Operational Network of Air quality Impact Resources

Tier 1 citizen sensing devices co-located at a Tier IV regulatory monitoring station in Barcelona. Source: Creative Commons

A framework for categorising air quality sensing devices

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Introduction

Air quality data enables local government authorities to make informed decisions that directly impact community and environmental health. Such data has traditionally been produced by regulatory authorities, however with recent developments in low-cost sensing and smart city technologies, new options for collecting air quality data at a local scale have emerged, presenting new opportunities to local governments.

Commercially available air quality sensing devices vary considerably in terms of cost, the quality of the data they produce, and their overall functionality, performance, and reliability. The OPENAIR *Framework for categorising air quality sensing devices* has been developed to associate air quality sensing devices of varying performance and quality of data output, with four 'tiers', each of which roughly characterises a type of data use (or data application area).

The framework is a reference tool intended to help guide practitioners to think about their devices and the data quality they require for their application. It is of broad relevance to any local authorities engaging with air quality data in the Australian context and has been adapted from previous work by the US Environmental Protection Agency (United States Environmental Protection Agency, 2022).

Who should use this resource?

This resource is for local government authorities or community organisations undertaking air quality projects. It provides a guide to staff responsible for the design and delivery of a smart air quality monitoring project that uses low-cost sensing devices. It may also be of interest to senior management and communications staff who wish to better understand the differences between new, low-cost sensing technologies and more traditional regulatory monitoring technologies. It assumes the reader has no background in air quality science or smart technology.

How to use this resource

This resource presents the OPENAIR *Framework for categorising air quality sensing devices* as a tool to establish a common language around the application of air quality data.

Use the framework to identify a data application Tier that aligns with the aims of a particular air quality monitoring project. Identification of a Tier supports discussion of a range of other activities relating to air quality sensing, including device calibration and data interpretation.

To use the framework, consider which of the four tiers most closely describes your own situation and needs. Table 1 provides a general guide to the details of each tier and you may also wish to refer to the case studies section below it for further interpretation and guidance.

Before you begin

Before you engage with this resource or start to make decisions about the type of sensing devices to procure for your project, you should establish a clear understanding of how you intend to apply new air quality data. To do this, create a clear business case that defines your specific air quality issue, associated stakeholders, and the scope and aims of your project. You also need to create a Data Use Action Statement that describes the intended relationship between the data that you collect, and data-driven activities that lead to planned outcomes and impacts. Refer to the OPENAIR supplementary resource *Identify template* for detailed guidance on this process.

SOME BASIC DEFINITIONS: Sensor vs sensing device

Sensor: A specialist component designed to capture empirical data about a directly observed phenomenon. A sensor is a component within a device that is generally sold to device manufacturers. A sensor cannot function separately to a supporting device.

Sensing device: A complete device, sold as a commercial product to end users. A sensing device will typically consist of some kind of device housing that contains sensor(s), as well as surrounding circuitry supporting their use (including a microcontroller, power supply components, communication modules, and on-board data storage).

WHAT ARE ‘LOW-COST’ DEVICES?

‘Low-cost’ refers to all devices in Tiers I, II and III of this framework – or all devices that are *not* regulatory grade (Tier IV). Low-cost devices may vary in cost from tens of dollars to thousands of dollars.

An overview of the framework

This OPENAIR *Framework for Categorising Air Quality Sensing Devices* consists of four tiers that characterise different data devices and applications according to the data accuracy they provide or require (see Figure 1 for an overview of these tiers). Local government air quality monitoring projects should align with Tier I, II or III. Note that Tier IV sits beyond the technical expertise, capacity, and data use requirements of most local authorities, and tends to be the domain of central government agencies.

The four tiers are intended to provide a general guide to data application areas (the terms associated with tiers are somewhat relative, and thus not all projects will fall neatly within them). This framework provides a useful starting point for local governments, allowing practitioners to understand data quality requirements relative to the type of sensing device selected, and the intended data application.

The relationship between device cost/complexity/functionality and the quality of data output

Figure 1 maps the relationship between the cost, complexity, and functionality of a device (on the x-axis) and the ability of a device to provide quality/accurate data (on the y-axis).

However, there is not always a clear or direct link between the functionality of a product and the accuracy of its data. For instance, a device might be a robust product that operates reliably under harsh conditions for a long period of time. It might be well-designed from a user experience perspective, with a range of helpful functions, good interoperability, and easily configurable settings. It might be made with high-quality materials and be well put together. It may have all of these attributes (and a relatively higher cost) and yet still produce relatively low-quality data. Conversely, some low-cost devices can be very simple and have limited functionality, yet still produce relatively accurate data. Cost, complexity, and functionality are therefore not the only reliable indicators of data quality.

Certainly, 'ultra-low-cost' devices (tens of dollars to a couple of hundred dollars) tend to be suitable only for Tier I applications (educational), while regulatory devices tend to be the most costly. However, the cost of 'mid-range' devices (several hundred to several thousand dollars) is *not* always a reliable indicator of their suitability for either Tier II or III applications. This is because there is too much variation in sensor performance within this cost range, combined with significant variation in possible project aims within Tier II and III applications.

As a result, it is not advisable to use the cost of a device as the only guide to sensor procurement, since a more expensive device does not necessarily yield better results. The decision about which low-cost sensing device is most suitable for your project relates to a broad number of factors (see the OPENAIR Best Practice Guide chapter *Sensing device procurement* for more details). One of the most important factors to consider is the ability of a device to provide you with data that is accurate enough for your chosen data application area. This framework will guide you through that process.

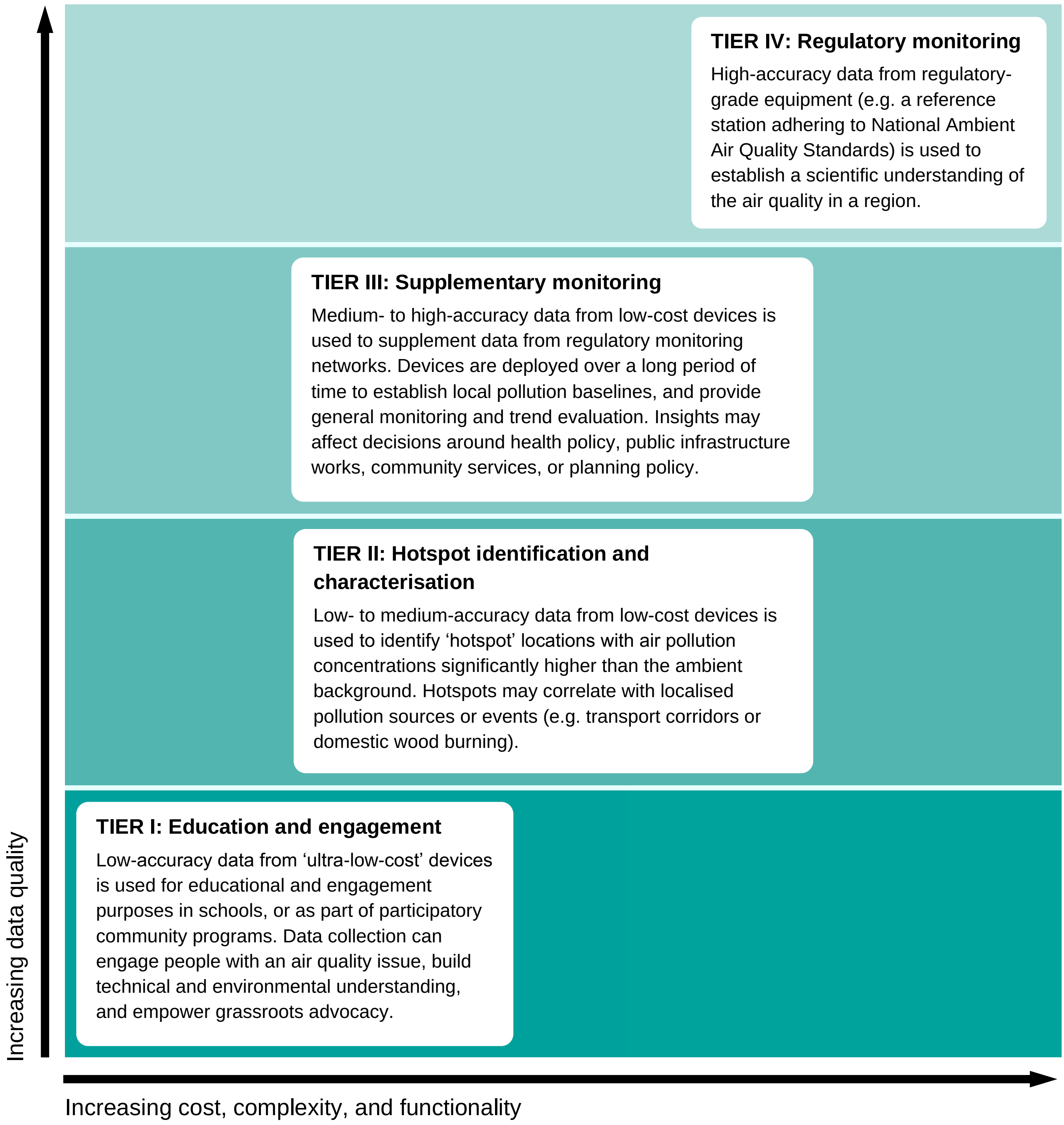

Figure 1. A framework for categorising air quality sensing devices (basic overview)

The framework in detail

Table 1 presents a detailed breakdown of the four tiers (including definitions, an overview of possible data applications, and example scenarios).

Table 1. OPENAIR data application tiers

Tier	Data application
Tier I: Education and engagement Accuracy required: Low	**Low-accuracy data from 'ultra-low-cost' devices can be used for educational and engagement purposes in schools, or as part of participatory community programs.** Simplicity, usability, robustness, and ease of set-up are critical device attributes. Data accuracy is less important, so long as a device responds in a predictable and expected way to changing conditions. **Data collection can:** • engage people with a specific local air quality issue, and with air quality as a more general concern • build technical understanding in the community relating to the internet of things, sensing, and data • build environmental understanding in the community relating to air quality science • empower grassroots advocacy for impact creation • leverage/support initiatives that aim for behaviour change (e.g. reducing car usage for local trips, or reducing/eliminating wood burning for home heating). **Example scenarios:** • Teaching school students (K-12) about air quality, general electronics skills, and data logging and analysis • Community participation and citizen science initiatives.
Tier II: Hotspot identification and characterisation Accuracy required: Low to medium	**Low- to medium-accuracy data from low-cost devices can be used to identify 'hotspot' locations with air pollution concentrations significantly higher than the ambient background.** Devices are used to investigate the concentrations, temporal trends, and dispersal patterns of pollutants from known air pollution sources into surrounding areas of high relevance to community health and well-being. Device deployments generally relate to identification or confirmation of 'hotspots' (where pollution levels are strongly suspected to be higher than the surrounding area), though may also include monitoring at control sites (where pollution levels are lower) and at vulnerable receptor sites, such as schools and aged care facilities (where pollution levels may or may not be elevated to levels of concern). Devices tend to be deployed for a limited period in a specific target location (e.g. near known pollution sources, such as highways, construction sites, or industrial facilities). A degree of data inaccuracy is allowable for hotspot identification. What matters is that the

Tier	Data application
	error/accuracy of data produced by the device is less than the size of the pollution elevation that is being investigated. The size of the pollution elevation being investigated may relate either to the actual size of the hotspot, or to a threshold concentration of concern determined by national guidelines (e.g. the Australian NEPM guidelines for daily exposure to $PM_{2.5}$ [1] are 25 µg/m^3). In either case, the change in concentration is measured relative to the ambient baseline for that location. Hotspot monitoring should be considered 'indicative'. It can initially confirm (or disprove) an existing hypothesis, and may be useful for securing funding and resources to explore a localised air quality issue more deeply. It is recommended that findings from hotspot monitoring are validated using higher-tier sensing equipment. **Data collection can:** • support the development of insights relating to the cause of hotspot creation, through correlation with existing localised pollution sources or events (e.g. transport corridors, industrial facilities, domestic wood burning), and through improved understanding of local microclimates (e.g. the movement and dispersal of polluted air at the human scale) • influence political, planning, or urban design decisions on a case-by-case basis, and have implications for future policy (but any deeper systemic changes should be validated using data from Tier III monitoring). **Example scenarios:** • determining whether a construction site creates elevated levels of dust that are a concern for the health and well-being of nearby residents • determining roadside air quality at a major public transport interchange, with potential future implications for public transport policy.
Tier III: Supplementary network monitoring Accuracy required: Medium to high	**Medium- to high-accuracy data from low-cost devices can be used to supplement data from regulatory monitoring networks (Tier IV).** Supplemental network monitoring is likely to involve the deployment of more sensing devices than are typically used for hotspot identification. Devices are deployed over a long (or indefinite) period to establish local pollution baselines, and provide general monitoring and trend evaluation. **To ensure alignment with the needs of regulatory authorities, note that:** • devices should ideally be procured and deployed with some degree of engagement and support from regulatory monitoring authorities

[1] $PM_{2.5}$ refers to airborne particulate matter (solids or liquids) that have a diameter of 2.5 micrometres or less. (NSW Health, 2020)

Tier	Data application
	• devices should be deployed and operated according to best practice guidelines that are recognised by the regulatory authority. **Data can supplement an existing regulatory network in two ways:** • By filling in spatial gaps (e.g. regulatory stations might be spaced several kilometres apart, so supplementary devices can provide data for locations between them, supporting improved spatial interpolation of regulatory data) • By filling in temporal gaps (e.g. a smaller reporting interval may be available from low-cost devices, providing higher temporal definition around short-term pollution events). **Data collection can:** • support the development of insights that may affect policy and planning decisions at a systemic level (at local government scale or higher). This may have implications for areas of impact as diverse as public health, public infrastructure and services, utilities, community services, urban development and design, industrial development, and climate mitigation and resilience. **Example scenarios:** • monitoring air quality trends seasonally • monitoring air quality around schools to ensure the health and safety of children • monitoring air quality in public spaces and publishing this data on your local government or community organisation website • deploying a network of sensors at key traffic intersections to inform road infrastructure decisions to improve air quality.
Tier IV: Regulatory monitoring Accuracy required: High	**High-grade monitoring devices provide scientific measurements of air quality in the local region.** In Australia, regulatory monitoring refers to highly accurate monitoring systems that are compliant with the National Ambient Air Quality (NAAQ) Standards, and are operated by state and territory governments. Sensing devices are calibrated to a reference method on a regular basis. Necessary security, power, and IT infrastructure are in place to ensure continuous operation and minimal loss of data points. **Example scenario:** A regional network of high-performance ambient air quality monitoring stations is managed by a regulatory authority. Data collection aligns with established standards. Data is used to support state and national policy, and is also the primary source of trusted real-time information for public authorities (e.g. health, transport, and emergency services), as well as for the general public.

Case studies

This section presents real-world examples of projects and air quality monitoring systems that align with each data application tier, helping to clarify the framework from an end-user perspective.

Tier I case study: DIY citizen sensing in Lake Macquarie

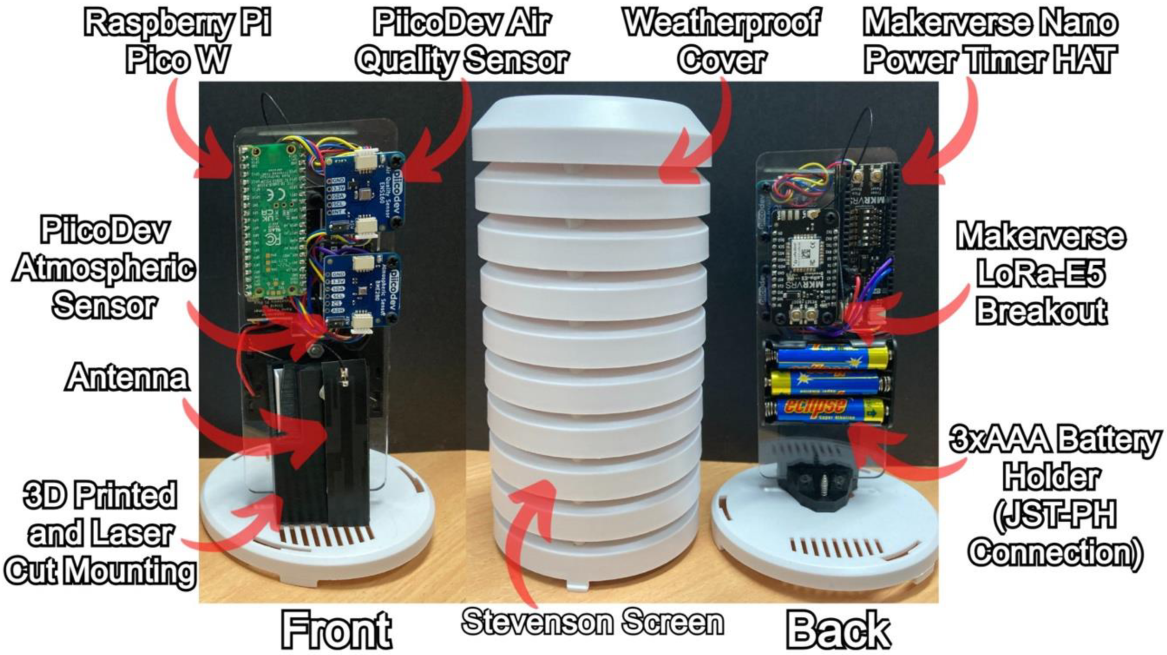

Figure 2. The DIY citizen sensor. Figure source: Lake Macquarie City Council and Core Electronics

Lake Macquarie City Council (LMCC) has developed a DIY air quality sensing device through their Fab Lab. The portable, battery-powered device (see Figure 2) consists of a single board computer (Raspberry Pi Pico), and transmits data over a community LoRaWAN wireless communications network (The Things Network). It measures temperature, air pressure, humidity, and gases using a range of low-cost sensors, and can be easily deployed in a wide variety of locations. The kit can be purchased as a package via Core Electronics, a local IoT provider that co-developed the device with LMCC.

The data quality output of these devices is likely to be fairly low; however, the focus is more on the educational and engagement outcomes that the device facilitates. LMCC has created a package of educational materials and a multiday workshop that teaches community members how to build, program, activate, and deploy their own device, as well as access and manage the data it generates. The program is building grassroots engagement with air quality and urban heat challenges in the area, and is supporting digital literacy in the community and in schools.

Tier II case study: low-cost monitors in Armidale

Wood smoke from domestic heating can be a major source of urban air pollution.

Since 2017, the University of New England and Armidale Regional Council have partnered to deploy 'Purple Air' monitors to measure air quality across the town of Armidale, New South Wales. The aim of the project was to understand spatial and temporal variations in particulate pollution associated with smoke from domestic woodfire heating.

$PM_{2.5}$ values were monitored at eleven locations, and substantial spatial variation was identified (Robinson, 2020). According to data from a nearby regulatory monitoring station (Tier IV), national air quality standards were exceeded 32 times during a study period. However, a low-cost sensor located within a residential area with wood smoke issues reported 63 exceedances over that same study period, suggesting that localised hotspots may be experiencing poorer air quality than otherwise indicated by state government monitoring. The study found that wood heater use results in increased community exposure to $PM_{2.5}$ pollution by at least $8\mu m^3$; increased mortality by 10%; and thousands of dollars per wood heater per year in healthcare costs.

The real-time display of information available from the Purple Air sensing devices has increased community awareness of air quality and health issues relating to domestic woodfire heating and bushfire pollution in Armidale. Data is now being used to support advocacy efforts to develop more effective air quality management policies for the town.

Tier III case study: Breathe London

A Node-S Clarity Sensor used in the Breathe London network. Image ource: Clarity Movement Co.

Breathe London (2019 to present) is a ‘hyperlocal’ air quality monitoring project that has used a large network of smart low-cost air quality sensing devices to measure various air pollutants (particulates and gases) in multiple local boroughs across Greater London. The project has been delivered by an evolving coalition of government, university, NGO, and industry partners, and is currently managed by the Environmental Research Group at Imperial College London.

The project has improved local government understanding of (and engagement with) localised air quality issues in areas adjacent to pollution sources (e.g. major roads) and vulnerable receptor sites (e.g. schools and hospitals). The data gathered has directly informed strategic planning, traffic interventions, and policy development (for instance, the development of London’s Ultra Low-Emission Zone). Live data has also been made available via community dashboards.

The Breathe London project pioneered a robust and well-documented methodology for the co-location and calibration of low-cost air quality sensors against reference grade equipment, and there was strong collaboration between the project’s governing coalition and regulatory monitoring agencies. Data from the Breathe London network has been used to supplement data from London’s regulatory network by adding air pollution data points to sites that were previously inaccessible, as shown in the London air quality map (Greater London Authority, n.d.).

Tier IV: NSW air quality monitoring network

A regulatory ambient air quality monitoring station in Wagga Wagga (NSW), part of the NSW government's state-wide monitoring network. Image source: Creative Commons

The NSW Department of Planning (DPE) manages a state-wide network of air quality monitoring stations that measure all notable air pollutants featured in the National Environmental Protection Measure for ambient air quality (Air NEPM). Stations incorporate high-performance, scientific-grade reference instruments that are installed and operated according to international and national standards for regulatory ambient air quality monitoring.

Data gathered by these stations is updated hourly to inform a real-time Air Quality Category for each region (NSW Department of Planning and Environment, n.d.), as well as rolling air quality forecasts. Data also supports air quality alerts, epidemiological studies, and scientific research. Stations are routinely checked for quality control, and sensors are maintained by professional staff.

For further details, please refer to the *NSW Air Quality Monitoring Plan 2021-25* (NSW Department of Planning and Environment, 2021).

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Associated OPENAIR resources

Best Practice Guide chapters

Sensing device procurement

The *Sensing device procurement* chapter provides guidance on the selection and procurement of smart low-cost air quality sensing devices. It explores critical considerations relating to the design and functionality of devices and the quality of the data that they produce, supporting procurement choices that are appropriate for the needs of a project and organisation.

Supplementary resources

Identify template

The *Identify template* supports the creation of a business plan and Data Use Action Statement as strategic foundations for a smart low-cost sensing project.

Further information

For more information about this project, please contact:

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This Best Practice Guide chapter is part of a suite of resources designed to support local government action on air quality through the use of smart low-cost sensing technologies. It is the first Australian project of its kind. Visit www.openair.org.au for more information.

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