SENSING CHANGE

How cities are using new sensing technologies to achieve air quality goals

C40 CITIES

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FOREWORD

Air pollution is a global health crisis and the largest environmental health threat the world currently faces. Nearly 13 people every minute die due to exposure to air pollution, making it the world's fourth-leading risk factor for early death. Despite improvements in air quality in some countries, pollution levels remain far too high in many of the world's most-populous and fastest-growing cities.

In September 2021, when the World Health Organisation (WHO) updated its Air Quality Guidelines, it spoke loudly and clearly on the profoundly harmful effects of air pollution, even at very low levels. Over the past few decades, a growing body of literature has reinforced how poor air quality negatively affects people of all ages, leading to ill health, increased hospital admissions and reduced life expectancy. This research underscores the public health imperative of actions to end our reliance on fossil fuels. The only pathway to creating breathable air in our cities is by decarbonising all sectors of our economy and eliminating fossil fuel combustion.

Fortunately, the solutions to improve air quality already exist, and have proven to be effective in many of the world's leading cities. To date, 38 C40 mayors have signed the C40 Clean Air Cities Declaration, committing to take bold action on sources of air pollution within their cities to bring levels in line with World Health Organisation Air Quality Guidelines. Air quality monitoring is a fundamental tool to ensure clean air in our cities. As well as providing data to understand pollution risk and information on sources and location of pollution, it can also evaluate how well policies are working and empower residents with information on their own exposure levels. Expanding pollution monitoring is a valuable tool for designing and implementing impactful and equitable climate solutions. Over the past few years there has been an increase in new technologies available for air pollution monitoring, creating new opportunities for cities – of all resource levels – to better develop and implement clean air actions.

This report highlights the innovative ways leading cities are using new technologies to achieve a range of air quality goals. We hope its findings provide valuable insights into how cities can improve the design and implementation of their monitoring plans, while simultaneously helping guide the wider air quality community through highlighting key questions and needs relevant to cities across the globe.

Mark Watts
C40 Cities Director

TO DATE, 38 C40 MAYORS HAVE SIGNED THE C40 CLEAN AIR CITIES DECLARATION, COMMITTING TO TAKE BOLD ACTION ON SOURCES OF AIR POLLUTION WITHIN THEIR CITIES TO BRING LEVELS IN LINE WITH WORLD HEALTH ORGANISATION AIR QUALITY GUIDELINES.

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The Clean Air Fund is a global philanthropic organisation that works with governments, funders, businesses and campaigners to create a future where everyone breathes clean air. **www.cleanairfund.org**

C40 is a network of nearly 100 mayors of the world's leading cities who are working to deliver the urgent action needed right now to confront the climate crisis and create a future where everyone, everywhere can thrive. Mayors of C40 cities are committed to using a science-based and people-focused approach to help the world limit global heating to 1.5°C and build healthy, equitable and resilient communities.

Through a Global Green New Deal, mayors are working alongside a broad coalition of representatives from labour, business, the youth climate movement and civil society to go further and faster than ever before.

The current Chair of C40 is Mayor of London Sadiq Khan; and three-term Mayor of New York City Michael R. Bloomberg serves as President of the Board. C40's work is made possible by our three strategic funders: Bloomberg Philanthropies, Children's Investment Fund Foundation (CIFF), and Realdania. To learn more about the work of C40 and our cities, please visit **www.c40.org**, or follow us on **LinkedIn**, **Twitter**, **Instagram** and **Youtube**.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Cities are particularly vulnerable to the impacts of air pollution. They are often locations of high pollution exposure and settings of extreme disparities in wealth, health and vulnerability to the effects of air quality and climate change.

Expanding air pollution monitoring is an important element of cities' commitments and efforts to develop and support control policies that address the complexity and variety of pollution sources that exist in cities. For cities new to air pollution monitoring, sensors can provide an affordable option to understanding basic information on their air pollution levels. Cities with existing monitoring networks can use sensors to expand spatial coverage, measure the impact of interventions, identify hotspots and engage local communities and raise public awareness. These networks can also be valuable for evaluating localised exposure and risk among vulnerable and marginalised communities, providing important information to advance solutions that mitigate inequities and protect historically disadvantaged communities.

The rapidly expanding lower-cost air quality sensor market presents valuable opportunities for urban air quality work, but requires that city staff navigate a plethora of options around network installation, data management and communication processes. Without clear information or guidance on characteristics such as data reliability, total project cost and product lifetime, city staff and other end users may face hurdles in successfully deploying new sensors.

Improving dialogue and collaboration between cities and technology providers can help ensure that new sensor technologies and data management platforms can be efficiently applied to solving urban issues. The following recommendations for sensor technology improvements draw on and respond to technical challenges identified by city staff in C40's Air Quality Network:

- Clear protocols on co-location methods and frequency of co-location studies
- Recent and reliable data on sensor accuracy, under local conditions, and reliable information on the useful lifetime of sensors
- Solutions to energy supply disruptions and city-specific conditions
- Robust and responsive customer support
- Training to build city staff capacity in sensor deployment and data analysis
- Solutions that anticipate and reduce e-waste from sensors
- Support with project-level budgeting
- Guidance on data sharing and data management platforms

By addressing city concerns and desires – around issues from sensor design and specific operating conditions to costing, longevity, waste mitigation, data management and training – sensor manufacturers have the opportunity to help cities better understand their air quality and also better serve an emerging, powerful market.

GLOSSARY AND ACRONYMS

Air Quality Management Plan (AQMP)	Air quality management plans (AQMPs) typically include a series of measures designed to manage and reduce air pollutants. These measures are based on an assessment of air quality and trend forecasts for the future, and detailed analysis of the level of concentrations, including the sources responsible.
Baseline data	Robust, sustained and accurate air pollution monitoring within a city to characterise city-wide air pollution levels.
Benzene (C_6H_6)	Benzene (C_6H_6) is a chemical compound that is harmful to human health. As an air pollutant, benzene can be emitted from domestic and industrial combustion processes, as well as vehicles.
Carbon monoxide (CO)	Carbon monoxide (CO) is a colourless, odourless gaseous air pollutant that can be harmful when inhaled in large amounts. CO is produced by incomplete combustion of carbonaceous fuels such as wood, petrol, coal, natural gas and kerosene.
Community engagement	The practice of including relevant stakeholders and communities, particularly marginalised groups, in the policy-making and urban governance process, in order to ensure a fair policy process with equitable outcomes.
Emissions vs concentrations	A city's air quality is affected by a number of factors. These include the weather, local geography and **emissions** sources from both within and outside a city. Emissions are measured in mass of a pollutant (or precursor pollutant) that is created or released through a certain activity. Some air pollutants of concern are not directly emitted, but form in the atmosphere through chemical reactions. Air quality is measured in **concentrations**, which are specific levels of a pollutant in a given area. Legal limits are set in relation to concentrations.
Health impact assessment	A practical approach used to judge the potential health effects of a policy, programme or project on a population, particularly on vulnerable or disadvantaged groups.
Lower-cost sensors	Range from simple single-pollutant sensors to multi-pollutant devices that include communications and meteorological monitoring capabilities. While they range in price, they tend to be lower cost than equipment that collects data at a quality that is certified for use in assessing regulatory compliance. Lower-cost sensors have great potential for real-time air quality monitoring in dense networks, and are in an early stage of development with rapid changes in technologies and providers.

Monitoring	An important part of air quality management is establishing, maintaining and increasing reliable city-wide air quality monitoring, and making data publicly available in an accessible format, in a timely manner or as close to real-time as possible.
Nitrogen oxide (NO), nitrogen dioxide (NO_2), and nitrogen oxides (NO_x)	All combustion processes produce nitrogen oxides (NO_x). In many cities, road transport and heating systems are the main sources of these emissions. NO_x is primarily made up of two pollutants: nitric oxide (NO) and nitrogen dioxide (NO_2). NO_2 is of most concern due to its impact on health. However, NO easily converts to NO_2 in the air, so to reduce concentrations of NO_2 it is essential to control emissions of NO_x.
Ozone (O_3)	Ozone (O_3) is not emitted directly into the atmosphere. It is a secondary pollutant generated by the reaction between NO_x, volatile organic compounds (VOCs), and sunlight. At high levels of NO_x near fresh sources of emissions, the reverse reaction occurs, where NO_x reacts with ozone and acts as a local sink (NO_x-titration). For this reason, sometimes O_3 concentrations are not as high in urban areas (where high levels of NO are emitted from vehicles) as in rural areas. Ambient concentrations are usually highest in areas downwind of major sources or in settings where air is trapped due to topographical features - particularly in hot, still and sunny weather conditions that give rise to summer 'smog'.
Particulate matter (PM)	Particulate matter (PM) is a complex mix of non-gaseous material of varied chemical composition. It is categorised by the size of its particles. For example, PM_{10} is composed of particles with an aerodynamic diameter of less than ten micrometres (µg) and $PM_{2.5}$ is composed of particles with an aerodynamic diameter of less than 2.5 µg. $PM_{2.5}$ is a component of PM_{10}. **$PM_{2.5}$ is thought to be the air pollutant that has the greatest impact on human health, based on current evidence.**
Regulatory (or 'reference grade') moni-toring stations	Highly accurate monitoring equipment that is expensive, and requires significant infrastructure and trained personnel to operate. This equipment is often certified by regulatory agencies to meet the standard for use in determining whether air quality levels comply with regulatory standards.
Source apportionment	The practice of obtaining information about pollution sources and the amount they contribute to ambient air pollution levels within a particular region.
Sulphur dioxide (SO_2)	Sulphur dioxide (SO_2) is a gaseous air pollutant composed of sulphur and oxygen. SO_2 forms when sulphur-containing fuel such as coal, oil or diesel is burned. Sulphur dioxide also reacts with other pollutants in the atmosphere to form sulphate particles, a major part of fine particle pollution in many global cities.

BOX 1 / MONITORING SPOTLIGHT: C40 SENSOR WORKING GROUP

City-to-city sharing is the basis on which C40 was founded and it continues to be at the heart of our mission: collaboration moves cities farther, faster. Mayors and city officials understand that by working together they can advise each other on what does and does not work, accelerating implementation of ambitious and effective air quality and climate solutions.

The **C40 Air Quality Network** brings together air quality management officials from 50 cities working towards shared goals. Peer-to-peer collaboration benefits city staff by cutting costs, preventing mistakes and building capacity to deliver action. Positive peer pressure also drives accelerated and scaled-up action. Once one city delivers a higher ambition policy or programme, it sets a new standard for all cities. The network is built on the principle that, while each city is unique, there are sets of commonly-applicable best practices that can be enacted with sensitivity to local context and circumstance.

In 2019, the C40 Air Quality Network established a Sensor Working Group to provide a unique platform for collaboration and sharing of best practice in deploying and using data from sensor monitoring networks. The cities in the working group have developed a high level of trust around a shared purpose, which has accelerated learning, allowing practitioners to rapidly deploy sensor networks that are better and cheaper.

City staff from the Sensor Working Group have contributed to this report, which provides case studies on urban approaches to sensor-based air quality monitoring studies. The document is meant as a resource for all cities, to improve the design and implementation of monitoring plans by leveraging the experiences of a diverse network of cities.

INTRODUCTION

1

Mumbai © Peter Adams / Getty Images

1.1. C40 Cities: Committed to cleaning the air we breathe

C40's vision is for all cities to achieve healthy levels of air quality (by meeting or surpassing **World Health Organization (WHO) Air Quality Guideline levels**) in the shortest possible time, while meeting the goals of the Paris Agreement.

To help meet this goal, in 2019, 35 cities launched the **C40 Clean Air Cities Declaration**, pledging to deliver clean air for the more than 140 million people that live in their cities. By signing this commitment, the mayors recognised that breathing clean air is a human right and committed to work together to form an unparalleled global coalition for clean air. The commitment creates a best practice framework for clean air in cities, with signatories committing to targets in line with WHO Air Quality Guidelines; implementing new substantive policies to address the top causes of air pollution within city control; expanding air quality management activities, such as air pollution monitoring and evaluating the health impacts from pollution; and publicly reporting on progress towards air pollution goals. As of May 2022, 38 mayors have signed the C40 Clean Air Cities Declaration. More information on the actions cities are taking through these commitments can be found on the Declaration page on the C40 website.

Cities are particularly vulnerable to the impacts of air pollution. They are often locations of high pollution exposures and settings of extreme disparities in wealth, health and vulnerability to effects of air quality and climate change. Currently, 56.2% of the world's population lives in urban areas, a figure that is expected to increase to 60.4% by 2030, with rapid urbanisation in low-middle income countries where air pollution levels are often the highest.

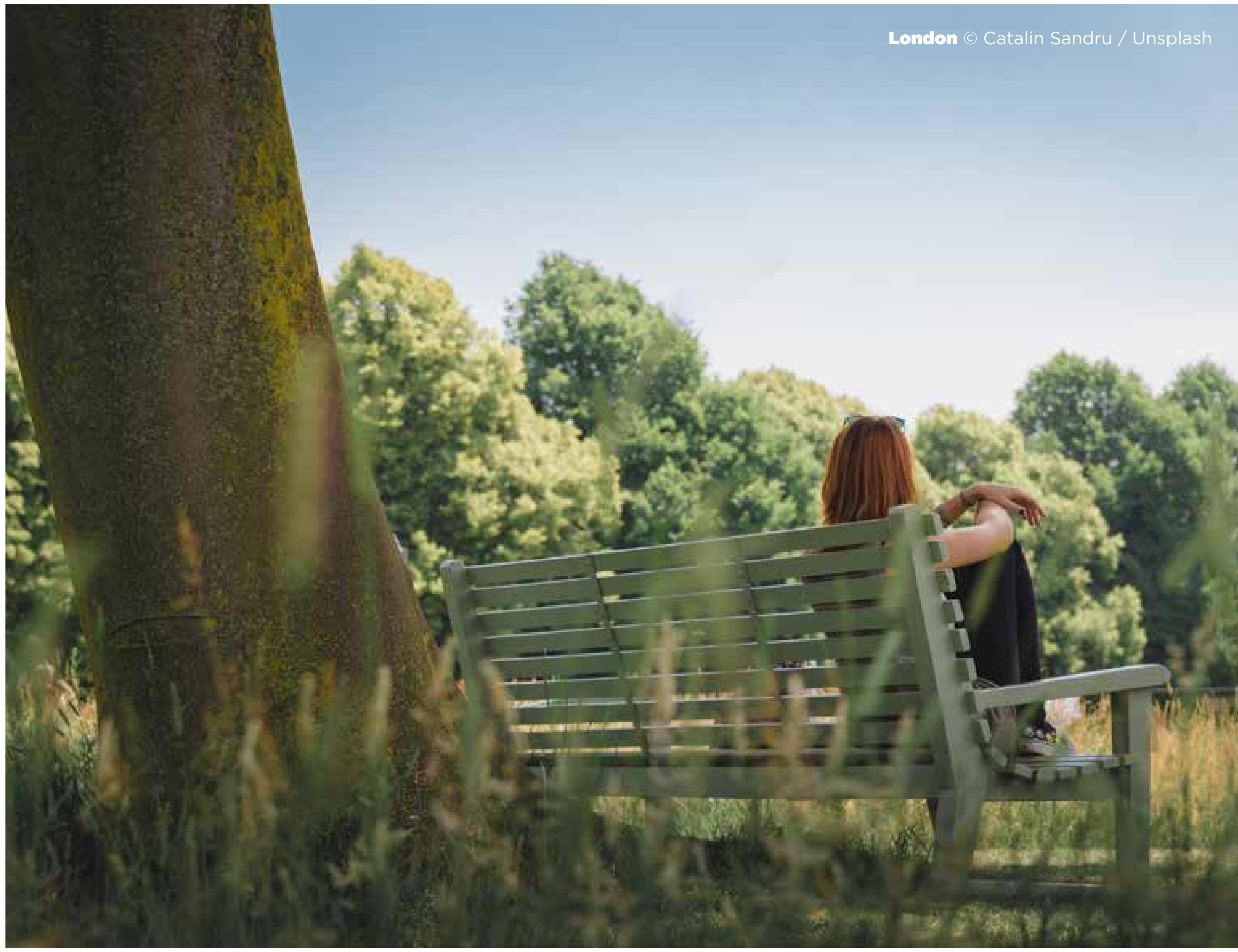
Expanding air pollution monitoring is an important element of cities' commitments and efforts to develop and support control policies that address the complexity and variety of pollution sources that exist in cities. There is growing interest in understanding how pollution varies from neighbourhood to neighbourhood, or even street by street; research has shown that levels can vary considerably within cities and the health impacts of air pollution are unequal and disproportionate. Cities are leveraging new technologies, such as distributed networks of lower-cost sensors, to better understand basic trends, assess changes over time, understand exposure hotspots, identify priority sources, engage local communities, empower residents with information and enforce local policies. Strengthening these types of data and evidence can help accelerate meaningful action on the important sources polluting our air.

1.2. The role of new sensor technologies

Adequate air quality monitoring is an important element of urban air quality management and a foundational step to creating clean air through effective control policies.

Cities monitor pollution to achieve a range of goals, such as:

1. Understanding **pollution risk and levels** relative to local and international health-based standards and guidelines.
2. **Understanding spatial patterns** of pollution and **locations of high exposures**.
3. Identifying **sources of pollution**.
4. **Expanding awareness** and **building evidence** to support clean air action.
5. **Tracking policy efficacy** and **enforcing regulation**.



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Regulatory monitoring sites, when available, provide accurate and detailed data useful for assessing compliance, tracking trends and informing research on the composition of the atmosphere. However, regulatory-grade monitors are expensive and require significant effort to install and maintain. Cities often have more flexibility to explore new innovations in air quality data collection, and are increasingly leveraging these technologies to answer a variety of questions. For cities new to air pollution monitoring, sensors can provide an affordable option to understanding basic information on their air pollution levels. Cities with existing monitoring networks can use sensors to expand spatial coverage, measure the impact of interventions, identify hotspots and engage local communities and raise public awareness. These networks can also be valuable for evaluating localised exposure and risk among vulnerable and marginalised communities, providing important information to advance solutions that mitigate inequities and protect historically disadvantaged communities.

IMPROVING DIALOGUE AND COLLABORATION BETWEEN CITIES AND TECHNOLOGY PROVIDERS CAN HELP ENSURE THAT NEW SENSOR TECHNOLOGIES AND DATA MANAGEMENT PLATFORMS CAN BE EFFICIENTLY APPLIED TO SOLVING URBAN ISSUES.

1.3. Sensor technology and protocol improvements that are critical to increasing city-level deployment

Cities are increasingly interested in deploying lower-cost air quality sensing solutions, a trend that parallels the proliferation of available sensor options. The rapidly expanding lower-cost air quality sensor market presents valuable opportunities for urban air quality work, but requires city staff to navigate a plethora of options around network installation, data management and communication processes. Without clear information or guidance on characteristics such as data reliability, total project cost and product lifetime, city staff and other end users may face hurdles in successfully deploying new sensors.

Improving dialogue and collaboration between cities and technology providers can help ensure that new sensor technologies and data management platforms can be efficiently applied to solving urban issues.

Through C40's Air Quality Network, city staff have highlighted common technical challenges that prevent them from successfully deploying sensors. The following recommendations for sensor technology improvements draw on and respond to these technical challenges:

1. **Clear protocols for co-location and frequency of calibration:** Cities want to be able to easily compare sensor performance with reference-grade monitors. To improve sensor performance, city staff request published information about the known accuracy of sensor equipment, including: routinely updated results of calibration studies, and procedures for co-locating sensors and adjusting sensor measurements.

2. **Recent and reliable data on sensor accuracy, under local conditions:** High humidity, dust and high $PM_{2.5}$ levels can affect sensor performance. Cities request clear, transparent guidelines of utility and uncertainty under varied operating conditions (i.e. more detailed specification sheets). There is a wide range of sensors on the market, and many sensors come with limited information on data quality under various conditions. Without information specific to a range of deployment conditions, cities are concerned that some sensors may not be reliable or accurate enough for ambient air quality characterisation. (More information on improving data quality can be found on the **C40 Knowledge Hub**.)

3. **Solutions to energy supply disruptions and city-specific conditions:** Intermittent electricity supply and high humidity are among the challenges that cities face in sensor deployment. Cities ideally want sensor systems with built-in solar panels, or batteries that last at least two weeks for ease of deployment. An integrated physical dryer could help mitigate humidity challenges.

4. **Estimating the useful lifetime of sensors:** Transparent communication around sensor longevity and lifespan will help cities manage expectations and correctly prepare a budget for projects. Cities request that sensor manufacturers better communicate the lifespan of sensors, what types of conditions can result in sensor decay, the cost of replacement parts and more.

5. **Robust and responsive customer support:** Lower-cost sensor technology is rapidly evolving. City staff place high value on responsive customer service and guidance documentation, and would welcome proactive communication if there is a newer version or modification of an existing sensor product or data management system.

Dar es Salaam © K15 Photos / Unsplash

6. Offer training to increase local staff capacity: Sensor manufacturers and other stakeholders are strongly encouraged to build long-term capacity by providing tailored and comprehensive training to city staff. Capacity-building gives cities the opportunity and freedom to work with manufacturers, instead of relying on manufacturers to manage cities' sensor networks.

7. Anticipate and reduce e-waste from sensors: Cities are creating procurement criteria to reduce sensor waste. (Read about Portland's experience in Box 2). Manufacturers can prepare to meet procurement criteria by designing ways to mitigate waste, by building modular components or reusing external housing components when possible. Integrating components to achieve maximum function with a minimum number of sensors will also reduce waste.

8. Support with project-level budgeting: Cities have requested training and support from the sensor community in understanding budget needs across entire projects to better design well-resourced and sustained sampling campaigns. Cities' sensor choices are influenced by their staff capacity needs and low-capacity cities may preferentially select sensor companies that offer access to a technical support team.

9. Guidance on data sharing and data management platforms: Cities request detailed guidance on data management and communications software. They often need a platform that can be used and shared across city agencies, research institutions and other entities. In some cities, state or federal government agencies provide data-sharing platforms for regulatory air quality data, but not for lower-cost sensor data, as it can be challenging to share sensor information with the general public. As a result, cities must develop sensor data platforms with other partners, such as local universities, to integrate disparate data and normalise information and messaging. Increased guidance is needed on what is the most appropriate approach for data platform ownership: should cities own the platform, but share the raw data to allow others to create apps and develop meaningful stories? Or can sensor manufacturers support cities to harmonise data protocols, so that data from multiple companies/products can be transmitted and visualised on a single data platform?

By addressing city concerns and desires – around issues from sensor design and specific operating conditions to costing, longevity, waste mitigation, data management and training – sensor manufacturers have the opportunity to help cities better understand their air quality and also better serve an emerging, powerful market. As the demand for (and expectation of) local air quality monitoring data grows, manufacturers can prepare by anticipating and preparing to meet the city-level needs described above.

BOX 2 / SENSOR WASTE AND SUSTAINABILITY: PORTLAND'S EXPERIENCE

Air pollution sensors have the potential to create new data to inform sustainability actions, but they also have the potential to create waste. The City of Portland developed procurement criteria to minimise electronic waste during its first air quality sensor testing project, the **Smart City PDX** programme. The criteria were used to decide which sensors to purchase and test, and focused on the ability to upgrade and modify a device.

Sensor components need frequent replacement and maintenance. In the United States, not many recycling facilities are equipped to recycle the small electronic components used in sensor devices or other materials used in device housing.

Creating and implementing these criteria led to a design change by a sensor provider, Apis, Inc., to improve sustainability. The sensor provider initially designed a modular sensor socket. The company was planning to start soldering sensors to circuit boards (a change that would have increased consumption of printed circuit boards and thus create more hazardous solid and liquid waste). When they saw the Smart City PDX procurement criteria, they decided to keep the modular design. This modular design is now a feature that they use to market their sensor product.

Using procurement criteria to reduce electronics waste within sensor projects is a process that is transferable to other cities. The sooner purchasers (such as cities) incorporate life-cycle requirements into sensor procurement, the sooner providers can make changes to their product design and manufacturing to meet those requirements.

Smart City PDX acknowledges that the most sustainable solution is to minimise the number of sensors used in the first place. Cities are encouraged to calculate and purchase the minimum number of sensors needed to address community needs and collect necessary data.

CITY CASE STUDIES

2

Lima © Aarom Ore / Unsplash

Addis Ababa © kaleab / Unsplash

> ***"We have seen rapid growth in the number of air quality sensors in the city and will have much better data for future monitoring and action."***
>
> **The Mayor of Addis Ababa, Adanech Abiebie (AQMP Forward Message)**

ADDIS ABABA:

Creating infrastructure for distributed sensor deployments

Annual average $PM_{2.5}$ in Addis Ababa is estimated to be 6–7 times higher than the WHO Air Quality Guidelines (5 µg/m³), ranging from 30-36 µg/m³ in 2016–2020. Increasing air pollution and its impact on public health is a growing concern for the city in the face of rapid economic growth and urbanisation. In June 2021, the city launched its first Air Quality Management Plan (AQMP) with the aim of achieving the following goals by 2025:

1. **Ambient concentrations of air pollutants comply with the relevant ambient air quality standards because of planned emission reductions.**
2. **Cooperative governance promotes the implementation of the AQMP.**
3. **Air quality management is supported by effective systems and tools.**
4. **Air quality decision-making is informed by sound research.**
5. **Knowledge and understanding among decision-makers, stakeholders and the general public is improved according to an education and outreach plan.**

In October 2020, the Addis Ababa Environmental Protection & Green Development Commission (AAEPGDC) and C40 began a strategic effort towards Goal 3 "Air quality management is supported by effective systems and tools", supported by the Clean Air Fund.

Various stakeholders have been deploying lower-cost sensors in Addis Ababa in recent years (20 in early 2021); however, operational challenges with power and internet connectivity meant that limited data was generated through these deployments. While three reference-grade $PM_{2.5}$ monitors exist in Addis Ababa, AAEPGDC and others have not been able to access these sites for continuous monitoring data or to calibrate lower-cost sensors.

The AAEPGDC, C40 and Industrial Economics held a four-day workshop in February 2021 with international and local stakeholders and relevant staff from national and local government agencies. The purpose of the workshop was to increase understanding among city staff of how to use and interpret air quality data in the context of local planning and evaluation, and, together with relevant parties, to produce a city-wide air quality monitoring strategy.

Through the workshop and the development of the air quality monitoring strategy, it was agreed that the city could substantially advance its air quality efforts by owning and operating its own reference-grade monitor for $PM_{2.5}$. By giving city and national officials unfettered, real-time access to data and serving as a hub for other organisations to co-locate their own lower-cost sensors, air pollution research in Addis Ababa could substantially advance along with the ability to support policy development, and to evaluate background concentrations and health risks.

Following the identification of a suitable site within the AAEPGDC compound and construction of a shelter, a Teledyne T640 was deployed in October 2021. The AAEPGDC, C40 and Industrial Economics held a two-day training session around the maintenance and operations of the monitor and the Campbell Konect data management system. There is now a newly established team within the AAEPGDC responsible for air quality monitoring and managing the monitoring site and data, allowing new air quality data to be visualised and shared publicly. The site is also being prepared for future sensor co-location studies.

BUDGET

- One full-time employee overseeing four to five full-time employee data analysts/field officers to manage the city-owned and operated air quality monitors and the data management system and to support non-city stakeholders with sensor calibration.
- Funding assigned to add an additional 15 lower-cost sensors across the city by 2030.
- Under the C40 project, US$ 23,000 was spent on the Teledyne T640 continuous $PM_{2.5}$ monitor.

Dar es Salaam © Peter Mitchell / Unsplash

DAR ES SALAAM:

Understanding basic information on pollution levels

In 2020, C40, Dar es Salaam City Council (DCC), the Stockholm Environment Institute (SEI) Africa, the Regional Centre for Mapping of Resources for Development and the Dar es Salaam Institute of Technology (DIT) partnered together to develop a basic understanding of air pollution across the city.

As a first step, a literature review and stakeholder mapping exercise was conducted to identify organisations and agencies that had ongoing or past activities around understanding the city's air pollution levels. DCC, SEI and C40 hosted a workshop with these stakeholders to 1) introduce the purpose of the air pollution study effort and 2) discuss air quality issues and (past, present, potential future) efforts to address it in the city.

Given the lack of reference (equivalent) monitors in Dar es Salaam, the project group proceeded to deploy 14 Purple Air sensors ($PM_{2.5}$) in the same location (DIT) for a short co-location study, to analyse replicability of the samples. Following this co-location study, the $PM_{2.5}$ sensors were then deployed across all five municipalities, at locations such as municipal offices, hospitals, and schools - where there was sufficient security and institutional staff on-site or nearby to troubleshoot any issues.

Dar es Salaam © Stockholm Environment Institute / C40

Figure 1 (left) and Figure 2 (right): Air quality sensors featured in a public location in Dar es Salaam.

To improve understanding of levels across the city, the project team also analysed historic satellite-derived estimates of $PM_{2.5}$, NO_2, SO_2 and CO from the US National Aeronautics and Space Administration and the European Space Agency. Together with information from the deployed sensors, the spatial and temporal patterns were analysed in relation to important local sources, identifying transport and industrial sources as important local sources. The study has also shown that pollution levels are higher than expected by the city.

A second stakeholder workshop was held to begin a dialogue on governance structures for implementing effective emissions control strategies and to identify resources available to sustain and increase air quality monitoring activities in Dar es Salaam.

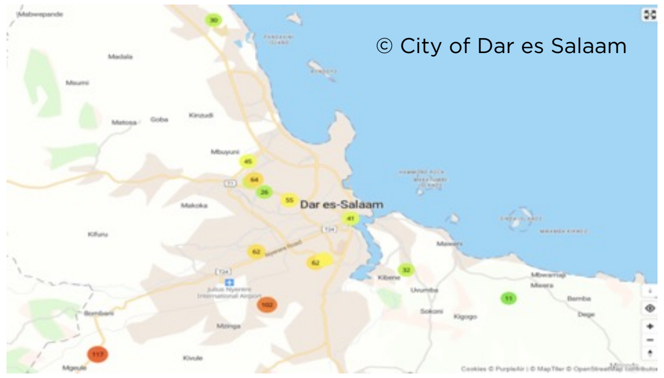

Figure 3: Locations of 14 sensors installed throughout Dar es Salaam.

BUDGET

- US$ 4,000 spent on 14 Purple Air ($PM_{2.5}$) sensors.
- Existing staff from Dar es Salaam City Council and the Dar es Salaam Institute of Technology maintain the sensors and data and work to identify further funding opportunities for additional sensor purchase.

DENVER:

Educating and empowering schoolchildren

Denver © Cassie Gallegos / Unsplash

"Real-time access to air quality data is empowering the residents of Denver with the knowledge and tools necessary to make informed decisions about air quality and their health. We look forward to continue growing the Love My Air programme within Denver Public Schools to protect children's health across our city."

The Mayor of Denver, Michael B. Hancock

Love My Air Denver

On 1 January 2019, the city and county of Denver was awarded a US$ 1 million grant from Bloomberg Philanthropies to develop Love My Air (LMA) Denver. The mission of the programme is to empower communities to live better and longer by reducing air pollution and limiting exposure through behaviour change, advocacy and community engagement. The approach includes installing lower-cost air sensors on public school campuses across the district and providing programmatic options for adoption by schools to allow for customised solutions tailored to the unique needs of individual school communities.

For the LMA programme, Denver uses Lunar Outpost Canary-S and Clarity Node S in the city's stationary ambient school sites. The city also employs the 2B Technologies' personal air monitor (PAM) for their in-school curriculum, which allows students to do their own projects with hand-held devices. They also use 2B Technologies, AQSync to collect additional air quality measurements through FEM (federal equivalent method) and near-FEM instrumentation to help fill gaps in the state monitoring network.

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Figure 4 (left): No idle zones are one way the LMA programme is reducing air pollution around schools. Figure 5 (right): A lower-cost sensor is placed outside of a school.

School prioritisation process/equity considerations

LMA Denver is working with 34 schools, elementary, middle and high-school levels, within the Denver public school system. The programme has identified high-priority schools using data on asthma rates and free and reduced lunch rates to ensure the programme has the greatest impact on Denver residents who are more vulnerable to health impacts from exposure to poor air quality.

The methodology behind programmatic engagement and implementation has been key to Denver's success. The city meets each principal at each school and explains the benefits of the programme for the health of their students and for improvements in ambient air quality. Getting buy-in from school leadership is an important step. During that engagement, the principal typically hands off the project to a school champion who becomes the program's main point of contact and helps rally other staff, students and parents through implementation. By working collaboratively with those champions and highlighting their work through quarterly newsletters, Denver can scale the programme efficiently and effectively.

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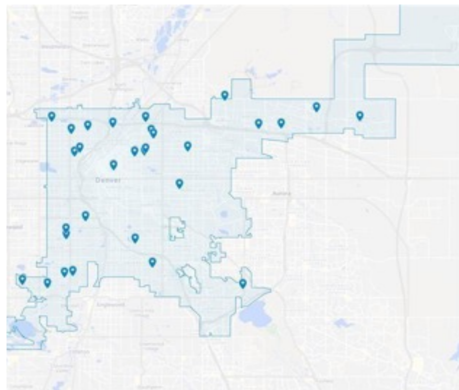


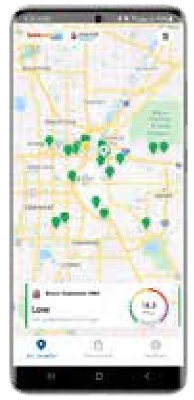


Figure 6 (left): Sensor locations throughout Denver. Figure 7 (right): The LMA dashboard allows for viewing of real-time air quality data at participating schools.

Inclusive participation of children, parents and teachers – including legal and tactful approaches

The development of the LMA programme was thoughtfully considered and collaboratively implemented with individual schools as well as the school district. It was necessary to work very closely with students, parents, teachers and nurses while piloting, then scaling, the programme. The programme was launched in three schools, at which Denver ran focus groups with each group of stakeholders. This information was synthesised and brought back to those same stakeholders for additional feedback and iteration. This process has been extremely valuable in creating a programme that meets the needs of residents as well as providing the opportunity for the city to build individual relationships and trust between local government and the community it serves.

Figure 8: Focus group of stakeholders in a Denver public school.

Outcomes and lessons learned

Through development and scaling, Denver has learned that communicating information about air quality is challenging and multifaceted. Individuals and stakeholders need to understand what air quality readings mean, as well as what they can do to protect their health and prevent contributing to pollution. In an effort to improve its communication locally, Denver has led a state-wide group of air quality practitioners to better inform how local governments can communicate air quality impacts and mitigation strategies in an understandable and uniform way. Denver's LMA programme provides a replicable model for other cities interested in using lower-cost distributed sensor networks to inform and improve air quality in their municipalities.

BUDGET

- Since 2018, US$ 1.52 million has been invested in Love My Air (US$ 850,000 from Bloomberg Philanthropies and US$ 674,000 from the City of Denver). This covers development of the programme, hardware, software, and 2 full time employees.
- Going forward the city expects an annual cost of US$ 250,000 in personnel (two full time employees) and US$ 125,000 in technology (sensor system and management) and outreach/engagement.
- The city also covers employment costs of the programme manager (US$ 150,000/ year) as well as programme overheads (US$ 224,000).

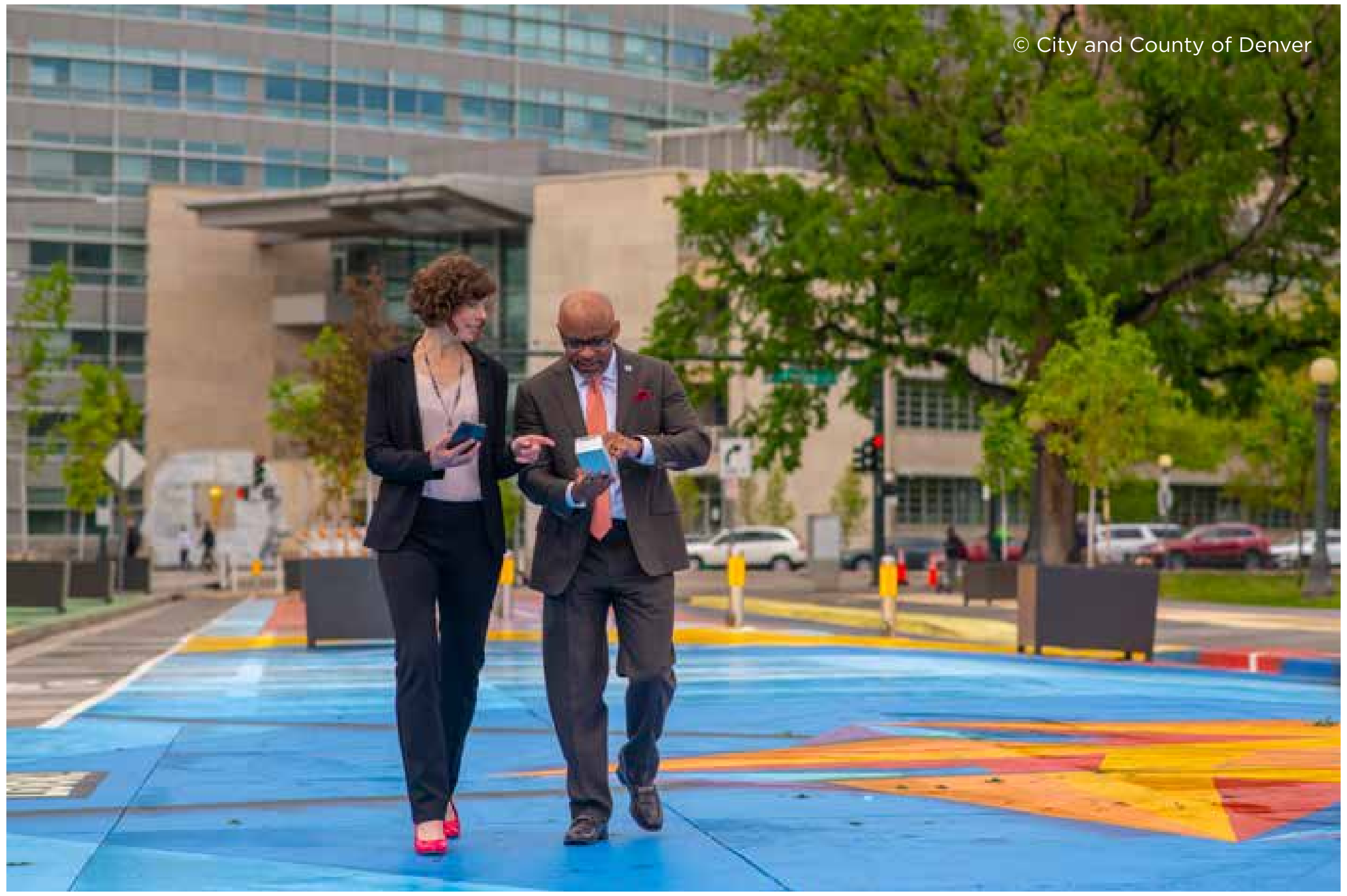
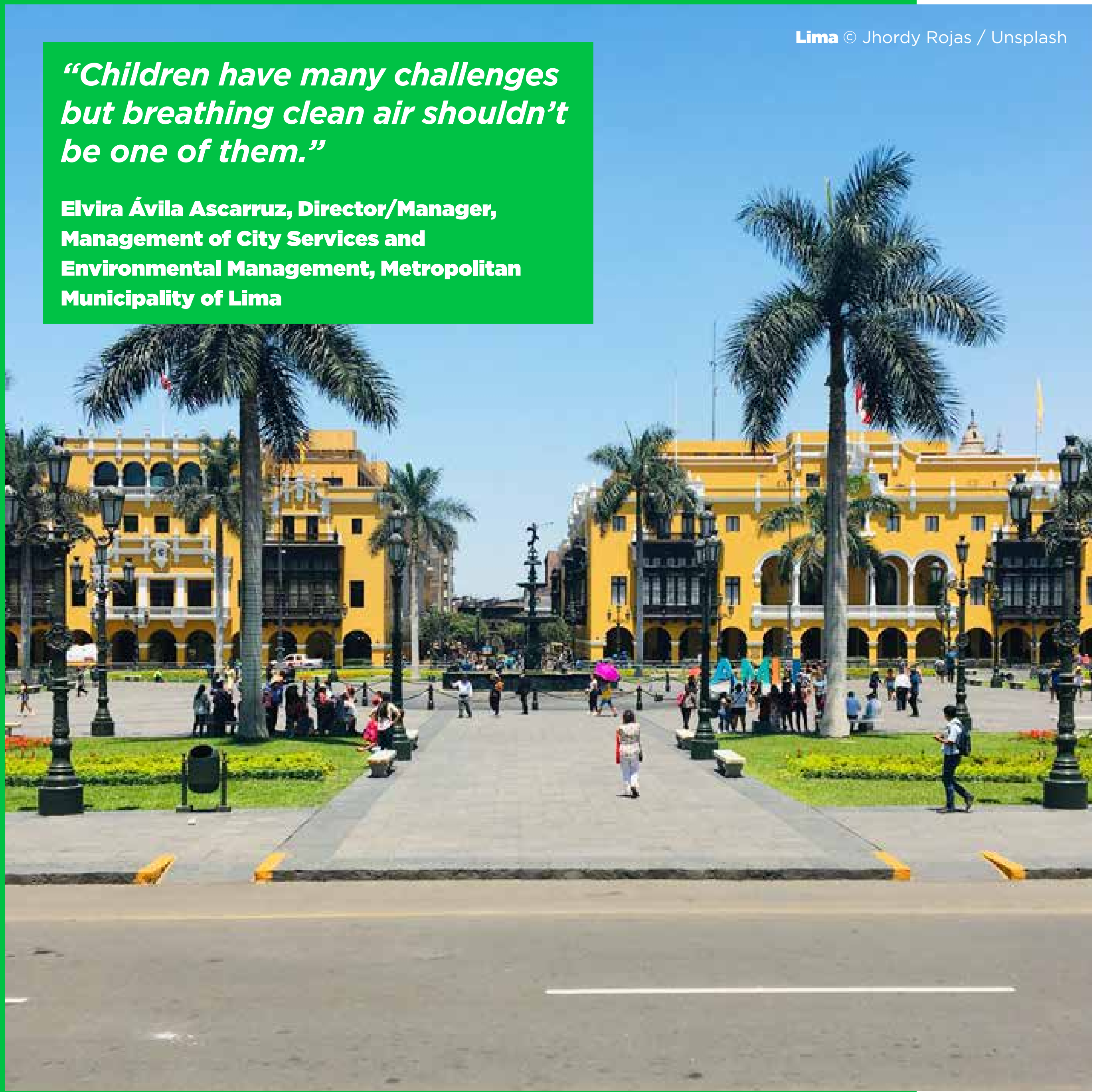


Figure 9: Mayor Hancock and Denver's air quality programme manager.

“Children have many challenges but breathing clean air shouldn’t be one of them.”

Elvira Ávila Ascarruz, Director/Manager, Management of City Services and Environmental Management, Metropolitan Municipality of Lima



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LIMA:

Measuring the impact of air pollution on early childhood

Overview of project: Why children and infants are vulnerable/at high risk

One in ten deaths of children under five years, worldwide, is caused by air pollution, according to the WHO. In metropolitan Lima, 4% of mortality is caused by air pollution, and young children are particularly affected. According to Peru’s National Ministry of Environment, fine particulate matter is the predominant air pollutant and is most harmful to people’s health. Recent studies have shown that particles can cross the placenta of pregnant women, exposing fetuses to air pollution; this elevates the risk of miscarriage, premature delivery and low birth weight.

Before 2019, Lima, and its surrounding province, had only 19 air quality reference stations. Given the size of the city, which is home to one-third of Peru’s population, it could not accurately assess its air pollution. The lack of monitoring instruments and public access to air pollution information concealed the city’s air quality problem and made it difficult for both authorities and citizens to take action to protect the environmental health of the most vulnerable groups.

With these challenges in mind, Lima is now implementing an air quality monitoring network focused on children, to design and implement actions that reduce air pollution and, specifically, exposure among infants.

Methodological approach and context

To increase public access to air quality information, in March 2020, Lima installed a monitoring network of 30 air quality modules with lower-cost sensors.

In March 2021, Horizonte Ciudadano Foundation (Chile) and Lima partnered to begin a project called *‘Aires Nuevos para la Primera Infancia’*, with the mission of monitoring air quality in Lima. The project focuses on air pollution exposure among infants. Five new air quality modules with lower-cost sensors were strategically placed around the city, adding capacity to the monitoring network; the sensors are located in hospitals, homeless shelters for children, kindergartens, paediatric centres, and schools. With this project, the city has strengthened its monitoring network by installing lower-cost, compact sensors in strategic areas that were previously unmonitored, allowing the city to present data in real time using a web-based application.

Lima currently has 35 active air quality modules with lower-cost sensors. The city plans to relocate the 30 original modules to integrate them into the childhood-focussed network.

Current plan to understand pollution risks to children and infants, including stakeholder and social engagement approaches

The project is being implemented by the city in eight phases. In each stage, the city works with institutions in the childhood air pollution network:

- **Stage 1:** Develop the network by placing sensors in childhood-focussed locations. The information is then processed and used to create awareness in teachers and caregivers, so that they can use the data to reduce children’s exposure to toxic levels of environmental pollution.

Lima © Willian Justen de Vasconcellos / Unsplash

- **Stage 2:** Train stakeholders, such as teachers and caregivers.
- **Stage 3:** Educate children directly. This will be accomplished through air quality workshops, home experiments and educational materials such as comics and newsletters. The city is working closely with academic institutions on the design and implementation of scientific projects and actions that will benefit children.
- **Stage 4:** Develop scientific research with the data collected.
- **Stage 5:** Install more sensors in areas where infants are present. Mobile monitoring will be done at a height of 95cm, to characterise levels in children's breathing zone and to evaluate children's pollution exposure (as compared to caregivers' exposure). The results will be used to recommend safe travel routes in areas near hospitals, schools and other child-centred locations.
- **Stage 6:** Carry out activities that educate and increase awareness among children on air quality conditions.
- **Stage 7:** Create an air quality strategy focused on children, to promote projects and actions focused on reducing exposures among children from their first years of life.
- **Stage 8:** Collaborate with the relevant stakeholders to support the design and implementation of actions for the benefit of children, reflecting lessons learned throughout the project.

© Lima

PHASES OF THE *AIRES NUEVOS PARA LA INFANCIA* PROJECT

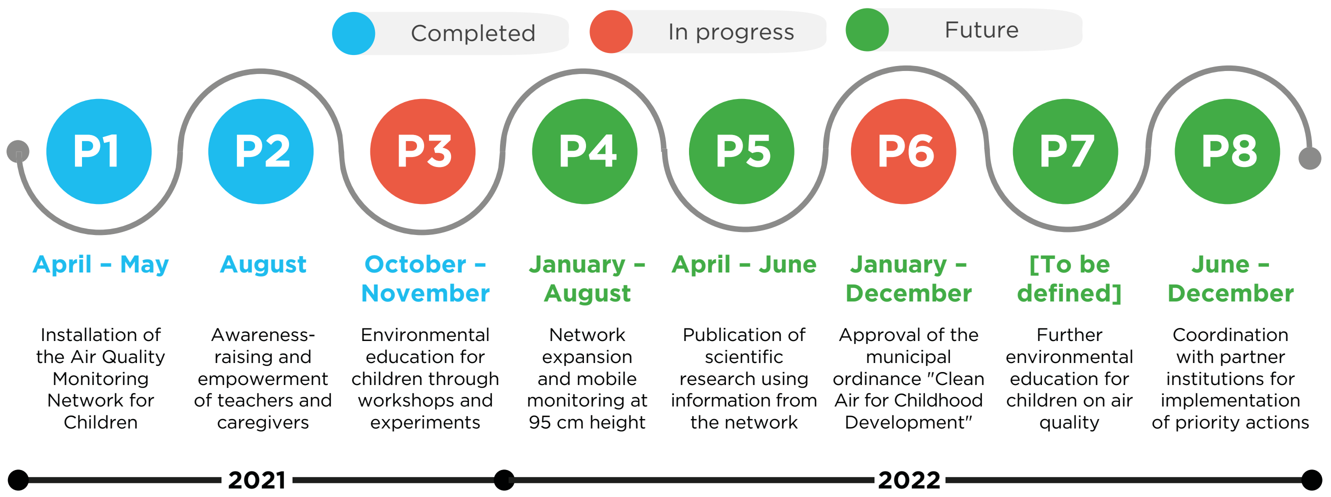


Figure 10: Phases of the Aires Nuevos para la Primera Infancia project.

Phases of Lima's *Aires Nuevos para la Primera Infancia* project plan.

In August 2021, the first *'Red de Aires Nuevos para la Infancia'* newsletter was published on Lima's Metropolitan Environmental Information System and on social networks. It identifies daily air pollution levels in the monitored areas and proposes measures to reduce levels of exposure among infants and caregivers.

As of December 2021, the first and second stages of the project have been finished, and the third phase is currently in progress. More than 200 caregivers and teachers have been trained, and more than 1,400 children (5–12 years) are attending air quality workshops. The capacity-building process has been designed to be replicated and there are plans to deliver it to new member institutions.

Some important lessons are emerging from the project already. Consistent cooperation and communication with partner institutions has been crucial to Stage 2 (teacher and caregiver education and awareness-building) and Stage 3 (children's educational activities and citizen science projects); especially in ensuring active, ongoing participation among stakeholders. As an example of the project's early success, several stakeholders are modifying the schedules to hold outdoor activities for children during the least polluted times of day. Two of the institutions in the network, Casa de los Pitufos (a shelter) and Divino Jesús (a residential education centre), have already started prioritising outdoor time when air quality is best.

As an example of how the data are being used to inform action, the sensor installed in the Fe y Alegría school was registering the highest levels of pollution in the network. Following the project's approach of creating actions based on data, the surrounding area is being changed to benefit the school's more than 1,200 students. The city is now working in alliance with nearby neighbours to create a 'calm zone' and a safe route, by planting with green mulch and paving roads in order to reduce pollution levels.

BUDGET

Fundación Horizonte Ciudadano monitoring network: five monitors purchased at a total cost of US$ 1,500.

Lisbon © Liam McKay / Unsplash

LISBON:

Increasing spatial coverage of real-time monitoring

Framework

Lisbon is committed to being one of the best cities in the world to live in. To achieve zero air pollution and create a healthier city, Lisbon has been leading on the development of an ambitious policy to minimise pollution impacts and maximise quality of life.

Over the last year, Lisbon has invested in a strategy to prevent, mitigate, monitor and undertake immediate action, to fight against pollution; both in normal conditions and in moments of disruptive events, such as the COVID-19 pandemic.

The city has implemented a range of policies to improve air quality, including nature-based solutions such as increasing the city's green space by 15% (300 acres) and adding more than 100 hectares of green canopy cover over the course of a decade. The city has improved the accessibility of its public transport systems, with the creation of a single monthly ticket for the metropolitan area. It has also increased the energy efficiency of the municipal and public transport fleets, substantially expanded the city's cycling network, improved public spaces, and restricted the space allocated for cars. To better understand the impacts of these policies and evaluate their success, the city must continuously and thoroughly assess its air quality.

To achieve its vision of zero pollution, the city has installed a complex local sensor network. With 80 monitoring stations and 650 sensors, the city is now able to monitor environmental quality indicators such as air quality, noise, traffic and meteorological factors. This network was designed, developed and implemented to receive and process information for decision-makers, operational and strategic service providers, parish councils, stakeholders, researchers, and citizens.

The network includes a warning system for each environmental indicator (based on national threshold values or limits). It is hosted on the Lisbon Intelligent Management Platform ('PGIL'), an integrated platform for intelligent city management, which centralises, manages, and analyses various data sources across the city's urban ecosystem. The information is available in real time and has already attracted a wide range of internal and external users (municipal staff, citizens, researchers, and other private entities).

Data can be downloaded from Lisbon City Council's open data portal *'Lisboa Aberta'*, a free data-sharing portal developed by the municipality and implemented by an external consortium. It aims to increase citizen participation, encourage data sharing and use, highlight the investment in information and communication technology, and enable replication.

Lisbon has also developed a system of indicators to issue warnings and alerts for relevant environmental parameters and to sound alarms when threshold values are exceeded. The aim is to give citizens immediate awareness of environmental hazards and their severity, and to coordinate the municipality's response (via an app, Microsoft Power BI).

Spatial coverage and installation

The sensor network was created to better characterise air pollution and other environmental indicators over Lisbon's entire jurisdiction; and to create uniform city zoning maps with information on air quality, noise, traffic and climate.

The following criteria were used to select locations for the sensor stations:

- City coverage with a 2x2 km grid.
- Meet project requirements of the Sharing Cities project.
- 24 parishes.
- Low Emission Zone.
- Map of climatopes (areas with similar microclimatic characteristics).
- Various land uses and classifications (green and blue areas – riverfront, public services, schools).
- Road network (main and secondary).
- Pollution hot spots (cemeteries, airport, cruise terminal).

Figure 11: Spatial distribution of the Lisbon sensor network, by type.

Figure 12: Sensor locations on light poles in Lisbon.

The network includes 80 monitoring stations, placed mainly on public lighting poles but also in other municipal and national facilities (such as green spaces, schools, urban parks, cemeteries, air quality and meteorological ground stations, etc.). The sensors hosted at the 80 stations measure air quality parameters (CO; NO_2; PM_{10}; $PM_{2.5}$; SO_2; O_3; C_6H_6), noise, weather (temperature, humidity, pressure, wind intensity and direction, rainfall) and traffic (number of vehicles and classes).

Overall, the sensing project has a 28-month timeline and is divided into three phases:

- **Phase 1:** The main objectives of this phase were to select sensor locations using the criteria above, choose equipment for each location, identify the type of energy supply needed, and select the communication network. The initial calibration of the equipment, including all installed air quality sensors, was carried out by an accredited laboratory. A subset of the sensors was co-located with the official Air Quality Measurement Network to calibrate the sensors. The first phase was completed in the first two months of the project, with the involvement of several Lisbon City Council departments (Public Space Management, Mobility, Police, and Public Lighting).
- **Phase 2:** This difficult phase involved integrating all data collection; calibration and validation of the entire sensor network; the calibration, replacement and verification of individual equipment; as well as the maintenance and repair of connections and communications whenever necessary. The phase started on 15 July with the monitoring of several parameters in sensing-as-a-service mode (24 months in progress). A calibration programme has also been established using a mobile station that will verify the calibration parameters of the various air pollutants during Phase 2.
- **Phase 3:** This phase establishes the requirements for de-installation and collection of equipment by the consortium. It has an estimated duration of one month.

Outcomes

The main objective of the Lisbon sensor network is to describe the status of the city's air quality, noise and urban climate; monitor environmental indicators in real time; and provide additional data to complement the official air quality and meteorology monitoring networks.

With the data collected from the network, Lisbon intends to update the city's strategic noise map as well as local climate and meteorological scenarios (describing current baseline conditions and future climate change in 2030 and 2050). There will be special emphasis on validation of an urban heat island study, as well as wind patterns and hydrological trends, distribution of air pollutants, and assessment of measures to reduce high emissions of NO_2, PM_{10} and $PM_{2.5}$.

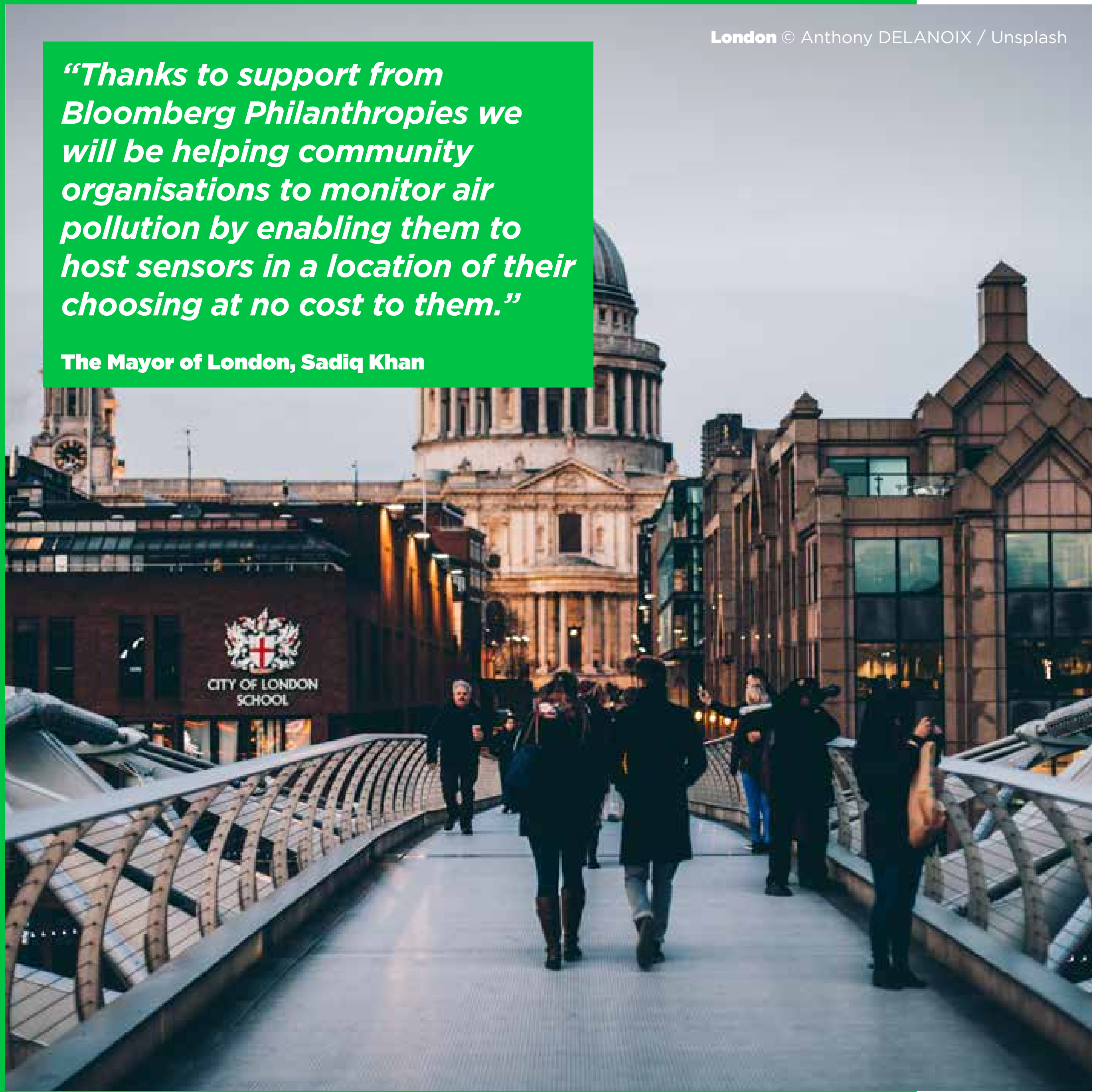
In 2022, after collecting six months of data, the city will produce a progress report with its first findings on the spatial dispersion of various pollutants, including a map of NO_2, PM_{10} and $PM_{2.5}$ dispersion in the city. This map will be an important tool for implementation of the Air Quality Improvement Plan, which is currently in force and is due to be completed in 2023. The map, and underlying data, will allow the city to measure and evaluate the effect of relevant policies and actions (both planned and ongoing), such as the expansion of or adjustments to the city's Low Emission Zone.

Monitoring points outside of pollution hotspot areas, such as in green and blue spaces, schools and playgrounds, will provide information about the influence of these spaces on surrounding air quality.

In the first months of the network's operation, the city has learned lessons around the difficulty of keeping the entire network in operation, to ensure real-time data communication for all relevant parameters and indicators. Another challenge is related to implementation of an interactive dashboard that facilitates monitoring and analysis of trends, using various sources of information like traffic congestion (from Waze), data from ground stations (air quality and meteorological) and satellite imagery.

BUDGET & RESOURCES

- The sensor project has a total cost of EU€ 349,900 (US$ 394,967), financed by the Lisbon City Council and co-funded by the Sharing Cities project (EU€ 20,000 / US$ 22,576) from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 691895.
- It is important to highlight the alignment between this project and the European programme Sharing Cities, a financing source dedicated to monitoring the city in areas such as energy efficiency, smooth mobility, renewable energies and smart buildings.
- The process was led by the Environment, Energy and Climate Change Department in collaboration with the Mobility Department and the Lisbon Urban Intelligence and Management Centre. Lisbon City Council's internal team comprises a multidisciplinary team of 15 people, who spend around 10–20% of their day on project management, with weekly meetings.
- It was essential to coordinate with external entities, including the Lisbon and Vale do Tejo Regional Coordination and Development Commission, as manager of the Official Air Quality Measurement Network and the Portuguese Environmental Agency. This enabled the team to not only to receive necessary authorisations but also facilitate access to the network stations and calibrate project sensors with the monitors in the official network.



London © Anthony DELANOIX / Unsplash

"Thanks to support from Bloomberg Philanthropies we will be helping community organisations to monitor air pollution by enabling them to host sensors in a location of their choosing at no cost to them."

The Mayor of London, Sadiq Khan

LONDON:

Engaging and empowering communities

The ambition of Breathe London is to create a comprehensive and scalable air quality sensor network for London's communities, making air quality data easily accessible and empowering Londoners with evidence to raise awareness and to inform future interventions.

The **Breathe London** air quality community sensing network launched in January 2021, following a successful two-year pilot that was financed largely by philanthropic funding from the Clean Air Fund and (CAF) supported by C40. The pilot phase incorporated three types of monitoring; fixed lower-cost sensors at over 100 locations; mobile monitors on Google Streetview cars; and wearable monitors measuring children's exposure on their route to school. The Mayor of London took over the funding of Breathe London in November 2020, investing in 136 small air quality sensors. Bloomberg Philanthropies subsequently joined the Mayor, investing in 60 additional sensors for London's communities and six sensors at cultural institutions and museums, making this a total of 202 (Mayor and Bloomberg) funded sensors. The network is delivered by scientists from the Environmental Research Group (ERG) at Imperial College London.

Empowering Londoners with hyperlocal air pollution data is a primary objective of Breathe London, and this is provided in three ways:

1. Real time data is shown on the Breathe London website, and is available to all.
2. Organisations, businesses and Londoners can buy into the network, which involves paying an annual fee to host a sensor in their preferred location, and receive all data management services.
3. There are also 60 sensors available for community groups to apply for, to host a free sensor in a location of their choosing.

Expected outcomes

- London will have an enhanced and advanced air quality monitoring network.
- A user-friendly data platform will enhance public awareness and support world class research.
- Researchers will be able to use on-site air pollution concentrations, recorded at hospital sensors, alongside patient records to better understand the relationship between air pollution and health effects.
- Schools and hospitals will be able to understand changes in local pollution levels and consider the impacts of measures they take to improve air quality.

Building the network

The Breathe London network is comprised of static lower-cost air quality monitoring sensors. It significantly reduces the costs of sourcing reliable air pollution data; in the past, most air quality monitoring was undertaken by central or local government, using reference-grade monitors. Reference-grade monitors are accurate but expensive to buy and maintain (GB£ 15,000 - 100,000), usually requiring roadside infrastructure to house them. The Breathe London sensors are smaller and weigh under 2kg, can be powered by solar panels or plugged into an electric connection, and are easy to install (by sensor hosts). They measure NO_2, PM_{10} and $PM_{2.5}$. Global sensing company Clarity Movement supplies the sensor nodes for the network.

It is important to note that all sensor hosts not only receive the sensor hardware, but also its servicing, replacement, data calibration, and software. Customers pay an annual fee of GB£ 2,000. Unlike other small sensor networks, the service includes data analysis undertaken by scientists at Imperial College. This combines Breathe London data with London's high-quality regulatory network (**londonair.org.uk**) to calibrate the measurements made by the lower-cost nodes. Real-time data is displayed on the **Breathe London website** alongside data from London's regulatory monitors, giving Londoners a holistic view of air quality across the capital.

This hybrid network of reference-grade analysers alongside citizen and community-led monitoring is a significant step forward in air

"I've often said, "If you can't measure it you can't manage it." Improving air quality monitoring gives us the data we need to tackle sources of pollution and protect public health. Bloomberg Philanthropies' partnership with Mayor Sadiq Khan and London does exactly that. Our joint investment supports high-quality air sensors across London and makes localised air pollution data available in real-time online. That will help policymakers identify problem areas and take steps to protect those who are most at risk, including school children and residents of lower-income neighbourhoods."

Michael R. Bloomberg, UN Secretary-General's Special Envoy for Climate Ambition and Solutions, Founder of Bloomberg LP and Bloomberg Philanthropies, and 108th Mayor of New York City

quality monitoring by small sensor networks, and a benchmark for other deployments. Now citizens can choose where they want to monitor air pollution and have access to the data in an integrated network across London, thereby empowering them with comprehensive and reliable data to make interventions or campaign for change.

In the first year, organisations including a property management company, hospitals and local authorities bought into the network. Some 141 sensors were bought by the South London Partnership, which is composed of five local authorities (Kingston upon Thames, Sutton, Richmond upon Thames, Merton, and Croydon). After the first year, there are nearly 300 sensors in operation.

Engaging communities

The Breathe London network forms a vital part of supporting London's green recovery from the COVID-19 pandemic by tackling environmental and health inequities.

Recognising that even a small annual fee will be prohibitive for community groups and individuals, there are opportunities for Londoners to acquire free sensors via the Breathe London Community Programme. This programme is aimed at vulnerable communities including low-income, Black, Asian and minority ethnic Londoners. Areas were identified in the Greater London Authority's **Climate Risk Mapping** analysis and includes areas with poor air quality, limited green space, or with high deprivation. The programme has an independent Community Advisory Panel drawn from a diverse group of health, social, and charitable organisations. The group provides advice on reaching groups and communities in areas hardest hit by pollution. Applications from areas of deprivation and those from Black, Asian and minority ethnic groups are given weighting in the selection criteria.

Several leading museums and cultural institutions, including the British Library, Kew Gardens, the National Gallery, the Science Museum, and the Serpentine will also join the network, supported by Bloomberg Philanthropies. Given their role as important community hubs, attracting thousands of visitors a year, the participating institutions will engage their visitors and other key stakeholders, and use the data collected to inform their activities.

Breathe Global

As C40 Chair, London Mayor Sadiq Khan has committed two-thirds of C40's budget to support climate action and green recovery efforts in Global South cities experiencing the worst impacts of the climate crisis. This also includes tackling air pollution and supporting air quality monitor networks in C40's member cities; 'Breathe Global' will aim to reach 100 cities using learnings from Breathe London.

Figure 13: An air quality sensor located at a Breathe London school.

How the Breathe Measuring the impact of transport interventions

Ultra Low Emission Zone

On April 8, 2019, London introduced the world's first Ultra Low Emission Zone (ULEZ), an area in Central London requiring drivers to meet minimum emission standards (e.g., Euro 6/VI for diesel vehicles) or pay a fee to enter the zone. With roughly seven months of mobile data before and after the policy went into effect, the Breathe London monitoring pilot enabled a detection of changes in the spatial pattern of pollution emissions that overlapped the period of sharpest impact for the ULEZ.

Breathe London monitoring data found that after the ULEZ start date, there was a drop in NO_2 levels at monitoring sites near roads inside the zone, and for all Breathe London sites across Greater London. Breathe London monitors also detected an improvement in NO_x emission intensity at many locations after the ULEZ policy took effect. These hyperlocal sensors were able to detect changes in the spatial pattern of pollution emissions, and complement the reference network to build our understanding of the impact of the scheme.

School Streets

As part of the pilot, **a study evaluated the air quality benefits of London's School Streets interventions**. Delivered as part of the Mayor's Streetspace plan, which aims to rapidly increase walking and cycling as London transitions out of the pandemic, School Streets are designed to restrict traffic near schools to reduce exposure to traffic-related air pollution. Thirty sensors from the Breathe London Network were installed at 18 primary schools to record NO_2 levels, and monitor the benefits of air quality in places where roads were closed in response to the

"I am delighted that Londoners will now have access to real-time, accurate air quality data for their area from more than 300 monitoring sites. This will improve awareness and help people reduce their exposure to polluted air."

The Mayor of London, Sadiq Khan

coronavirus pandemic. The Breathe London monitors were able to detect changing levels of pollutants, in locations where regulatory monitors may not have otherwise. Closing roads around schools to traffic at pick-up and drop-off times reduced polluting NO_2 levels by up to 23% and was strongly supported by parents.

Bus garage

During the pilot phase (described below), the network highlighted unusually elevated levels of air pollution in certain locations. One hotspot was close to a bus garage in Holloway, North London. While the introduction of the ULEZ and transition to Euro VI and electric buses led to a reduction in the number of air quality exceedances, Transport for London worked with the bus operator to investigate what more could be done, including stopping buses from idling outside the garage while waiting to park. This spike in pollution would not have been discovered without the use of Breathe London's sensor network need to add a space in between these words. The lessons learned in Holloway can now be applied to bus garages across London.

Pilot

The initial pilot phase lasted 12 months, with a 12-month extension agreed with CAF, as the pilot phase was delivering valuable insights into London's air quality and some technical elements of the network were still being developed. CAF chose London to pilot this new approach in part because of London's extensive existing air quality reference monitors, which meant data collected from the new lower-cost network could be properly validated. After a successful pilot, CAF were ready to apply the learnings from London in cities with less capacity and so they began focusing their funding outside of London.

> ***"As we look towards a recovery from the coronavirus pandemic, it is vital that we create a city that is cleaner and greener. Never has tackling London's toxic air been more important, which is why I am taking these bold and innovative steps to improve it."***
>
> **The Mayor of London, Sadiq Khan**

The most recent publications on **sensor uncertainty** and **mobile monitoring** were published in February 2022.

BUDGET

- The Mayor of London is investing a total of GB£ 790,800 (US$ 1 million) over four years, from 2020-2021 to 2023-2024.
- Bloomberg Philanthropies is investing US$ 1 million over three years.

BOX 3 / COVID-19 SPOTLIGHT: THE IMPACT OF GLOBAL SHUTDOWN ON LONDON'S POLLUTION DATA

Air quality and its relationship to COVID-19 has gained wide media attention, is of high interest to C40's mayors and is a topic of active research. Cities are working together to understand changes in pollution levels during the lockdown period.

Several cities with robust local networks and high staff capacity have been able to evaluate, under real-world conditions, how activity changes in sources of pollution affected local air quality, providing valuable information to policy-makers moving forward. **In London, for example**:

- COVID-19 and the subsequent lockdown restrictions dramatically impacted on air quality in London. Evidence indicates that air pollution levels initially decreased following the pandemic. In response to a UK government call for evidence, the Mayor published data that showed NO_2 levels during lockdown were roughly half their usual levels on some roads, but has since returned to previous levels of car use.
- Similarly, analysis of the latest data from the Breathe London air monitoring network identified that NO_2 fell by up to 50% at commuter hotspots in London during lockdown.
- The analysis focused on pollution levels during rush hour periods in the first four weeks of lockdown. During the period, on average, NO_x levels decreased by 30% around key transport routes in inner London.

LOS ANGELES:

Empowering residents of historically disadvantaged communities with data through collaborative approaches

The Watts Rising Collaborative, with a US$ 32 million grant from the Strategic Growth Council's Transformative Climate Communities (TCC) programme, is leading the Watts Rising programme, which includes more than 25 climate- and equity-focused projects being delivered by more than 30 organisations.

The overarching goal of these projects is to create a healthier and more resilient Watts neighbourhood. The projects are tackling this challenge in a wide variety of ways – from tree planting to bus electrification to the installation of solar panels on more than 100 rooftops – the overall programme's breadth is massive.

As a complement to the TCC projects, the Watts community identified a need and desire to deepen the community's understanding of local air quality. In response, a partnership was born between the City of Los Angeles (LA) and the TCC Watts Rising community groups to create a hyperlocal air quality monitoring programme. This project sets out to establish a state-of-the-art hyperlocal air quality monitoring network to provide insights and learnings around the neighbourhood's air quality.

The objectives of this project include:

- Providing real-time, hyperlocal and actionable measurements of $PM_{2.5}$ and NO_2 at seven sites and $PM_{2.5}$, NO_2, and O_3 at six sites within the community.
- Engaging vulnerable populations including children and seniors by strategically installing sensors near parks and schools.
- Catalysing air quality awareness and education in the community through outreach initiatives centred around the monitoring efforts.
- Providing long-term tracking of air pollution in Watts, which may serve as a tool to assess the benefits of other Watts Rising climate projects.

Prioritisation for sensor placement was driven by community feedback during a kick-off meeting with community leaders at the beginning of 2020. The project launched in July 2020, with 13 lower-cost sensors (Clarity and Aeroqual) being installed on city street lights in areas recommended by community members including, schools, senior centres and parks (areas where children, elders and families spend recreational time.

Through denser sensor deployments in the Watts neighbourhood, this project is critical for advancing community interests in hyperlocal air quality. It capitalises on new low- to mid-cost sensor technology that provides insights about the air residents are exposed at a block-by-block level – something that regulatory, regional monitors aren't equipped to do.

Community air quality monitoring is a critical component of LA's Green New Deal environmental justice and clean air objectives, as it brings a greater level of awareness about health-harming pollutants in a historically under-served yet over-burdened community.

In October 2020, the **Watts Rising air quality monitoring data portal** was launched. Periodic updates of air quality insights are posted on the website. Additionally, periodic community meetings will allow community members to ask questions about the data and delve deeper into insights and learnings.

Figure 14: An Aeroqual sensor that tracks $PM_{2.5}$, NO_2 and O_3 installed on a city street pole in Watts.

Los Angeles © Alexis Balinoff / Unsplash

Figure 15: Map of Watts sensor network showing locations.

Figure 16: Community participation is a critical element in setting programme visions and goals.

© Irene Burga, Air Quality Advisory, Mayor's Office of Sustainability

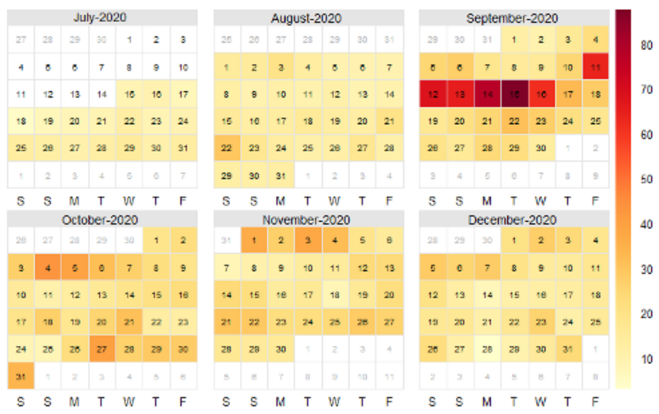


Figure 17: $PM_{2.5}$ data results showing that smoke events associated with wildfires led to elevated $PM_{2.5}$ concentrations in September and October 2020.

BUDGET

- Los Angeles is funding the Watts Rising Air Quality Monitoring project through a US$ 60,000 allocation in the city budget.
- The spending has been on the hardware sensor devices as well as a contract with Sonoma Technology Inc. to carry out reports summarising data analyses and insights over the course of the project.
- The project will run for approximately 2.5 years from start to completion.

MUMBAI:
City piloting of lower-cost sensors for national adoption

> *"The future of air quality monitoring lies in a hybrid approach combining regulatory grade monitors and sensors to provide hyperlocal data at a high temporal frequency. The results from Mumbai's sensor experiment clearly demonstrate that indigenous sensor technology is ready to be deployed at scale for air quality monitoring in the country."*
>
> **Dr. S.N. Tripathi, Department of Civil Engineering, Indian Institute of Technology Kanpur and National coordinator, National Knowledge Network, National Clean Air Programme**

Mumbai © Hardik Joshi / Unsplash

In partnership with the Maharashtra Pollution Control Board and the Indian Institute of Technology Kanpur, Bloomberg Philanthropies supported a lower-cost sensor pilot project in Mumbai. The project involved a first-of-its-kind assessment in India of lower-cost air monitoring sensors from November 2020 to May 2021. Monitoring air pollution is challenging in a resource constrained situation. Continuous ambient air quality monitoring stations (CAAQMS) that are used by government agencies to monitor the concentration levels of particulate matter are expensive. Lower-cost sensor networks could be the answer to dense air quality monitoring in the future. However, lower-cost sensors require in-field calibration to improve their precision and accuracy in comparison with CAAQMS.

This project introduced the possibility of scaling up air quality monitoring using lower-cost sensor-based technologies across India and specifically in National Clean Air Programme (NCAP) cities. The main goal of the project was to work with the state pollution control board to pilot test the incorporation of lower-cost sensors into the air quality management system in the state of Maharashtra and showcase this as a model for national adoption which could benefit regions with very little or no existing monitoring capacity.

Objectives

- Assess how well various models of Indian lower-cost sensors work in the Indian environment.
- Build comfort and familiarity among air quality regulators with the use of lower-cost sensors.
- Incorporate lower-cost sensors into the air quality management system in Maharashtra, and showcase this as a model for national adoption.
- Develop a robust machine-learning-based method for the calibration of $PM_{2.5}$ lower-cost sensors.

Forty sensors developed by four Indian start-ups were co-installed with the Maharashtra Pollution Control Board's 15 regulatory grade CAAQMS in the greater Mumbai Metropolitan Region. Sets of four sensors were placed next to regulatory/government monitors, which cover the entire city of Mumbai. The specific regulatory monitors selected for co-location were chosen so that there would be a representative sample of five settings - background, industrial, residential, commercial and traffic-impacted. While evaluating the sensors, the project also aimed to develop a robust machine-learning-based method for the calibration of $PM_{2.5}$ lower-cost sensors. The 15 locations selected for co-location are: Airport, Sion, Nerul, Vileparle, Mahape, Vasai, Borivali, Kalyan, Powai, Colaba, Mulund, Bandra, Kandivali, Worli, and Kurla.

Four Indian startups—Airveda Technologies Private Limited, Personal Air Quality Systems (PAQS) Private Limited, Respirer Living Sciences Private Limited, and Oizom Instruments Private Limited— were shortlisted to participate in the experiment. The lower-cost sensors used by each startup device are as follows: Respirer (PlanTower), Airveda (Nova Fitness), Oizom (Nova Fitness) and PAQS (Telaire Dust Sensor).

Project Findings

- The uptime, or time during which the sensors were operational on a monthly basis, for lower-cost sensors was found to be comparable or superior (> 90%) to the CAAQMS monitors and required the least manual assistance during operation over the seven-month-long deployment.
- Machine-learning-based regression techniques were used to process the raw lower-cost sensor readings and calibrate results to reduce the mismatch between calibrated values and CAAQMS measurements. Twenty of the lower-cost sensors developed by indigenous start-ups have produced readings that differ from regulatory grade (CAAQMS) monitors by 10-15%.

- The findings reveal that after calibration, the error (calculated as the ratio of the difference between the lower-cost sensor readings and the CAAQMS readings) is below 15% for two sensors and below 20% for other two sensors. The existing calibration methods for lower-cost sensor devices perform well at the same site and device at which they are trained.

- This work also focused on the development of a calibration model which is independent of the location and device. This calibration model could make scaling up more cost effective.

- Sensors co-deployed with regulatory monitors in Mumbai that measured $PM_{2.5}$ were in close agreement with readings from monitors in diverse environments with high and low pollution loadings. For example, at the background site, lower-cost sensors measured mean $PM_{2.5}$ at 67 μg/m³, while the regulatory monitor measured $PM_{2.5}$ at 62 μg/m³. For campus, industrial and traffic sites, lower-cost sensors measured $PM_{2.5}$ at 60, 94, 74 μg/m³ respectively, whereas CAAQMS monitors gave mean values of 67, 91 and 76 ug/m³.

- The large amount of co-located data (from the sensors and regulatory monitors) helped IIT Kanpur develop new machine learning models that could help reduce the duration of co-location needed and enable in-field calibration, thereby substantially reducing overall cost of monitoring in cities.

Airveda

Oizom

Respirer

PAQs

Figure 18: Lower-cost sensor devices of the four Indian start-ups.

- The performance of the lower-cost sensors was relatively better from November to March, when compared with the performance from April to June. In the latter period, the level of atmospheric humidity was much higher, implying that in certain instances sensors may require more than one calibration in a year-long deployment.

- Learnings from this pilot have led to increased interest from other states and cities. IIT Kanpur has already deployed more sensors in cities such as Jaipur and Lucknow, and there are plans to expand the network to rural areas in India.

- The findings of the study have thrown open the possibility of expanding the country's monitoring network at a fraction of the existing cost.

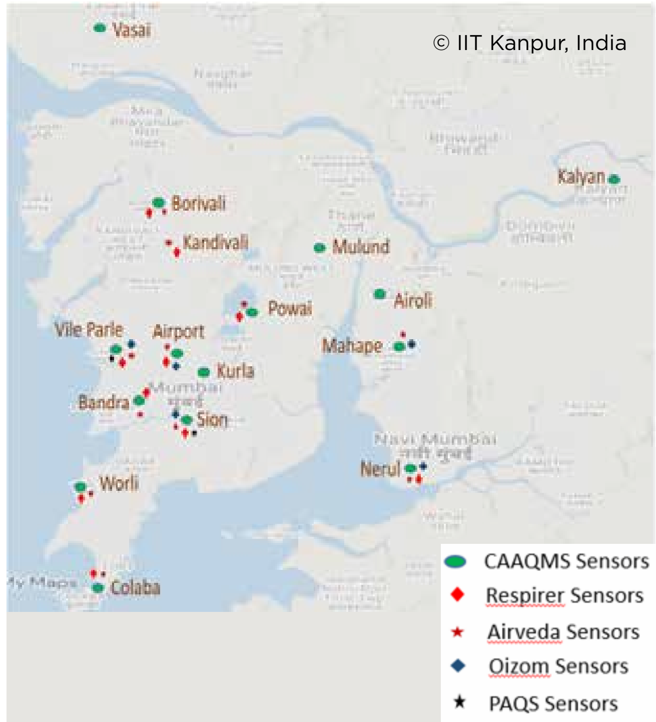


Figure 19: Sensor deployment status. CAAQMS denotes the Maharashtra Pollution Control Board sensors used for co-location.

Figure 20: Photographs of the installed devices.

Paris © Rishabh Varshney / Unsplash

“Breathing clean air is a fundamental right and a public health measure. Alongside many other cities around the world, Paris is committed to pursuing actions to tackle pollution in line with the Paris Agreement.”

The Mayor of Paris, Anne Hidalgo

PARIS:

Piloting lower-cost sensors to better understand air quality at Parisian schools

Understanding air pollution in schools

Air pollution is responsible for at least 40,000 premature deaths in France every year and **nearly 1 in 10 deaths in the Ile-de -France region**. Paris has been leading efforts to improve its air quality by implementing ambitious policies to protect the health of its citizens, including those most vulnerable to it: children. Mayor Hidalgo has pledged to phase out heavily-polluting diesel cars by 2024 and has deployed over 160 School Streets, pedestrianising roads around schools.

In 2019, Bloomberg Philanthropies and the City of Paris launched a joint project to better understand and improve air quality at schools throughout the city. The pilot project was led by Airparif–the independent air quality observatory of the Île-de-France region accredited by the French ministry in charge of the environment–deployed and tested a network of Clarity lower-cost sensors to provide new insights and hyperlocal data on air quality and children's exposure to air pollution.

The year-long large-scale pilot project also evaluated the performance of lower-cost sensors and other monitoring technologies, such as diffusion tubes, in real-world conditions in a major European city.

Piloting innovative monitoring tools

The pilot study took place over the course of one year, from September 2019 to September 2020. A total of 138 Clarity lower-cost sensors, measuring $PM_{2.5}$ and NO_2 levels, were deployed at 44 Paris schools, nurseries and along neighbouring streets. Micro-sensors were installed in school courtyards and playgrounds and in nearby streets to assess children's pollution exposure at these locations.

The project combined different monitoring technologies, including Clarity micro-sensors, diffusion tubes and 16 reference stations. The use of multiple tools helped to detect defective devices before deployment, calibrate the devices and inform post-processing of the raw data.

During the year-long project, partners jointly carried out the pilot project in the following steps:

- **Two Initial Test Phases:** Using co-location at Airparif reference stations, defective devices were identified and removed (approximately 10% per batch, which corroborates findings from Airparif and its partners in previous micro-sensor experiments). This testing phase prior to field deployment is crucial for any project using micro-sensors to ensure data quality control and assurance.
- **Micro-Sensor Sampling:** A total of 138 lower-cost sensors supplied by Clarity were deployed. The sampling plan was designed to cover schools most exposed to air pollution, as well as sites located both near and far from pollution sources. This ensured a representative sample of the range of air pollution exposure experienced in Parisian schools and nurseries. The rest of the sensors were installed in the streets adjacent to the schools to assess variability in pollution concentrations measured in streets and schoolyards. Measurements were also taken at other points of interest, such as major intersections with potentially high concentrations in pollutants, and next to Airparif's reference stations, to verify measurements throughout the experiment.
- **Diffusion Tube Measurement:** Alongside the deployment of micro-sensors, NO_2 measurement campaigns were carried out using diffusion tubes. These measurements took place over 11 weeks during four time periods (October-November 2019, March 2020, June-July 2020 and September 2020)

Paris © Alexander Kagan / Unsplash

"Data is a critical tool in the fight against air pollution, particularly to protect the most vulnerable, including children."

Michael R. Bloomberg, UN Secretary-General's Special Envoy for Climate Ambition and Solutions, Founder of Bloomberg LP and Bloomberg Philanthropies, and 108th Mayor of New York City

in 40 schools and 16 surrounding streets following the same sampling plan used for the micro-sensors. The objective was to assess the in-situ performance of the micro-sensors, provide reference information from the schoolyard to the street and measure the difference in exposure between these two environments.

- **Evaluation Period:** The project collected seven months of data on the performance and capabilities of the micro-sensors for tracking background concentrations of fine particles. These data were compared with Airparif maps developed with modelled data and observations (Hor'air) and shared online on Paris.fr. The objective was to assess the capability of the micro-sensors for supplementing or strengthening this data-sharing service.

Project findings

The findings of the project, which included lower-cost sensor data in conjunction with diffusion tubes and existing monitoring systems, confirmed that air pollution levels were significantly lower in schoolyards than in nearby streets.

The study published by Airparif found that concentrations of air pollutants were inversely correlated with distance of school buildings from nearby streets; and that there was a "sheltering effect" provided by school walls. The study showed a 36% average difference in NO_2 concentrations observed between school courtyards and neighbouring streets, finding that school air quality was in line with the WHO air quality guidelines. However, the shielding effect of walls, and distance from the main roads, that was observed for NO_2 did not carry over to $PM_{2.5}$ concentrations.

During the pilot programme, Airparif evaluated the performance of the sensors and quality of the data they collected. For $PM_{2.5}$, the technology provider Clarity developed a correction algorithm based on measurements from Airparif reference stations. The algorithm greatly improved the micro-sensors measurements compared to raw data and was effective for sites in a background situation (e.g. those located in school yards).

The results obtained from $PM_{2.5}$ sensors placed in schools showed that the concentrations in the school yards were similar to those measured by the Airparif reference network background stations. This indicates that the city's background pollution is the main cause of air pollution exposure in schools.

For NO_2 pollution levels, sensor data showed some inconsistencies which led Airparif to decide not to use the data for the study. Airparif used the NO_2 data collected by diffusion tubes installed at the different locations to complete their analysis.

Outcomes and lessons learned

The pilot project showed the benefit of pairing micro-sensor networks with the reference network during various phases of implementation, to ensure: detection of defective devices before deployment, calibration of the devices (in particular to offset a drift over time, which was already perceptible in this one-year experiment), and post-processing of raw data with an algorithm tailored to the location. In its conclusions, Airparif recommended using a micro-sensor network alongside its reference station data to adequately calibrate the sensors, monitor pollution and inform the public.

Lower-cost sensors perform differently depending on the location where they are installed and on their use. This full-scale experiment has provided important learnings for other cities that are considering deploying lower-cost monitoring campaigns to inform policy and tackle pollution. At times, sensors can present uncertainties both in accuracy and in the ability to capture the temporal variability of ground-level concentrations. Post-processing and calibration are necessary throughout the data collection phase.

The study and results of the pilot project were published by Airparif in May 2021 and presented to city authorities, civil society and schools. The report included a factsheet for the participating schools, with air quality data collected at each location.

Costs and next phase of the partnership

The pilot project was funded by Bloomberg Philanthropies through support to Airparif and Clarity. The budget covered the network of Clarity sensors, maintenance costs and data analysis by partners. The City of Paris also provided in-kind assistance to the project.

Following the completion of the pilot, Bloomberg Philanthropies and the City of Paris announced the extension of their partnership with the launch of a new measurement campaign, led by Airparif, to monitor ultrafine particles in Paris and engage citizen participation in tackling air pollution.

© Airparif

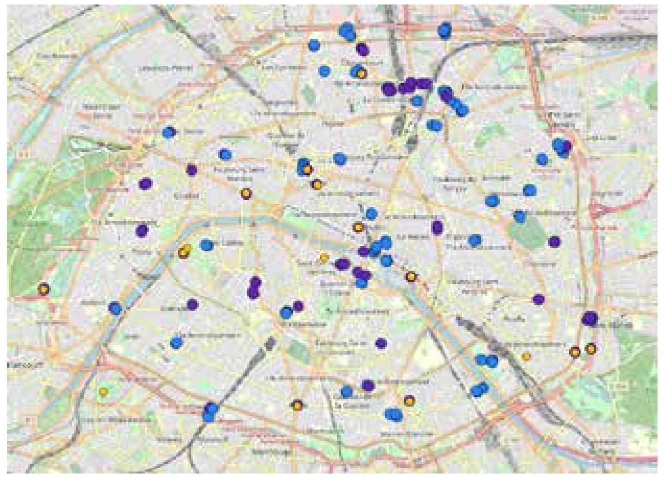


Figure 21: Map of Paris with monitoring sites equipped with micro-sensors (in purple), monitoring sites equipped with micro-sensors and diffusion tubes (in blue), and reference stations of the Airparif network (in orange).

Quezon City © Ros / Unsplash

"Through this technical assistance programme, the city is empowered to operate and manage its air quality monitoring systems through the skillful guidance of C40 Cities and Clean Air Asia. We are advancing steadily to the attainment of cleaner air for our citizens as promised. Having real-time air quality data across the city can lead to more specific air quality management actions and decisions – identifying sources and locations we need to focus on while providing guidance on health exposure of our citizens through the air quality index."

The Mayor of Quezon City, Josefina Belmonte

QUEZON CITY:

Collecting baseline data and identifying hotspots

In 2020, C40, Quezon City Local Government (QCLG) and Clean Air Asia partnered to develop an air quality baseline study to support the delivery of Mayor Joy Belmonte's commitments to the C40 Clean Air Cities Declaration.

Sensor selection

An initial assessment was conducted to identify existing monitors and sensors, key air pollution sources and critical population receptors (such as densely populated residential areas and locations with marginalised/vulnerable populations). This information was used to identify the pollutants of concern, and thus the most appropriate monitoring instruments to deploy that would complement rather than duplicate existing infrastructure. The proposed sensors were discussed with various city, national government agencies and academic stakeholders to ensure alignment with other monitoring, research and management goals and to understand any previous challenges in conducting and sustaining urban air quality monitoring systems. Ultimately, eight Clarity Node-S units, one Clarity-2BTech Ozone Sensor and one Davis Instruments Weather Station were purchased and shipped to the Philippines.

Site identification

To select sites to deploy sensors, a mapping exercise was conducted to identify areas with marginalised/vulnerable populations not currently covered by existing monitors. This population-oriented approach to sensor deployment was taken to ensure a focus on understanding community exposure while guiding local government interventions to improve public health and revitalise the urban environment. Following this mapping (see diagram), a cross-departmental exercise was conducted to nominate sites within the identified areas, using a siting checklist developed by Clean Air Asia.

Over the course of a week, two to four personnel from the Climate Change and Environmental Sustainability Department conducted inspection visits to the locations identified to ensure they were suitable for monitoring and that the sites could be managed and looked after by a local partner in partnership with QCLG personnel. Significant time (several weeks to several months), partly due to the COVID-19 pandemic restrictions, was required to secure permits and agreements with site owners/managers for the units. Once the sites and respective managers were confirmed, Clean Air Asia held a 2–3 day training workshop on the operation and maintenance of the sensors, in addition to establishing data management processes. At the same time, the $PM_{2.5}$ sensors were moved to the nearest reference monitor for a two-week colocation study.

© Baseline Air Quality Study Final Report

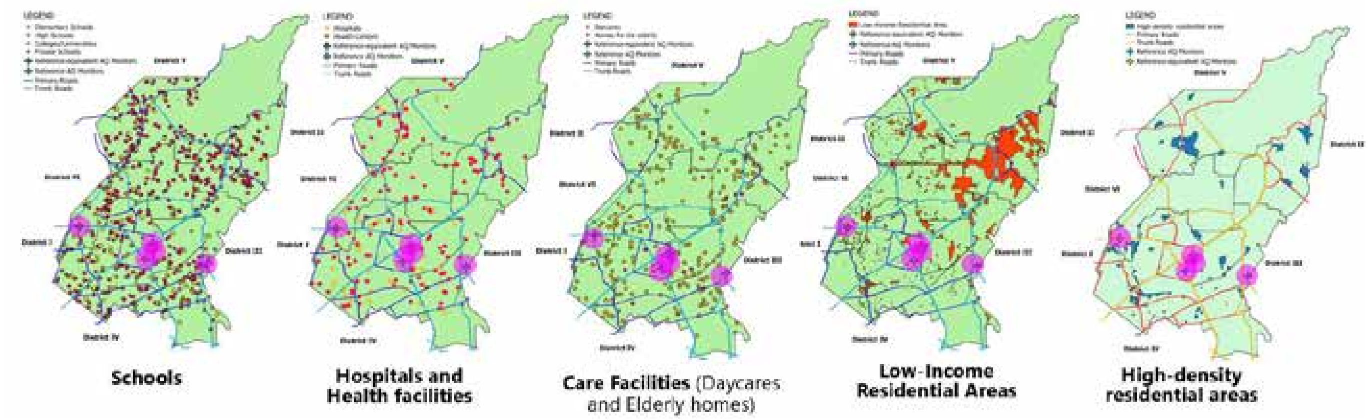


Figure 22: Site selection based on marginalised/vulnerable areas.

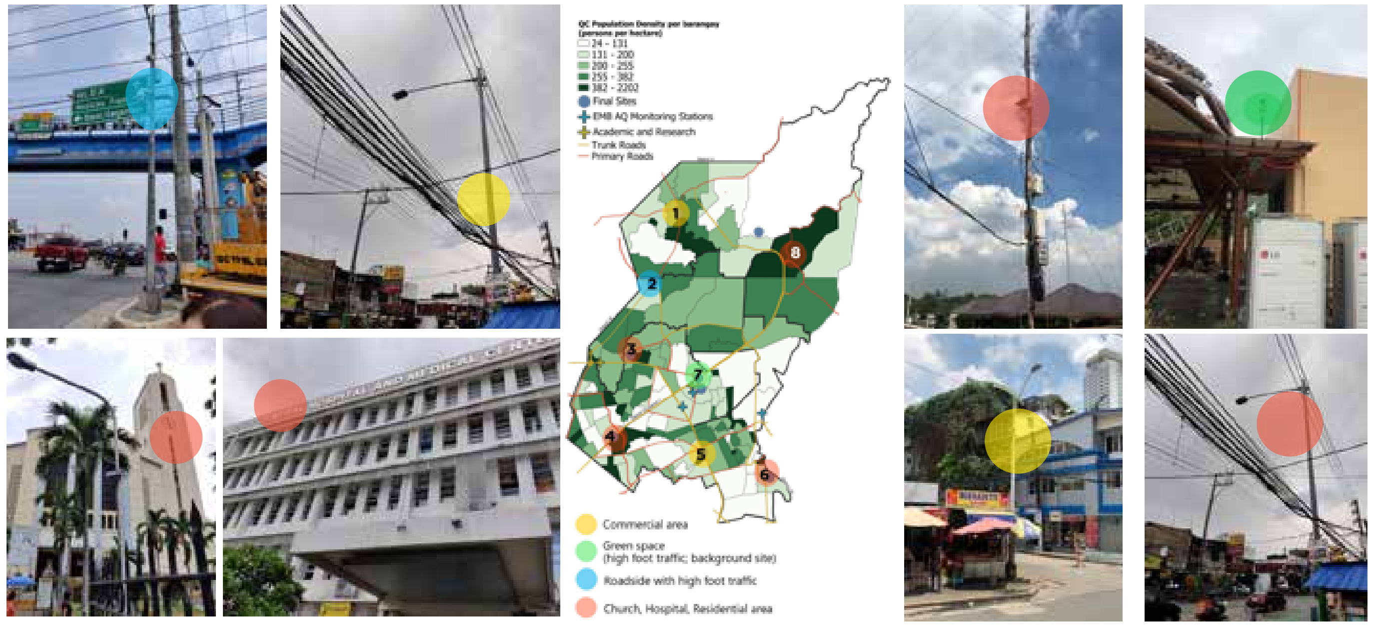


Figure 22: Selected sensor locations.

Identifying baseline levels and hotspots

Once the sensors were deployed, Clean Air Asia and Quezon City began to collect additional, pre-existing sources of information on air quality in the city to compare with monitored data. The sources included existing air pollution studies in Metro Manila, Philippines, pre-existing air quality data from government and academic institutions, information from published scientific journals, satellite-based pollution data and meteorological data. The comparison provided a comprehensive understanding and context for the baseline concentrations of air pollutants in Quezon City. Data from the air quality monitoring network was analysed to assess changes in air pollution levels in the context of activity changes due to the pandemic and other incidences that can have an impact on air quality (e.g. Taal volcanic eruptions).

Sites with elevated daily and hourly values are being identified for immediate action. From measured averages, reduction targets can be set per site while specific actions from the city's Air Quality Management Plan (AQMP) can be implemented.

The baseline results will thus provide insights and opportunities for clean air interventions that are integrated into the city's AQMP and aim to meet World Health Organisation Air Quality Guideline values for criteria pollutants by 2030.

BUDGET

- Two to four full-time employees to manage the city-owned and operated sensors and data, plus two to four full-time employees assigned to overseeing the deployed sensors.
- Funding assigned to purchase one reference equivalent monitor (with PM_{10}, $PM_{2.5}$ and NO_2 analyser), 5 weather stations, 12 lower-cost $PM_{2.5}$ and NO_2 sensors.

BOX 4 / WILDFIRES: HOW CAN CITIES IMPROVE AND EXPAND SENSOR NETWORKS AND COMMUNICATIONS

During the 2020 extreme smoke events in Portland, Oregon, due to wildfires, city of Portland staff received questions from community members and staff showing confusion and frustration. Which data source should I look at for information? Why do one website's $PM_{2.5}$ measurements differ from another one? Why does one website show a five-day forecast but regulatory agencies do not? Which one do I use to inform my programme decisions? These were questions received from stakeholders who speak English as their primary language. As city staff looked at the next steps for their air quality sensor and communication project, they wondered: what questions and needs did we miss?

The City's Bureau of Planning and Sustainability team used remaining funds in the sensor project to shift and focus on improved communication and actions during wildfire events. Smart City PDX partnered with Familias en Acción, a culturally specific organisation that promotes health for Latino/x/e communities in Oregon, to build an interactive workshop to prepare for wildfire emergencies and smoke impacts. Familias en Acción communities have shared knowledge about the importance of emergency preparedness and poor air through a series of focus groups informing the workshop. They also identified a lack of resources available in Spanish.

The El Aire Que Respiramos (The Air We Breathe) workshop focused on actions to take for wildfire emergency preparedness and how to mitigate smoke-related health effects. A discussion of what air quality means facilitated a culturally specific way to talk about air pollution and health. The workshop also focused on how to find reliable, accessible information during a smoke event. There are many resources online but not all are available in Spanish. Regional blogs and apps in Spanish have been shared. For important data-focused resources only available in English, the curriculum walks through how to access and read them – for example explaining what the data means and how one can use the colours and numbers to get the necessary information. Grant funds also supported the provision of go-to emergency kits and do-it-yourself air filters. Instructions to build the filters are in Spanish and accompanied with photos of the materials they receive.

The Familias en Acción staff are essential to helping city staff adopt communications and resources to resonate with and meet the needs of the communities they serve. Organisation staff and a Spanish-speaking city staff member facilitate and present the workshop. This coaching method ensures the organisation's staff can present the full workshop in future iterations. Materials and methods are designed with the goal to be used in future, on-going workshops given the increasing frequency of wildfires and growing needs for emergency preparedness due to climate change.

3

CONCLUSION AND RECOMMENDATIONS

Lisbon © Kit Suman / Unsplash

These cases studies highlight how cities have used new sensor technology to address pressing air quality concerns, such as identifying inequitable exposures to air pollution, identifying emission sources, creating new opportunities to communicate the risks of air pollution, and identifying new ways to design and implement measures that accelerates progress towards local, sub-national, national, or international targets and standards, such as those set through C40's Clean Air Cities Declaration.

Local experts are keenly aware of both the opportunities and limitations associated with the sensors. Through discussions with cities on what would encourage further uptake of new monitoring technologies, key themes and recommendations for the wider monitoring community have emerged:

- Clear protocols on co-location methods and frequency of co-location studies.
- Recent and reliable data on sensor accuracy, under local conditions, and reliable information on the useful lifetime of sensors.
- Solutions to energy supply disruptions and city-specific conditions.
- Robust and responsive customer support.
- Training to build city staff capacity in sensor deployment and data analysis.
- Solutions that anticipate and reduce e-waste from sensors.
- Support with project-level budgeting.
- Guidance on data sharing and data management platforms.

Through close cooperation with cities, the air monitoring community - including sensor manufacturers - can leverage new technologies to enable emissions reductions that increase the quality of life for hundreds of millions of residents, reduce harmful greenhouse gas emissions, and shrink inequities in exposures and health within our cities. C40 Cities continues to work with cities to eliminate data and public awareness barriers to effective policy implementation through a variety of programs and partnerships with cities. Recognising the importance of data and effective communications in reducing air pollution in cities, C40's Chair and Mayor of London, Sadiq Khan has made air quality a priority of his chairmanship, working to expand air quality monitoring in cities through the breathe global initiative, to provide local communities and mayors around the world with the tools and data they need to reduce toxic air pollution and climate emissions.

THROUGH CLOSE COOPERATION WITH CITIES, THE AIR MONITORING COMMUNITY - INCLUDING SENSOR MANUFACTURERS - CAN LEVERAGE NEW TECHNOLOGIES TO ENABLE EMISSIONS REDUCTIONS THAT INCREASE THE QUALITY OF LIFE FOR HUNDREDS OF MILLIONS OF RESIDENTS, REDUCE HARMFUL GREENHOUSE GAS EMISSIONS, AND SHRINK INEQUITIES IN EXPOSURES AND HEALTH WITHIN OUR CITIES.

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