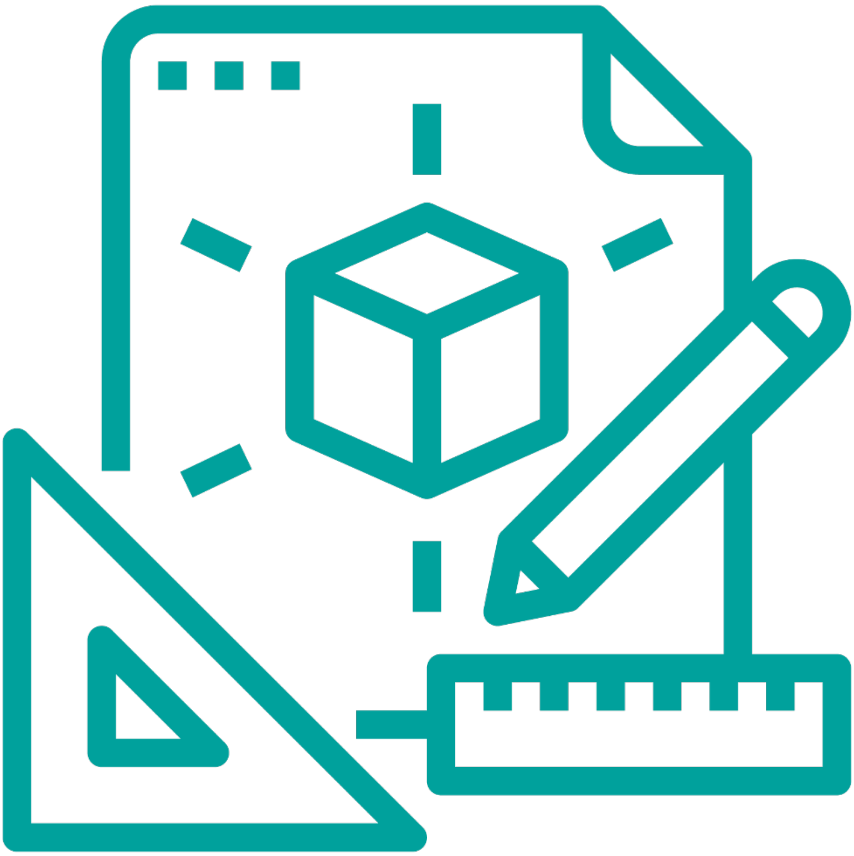
OPENAIR

Operational Network of
Air quality Impact Resources

Best Practice Guide

BP201 | Develop

Sensing device procurement



Introduction

When it comes to choosing smart low-cost air quality sensing devices, a wide variety of options are available. The different characteristics of devices on the market can be overwhelming, and make the selection process difficult to navigate. The cost can also range from hundreds of dollars to several thousand dollars per unit. You need to select devices that meet the data collection needs of your project, while also ensuring they can be fully supported during set-up and ongoing operations. You should aim to find an optimal balance between cost, performance, functionality, and the practical or resource constraints of your project.

This OPENAIR Best Practice Guide chapter presents some general guidance on the selection and procurement of smart low-cost air quality sensing devices. It will help you to define what it is that your project is doing and why, to outline the workflow involved, and to focus on key factors for consideration in the selection process.

Who is this resource for?

This chapter is primarily intended as a tool for local government staff tasked with the design and delivery of a smart air quality monitoring project. It may also be of interest to local government staff in roles that support this kind of project, including:

- environmental officers
- planners
- infrastructure/asset/facilities managers (e.g. those in charge of street poles and signage, parks, or sports facilities)
- information, communications and technology professionals.

How to use this resource

This Best Practice Guide chapter provides a high-level introduction to what to consider when you are selecting and procuring smart low-cost air quality sensing devices and supporting services and platforms.

Once you are ready to undertake your own selection and procurement process, we recommend that you refer to the more detailed, practical guides provided as OPENAIR supplementary resources: *Technical requirements template*, and *A guide to developing technical requirements*.

What are smart low-cost sensing devices?

SMART

A smart device is one that can form a connection with the internet. This connection enables the device to share data that it collects in near-real-time[1]. Smart devices can provide a continuous stream of data about real-world phenomena, and this data can be used to support real-time operations and decision-making. Data can also be sent *to* a smart device, for example to reconfigure its settings wirelessly. This can be critical for large networks, where manual updates of each unit would be prohibitively time-consuming.

LOW-COST

Low-cost smart air quality sensing devices can range in price from a couple of hundred dollars to several thousand dollars. Even the most expensive of these are still classed as 'low-cost' relative to regulatory equipment, which costs tens or even hundreds of thousands of dollars. The device with the right cost and performance for your project will depend upon your data use case.

The lowest-cost air quality sensing devices tend to produce poorer quality data, and are most appropriate for supporting education and engagement. With increasing cost, higher performance low-cost devices can be used for pollution hotspot identification, and – in some cases – can supplement regulatory air quality monitoring of the kind done by state authorities.

SENSOR

A sensor is a specialist component, designed to capture empirical data about a directly observed phenomenon. Sensors are embedded components that are generally sold to device manufacturers (rather than to end users). A sensor cannot function separately to a supporting device.

DEVICE

A complete device is sold as a commercial product to end users. A sensing device will typically consist of the following components: housing; a micro-controller; a sensor board; one or more sensors; a power supply/battery; a communications module; and local data storage.

[1] 'Near-real-time' is a term often used in connection with smart devices. It refers to the fact that many devices do not form a continuous live connection with the internet. Instead, they make periodic data uploads (e.g. once every 15 minutes) that represent the measurement in question over the previous reporting interval. This means that the data they share is 'near' to real time, but not actually 'live' in the truest sense of the word.

The benefits of using smart sensing devices

Smart sensing technologies provide you with near-real-time data that can be automatically integrated with digital platforms and services. This creates multiple benefits, allowing you to take the following actions:

- Provide real-time air quality updates to your community, and to critical service providers (both within and outside your organisation).
- Respond to air quality events as they happen.
- Efficiently fine-tune your sensing network. Live data can give immediate insights into the appropriateness of device deployment, allowing you to consider changes to how or where devices are deployed, and supporting the rapid implementation of iterative improvements.
- Develop integrated, responsive, and increasingly sophisticated smart city outcomes by automatically combining sensor data with other live data sources (e.g. air quality data + traffic data + pedestrian counts ➔ real-time traffic management to reduce air pollution).
- Establish rolling, near-term 'nowcasting' and forecasting that can predict air quality conditions in the coming hours and days.
- Identify and respond to faulty devices as issues occur, rather than finding out months later.
- Update device settings 'over the air' for optimisation and troubleshooting, saving significant operational costs associated with manual access (particularly relevant to larger networks).

DO YOU ACTUALLY NEED SMART SENSORS?

Before choosing to invest in smart air quality sensing devices, it is worth considering if the benefits that they deliver are essential to the aims of your project. Smart sensors need a range of supporting services and infrastructure to function, which requires funds to establish and operate, time to set up, and specialised skills and expertise. Simpler technologies (such as data loggers and gas diffusion tubes) do not allow for real-time insights or sophisticated smart city integrations, but if you just need a low-cost, one-off snapshot of air quality in a few key locations – with no complications or extras – then you should consider these low-tech options.

A gas diffusion tube used by the City of London. Image source: Creative Commons

The selection and procurement process

It is advisable to allow at least six months for the process of selecting and procuring smart sensing devices (as it can be complex and prolonged). Table 1 provides an overview of this process.

Table 1. The device selection and procurement process

Step	Description
1. Establish a business case and clear data requirements	Establish a business case and data use case. Identify data that you aim to collect, the data-driven activities that you aim to deliver, and the outcomes and impacts that you aim to achieve, providing a foundation for assessing appropriate sensing devices.
2. Develop technical requirements and plan the design of your sensing network	**Develop a list of technical requirements** for the performance, functionality, and design of devices, platforms, and **services.** Develop a high-level design plan for deploying sensing devices, balancing the needs of a data use case against practical constraints**.**
3. Select device types, communications, power, and an IoT platform	Select one or more types of device that you will procure, based on your technical requirements and high-level deployment plan. Confirm a general plan for communications and power. Select an IoT (Internet of Things) platform to host devices.
4. Select and procure communications hardware/services	Develop a detailed plan for data communications. If you require private gateways, determine how many you need, create detailed deployment plans, and secure approvals. Procure all hardware/services required.
5. Activate data communications	Deploy and activate all communications hardware/services required. This enables you to test communications coverage at all deployment locations.
6. Plan and approve details of all deployments	Plan and approve each specific device deployment. Test communications at each location. Specify power and mounting requirements.
7. Place an order	Place an order for all specific device components. Be clear about what support services you require for device onboarding and operations.
8. Shipping (8-10 weeks)	Expect to wait at least 8-10 weeks between placement of an order and receipt of goods. Overseas shipping may take even longer.
9. Device onboarding (1-2 weeks)	The onboarding of devices to your communications server and IoT platform is often handled by the device vendor, adding at least 1-2 weeks of lead time.
10. Receive devices	Receive devices, ready for activation and deployment.

Factors to consider when selecting sensing devices

In selecting a smart low-cost sensing device for your air quality monitoring project, it may help to consider several key factors. By carefully evaluating each factor (relative to your business case, data requirements, and practical constraints), you can identify a list of technical requirements related to the performance, functionality, and design of your ideal air quality sensing device. Use the OPENAIR supplementary resource *Technical requirements template* to develop this list. For more detailed guidance on this process, please refer to the OPENAIR supplementary resource *A guide to developing technical requirements*. Please click on the hyperlink for each factor listed below to go directly to the relevant information.

1. Environmental parameters measured
2. Sensor performance and technical requirements
3. Communications technology
4. Proprietary technology vs open technology
5. Environmental factors and robustness
6. Lifetime requirement
7. Power supply technology
8. Size, form, and aesthetic
9. Modularity
10. Platforms and support services

1. Environmental parameters measured

A weather station at Sydney Olympic Park provides a range of secondary meteorological data to support the interpretation of urban heat data from a network of 50 low-cost temperature and humidity sensors. Image source: UTS

An effective air quality monitoring project should aim to focus on just two or three pollutants associated with one or two pollution sources. This will help you to determine which environmental parameters to measure. There are two categories of parameters:

1. ***Primary parameters.*** The primary focus of your investigation. These may be the parameters that are most strongly associated with negative impacts, or they may be parameters that are the most reliable proxy indicators for some other pollutant or phenomenon that is harder to measure.
2. **Secondary parameters.** These support the accurate interpretation of primary parameters (e.g. temperature and humidity), or otherwise help in understanding the nature of the air quality issue you are investigating (e.g. additional gases that have chemical relationships with primary gases).

You should select a device that measures all your primary parameters, and ideally all your secondary parameters (where possible). In some cases, you may need to select multiple types of device to cover all the necessary parameters.

Table 2 provides an overview of common air quality issues that can be addressed using smart low-cost air quality sensing devices. A series of primary and secondary environmental parameters are suggested for each issue. Note that locally accurate meteorological data (particularly wind and rain) are universal secondary parameters for all air quality and urban heat monitoring use cases.

Table 2. Common air quality issues and associated environmental parameters

Air quality issue	Primary parameters	Secondary parameters
Urban heat	Temperature, Relative Humidity (RH)	O_3, NO_2
Road traffic emissions	$PM_{2.5}$[2], NO_2	Temperature, Relative Humidity (RH), PM_{10}, O_3, CO, CO_2
Diesel emissions associated with non-traffic sources	$PM_{2.5}$, PM_{10}	Temperature, Relative Humidity (RH), NO_2, SO_2
Aviation emissions near airports	$PM_{2.5}$, NO_2	Temperature, Relative Humidity (RH), O_3, PM_{10}, CH_4, CO
Wood smoke from fuel burning	$PM_{2.5}$, PM_{10}, NO_2	Temperature, Relative Humidity (RH), CO, CO_2
Smoke from bushfires or controlled landscape burning	$PM_{2.5}$, PM_{10}, NO_2	Temperature, Relative Humidity (RH), CO, CO_2
Dust from construction, mining, and quarries	$PM_{2.5}$	Relative Humidity (RH), PM_{10}, PM_1
Coal dust from trains and mines	$PM_{2.5}$	Relative Humidity (RH), PM_{10}, PM_1
Industrial air pollution sources	$PM_{2.5}$, NO_2	Temperature, Relative Humidity (RH), PM_{10}, SO_2, VOC
Natural air pollution sources	PM_{10}, O_3, VOC	Temperature, Relative Humidity (RH), $PM_{2.5}$

TIP: For more detailed discussion of each air quality issue listed in Table 3, please refer to the OPENAIR supplementary resource *A guide to developing technical requirements*.

[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 VARYING DIFFICULTY OF MEASURING DIFFERENT PARAMETERS

The difficulty of obtaining useable and reliable data using low-cost sensing devices varies depending on which environmental parameters you want to measure.

More difficult types of monitoring should be approached with the understanding that there is often considerably more time, effort, and resourcing required to achieve meaningful and reliable outcomes.

Difficulty	Parameters	Reason
Easy	Temperature, Humidity, Meteorology	Temperature and humidity sensors are highly reliable and not prone to variation, drift, or interference. Meteorological sensors are also reliable, provided you follow methodological guidelines for their deployment.
Moderate	Particulate Matter (PM)	Low-cost PM sensors generally employ a light-scattering technique to estimate the concentration of suspended particles in a body of air. While variation between sensors is low, and they tend not to drift in their accuracy, humidity interference *is* a concern and must be corrected for. Particles that are not the focus of your study can also influence what you measure (e.g. salt aerosols and pollen), and confuse the interpretation of data relative to your focus issue.
Hard	Gases	Gas sensors are highly susceptible to temperature interference. They can vary considerably between devices, making calibration more complex. They degrade over time, causing their calibration to drift. Atmospheric chemistry between multiple gases (e.g. NOX, O3, and VOCs) can be very complex, making it difficult to interpret data relative to your focus issue.

FIT FOR PURPOSE DEVICES

The performance of low-cost sensing devices is highly variable. The best approach is to choose the device that most closely fits the purpose of your project. For example, a very basic device might be ideal for engaging students or community groups on air quality issues. A mid-range device might adequately serve a project’s needs, and provide significant cost savings compared to a top-of-the-range option.

2. Sensor performance and technical requirements

The performance of a sensor or sensing device relates to the quality and attributes of the data that it produces. There are standardised key performance indicators or 'data quality metrics' that can be found on sensor or sensing device specification sheets. Make sure that you obtain specification sheets for any devices that you might consider procuring, and use the information in Table 3 to help you interpret them. You can refer to the OPENAIR supplementary resource *A framework for categorising air quality sensing devices* to align your data use case with device performance.

Table 3. A guide to common data quality metrics

Data quality metric	Description	Example
Range	Range is defined by an upper and lower value for the parameter being measured. A sensor or device is capable of providing accurate measurements when the parameter being measured falls inside this range. Gas sensors are of note here, because they tend to come in two varieties: those designed for measurement of very low or ambient gas concentrations (required for ambient air quality sensing); and those designed for higher gas concentrations (required for source point monitoring). Each type is defined by its operational range.	A nitrogen dioxide (NO_2) sensor might have a range of: • 0-3 ppm (parts per million), or • 0-3000 ppb (parts per billion)
Error/accuracy	'Error' and 'accuracy' are two terms used interchangeably on specification sheets. They relate to how much a measurement can be expected to deviate from the 'true' phenomenon being measured. Lower values mean that the data is more accurate (or has lower expected error). Error/accuracy can be expressed as: • +/- percentage of the measured value • +/- a specified number of units of the measured parameter Note: percentage defines error at higher pollution concentrations, while units of measurement are used at lower concentrations.	A particulate sensor might have the following error metrics on its specification sheet: • ±10% at 100 to 500µg/m³ • ±10µg/m³ at 0 to 100µg/m³

Data quality metric	Description	Example
Resolution	Resolution describes the smallest distinguishable change in the environment that a sensor or device can detect. It is expressed using the unit of measurement for the parameter. High resolution might be required for air quality sensing in contexts where you want to understand very small differences in ambient background pollution. It may be less critical if your focus is on detecting major pollution threshold breaches, or general trends.	A nitrogen dioxide (NO_2) sensor might have a resolution of: • 1 ppb (parts per billion), or • <20 ppb (parts per billion)
Correlation/R^2	The correlation coefficient (R^2) indicates how closely aligned the measurements are between a sensor/device and a high-performance reference instrument. An R^2 value of 1 indicates a perfect relationship between the two measurements. R^2 is expressed as a fraction of 1.0. The higher the value, the better the data quality. You may also see R^2 referred to as 'precision to reference instrument'.	A nitrogen dioxide (NO_2) sensor might have an R^2 of: • >0.85
Reporting interval	The reporting interval (or measurement frequency) is the period of time between data packets reported by a device. Since it relates to an entire data packet, it applies to all telemetry collected and sent by a device. It is thus only applicable to a device (rather than to individual sensors). Reporting interval should be distinguished from 'sampling rate', which is the period of time between measurements taken by a sensor. A device might collect many of these measurements, calculate an average from them, and report that derived value in the next data packet.	Reporting interval may be noted as a standard interval (e.g. 15 minutes), which relates to factory settings; and a minimum interval (e.g. 3 minutes), which is the shortest period to which the device can be reconfigured.

SENSOR PERFORMANCE ≠ DEVICE PERFORMANCE

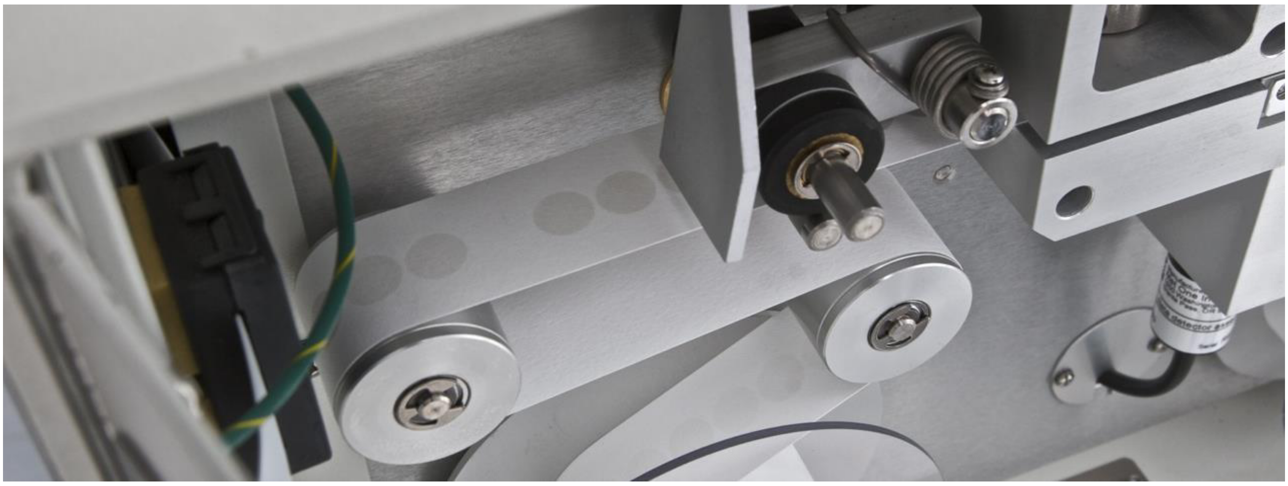
Most device specification sheets will list sensor performance metrics provided by the manufacturer of the sensors. These are calculated under ideal laboratory conditions that are only representative of real-world settings. Take care not to assume that these metrics apply to the operation of the device and the data that it produces.

Instead, think of a device as a complex ecosystem of parts and programming that affects the performance of a sensor in several ways. The design of the device housing, the position of the sensor within the device, the air flow around the sensor, and the way that the device is configured all impact the data that is produced.

Most commonly, the data output of a device will be *lower* than that stated for its sensor components. For this reason, device data sheets should be understood as a useful indication of data quality, but by no means a definitive one. When you read a data sheet, it is advisable to err on the side of caution, and be conservative in your consideration of the device's appropriateness to your data use case.

In order to get a more accurate understanding of device performance, you must access information on how a device performs as an integrated whole.

Some devices are independently benchmarked against reference equipment, either in a lab or in an outdoor co-location with regulatory sensors. For these devices, a much clearer understanding of their data quality output during 'normal' operation is available, allowing you to more accurately assess the suitability of a device for your intended data use case. Note that many commercial devices have not been independently benchmarked, and the data quality from these devices is more of an unknown



High-performance reference equipment for particulate pollution can be used to calculate performance metrics for lower-cost sensors and devices. Note the light grey circles where air is blown through the filter tape. Image source: Creative Commons.

3. Communications technology

Smart sensing devices need to transmit or receive data. This can be done either through a wired ethernet connection, or using a range of possible wireless communications technologies. Each technology option has advantages and disadvantages, and should be considered in terms of its ability to serve the aims of your project, and your ability to establish and maintain the technology.

Table 4 provides an overview of the five most common wireless communication technologies for smart air quality sensing. Table 5 provides a simple assessment guide to each of them. For a more in-depth exploration of communications technologies and how to select an option that is best for your project, please refer to the OPENAIR Best Practice Guide chapter *Data communications procurement*.

Table 4. Overview of the five most common communications options for low-cost air quality sensing

Communication option	Description
Wi-Fi	A nearly ubiquitous technology for localised wireless communications within 100m of a gateway. As the user, you own and manage all infrastructure and services. Zero-marginal cost per device is possible. Power demand and a short range of signal severely restricts device deployment options.
LoRaWAN	A Long Range Low Power Wide Area Network (LoRaWAN) is used at precinct/city scale. Commercial options include proprietary-managed services (less flexible), and fully open networks that can support free community access. Zero-marginal cost per device is possible (with open network business models only).
Sigfox	An alternative Low Power Wide Area Network option that is fully proprietary, which reduces flexibility and device options, and means a moderate per device cost. Relatively good existing urban coverage. Lack of bi-directional communications is a notable drawback.
4G/LTE	The main communications technology used to support the mobile phone network. Widespread coverage with good reliability and low patchiness/intermittency issues in urban areas. A little more complex to set up devices. Cost per device is relatively high.
NBIoT	Narrow Band Internet of Things (NBIoT) is a service from the main mobile carriers that makes use of existing 4G/LTE gateways. It is optimised for device communications and IoT, being low power and somewhat less costly than standard 4G/LTE.

*A LoRaWAN gateway on a rooftop in Sydney, Australia.
Image source: UTS*

Table 5. Assessment guide for common communications technologies

Communication technology/ characteristics	Wi-Fi	LoRaWAN	Sigfox	4G/LTE	NBIoT
Commercially available device options	***	***	**	***	**
Existing gateway infrastructure	**	*	**	***	***
Flexibility of device deployment	*	***	***	***	***
Power demand	*	***	***	**	**
Signal range	*	***	***	***	***
Patchiness and intermittency of signal within an area that has coverage	**	**	**	***	***
Ease of device set-up	***	***	***	**	**
Bi-directional communications	Y	Y	N	Y	Y
Data security	***	***	***	***	***
Reliability of service	***	**	**	***	***
Service Level Agreements (SLAs)	N	N	N	Y	Y
Cost per connected device	***	***	**	*	**

4. Proprietary technology vs open technology

Many low-cost air quality monitoring devices are proprietary technologies sold through a 'technology as a service' model. The customer buys a complete package of hardware, software and data services (and in some cases, does not even own the hardware, instead paying a subscription for data access).

Open technology refers to devices, communications, software, and data platforms that prioritise transparency, accessibility, and interoperability.

Despite an emerging best practice consensus in favour of open technology for IoT and smart cities, there are pros and cons to both options. Open technology is inherently more flexible, and thus conducive to the growing maturity of a smart city strategy, but it demands more in-house expertise and resourcing. Proprietary technology is more restrictive in its applications, but efficiently outsources expertise and effort to a contractor. Local governments should consider their particular strategic and operational requirements to assess which option is most appropriate. Table 6 provides a brief overview of key factors worth considering when making your choice.

Table 6. Factors relating to the choice of open vs proprietary technology

Factor	Description
The planned scale of your future sensor network	If you plan to expand a sensing network over time and evolve your approach, then the flexibility of open technology becomes more appealing. Proprietary options may restrict this kind of growth or change.
Smart city development aspirations	If you plan to mature your smart city strategy over time, then open technology options are advisable. They tend to align with emerging smart city best practice because they prioritise transparency, accessibility, and interoperability.
Technology and data integration intentions	If you plan to integrate many smart technologies and data sources, then more open technologies are advisable. If you want to keep data collection and data utilisation relatively simple and self-contained, then proprietary solutions may be ideal.
Transparency of data processing	Open technologies feature transparent processing of data which is often missing in 'black box' proprietary services. Data transparency can be critical to your ability to interpret and share data, and to support a maturing data policy.
Position on vendor lock-in	Open technology helps to avoid vendor lock-in by supporting more modular approaches to system design, giving you the freedom to swap out specific commercial providers or equipment in favour of alternatives.

Factor	Description
In-house technical and resourcing capacity	Open technology generally requires you to have more in-house technical knowledge and resourcing capacity for set-up and operations. Proprietary options tend to outsource much of this to a service provider.
Digital asset management	Open technologies can generally be integrated with an existing digital asset management system. This is usually impossible with proprietary systems.
Data ownership and management	Open technologies are more likely to enable full ownership of sensor data, and the ability to manage it in accordance with a clearly defined internal data policy.
Data sharing	Open technology provides more flexible options for managing data access and sharing data with a variety of users. Proprietary options will support some types of data sharing, but these tend to be quite restricted and inflexible.

5. Environmental factors and robustness

Regional climate factors – and the microclimate of a location where you intend to deploy a device – will determine the environmental conditions to which the device will be exposed, and how robust it needs to be. Extremes of temperature, weather, humidity, and salt aerosols can take their toll on devices across their functional lifetimes.

Physically robust devices must be engineered to a high standard, using the highest-grade materials and parts, often resulting in a premium price tag. Less robust options may still suit your project's needs, while being more affordable. By clarifying how robust you need your devices to be, you can avoid over-engineered options at unjustifiable expense. Figure 1 presents four practical considerations relating to device robustness and associated performance.

IP rating

An IP (Ingress Protection) rating certifies commercial products for their ability to withstand ingress from dust and water. The highest IP rating relevant for electronic devices deployed outdoors in unsubmerged contexts is IP67, which is the gold standard for smart air quality sensing devices. However, an IP rating of 64 is common among many low-cost IoT devices, and ensures that a device is fully protected from torrential and prolonged rainfall. A higher IP rated-device may cost more, though this is not always the case.

Quality of build

The quality of engineering and fabrication of a sensing device can vary considerably. There are a few questions linked to high or low quality of build and general performance to bear in mind during your procurement decision-making:

Has the device been used successfully in the past? Is there positive word-of-mouth reputation? Is the manufacturer well-established and trusted? Has the device been independently benchmarked outdoors and had its robustness assessed?

Robust materials

Coastal settings that are subject to salt aerosols can cause the corrosion of steel components in devices, mounting brackets, and fixings. Similar issues can occur in cold climates where salt is used to de-ice roads. Marine-grade stainless steel, galvanised steel, and high-grade UV-resistant plastics are common solutions to corrosion.

Solar radiation shield

A solar radiation shield (or Stevenson screen) is a housing designed for meteorological sensors. It prevents thermal radiation from heating up the sensor or surrounding components, while enabling the highest possible airflow around the sensor from all directions. If your focus is on urban heat monitoring and you care about temperature differences of a degree or two, or if you are studying noxious gases (such as NO_2), then it is advisable to use a radiation shield.

Figure 1. Practical considerations relating to device robustness and performance

6. Lifetime requirement

Your chosen use case will determine the lifetime requirement for a device. Different device options will have different functional lifetimes. The functional lifetime of a sensing device is linked to a complex mix of factors (see Table 7), all of which should be considered when choosing an option that meets your project's needs.

Long term or open ended monitoring projects may require periodic equipment refreshes to be budgeted for. As technology changes rapidly, these refreshes are an opportunity to examine the new options that may be available in the market.

Table 7. Factors that impact the functional lifetime of a sensing device

Attribute	Explanation
The complexity of a device	The more complex a device is, the higher the chance that things can go wrong. More complex devices usually have more moving parts, individual components, and potential failure points. Sometimes, more sophisticated functionality can translate to a higher risk of failure.
The quality of a device	Some devices are made to higher standards than others. A high-quality, well-engineered device is more likely to operate reliably for its full projected functional lifetime.
The lifetime of gas sensors	A gas sensor incorporates a chemical agent that reacts with the target gas and slowly degrades. Over time, sensor accuracy will drift until it reaches a point where readings are no longer reliable. If pollution levels are very high, this process will occur faster.
The lifetime of particulate sensors	Particulate sensors have moving parts that can wear out (e.g. fan failure). Particle deposition on components and receptors can also cause particulate sensors to fail. This can occur over relatively short periods under heavily polluted conditions (e.g. an extreme bushfire season).
Battery life	Battery life is a product of battery type; battery size; power cycling (rechargeables only); and depth of discharge (DoD) exceedance (which results in immediate, permanent damage). For devices reliant upon a single battery for their deployed lifetime (i.e. no mains or solar recharge), some additional factors shorten the battery life, including higher sampling rate[3] or reporting interval[4]; marginal communications coverage and strength (for LPWAN communications); and more onboard processing capacity.
Modularity	A modular device has the potential to be reconfigured or updated over its functional lifetime. This can help to extend the device lifetime. Components (such as gas sensors or batteries) can sometimes be replaced, which can significantly extend the lifetime of the device. Some devices reach the end of their functional lifetime prior to any sort of component failure, due to becoming redundant in terms of their functionality relative to the aims of the project and/or organisation. A more modular design gives flexibility to repurpose a device to a new project or use case, extending its functional lifetime.

[3] Sampling rate refers to the frequency that a device takes a measurement of a given parameter. For example, a gas sensor reading might be taken every two seconds for a 60-second period, producing 30 readings that are combined to produce an output expressed as a mean or median.

[4] Reporting interval refers to the frequency that a device sends live data packets over a communications network. Each time a packet is sent, power is used. A device that reports once an hour will use a quarter of the power that a device reporting once every 15 minutes would use.

7. Power supply technology

When you procure a sensing device, you must choose a power supply option that supports your use case, and aligns with the practical constraints of your deployment locations. There are three possible power supply options (see Figure 2).

Batteries only

For devices with low power demand only; highly versatile deployment location options; battery lifetime limitations a major consideration.

Solar + batteries

Supports devices with moderate power demand; deployment locations are limited to those with adequate direct sun; battery life tends to outlast the device's lifetime.

Also consider system specifications: larger systems support higher power demand and provide more redundancy, but may be impractical or aesthetically inappropriate.

Mains power

Supports devices with high power demand; deployment locations are limited to those with access and approval; a battery system may be added to counter intermittent supply.

Figure 2. Power supply options

The most suitable power supply option for your deployment context is determined by a combination of the power demand of your planned sensing activity (see Table 8), and various practicalities of supplying power in your chosen deployment locations (see Table 9).

Table 8. Factors affecting power demand (relating to design and configuration of a device)

Aspect of device design	Explanation
Type of sensors	Some types of sensor use more power than others. Particulate sensors (which use heating elements and fans) use more power than gas sensors. Both use considerably more power than temperature/humidity sensors.
Number of sensors	Some devices are simple, with only one or two sensors. Others (e.g. weather stations) can feature an array of sensors. The more sensors in a device, the greater the power demand.
Communications technology	Some communications technologies are optimised for low power usage (e.g. LPWAN), whereas others are energy-intensive (e.g. Wi-Fi).

Aspect of device design	Explanation
Onboard processing	Devices that include higher amounts of onboard data processing have higher power demand.
Reporting interval	Reporting interval is the frequency that a device reports data. Each report requires power, so a higher reporting interval uses up more power in a given period.

Table 9. Practicalities of supplying power in your chosen deployment locations

Power supply option	Deployment location	Description
Battery	Locations with marginal signal strength	Locations with marginal signal strength may be a particular problem for devices that rely upon LPWAN communications technologies (LoRaWAN and Sigfox). This is generally the result of high-rise urban settings, undulating terrain, and dense tree canopies. A solution to this challenge is to optimise device communications settings for marginal coverage. However, this results in a trade-off with power demand. The upshot is that this may rule out a battery-only power supply option.
Solar	Locations with low solar exposure	Solar exposure can vary significantly as a result of deployment location and time. Buildings and trees can cause alternating periods of direct sun and full shade throughout a day. Trees can provide shade in summer, but not in winter. Prolonged periods of poor weather may reduce total daily solar exposure below a critical threshold, whereas winter solar aspect may result in too much shade. To address these challenges, a larger solar panel can be used. However, this brings additional complexity, cost, and aesthetic considerations.
Mains	The availability of locations with accessible mains power	Devices reliant upon mains power are limited to locations where power is available. Approval for connection is not always achievable. Gaining this approval, where it is possible, can be a complex and time-consuming process.
	Intermittent mains power	Mains power can be intermittent. For example, street light circuits often switch off during the day.

Power supply option	Deployment location	Description
	Cost of installing mains power	Connection of a device to mains power requires a licensed electrician. Often, power needs to be extended from a nearby source, and converted through a transformer to the appropriate voltage. If you are deploying on street poles, the installer will need a 'working at heights' licence, and may also need high voltage certification if they are working close to overhead cables. They may require the use of a cherry picker/hydraulic crane. The installation itself will take longer than a solar install. All of this can amount to installation costs far higher than any associated with the installation of solar or battery-only devices. If costs are a concern, this can be a reason to choose solar over mains options.
	Time for installation approvals	Installation of a smart device on any asset requires detailed proposals and an approval process. The complexity of a proposal, and the time taken for it to be assessed and approved, tends to be much higher for mains-powered installations than it is for solar or battery-only installations. If time is critical, this may be a reason to avoid mains power, particularly if it would require many different custom installation solutions across multiple sites.
All	Operational costs	All three power supply options have ongoing operational costs. For battery-only devices, the cost of replacing batteries across a whole network of devices can be high. However, in many cases batteries can last for several years, meaning that a battery change within a standard project timeframe can often be avoided. Solar-powered devices can suffer faults and power dropouts, particularly in cases where panel and battery size are minimised and power usage is optimised (which reduces resilience to adverse conditions and fouling). Solar-powered devices require constant active maintenance, including regular physical inspection. Mains-powered devices consume power that might incur a recurring fee. This will also require associated administration, at additional cost.

8. Size, form, and aesthetic

The size, form, and general aesthetic of devices can matter a great deal if they are to be deployed in public places. It may often be the case that more compact and aesthetically designed products have a higher price tag. You should have a clear idea of your aesthetic requirements, and make sure that you procure a device that meets them. Table 10 provides an overview of key aesthetic considerations.

Table 10. Aesthetic considerations relating to device selection

Aesthetic consideration	Explanation
Pole clutter	Pole clutter relates to the proliferation of hardware on street poles, which can lead to an unsightly mess that spoils the look and feel of a public space.
Size of solar panel	Solar panels vary in size, and they are often made as small as possible to reduce aesthetic impact and minimise wind loading. However, it is advisable to weigh the aesthetic benefits of a small panel against the risk of power failure. In locations with low sun exposure, smaller solar panels result in little contingency for poor weather and winter sun. A small panel is also more susceptible to failure due to fouling, such as from wet leaves or bird droppings.
Mounting solutions	Air quality monitoring devices generally need to be held out from a mounting surface (e.g. a street pole) on a bracket, to avoid thermal interference and ensure good airflow. The mounting solutions available may be restricted by the device option that you choose, and the mounting hardware itself can vary in aesthetic appeal and robustness. You might also consider developing custom mounting solutions that do not come with devices as a standard option.

9. Modularity

Some commercially available sensing devices are designed as modular systems that allow different sorts of sensors to be added or removed. There are two benefits to modularity:

1. **Modularity supports flexibility for evolving data needs** Your project might start out with a focus on particulates and NO_2, but in a year's time you may decide that you also want to monitor CO_2. Rather than installing separate devices, having the option to add a CO_2 sensor to your existing device can be cost-effective and operationally efficient. This ability to expand the functionality of existing devices may extend beyond air quality (e.g. to noise monitoring).
2. **Modularity makes it easier to replace sensors, thus extending the operational lifetime of a device** Gas sensors degrade chemically over time, and particulate sensors can become fouled through deposition. These processes place limits on the lifetime of sensors. If sensors can be replaced, then the overall lifetime of a device might be significantly extended. The cost of any replacement service (which may include device retrieval, shipping, and reinstallation) should be considered.

10. Platforms and support services

Sensing devices vary widely in terms of the platforms and support services that are packaged with them. You should be aware of these details when making a procurement decision.

Platforms

Smart sensing devices are hosted and managed within an IoT platform, which interprets, displays, stores and manages data from those devices. Many devices come packaged with an IoT platform. It is therefore advisable to consider your platform needs at the same time as you are selecting devices.

The suitability of an IoT platform may be assessed in two ways:

a. Platform qualities and attributes

Qualities and attributes relate to the way in which a platform can fit into a broader architecture and project ecosystem and meet the design needs of a project and its users. It includes things like interoperability, hosting, scalability, and performance).

b. Platform functions and features

Common platform functions and features to consider include:

- Ease/complexity of device onboarding
- User accounts and access management
- The flexibility of data search/query functions
- Customisable graphs
- Map-based visualisations for device management and data interpretation
- Customisable alerts
- Customisable APIs
- Bulk import/export of data
- Bundled data storage

Support services

Sensing devices require support throughout their setup and operation. Support may be covered in-house, or it can be outsourced to the device supplier or IoT platform supplier as a service. Either way, support service needs should be factored into device procurement decision-making.

There are four main types of support services to consider:

1. Device configuration and onboarding services
2. Network deployment and initial verification support
3. Ongoing technical support (device management)
4. On-the-ground maintenance

References

NSW Health. (2020). *Particulate matter (PM10 and PM2.5)*. NSW Government. https://www.health.nsw.gov.au/environment/air/Pages/particulate-matter.aspx

Associated OPENAIR resources

Best Practice Guide chapters

Platforms and digital services criteria

This Best Practice Guide chapter provides guidance for the selection of appropriate platforms and digital services to support smart air quality monitoring. Please refer to this for further information on platform qualities and attributes.

Data communications procurement

This Best Practice Guide chapter explores the various communications technologies that can support smart low-cost air quality sensing, and provides advice on selecting technologies that are appropriate for a project and organisation.

Sensing device troubleshooting: common problems and how to fix them

This Best Practice Guide chapter introduces a framework of common problems that can arise with smart low-cost air quality sensors and the provision of useful data. It includes some practical information to help diagnose issues, fix them, and mitigate against reoccurrence.

Supplementary resources

Technical requirements template

This template is an extended, step-by-step tool that supports the development of technical requirements for a smart air quality monitoring project. These requirements define the details of technologies (sensing devices, platforms, and services) that can meet the specific needs of a project, and are intended to support procurement decision-making.

A guide to developing technical requirements

This resource is a companion guide to the *Technical requirements template*. It provides additional information to assist users in completing the template.

A framework for categorising air quality sensing devices

This resource presents a new framework for categorising air quality sensing devices in an Australian context. It identifies four tiers of device types, separated in terms of functionality, and the quality and usability of their data output. It is designed to assist with the selection of devices that are appropriate for meeting the needs of a project and an intended data use case.

A reference architecture for smart air quality monitoring: detailed guide

This resource is an extended, stand-alone guide to the OPENAIR reference architecture for smart air quality monitoring. The reference architecture is a framework that identifies the various technical components of a complete air quality sensing network, and shows how devices, communications, platforms, databases, and user interfaces integrate and support the flow and management of data. It is a generic reference that can help local governments to design and implement their own technical solutions.

Sensing device troubleshooting: extended guide

This resource presents an extended, systematic list of problems that can arise with smart low-cost air quality sensors and the provision of useful data. It includes practical information to help diagnose, fix, and mitigate each type of issue.

Further information

For more information about this project, please contact:

Peter Runcie

Project Lead, NSW Smart Sensing Network (NSSN)
Email: peter@natirar.com.au

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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