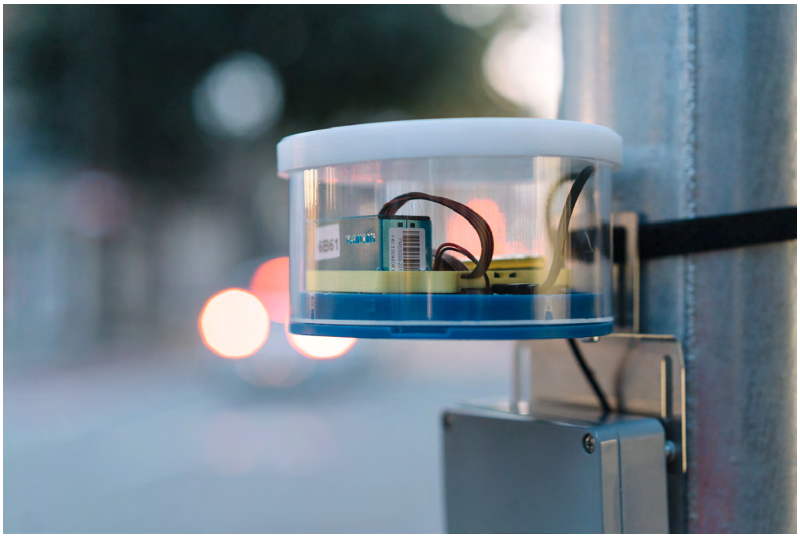

Figure 1: Smart Citizen Kit.

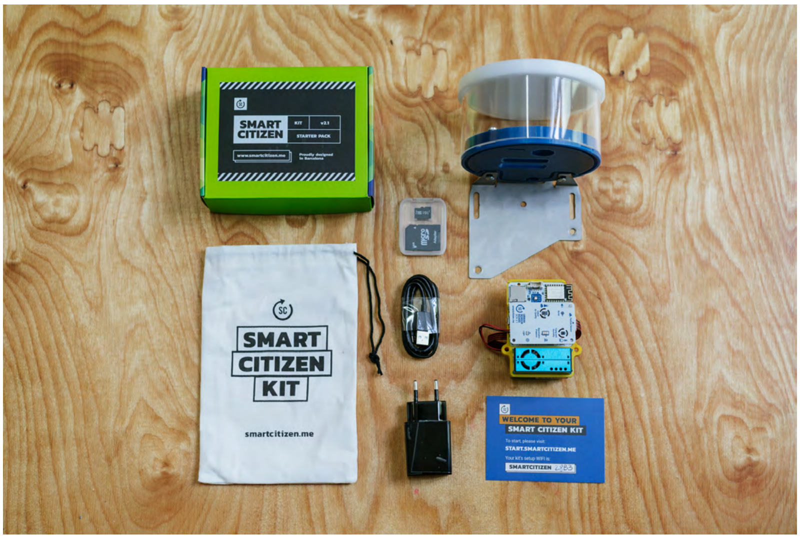

Figure 2: Smart Citizen Kit - components.

- The **Smart Citizen Kit**, a very low-cost set of environmental sensors - in the range of €100 - assembled into an easy to configure hardware (see Figures 1 and 2). The Kit stems from the complete redesign of a piece of hardware already tested in previous funded projects for more than five years. In this new version, additional sensors have been added, and all the electronics design has been redone from the ground up, in order to improve data accuracy and reduce manufacturing costs. The Kit is composed of two boards: the data board, which contains the data acquisition, the power management, and the communication unit; and the urban sensor board, which contains a set of sensors aimed at outdoor environment measurement of parameters such as: particulate matter (PM), air temperature, relative humidity, noise level, ambient light, total Volatile Organic Compounds (tVOC) and barometric pressure.

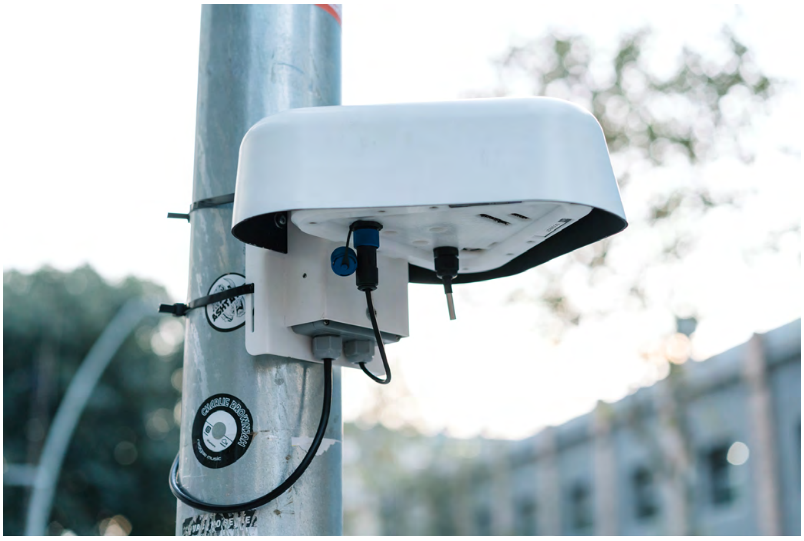

Figure 3: Living Lab Station.

- The **Living Lab Station** (here seen in Figure 3 from an installation in Barcelona, Spain), is a more complex system equipped with high-end sensors, aimed at providing Living Labs - the people driven innovation ecosystems established by the iSCAPE project in the six European pilot cities with a solution for monitoring the performance of their community empowerment actions from a scientific point of view. It is also aimed to serve as a tool to engage citizens more deeply in air pollution control, reduction and prevention activities. The Living Lab Station has been designed according to a modular principle, with sensors that can be easily added to expand the capabilities of the installation, replaced if damaged or when their lifetime is over. The Living Lab Station builds on top of the Smart Citizen Kit's urban sensor board and includes an extra set of more accurate sensors especially aimed at measuring air pollutants. The extra set is composed of a Gas Pro Sensor Board, featuring electrochemical sensors capable of measuring Carbon Monoxide, Nitrogen Dioxide and Ozone, and two PM sensors capable of measuring $PM_{2.5}$ / PM_{10}.

The two solutions were iteratively developed and real-life tested in the six iSCAPE pilot cities, each of them running two distinct Citizen Science workshops with 93 participants overall (for more information on the Citizen Science workshops, have a look at Policy Brief No. 9 “Citizen Science: A collaborative approach to air pollution control”), and using the Living Lab Stations to monitor interventions. The short-term goal was to educate the Living Lab members and the general public on the use of the Smart Citizen Kit while at the same time building an air quality monitoring community, motivated to influence and change local policies thanks to their engagement in the iSCAPE pilots. In the long-term, the aim is to create local groups of citizen scientists actively working and collaborating with the Living Labs themselves, including self-initiated projects.

By involving people as enablers and users of the resulting, “crowdsourced” sensing system, several important goals can be readily achieved; these include: a) the development of local pollutant maps supplementing conventional air pollution surveillance and improving emergency response management, hazardous link detection, and source compliance monitoring, b) the possibility of assessing individual exposures to air pollutants, thus improving the knowledge and awareness of the general public regarding urban pollution and its links with human health and wellbeing.

Data quality

Several challenges also need to be addressed before such crowdsourced campaigns can be widely adopted. These are related to maintaining the citizens engaged and the sensors in operation, as well as measuring more precisely, improving the quality of gathered data.

While many scientific studies have utilized low-cost PM and gaseous sensors in a variety of air pollution monitoring activities, only a few have reported about the performance of those sensors and the associated data quality. To further exacerbate the matter, existing evidence derives from different experimental set-ups, reference equipment, and environmental conditions, making it infeasible to compare the assessment results with each other and draw general conclusions regarding data quality.

Improper sensor calibration seems to be a major issue plaguing data quality. The sensor response is largely impacted by environmental conditions, particle characteristics (for PM sensors), and gaseous cross-sensitivities (for gas sensors). Thus, calibration methods that do not include these factors are bound to produce erroneous data. Thus, in order to deploy a large-scale sensor network and meaningfully use the plethora of data generated through it, it is imperative to formulate a standard protocol with guidelines for assessing the short-term and long-term reliability of low-cost sensors, which can be used by everyone.

Based on an extensive scientific literature review, the iSCAPE project has developed a detailed calibration procedure, which is documented as separate deliverables in D3.13 ‘Comprehensive release of High-end and Low-cost Sensing Platforms’, and D7.8 ‘Sensor Monitoring Experiences and Technological Innovations’ (see section Read More below) as well as **online**.

Sensor specifications and calibration procedures

The environmental set of sensors available in the Smart Citizen Kit (see Figure 4) provides off-the-shelf measurements that do not require intervention by the end user in order to calibrate the data. The sensor selection is aimed particularly at avoiding the need of performing this task, by pre-calibrating the sensors and implementing their corrections in the device. In the case of the tVOC sensor, the measurement is corrected internally using temperature and humidity metrics, and it should be considered as an indicative measurement, not an absolute one.

In the case of the Living Lab Station, the calibration of the set of electrochemical sensors (CO, NO2, O3) need to follow one of these two options: a) calibration on the field by sensor co-location with high-end measurement instruments, for a period of 3-4 weeks, depending on the location; or 2) usage of generic models developed from other sensors, which use manufacturer data, and that are currently in an experimental stage. In the case of option 1, these sensor deployments should at least deliver the following outputs: (i) a checked reference benchmark for the sensors to be compared against it, (ii) sufficient sensor stabilisation time and varied operational conditions, and (iii) careful monitoring of the sensor's correct operation: connectivity and power supply, among others.

Measurement	Units	Sensors
Air temperature	ºC	Sensirion SHT-31
Relative Humidity	% REL	Sensirion SHT-31
Noise level	dBA	Invensense ICS-434342
Ambient light	Lux	Rohm BH1721FVC
Barometric pressure	Pa	NXP MPL3115A26
Equivalent Carbon Dioxide	ppm	AMS CCS811
Volatile Organic Compounds	ppb	AMS CCS811
Particulate Matter PM 1 / 2.5 / 10	µg/m3	Planttower PMS 5003

Figure 4: Smart Citizen Kit measurement list.

"Indoor measurements created a great disappointment in the teams, due to the surprisingly bad air quality results."

From the report of one of the city pilots.

Implementation Tips

Figure 5 shows the full list of measurement types available at a Living Lab Station. In terms of implementation, the main conclusions of our action research are as follows:

Measurement	Units	Sensor	Component
Air Temperature	°C	Sensirion SHT-31	Urban Sensor Board
Relative Humidity	% REL	Sensirion SHT-31	Urban Sensor Board
Noise Level	dBA	Invensense ICS-434342	Urban Sensor Board
Ambient Light	Lux	Rohm BH1721FVC	Urban Sensor Board
Barometric pressure and AMSL	Pa and Meters	NXP MPL3115A26	Urban Sensor Board
Carbon Monoxide	µg/m3 (Periodic Baseline Calibration Required)	SGX MICS-4514	Urban Sensor Board
Nitrogen Dioxide	µg/m3 (Periodic Baseline Calibration Required)	SGX MICS-4514	Urban Sensor Board
Carbon Monoxide	ppm	Alphasense CO-B4	Gas Sensor Pro Board
Nitrogen Dioxide	ppb	Alphasense NO2-B43F	Gas Sensor Pro Board
Ozone	ppb	Alphasense OX-B431	Gas Sensor Pro Board
Gases Board Temperature	°C	Sensirion SHT-31	Gas Sensor Pro Board
Gases Board Rel. Humidity	% REL	Sensirion SHT-31	Gas Sensor Pro Board
PM 1	µg/m3	Plantower PMS5003 Dual System	PM Sensors Board
PM 2.5	µg/m3	Plantower PMS5003 Dual System	PM Sensors Board
PM 10	µg/m3	Plantower PMS5003 Dual System	PM Sensors Board

Figure 5: Living Lab Station measurement list.

1. To **measure $PM_{2.5}$ and PM_{10}**, several low-cost optical sensors are available in the market. The low-cost sensors tend to perform reasonably well as compared to conventionally used particle monitors of significantly higher cost;

2. To **measure gaseous air pollutants such as O_3, NO_2, CO, and NO**, two types of low-cost sensors are generally available in the market: MOS (Metal Oxide Sensors) and EC (electrochemical) sensors. The performance characteristics of these gaseous sensors are very variable with the discrepancy attributed to the differences in the data processing algorithms and test conditions and methods used. Therefore, these sensors clearly need careful calibration such that the various factors that influence their response, are accounted for before usage;

3. The electrochemical sensors are typically more expensive than MOS sensors, but have better performance characteristics;

4. During the iSCAPE project, weather conditions, noise, light and PM sensors have been validated against reference values via both in-house and external measurements and thus provide accurate data. Gas sensors are to be considered qualitatively in the case of Metal Oxide Sensors (tVOC in the Smart Citizen Kit), while the Living Lab Stations electrochemical sensors have shown great data accuracy with proper calibration algorithms;

5. The sensors can work in network or local mode. In network mode, the individual sensor publishes the collected data to an online platform through Wi-Fi connection every minute. In local mode, all the data is stored locally in a sd-card in CSV format, and can be later uploaded manually to an online platform. Conversely, every data collected by each sensor is available for anyone to download at any time as a CSV file. Besides, one can also use available or newly developed Application Programming Interfaces (APIs) to build custom applications interacting with one's own device.

Thanks to their modular design and low cost of acquisition and installation, the installation of the sensors is at a stage of being sufficient mature and reliable to be further and more extensively integrated in urban infrastructures.

Keywords to remember

Air pollution:

Harmful emissions of particulate matter (PM), nitrogen oxides (NO_x), carbon monoxide (CO) and other volatile organic compounds (VOCs). Air pollution is particularly harmful for children, senior citizens and people with breathing related health issues.

Citizen Science:

Refers to the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort, surrounding knowledge or with their tools and resources.

Living Lab:

A citizen-centred urban innovation ecosystem, based on systematic user engagement in real-life settings through a wide variety of methods and tools, with the participation of multiple stakeholders in the co-creation of innovations.

Sensor:

A device that detects some type of input from the physical environment - for instance, light, heat, motion, moisture, pressure, etc. - and responds to it with a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

Read More

The content presented herein is based on the following key project deliverables: **D1.5** 'Summary of Air Quality Sensors and Recommendations for Application' (October 2018), **D3.1** 'Comprehensive Release of High-end and Low-cost Sensing Platforms' (July 2019), **D4.7** 'Citizen Science Communities Report' (May 2019), **D7.8** 'Sensor Monitoring Experiences and Technological Innovations' (November 2019) as well as the technical documentation available at **http://docs.smartcitizen.me/**. The Smart Citizen Kit is an initiative of Fab Lab Barcelona and the Institute of Advanced Architecture of Catalonia, and it's commercially available at Seeed Studio.

All reports are available on the iSCAPE project website: www.iscapeproject.eu

Impressum

Acknowledgements and Disclaimer

Authors of this Policy Brief are Mr Guillem Camprodon and Mr Óscar González from the Institute of Advanced Architecture of Catalonia, with support of Mr Francesco Molinari.

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The iSCAPE project

iSCAPE aimed to reduce urban air pollution and the negative impacts of climate change by leveraging sustainable passive control systems, behavioural change initiatives and the Living Lab approach.

For more information: www.iscapeproject.eu.

iSCAPE partners:

University College Dublin	
University of Bologna	
University of Surrey	
Finnish Meteorological Institute	
Hasselt University	
TU Dortmund University	
JRC - Joint Research Centre - European Commission - Institute for Environment & Sustainability	
Institute for Advanced Architecture of Catalonia - FabLab Barcelona	
T6 Ecosystems S.r.l.	
Nanoair Solutions S.r.l.	
Future Cities Catapult Ltd.	
Dublin City Council	
Regional Agency for Prevention, Environment and Energy of Emilia-Romagna	
European Network of Living Labs	
Trinity College Dublin	

Smart Control of Air Pollution - Policy Briefs

The Smart Control of Air Pollution - Policy Briefs series summarises key outcomes of the iSCAPE project with a clear policy orientation, to provide practical information to EU local decision-makers and other urban stakeholders. They cover the following topics:

- **No. 1** Living Labs for air pollution control and prevention
- **No. 2** iSCAPE manifesto for citizen engagement in science and policy
- **No. 3** Effectiveness of travel behavioural change interventions
- **No. 4** Simulating change in urban air quality and climate conditions
- **No. 5** Urban strategies and interventions for planning healthier cities
- **No. 6** Improving air quality and climate with green infrastructure
- **No. 7** Air quality sensing and real time reporting in cities
- **No. 8** Introducing infrastructural passive control systems in cities
- **No. 9** Citizen Science: a collaborative approach to air pollution control