OPENAIR

Operational Network of Air quality Impact Resources

Emerging data use case compendium

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Introduction

The World Health Organization considers air pollution to be the most significant environmental threat to public health worldwide. It is becoming increasingly important to understand air pollution at a local scale, to effectively address its impacts on public health, social well-being, local economies and climate change. Improved understanding has widespread implications for multiple sectors, including planning, urban design, construction, transport, energy, water, public health and public services.

New and emerging smart low-cost air quality sensing technologies, combined with best practice sensing methodologies, can help governments, researchers, industry, and communities to understand, manage, and resolve localised air quality issues.

A ‘data use case’ describes how data can be used to develop information or insights that may then be harnessed to achieve a goal. Data use cases demonstrate how data from smart low-cost environmental sensing devices can be used to support specific outcomes and impacts and may help organisations to develop their own impact strategies.

Who is this resource for?

This OPENAIR supplementary resource can be used by local governments, communities, researchers, or individuals who are designing their own data use case in response to a current or emerging problem statement related to air quality. Local authorities and organisations can use smart low-cost distributed sensing technology to monitor air quality at the microclimate scale and apply this highly localised data in a variety of use cases.

How to use this resource

This supplemental resource can be used as a detailed guide to emerging use cases for data collected using smart low-cost air quality sensing devices. It is an extended version of the OPENAIR best practice guide *Emerging data use cases*, and is best referred to during the early planning stages of an air quality monitoring project, to help inform high-level strategy for impact creation.

This resource introduces the idea of ‘technology readiness’, where a combination of technological and methodological factors creates a foundation upon which data use cases can be built. The maturation of emerging data use cases is largely contingent upon the maturation of these technology readiness factors.

In this resource, a simplified data use case maturity framework is proposed, and twelve emerging data use cases are presented. These may be of interest to local governments seeking to understand the value that smart low-cost environmental sensing technologies can deliver in the coming years. The focus throughout is on fixed sensing technologies (i.e. deployed in a single, static location for a prolonged period), as opposed to mobile sensing devices (usually vehicle-mounted) or wearable sensing devices.

Technology readiness

Smart low-cost air quality monitoring in real time is now increasingly feasible due to an emerging cluster of new technologies. This kind of monitoring has the potential to transform how authorities, researchers, and the public engage with air quality issues. These technologies can be used to capture air quality data at hyperlocal spatial scales, and at sub-hourly intervals. The data they generate is distinct from the data already available through regulatory monitoring networks, and can support a range of emerging data use cases.

The readiness or ability of technology to support a data use case depends on:

- the **sensing devices** deployed
- the **technologies that support** and connect those devices
- the **methodologies** for configuring, deploying, and operating the sensing network
- how **data is shared**
- the available **data interpretation** capabilities for making sense of the data.

Readiness requires technological innovation at multiple levels, as well as a maturation of applied methodologies and strategic design approaches. As the smart city sector develops, new data use cases for smart sensing technologies will continue to expand.

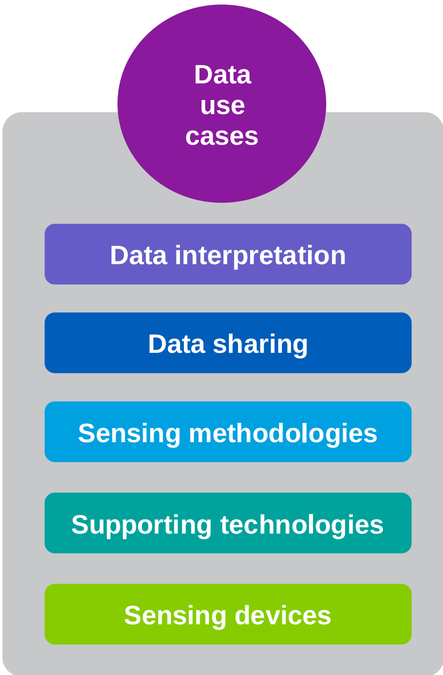


Figure 1. Readiness factors: the foundations of data use case maturity

Sensing technologies

Figure 2 charts how the complexity of air quality monitoring depends on which environmental variable is being measured. Urban heat is relatively simple to measure, with only minor data quality concerns. Particulate matter sensing is more complex, while gas sensing is highly complex and prone to multiple data quality challenges. The differences relate to how these sensing technologies work on a practical level, as well as the complexity of atmospheric gas chemistry relative to simpler physical properties of the air that govern heat and particulates.

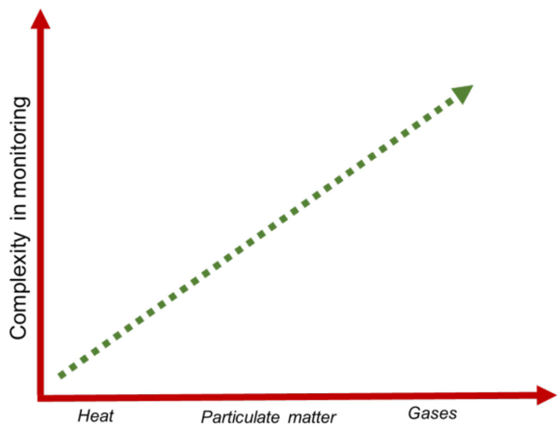


Figure 2. Air quality monitoring complexity varies depending on what is being measured

This varying complexity of air quality monitoring has a bearing on the relative maturity of proposed data use cases. For instance, data use cases that rely on urban heat or particulate matter data may have fewer technical and operational barriers to maturity than those that require gas data.

All sensing technologies are rapidly improving through ongoing research and development, and these innovations will support new data use cases over time.

Supporting technologies

Sensing devices require a range of integrated supporting technologies to operate, and to deliver reliable, high-quality data that serves a data use case. Supporting technologies include the design and functionality of smart devices (which integrate sensors into functional hardware systems), the connection of those devices via wireless communications networks, and the integration of devices and data flows with platforms and digital architectures (see Figure 3). The emergence of new use cases for data from sensing devices is not simply the result of new sensing technologies becoming available. It is also linked to the steady development of the broader technology landscape that supports the Internet of Things (IoT).

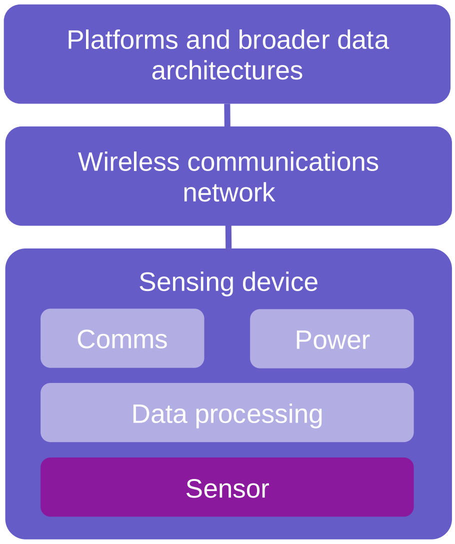


Figure 3. Supporting technologies for smart low-cost sensing

Sensing methodologies

Technology use alone does not guarantee useable data. A data use case relies on the way that technologies are *applied* in a particular context. This includes the way that sensing devices are configured and calibrated, where and how they are deployed, how they are managed and operated, and what metadata is collected (see Figure 4). The methodologies associated with the use of smart low-cost sensing networks are not yet standardised, and are still under development. The maturation of any given data use case depends on the ongoing, iterative improvement and maturation of the associated methodologies by a community of practitioners.

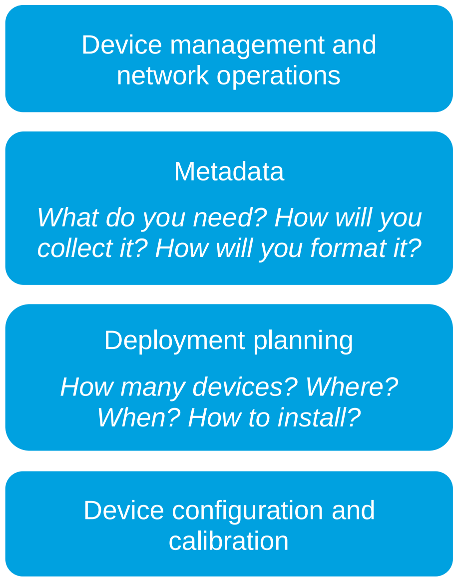


Figure 4. Sensing methodologies for smart low-cost sensing

Data sharing

Data sharing is often critical to unlocking the value of data. Many emerging data use cases rely on data sharing at increasingly large scales, and with a high degree of associated trust. The maturation of many data use cases is therefore contingent upon the development of common data sharing best practice, and the expansion of a data sharing ecosystem for smart low-cost sensing (see Figure 5).

There is a growing role for state government as a data steward, supporting the sharing and harmonisation of local government data. In turn, local governments may also choose to support the sharing and harmonisation of community data generated through citizen science initiatives. Trust in shared data relates to its quality and reliability. These factors are linked to the maturation of sensing methodologies, but also rely on the standardisation and adoption of best practice data sharing protocols.

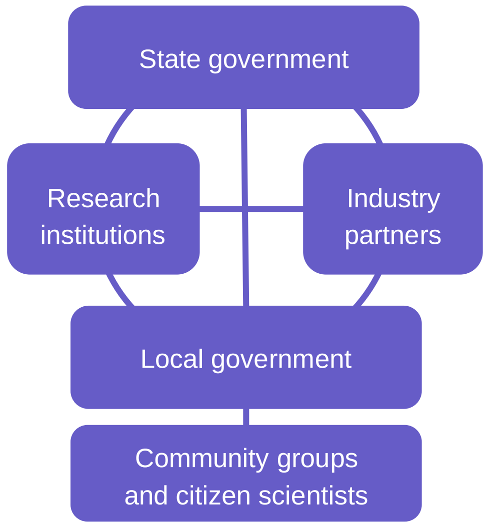


Figure 5. The data sharing ecosystem for smart low-cost sensing

Data interpretation

Raw data must be interpreted to extract useable information capable of supporting a data use case. Basic data interpretation involves correcting raw data for interference and biases, harmonising formats to allow comparison of multiple data sets, and applying quality control filters (see Figure 6). The specific requirements of correction, quality control, and harmonisation will vary by data use case.

An organisation's ability to carry out advanced data analytics is critical to many data use cases. This might include statistical analysis of data sets, the application of threshold triggers and alerts, or using data as an input for a model. Analytics approaches are generally developed with specific data use cases in mind. For example, several data use cases for local government air quality data involve using it to supplement data from state-managed regulatory monitoring networks. Once the challenge of data sharing is overcome, a model is required that combines smart low-cost sensing data with regulatory data, synthesising new outputs. These outputs can then support initiatives such as improved public health alerts, or the optimisation of controlled landscape burning to minimise smoke impacts on communities.

Data interpretation capabilities are generally developed through collaboration between state and local governments, the research sector, and industry, and are a crucial factor in the maturation of emerging data use cases.

Figure 6. The stages of data interpretation required to support data use cases

Data use case maturity

Data use cases can be considered according to their relative level of maturity. This document uses a four-stage maturity framework (Table 1) that is loosely aligned with the Australian Government's Technology Readiness Level framework[1].

Smart low-cost environmental sensing is still an emerging and experimental approach for engaging with city challenges. Cities that choose to experiment with these technologies are showing innovation leadership and will find themselves on the front foot as these use cases mature and start to deliver more large-scale systemic change.

Table 1. Maturity levels for data use cases

Maturity level		Description
1	**Concept development**	No clear examples of this data use case are yet evident.
2	**Research and pilots**	Early research and pilot projects are evident. Uncertainty and risk remain relatively high. There is heavy dependency on external funding, such as grants.
3	**Early scaling**	There are examples of multiple deployments (associated with a single data use case) that extend beyond an initial pilot project. Technologies and methodology are being actively developed and matured. Measurable benefits are emerging, and economies of scale are developing.
4	**Approaching maturity**	The solution has matured to a point where there is now widespread interest and investment by commercial and/or public sector stakeholders. Return on investment can be clearly articulated. The data use case is beginning to show evidence that it can result in systemic change.

Discussion of maturity levels for data use cases

Maturity level 1: Concept development

Level 1 data use cases are in early concept development. These are ideas that are being actively discussed in academic literature, and/or within the smart city industry. Often the reason they are not yet evident as pilots is that there are barriers to demonstrating them, even in very basic form. For example,

[1] Maturity level 1 corresponds with TRL1 (non-applied initial research); Maturity level 2 corresponds with TRL1-6 (engineering pilot scale demonstration); Maturity level 3 corresponds with TRL7-8; Maturity level 4 corresponds with TRL9.

where a proposed data use case requires widespread interoperability or data aggregation as a foundation, it may need to wait until these underlying capabilities mature in order to make it viable.

Maturity level 2: Research and pilots

Level 2 data use cases have one or more research projects or pilot demonstrations associated with them. The examples in this compendium of emerging data use cases have been included because they have seen initial success, and are likely to scale and mature in the coming years. They tend to be place-based and self-contained, and to have less reliance on a larger technology ecosystem to be viable (relative to level 1 data use cases).

Maturity level 3: Early scaling

Several smart low-cost air quality monitoring networks are evident at city scale around the world. Notable large-scale examples include the Breathe London network, and Chicago's Array of Things. Numerous city-led pilot platforms have also been continued beyond pilot project phases. All of the examples included in this compendium have seen multiple rounds of funding, and they continue to support research, collaboration, and a range of insights that benefit local governments and other associated stakeholders.

Note that many of the level 2 data use cases outlined in the compendium have been delivered within the context of these city-scale networks. However, none of these networks has so far developed a specific, well-defined data use case that has scaled *beyond* a pilot demonstration. As such, they are being maintained largely as ongoing testbeds for new research and pilot projects, rather than as platforms for a more scaled roll-out.

Maturity level 4: Approaching maturity

There are currently no use cases for low-cost sensing data that fit a level 4 maturity rating. It is reasonable to assume that emerging use cases that are currently in research and pilot phases may mature to reach level 4 in the near future. To achieve this, it seems likely that fundamental sectoral developments will be required, such as the development of new interoperability and methodological standards and best practice, and widespread recognition and acceptance of new technologies by key stakeholders.

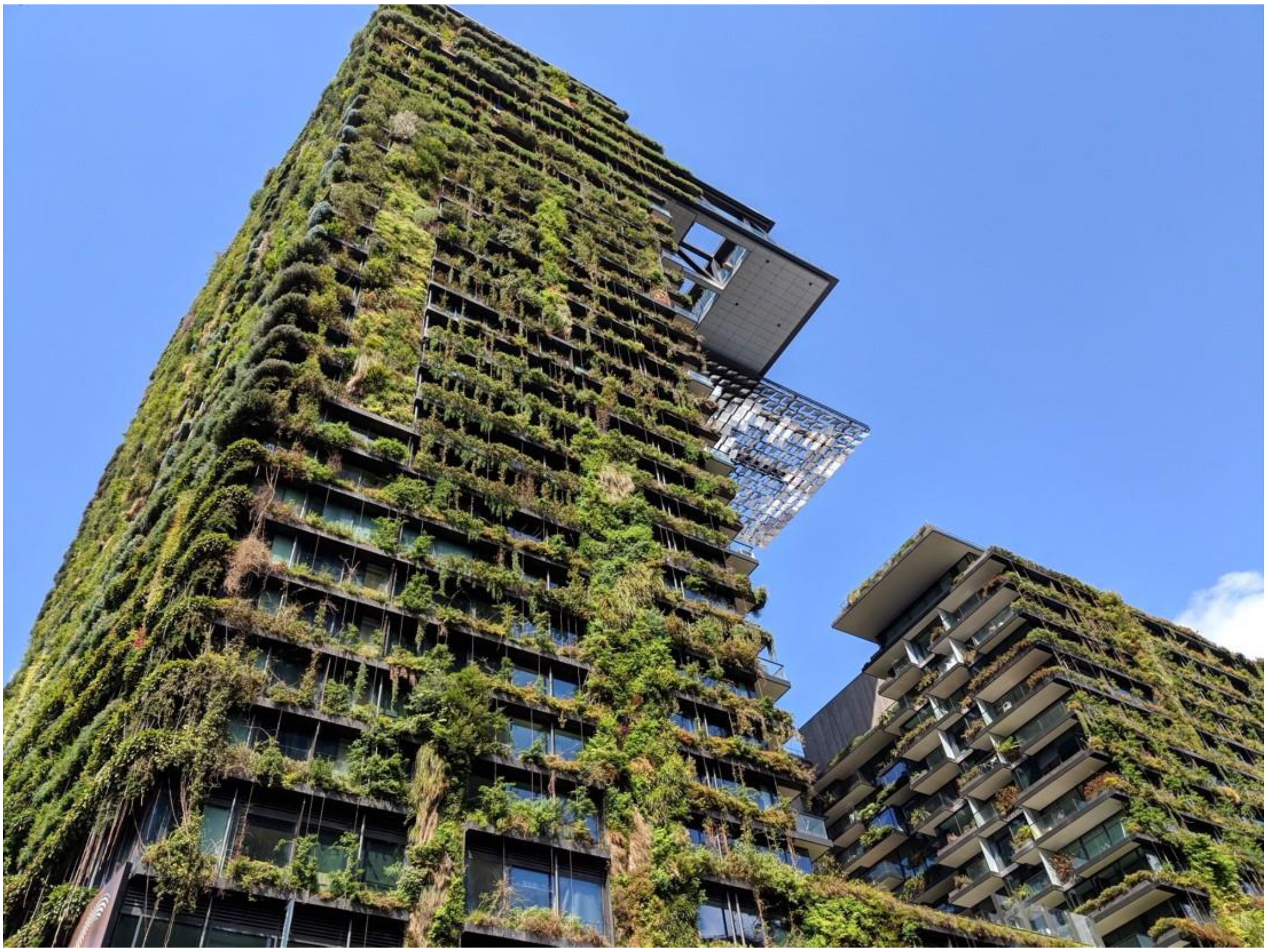
Emerging data use cases

Table 2 provides an overview of the data use cases described in this resource. All of the data use cases presented in the compendium are emerging, with the majority existing as pilot projects (maturity level 2), and some being early concepts with no clear examples (maturity level 1). However, many of these data use cases will likely develop towards increasing levels of maturity over the coming years.

Table 2. An overview of emerging data use cases for smart low-cost environmental sensing technologies

Data use case	Maturity level	Sectors
Evaluation of urban green infrastructure as a mitigator of air pollution and urban heat	2	Urban design; planning; climate resilience
Evaluation of urban transport and land use changes on local air quality	2	Transport; urban design; planning; climate resilience
Mitigation of dust surrounding construction sites, mines, and quarries	2	Construction; mining; rail
Reduction in the use of domestic wood heaters in locations with cold winters	2	Housing; energy
Smart water precincts: smart irrigation and water management	2	Water; urban design; climate resilience
Monitoring air quality and heat at schools and childcare centres	2	Education; planning
Investigation of the build-up of localised pollution in street canyons	2	Transport; urban design; planning
Passenger journey comfort, smart wayfinding, and transport optimisation	2	Transport; urban design; public services
Supporting environmental justice for vulnerable communities impacted by localised pollution	2	Justice and equality; public health
Smart building integration for thermal comfort and improved indoor air quality	1	Buildings; planning; energy
Improved alerts from local health authorities relating to poor air quality	1	Public health
Improved management of fuel reduction burning and response to associated smoke impacts	1	Land management; climate resilience

Evaluation of urban green infrastructure as a mitigator of air pollution and urban heat



Green walls like this one in Central Park, Sydney (NSW) can actively clean pollutants from the air.
Image source: Creative Commons

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ [2] and PM_{10}; Nitrogen Dioxide (NO_2); Ozone (O_3); meteorology (can be sourced from the Bureau of Meteorology)

Problem

Urban green infrastructure (UGI) describes parkland and remnant bushland, as well as a range of built environment features that incorporate plants (including lawns, green roofs and walls, and tree canopy cover). Local governments may seek to preserve or expand existing UGI, or establish it at new locations as part of urban development strategies.

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[2] PM (particulate matter) refers to airborne solids or liquids. Its size is measured in micrometres and is indicated by the subscript. E.g. $PM_{2.5}$ has a diameter of 2.5 micrometres or less. (NSW Health, 2020)

The positive impacts of UGI on air quality and urban heat are broadly understood. However, the capacity for impact varies according to multiple local factors, including the size of the space, aspect, topology, soil type, climate, weather, vegetation types, and active management practices. All of these factors can combine to create unique local contexts that provide varying degrees of urban cooling, or pollution mitigation. This means that relationships and processes that are true for one place, may not apply in another. For example, certain plant species may be more effective for filtering air than others, but their effectiveness may be contingent on soil and climate. Or a minimum park size for effective urban cooling may relate to air movement and whether or not it is irrigated. This all means that a local government seeking to develop appropriate, location-specific planning policy and design guidelines that optimise the benefits of UGI, needs to develop its own understanding of these relationships and processes in the locations that it manages.

Aims

To understand the particular local relationships between the built and natural environment, UGI design, and positive impacts of UGI (such as heat and air quality mitigation). To use these understandings to update planning policy and design guidelines. Insights may also influence decision-making at the scale of individual developments.

Methodology

There are many ways to measure the localised impacts of UGI on urban heat and air quality. In each case, a nearby location with no plants/trees would need to be studied for comparison purposes. Some examples of methodological approaches are to:

- monitor a street with significant tree canopy, and a nearby street with no tree canopy (ideally, choose locations with significant vehicle traffic, such as a major bus route)
- monitor air quality next to a green wall, and next to an adjacent wall with no green infrastructure
- monitor air quality and heat above a green roof, and above an adjacent roof with no greenery
- monitor the relative temperatures in dense remnant bushland, under parkland trees, above grass in full sun, and above concrete (all in close proximity)
- monitor the temperature and air quality associated with different trees (e.g. European tree species versus eucalyptus species).

Maturity level 2: Research and pilots

Case study example:

- Evaluation of the impact of a green roof on localised air quality at Barangaroo, Sydney

  Developer Lendlease and the University of Technology Sydney deployed two smart low-cost air quality sensing devices on a newly installed green wall to measure its ability to remove $PM_{2.5}$, O_3 and NO_2. The project report states that the study proves a return on investment, which builds a case for future use of green roofs by Lendlease (Irga et al., 2021).

Evaluation of urban transport and land use changes on local air quality

The Breathe London monitoring network has been used by London boroughs to understand the impact of the Ultra Low Emission Zone on local air quality.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; Nitrogen Dioxide (NO_2); Ozone (O_3); meteorology (may be sourced from the Bureau of Meteorology)

Problem

Motor vehicle emissions are among the largest sources of urban air pollution, and represent a significant and growing threat to human health and well-being. The design of transport infrastructure and land use can either create *or* mitigate localised air pollution hotspots.

The specific relationship between the design of the built environment and local 'microclimates' (a term used to describe highly localised environmental conditions) varies from place to place. Local governments often lack access to data that might inform planning and transport policy that optimises positive outcomes in a particular locality.

Aims

To understand the particular local relationships between urban transport, land use, urban heat, and air quality. To use these understandings to update planning and transport policy. Insights may also influence decision-making at the scale of individual developments (e.g. provision of active transport infrastructure; car exclusion zones).

Methodology

Local governments might start by identifying specific locations where urban redevelopment is planned. This could be a location that currently has cars but will become car-free or have reduced traffic (for instance, a public square scheduled for significant redevelopment). This type of monitoring may require data collection over an extended period.

Alternatively, two locations could be selected for monitoring that are similar except for a critical factor affecting air pollution levels (for example, two parallel north/south roads: one with heavy traffic; the other a pedestrian precinct with no cars). Sensing devices can be deployed at both locations to determine the relative impact of traffic on air quality.

Urban and peri-urban development sites managed by private developers also present a significant opportunity to explore large-scale land use change over time.

Maturity level 2: Research and pilots

Case study examples:

- WeCount's citizen science project for traffic and air pollution monitoring

  WeCount is an EU-funded project that brought together city governments (in Dublin, Cardiff, Barcelona, Madrid, Leuven, and Ljubljana) with local community members and university researchers. Citizens collected data using low-cost air quality sensing devices, and used this data to inform transport planning and to support data-driven decision-making for better air quality (SmartDublin, 2021).

- Breathe London/Borough of Kingston's School Street initiative

  The Borough of Kingston in London (UK) is using smart low-cost air quality sensing devices (part of the city-wide Breathe London network) to monitor air quality in the streets around schools. Data has directly informed evidence-based traffic interventions that have resulted in improved air quality during school drop-off and pickup times (Kingston Council, 2021).

Mitigation of dust surrounding construction sites, mines, and quarries

A low-cost particulate sensing device installed to monitor dust arising at the construction site, Parramatta, NSW. Image source: UTS

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; noise; soil moisture; meteorology (may be sourced from the Bureau of Meteorology).

Problem

Construction site dust is most notably a concern with brownfield developments that are likely to be surrounded by residential communities. Large sites may have prolonged development periods (often lasting several years) which make dust impacts on communities a concern. Other significant sources of dust are mines, quarries, and major road or rail corridor developments (all of which involve heavy vehicle activity, earth moving, and rock blasting).

A range of activities (including demolition, earth moving, heavy vehicle movements on unsealed site roads, and concrete cutting) can be responsible for emitting dust into the air. The creation of dust, the degree to which it becomes airborne, and its dispersal to adjacent areas depends on a combination of on-site activities, mitigation measures, and weather conditions.

Aims

To understand the impact of site dust on the surrounding area, as well as the conditions and activities associated with dust creation and dispersal. To investigate the effectiveness of dust mitigation measures and update operational approaches accordingly. To support engagement by the site owner and local government authority with community members regarding dust concerns. To inform future local government planning and environmental management policy.

Methodology

Particulate matter sensing devices can be used to monitor airborne dust around the perimeter of a site, and can determine pollution hotspots, dispersal patterns, and temporal trends. Noise data can be used as an indicator of on-site activity and may be correlated with air quality measurements. Meteorology and soil moisture data can enable modelling of relationships between environmental conditions that lead to dust creation and dispersal (with reference to recorded dust concentrations).

Maturity level 2: Research and pilots

Case study example:

- Climate Responsive Neighbourhoods project, Melrose Park, Parramatta (NSW)

  The Melrose Park Climate Responsive Neighbourhoods project was delivered by the City of Parramatta, the University of Technology Sydney, and a private developer. A network of smart low-cost air quality and noise sensing devices was distributed across a 30-hectare brownfield development site, and throughout surrounding residential areas. The project explored how the data could support the developer and local government to improve dust mitigation strategies, and to better understand and respond to community concerns (UTS-ISF, 2020).

Reduction in the use of domestic wood heaters in locations with cold winters

An example of wood smoke settling near the ground in a residential area of Katoomba, NSW. Image source: UTS

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; meteorology (may be sourced from the Bureau of Meteorology)

Problem

Many regional towns and peri-urban communities in Australia experience cold winter months, and residential buildings are often heated using wood-burning stoves and fires. The topology of some locations can create a localised phenomenon where smoke from wood heaters settles and does not readily disperse. There is clear scientific evidence that this smoke has a measurable negative impact on human health.

Aim

To generate localised, real-time air quality data to help local governments understand where wood smoke is being created, how it is dispersing, where it is gathering or lingering, and under what conditions this phenomenon occurs. Insights can inform strategies for community engagement that emphasise behaviour change, or incentivise residents to upgrade domestic heating infrastructure.

Methodology

Particulate matter sensing devices can be located in areas where smoke is known to collect, such as at the bottom of valleys. Data from these devices can be used to confirm the presence of hotspots, and compared with data from devices in nearby areas that do not experience woodsmoke issues (e.g. along ridge lines). Larger networks of devices can support a more detailed understanding of wood smoke at a granular spatial scale. When paired with demographic data, this information may help local governments to target specific groups in specific locations as part of any campaign to transition homes to other heating options.

Maturity level 2: Research and pilots

Case study example:

- Woodsmoke monitoring in Armidale, NSW

  A community initiative using smart low-cost particulate pollution sensing devices is exploring the hotspots and dispersion patterns of woodsmoke in Armidale, NSW. This project is led by Dorothy Robinson, a local researcher from the University of New England (Robinson, 2020) (Sustainable Living Armidale, n.d.).

Smart water precincts: smart irrigation and water management

The SIMPaCT project has piloted the use of smart irrigation at Sydney Olympic Park, making use of real-time data from a network of low-cost urban heat and soil moisture sensing devices. Image source: Western Sydney University

Low-cost sensing data requirement

Temperature and humidity; soil moisture; water meters; meteorology (may be sourced from the Bureau of Meteorology)

Problem

Urban green spaces are a vital public amenity, and also have the potential to cool cities. Where green space is contingent upon regular irrigation, however, water supply can sometimes become challenging (particularly during periods of drought or water restrictions).

Aims

To support urban heat mitigation and maintain essential public amenities through healthy green infrastructure, while ensuring maximum water efficiency and climate resilience.

Methodology

Urban heat and soil moisture data from low-cost sensing devices, used alongside water flow and meteorological data, can drive predictive models for soil moisture and generate optimal irrigation schedules.

Maturity level 2: Research and pilots

Case study example:

- Smart Irrigation Management for Parks and Cool Towns (SIMPaCT)

  The SIMPaCT project was delivered in a 40-hectare parkland at Sydney Olympic Park (NSW). The solution uses networks of smart low-cost soil moisture and ambient temperature/humidity sensing devices to provide data to an AI model, which in turn predicts soil moisture and optimises irrigation scheduling (SIMPaCT, n.d.).

Monitoring air quality and heat at schools and childcare centres

Image source: CleanAir Schools (NSW)

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; meteorology (may be sourced from the Bureau of Meteorology)

Problem

Children are particularly vulnerable to the health impacts of poor air quality and extreme heat. Numerous studies have linked poor indoor and outdoor air quality in schools to reduced academic performance. Indoor air quality is affected by outdoor air quality when pollution levels are high, and especially in classrooms with natural ventilation (or in old buildings with high air infiltration). Extreme heat is an increasingly common concern that directly impacts the health and well-being of children during school hours, and is expected to increase in frequency and severity with worsening climate change. The health impacts of poor air quality also increase during extreme heat.

Aims

To understand heat and air quality inside classrooms and on school grounds, so that schools and educational authorities can take actions to reduce health impacts on children. These actions might include changes to the design of new buildings (e.g. good insulation and low infiltration); retrofits to existing buildings (e.g. upgraded heating, ventilation and air conditioning (HVAC) equipment); changes to the design of outdoor areas (e.g. more tree cover and light-coloured surfaces); changes to the timing and location of school activities; and updated policy (e.g. response to bushfire smoke events).

To use low-cost sensing projects as tools of education by making the data they collect accessible and understandable to teachers and students, and by integrating projects into the school curriculum (thus supporting a number of key STEM deliverables).

Methodology

Low-cost environmental sensing devices enable schools and childcare centres to monitor air quality and heat inside classrooms, and in outdoor play areas. Suitable sensing devices may help to develop a reliable understanding of how environmental conditions change over time, relative to weather. They can also be used to identify outdoor microclimates (i.e. hot and cool spots on campus), or classrooms with notably poor ventilation or heat issues.

To support STEM educational outcomes, educators can choose from a growing variety of ultra-low-cost DIY sensing kits, allowing students to produce and analyse their own data.

The best way for a school to engage with this technology would be as a participant in a larger initiative managed (and/or funded) by a local government or university. This would enable the supporting infrastructure (e.g. data platforms) to be shared by multiple users, and creates an opportunity to connect multiple schools, amplifying grassroots engagement and educational outcomes.

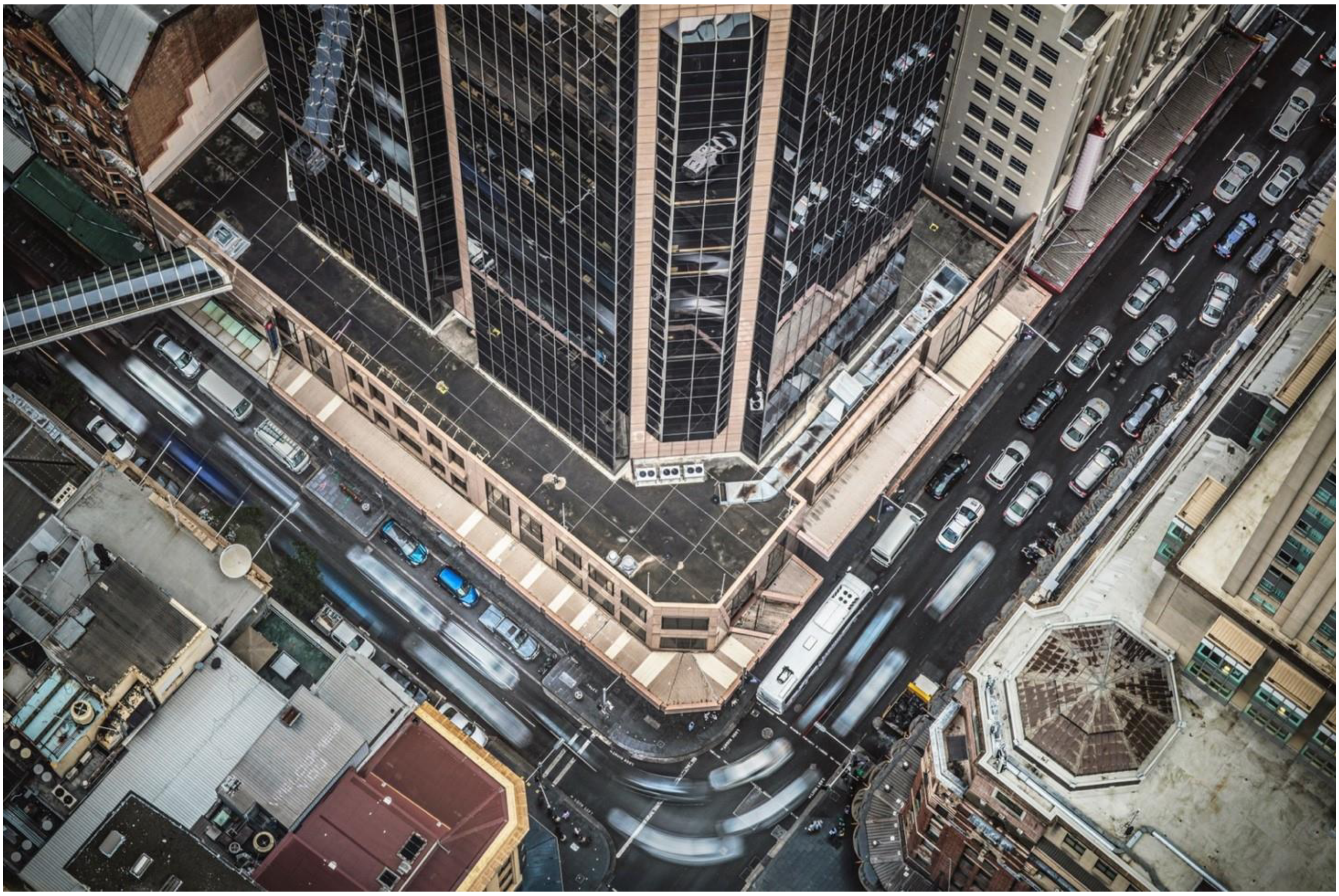
Maturity level 2: Research and pilots

Case study example:

- CleanAir Schools (NSW)

  CleanAir Schools is an initiative led by the University of NSW, with funding from the NSW Department of Education, that has installed over 100 low-cost air quality monitoring devices in schools across NSW. The initiative includes a STEM educational component that engages students with the technology and the data it produces, as well as with air quality as an issue that impacts their health and well-being (CleanAir Schools, n.d.).

Investigation of the build-up of localised pollution in street canyons



A street canyon in Sydney, NSW.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; meteorology (may be sourced from the Bureau of Meteorology)

Problem

Air circulation on inner-city streets between high-rise buildings can be poor, resulting in air pollution from localised sources (such as vehicles and buildings) becoming trapped. This can be a problem for the health and well-being of pedestrians and people living and working in the inner city. Diesel buses on busy routes are a common concern. Large commercial buildings can also be pollution sources, especially at times when they use emergency diesel power generators.

The impact of street canyons on air quality microclimates is not well-understood, and each specific location will have unique local attributes relating to the built form, topology, and aspect. Certain streets may have higher numbers of pedestrians than others, making exposure concerns greater. Certain streets may also experience higher levels of pollution (e.g. those along a major bus route), making the impacts of canyoning on local air quality more severe.

Aims

To conduct location-specific studies of street canyon impacts on air quality in order to understand risk, and to inform future planning and development policy. Once baseline conditions are established, local governments can consider mitigation approaches. Cars and buses might be removed from a street canyon altogether, in favour of a pedestrian precinct, cycleways, or light rail. The collected data might also build a case for electric buses. Other mitigation measures may include green walls or street trees.

Methodology

Start by identifying specific street canyons of interest. These might have high vehicle traffic, high pedestrian traffic, or be scheduled for some form of major redevelopment. A study might deploy air quality sensing devices to compare existing conditions in a street canyon with a nearby street that does not have canyon characteristics. It might also establish a baseline of air quality data prior to redevelopment, to track any subsequent changes to local air quality. These types of studies will generally rely on the accumulation of longitudinal data (rather than on live air quality data).

Maturity level 2: Research and pilots

Case study example:

- Several academic studies have explored the use of low-cost air quality sensing technologies for measuring and understanding air quality in urban street canyons (Galatioto et al., 2014; Huang et al., 2021; Zimmerman et al., 2020). However, there is no clear evidence so far of these findings directly informing city policy.

Passenger journey comfort, smart wayfinding, and transport optimisation

Around 20,000 people pass through Sydney's Central Station (NSW) each day, and during periods of extreme heat or poor air quality, real-time environmental data could be used to improve passenger experience and well-being.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; Nitrogen Dioxide (NO_2); Ozone (O_3); meteorology (may be sourced from the Bureau of Meteorology)

Problem

People using public transport – and especially passengers passing through large transport hubs – are negatively impacted by extreme heat and poor air quality. People who use active transport (walking or cycling) are also impacted by these environmental conditions, resulting in potential health concerns.

Aims

To provide public and active transport users with accurate, real-time information about highly localised heat and air quality conditions, so that they can plan journeys to minimise discomfort or health impacts. To encourage transport authorities to use this same data to help manage and influence passenger movements, and to reduce the risk of medical incidents within transport hubs, thus avoiding overcrowding and delays to services.

Methodology

Smart low-cost environmental sensing devices deployed within transport precincts can be used to create an accurate, real-time understanding of conditions affecting passengers. Larger, city-scale monitoring networks can provide street-level maps of air quality at a scale that matters to people. Locations in areas with high foot traffic, or along major commuter routes (e.g. cycle paths) can be prioritised for sensing device deployment.

Maturity level 2: Research and pilots

Case study example:

- City of Melbourne's Cool Routes project (VIC)

  An online, interactive route-planning map that helps citizens find the coolest routes through the city on hot summer days. The Cool Routes tool makes use of real-time data from the City of Melbourne's network of smart low-cost urban heat sensing devices (City of Melbourne, n.d.).

Supporting environmental justice for vulnerable communities impacted by localised pollution sources

The Vallejo Citizen Air Monitoring Network in the San Francisco Bay Area (U.S.) uses a network of smart low-cost air quality sensing devices to capture data to support local environmental justice campaigns. Image source: Creative Commons

Low-cost sensing data requirement

Temperature and humidity; all air pollutants (depending on source/issue of focus); meteorology (may be sourced from the Bureau of Meteorology)

Problem

Poor air quality and urban heat do not impact everyone equally. People from marginalised and lower socio-economic groups are more likely to live and work in locations with air pollution and high urban heat. They are also more likely to suffer adverse impacts to their health and well-being. At the same time, these people tend to have the least political power to protest and create change that benefits their communities. The recognition of these inequalities (and attempts to redress them) is referred to as 'environmental justice'.

Aims

To support advocacy and environmental justice campaigns to empower communities, and leverage outcomes that improve people's health and well-being.

Methodology

Smart low-cost sensing technology is affordable and accessible to communities who are engaged with environmental justice campaigns. The ability to collect and publish new data about environmental conditions that impact communities can be a powerful tool for raising awareness and building support for a campaign. It can also add weight to advocacy arguments that can help to leverage political outcomes.

The use of low-cost sensing devices by citizens, as a form of citizen science, is critical to this approach. By taking ownership of the technology and the data it produces, community members can be empowered to become more effective leaders and advocates.

Maturity level 2: Research and pilots

Case study examples:

- Science for Change Kosovo (SfCK), and the Kosovo Making Sense movement

  Science for Change Kosovo is a youth-led grassroots movement (active since 2014) that monitors air pollution and mobilises community action for environmental justice. The movement is based on deeply participatory principles and has used ultra-low-cost air quality sensing devices to gather air quality data that has supported successful community advocacy. Their most notable success has been a legislative change that requires state authorities to publicly release more current data from regulatory air quality monitoring stations (Making Sense, n.d.).

- The Vallejo Citizen Air Monitoring Network

  The Vallejo Citizen Air Monitoring Network is an initiative in the San Francisco Bay Area in the U.S. that connects residents, community groups, and experts to build knowledge and understanding of air quality from a community perspective. It empowers community members to fight for cleaner air and positive local solutions (Vallejo Citizen Air Monitoring Network, n.d.).

Smart building integration for thermal comfort and improved indoor air quality

Building ventilation can be optimised to prevent outdoor air pollution from entering indoor spaces.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}

Problem

Indoor and outdoor air quality are causally connected, and data about both can inform new understandings of how buildings inhale, retain, and exhale particulate pollution through the study of the indoor/outdoor (I/O) air quality ratio. During extreme air pollution events (such as the catastrophic bushfires in the Australian summer of 2019/2020), particulate pollution is drawn into buildings via HVAC systems, and through doors, windows, vents, and cracks in the building envelope. This can result in poor indoor air quality, with pollution that significantly exceeds recommended healthy levels.

Buildings also respond differently to outdoor temperature extremes. Thermal mass, insulation, colour/reflectivity, shading, ventilation systems, green infrastructure, ingress points, and internal heat sources can all change the heat profile of a building (particularly the rate at which internal spaces heat up, retain heat, or cool down relative to outdoor temperatures). This, in turn, impacts the thermal comfort of building occupants, as well as the energy demand of the building.

Urban microclimates can result in outdoor temperatures varying by as much as ten degrees over relatively short distances. The combination of the design of a building, and the surrounding microclimate, creates the specific thermal comfort (or discomfort) experienced by occupants of a building. The effective control of *indoor* thermal comfort is thus dependent on responding to the microclimate conditions *outside* a building. However, most buildings have no source of data on these external microclimate conditions.

Aims

To use smart low-cost sensing devices to measure and understand the indoor/outdoor ratio of particulate pollution, temperature, and humidity. This may improve the management of buildings for improved health and thermal comfort outcomes, and generate better public health advice. Other key outcomes could include:

- Optimising HVAC systems to suit a building's local context, by:
    - making operational changes to system settings and cycles
    - reviewing/applying appropriate filtration
    - anticipating and planning filter changes based on local trends
- Updating operational policy related to extreme heat and pollution events, such as bushfire smoke inundation (e.g. all windows to be closed during a particulate threshold exceedance event)
- Integrating live data with a building management system to trigger an automated response that optimises internal cooling and/or mitigates indoor pollution
- Improving health advice and communications to building occupants
- Improving institutional policy related to heat, air quality, health, and climate change resilience (e.g. local health district policies)
- Suggesting changes to building standards and regulation as a result of research
- Improving energy demand management.

Maturity level 1: Concept development

There are no existing case studies for this data use case.

Indoor air quality is a current major concern, with commercially mature data use cases. However, the focus so far has been on indoor pollution sources (such as volatile organic compounds off-gassed from building materials, and CO_2 build-up from high room occupancy and poor ventilation). What is generally missing is the connection with *outdoor* air quality. This may be because buildings are generally managed as if they are self-contained, rather than as elements set within a wider surrounding environment.

The integration of outdoor air quality and temperature data with building management systems (BMS), relies on the maturation of emerging low-cost outdoor sensing technologies, and the interoperability of both technologies. The BMS sector is notorious for poor interoperability, with many proprietary systems that do not integrate well with other technologies. As the availability and quality of hyperlocal, real-time outdoor environmental data increases, we may start to see a shift in the BMS sector, with better integration of this new type of data.

Improved alerts from local health authorities relating to poor air quality

Smoke over Canberra (ACT) during the 2019/2020 Black Summer bushfires.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; Nitrogen Dioxide (NO_2); Ozone (O_3)

Problem

State government-managed regulatory monitoring services provide air quality data with relatively poor spatial and temporal resolution. This can restrict the ability of local health authorities to provide accurate, up-to-date information to the public. For example, smoke from bushfires can have different impacts on areas in close proximity: one part of a town might have heavy smoke exposure, while a nearby area might have relatively little. Smoke in any given location can also arrive or dissipate over periods of several minutes, as narrow plumes shift with prevailing wind. Regulatory air quality monitoring will report a single air quality value for an entire suburb or town, with hourly updates. This misses localised variation and sub-hourly fluctuations. Similar localised and short-period variations in air pollution can occur with transport emissions, industrial emissions, and wood smoke.

If official air quality alerts do not correspond with what people are directly experiencing or observing, there can be an erosion of public trust in health authorities. There are accounts of health authorities in NSW using unstandardised, ad hoc methods of data correction to try to compensate for the limitations of regulatory air monitoring data (Kolbe & Gilchrist, 2009).

Aim

To make real-time, localised air quality data more widely available and accessible, enabling local health authorities to issue more accurate public health alerts relating to air quality. This may support improved public health outcomes, as well as improved public trust in public health alerts.

Methodology

Local governments can use low-cost air quality sensing networks to collect real-time data with finer spatial and temporal resolutions than the data available from state government-managed regulatory sources. Sensing devices can be strategically located near to known pollution sources, or in communities most likely to be impacted by poor air quality. This data can then be shared with local health authorities.

Ideally, state regulatory authorities will adopt an intermediary role as data stewards, facilitating data sharing, and using low-cost sensing data to supplement data from regulatory monitoring stations. This would mean that local sensing data can be corrected and verified, improving the confidence of health authorities that it is reliable and safe to use.

Maturity level 1: Concept development

There are no existing case studies for this data use case.

This data use case is likely dependent on widespread sharing of air quality data between local governments and state authorities responsible for regulatory air quality monitoring. The OPENAIR project included a demonstration of this, with a pilot data sharing platform managed by the NSW Department of Planning and Environment, which ingests and harmonises data shared by several local governments contributors (NSSN, n.d.). As initiatives like this develop, more locally collected data will be shared, harmonised, corrected, and quality-controlled, leading to improved trust in its accuracy. This will likely be the turning point in terms of data from smart low-cost sensing devices being widely used by local health authorities.

Improved management of fuel reduction burning and response to associated smoke impacts

Controlled burning can produce levels of smoke that are hazardous to nearby communities, but new data can support improved understandings of how smoke behaves under various conditions.

Low-cost sensing data requirement

Temperature and humidity; $PM_{2.5}$ and PM_{10}; meteorology (may be sourced from the Bureau of Meteorology)

Problem

Fuel reduction burning is a landscape management practice that reduces the amount of fuel present in the understory of bushland. This reduces the risk and severity of future uncontrolled bushfires. The most strategic locations for conducting fuel reduction burning are in bushland adjacent to populated areas. The safest time to do such burns is in periods of low wind, cool temperatures, and stable atmospheric conditions, but this combination of factors is known to create strong localised smoke impacts. The result is that smoke from controlled burns often settles in populated areas, causing ambient air quality statutes to be exceeded. These smoke impacts may be equally as severe as those caused by unplanned bushfires.

Methodology

Smart low-cost air quality sensing devices can be deployed and managed by local authorities in areas where smoke from fuel reduction burning is a known issue for communities. These networks can provide real-time data that is often not available from more sparsely distributed regulatory air quality monitoring stations. If this more localised data is shared with state government authorities, it can supplement data from the regulatory monitoring network, and may potentially be used to improve modelling of smoke dispersal. Improved models can inform real-time community messaging and decision-making during burn operations. They may also support changes to operational strategies that result in reduced smoke impacts.

Maturity level 1: Concept development

There are no existing case studies for this data use case.

This data use case likely depends on widespread sharing of local government air quality data with state authorities, and vice versa. It may also require any locally generated data to be used (and communicated) by health authorities. This could contribute to improved public understanding of how fuel reduction burning impacts peri-urban communities, and apply social pressure to land managers to improve their management approaches.

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Associated OPENAIR resources

Best Practice Guide chapters

Emerging data use cases

This Best Practice Guide chapter introduces a range of emerging applications for smart low-cost air quality sensing technologies. The focus is on the data produced, and how it can be used to create impact.

Air quality as a local issue

This Best Practice Guide chapter provides a detailed introduction to air quality as a local issue. It explores sources and types of air pollution, impacts of air pollution, and why local action is needed.

Smart air quality monitoring

This Best Practice Guide chapter provides a more detailed, non-technical introduction to smart air quality monitoring.

IoT reference architecture for smart air quality monitoring

This Best Practice Guide chapter introduces the OPENAIR reference architecture for smart air quality monitoring. The reference architecture is a framework that identifies the various components and data flows that make up a complete technical solution for smart air quality monitoring. It is a generic reference that can help local governments to design and implement their own technical solutions.

Sensing device deployment planning: high-level design

This Best Practice Guide chapter explores the high-level design of a smart air quality monitoring network. It provides general guidance for selecting where to deploy devices, what to mount them on, how to mount them, and how to support their operation. These critical considerations will vary between data use cases.

Sensing device deployment planning: detailed design

This Best Practice Guide chapter explores the detailed design of a smart air quality monitoring network. It builds upon high-level design activities, and provides guidance for planning and documenting the details of specific device deployments.

Data interpretation: overview

This Best Practice Guide chapter provides guidance on interpreting data produced by smart low-cost air quality sensing devices. It outlines the three main stages of the process (data correction and harmonisation; data quality control; and data analysis), explores the relationship between data interpretation and impact creation, and supports the planning of a data interpretation strategy.

Activities for impact

This Best Practice Guide chapter introduces a range of activities that can be undertaken by a local government to create impact relating to an air quality issue. Activities are categorised into four impact areas: transport; built environment; green infrastructure; and community engagement.

Further information

For more information about this project, please contact:

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This Supplementary Resource 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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