Selecting low-cost sensors for air quality monitoring

Sustainable Communities and Waste

National Environmental Science Program

Guidance for local governments

About this fact sheet

Low-cost sensors (LCS) to monitor air quality are a rapidly developing area of technology. Dozens of models with widely varying costs and capabilities are now available to the Australian market. For local governments, selecting a model that's fit-for-purpose can be time-consuming.

This fact sheet provides guidance for local governments seeking to acquire LCS devices for their air quality monitoring projects. It describes key attributes or concerns to consider when selecting a device.

This advice complements our online LCS selection tool: monitors.cleanairstars.com

This guidance covers LCS that measure particulate matter (PM), polluting gases and VOCs. It does not cover carbon dioxide (CO_2) monitors, such as the Aranet4, commonly used to check whether indoor ventilation is adequate.

Matching device choice with monitoring goals

Local governments manage a considerable amount of planning and control related to emissions, for example, through their responsibility for factory and business sites, and their influence on motor vehicle traffic flows.

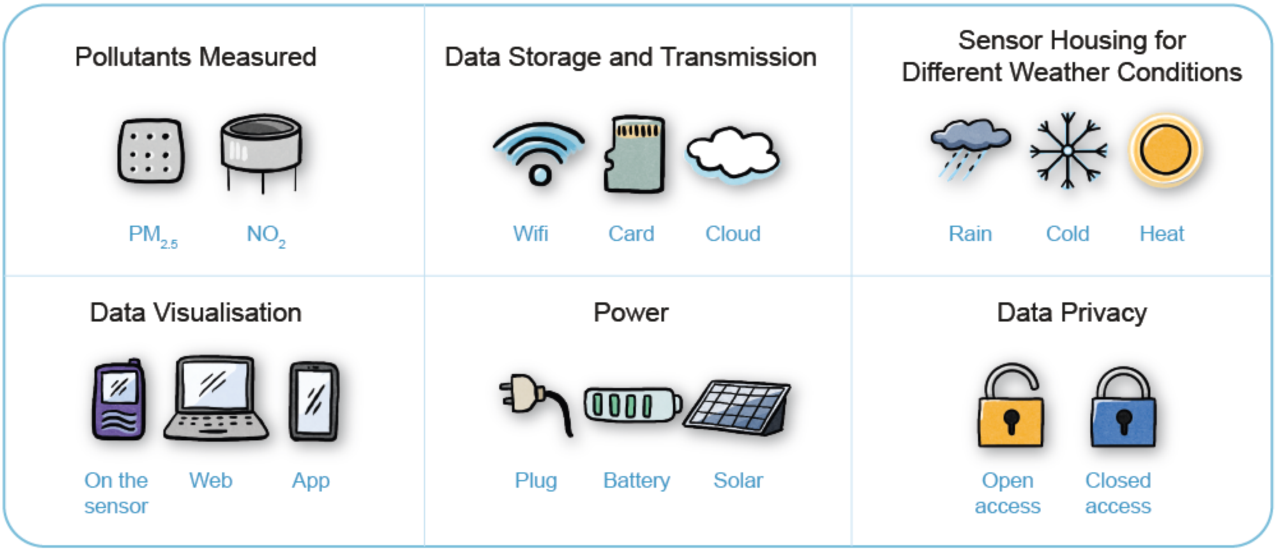
In past many local governments lacked the capacity to monitor these emissions. It's demanding and expensive to run reference-grade air quality monitoring stations, like those operated by state regulatory bodies. Increasingly, LCS devices fill this important gap.

Local governments' purposes for collecting air quality data vary, however, they generally seek to respond to community or council concerns about air pollution events and sources. These air pollution problems may be chronic or widespread, such as urban smog or bushfire smoke, or localised or acute, such as episodic industrial emissions.

By using LCS for air quality initiatives, local governments can:

- facilitate community action to reduce exposure
- inform policy responses
- educate the public and raise their awareness.

Correctly matching the choice of sensor model with the goals of a monitoring project is a crucial step for any air quality initiative.



Key user concerns for LCS selection

The following are some key concerns or attributes to consider when selecting an LCS device for your project.

Understand device costs & related expenses

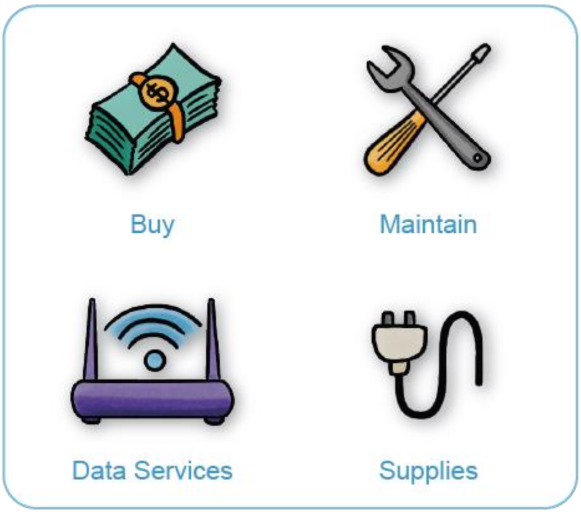
The purchase price of LCS devices varies. For purposes of this fact sheet and associated online tool, LCS are defined as devices costing less than AUD$10,000.

Device costs generally increase with the number of pollutants measured and the degree of sensor accuracy and sensitivity.

Most LCS manufacturers offer units for a one-off purchase price, but some are available on a subscriber basis. Some manufacturers offer discounts on purchases of multiple units.

When costing a device for your project, consider the total cost of ownership. This includes not only purchase costs or subscriber fees for the device, but also any ancillary costs and long-term operating costs, especially for more expensive models, such as:

- mounting station and installation costs
- power-related costs (for example, solar panels)
- subscriber services for data transmission, storage, or visualisation
- technical support
- maintenance, including repairing or replacing sensor components
- calibration services.



Study duration is an important aspect of cost, especially for solutions with high maintenance requirements. ‘Plug and play’ models afford the option to easily replace individual sensors on the device, an option that might suit longer-term monitoring projects.

Select a device that measures target pollutants

Be sure the device you select measures the pollutants of concern. Be aware that the type and number or target pollutants a device measures can affect its cost.

These are the main classes of target pollutants measured by LCS devices:

1. **Particulate matter** is fine particles, typically PM_1, $PM_{2.5}$, and coarser particles of PM_{10} or less, usually measured by an optical particle counter. Most LCS measure $PM_{2.5}$ with reasonable accuracy (see 'Accuracy' section) but typically do a poor job of measuring PM_{10}. PM sensor lifetimes vary among brands and models, but generally range from 1-4 years.

2. **Gas phase pollutants**: Nitrogen dioxide (NO_2) or ozone (O_3) are often gases of interest to air quality monitoring projects. Most LCS use electrochemical sensors to measure these gases. LCS gas sensors generally perform with less accuracy than PM sensors; it's possible but generally more costly to purchase devices that achieve accurate gas measurements. Gas sensor lifetimes vary, but generally range from 6 months to 2 years.

3. **Volatile organic compounds (VOCs):** This class of pollutants spans a wide range of particles. LCS typically measure VOCs by metal oxide semiconductors (MOS) or photoionization detector (PID) sensors. Most MOS and PID sensors for VOCs perform poorly on accuracy and can be very costly.

Meteorological data

Be sure to check whether the device you select measures meteorological variables if you require data on temperature, humidity, barometric pressure, or wind.

Most (but not all) base models measure temperature and humidity. It's a good idea to check independent evaluations, if they're available, or otherwise gauge the accuracy of LCS meteorological data. Some devices only measure internal temperature and humidity to improve their calibration models, and these devices are unsuitable for measuring weather conditions. If meteorological datasets are crucial to your project, and accuracy is an issue with the LCS model you select, you may opt to buy a separate weather station.

Consider sensor attributes that affect data quality

Accuracy: Depending on your project's goals, accuracy can be a critical user concern. Accuracy varies greatly among different models of LCS devices, and even within models for the different pollutants they detect. For each pollutant you seek to measure, be sure the sensor meets your requirements for accuracy.

Technically speaking, accuracy refers to how well a sensor's pollution measurements agree, or correlate, with measurements of a reference instrument of known high accuracy, such as a regulatory monitor. Accuracy is often expressed as an R^2 value, a statistical term called the coefficient of determination. The closer the R^2 value to 1, the stronger the correlation and the greater the accuracy, with 1 being perfect correlation. Although there is no Australian standard for R^2 values in LCS, the US Environmental Protection Agency selects a target value of $R^2 \geq 0.70$ in its evaluations of $PM_{2.5}$ sensors.

R^2 values are generally higher for sensor data that's averaged over longer periods (for example, 24 hours versus 1 hour or 1 minute). This is because longer averaging

periods reduce the 'noise' in sensor data caused by factors ranging from electrical interferences and sensor precision to rapid weather changes.
Reliable manufacturer information about accuracy is often lacking. This shortfall is a problem for potential LCS users for whom accuracy is critical. Accuracy and other performance information is available for some LCS models from independent evaluations and published literature (see 'Resources'.) Checking these evaluations before you buy can help gauge the suitability of a device. These independent evaluations may also help you understand how sensor readings vary with humidity or temperature.

Fewer independent evaluations are available for LCS performance on gas-phase pollutants and VOCs than for PM, but the number of evaluations is increasing. Be aware, however, that field test conditions of independent evaluators may not be analogous to your study area conditions. They can also provide biased statistics for both gases and particles due to fluctuations in pollutant concentrations and changing seasonal conditions.

Precision refers to how well a sensor reproduces a measurement under identical conditions, that is, the degree of agreement among repeat measurements. High sensor precision is particularly important for initiatives that seek to measure small variations in pollutant concentration.

Sampling rate (sampling interval or sampling frequency) refers to the rate or time interval at which a sensor can take measurements. This attribute may be important when monitoring projects must capture data about a pollutant plume that changes rapidly in concentration or is short-lived in time. Where air quality conditions are less variable, sampling rates on timescales of minutes or hours are likely adequate. Be aware that for some sensors, sampling frequency is reduced if the power source switches from mains to battery or solar.

Measurement range and detection limit: Make sure the device you choose can measure target pollutants across the full range of concern, from highest to lowest concentrations, anticipated in your study area. Check the manufacturer's technical specifications for the limit of detection, the lowest concentration of a pollutant the device can detect.

Calibration: Demonstrating measurement accuracy is important for some local government air quality monitoring projects. Some sensors are factory-calibrated prior to sale. Their settings are checked and adjusted, if necessary, to ensure sensor measurements compare well with a known and certified standard.

For some air quality monitoring projects, it may be necessary to field calibrate sensors, by co-locating the device with a reference instrument. These calibrations may be necessary to account for impacts that various air pollutants and weather (particularly humidity and temperature) can have on sensor accuracy. These weather effects may be substantial. Calibration allows users to address drift (wherein monitors deployed in the field gradually become less accurate).

Calibration models range from simple linear ones to complex multilinear models. Depending on your data analysis expertise and the complexity of calibration required, you may want to check whether the manufacturer provides calibration expertise. Some manufacturers offer customers the option to return a device to their factory to be recalibrated.

If calibration is important to your project, be sure to investigate further. Before buying, ask the manufacturer how to calibrate the instrument. Learn about any additional costs related to calibration, co-location and correction services, and factor in the extra time and planning required to carry out these activities.

Consider how the device manages data

Data transmission: Check whether the LCS device's mode of data transmission is compatible with your project. Some models only offer Wi-Fi, a viable option in homes or other settings where those conducting the monitoring have control over the Wi-Fi and LCS device settings. However, dependable and adequately strong Wi-Fi transmission can be extremely difficult to obtain and sustain in other settings, such as schools and other government buildings, and unsecured outdoors areas.

Fortunately, many LCS manufacturers offer models with a wide range of other transmission options, including Bluetooth, satellite, 4G and low-power wide-area network (LoRaWAN). In a minority of more basic models, data is stored on the device, for example, on an SD card for manual retrieval. Regardless, be sure to consider any additional costs for data retrieval or transmission, such as mobile subscription services.

Data storage, handling and access: For some projects, on-board data storage of an LCS device is an important consideration.

For devices that store data locally, you'll need to manually access or physically upload the data to a website or computer data analysis tool. Many models store data on central servers, from where you can download it. For some products, data can be called through an Application Programming Interface (API).

Manufacturers use models or equations to convert the raw sensor data into final reported pollution information. If access to raw data (for example, for calibration purposes) or other specific data formats is important to your project, check with the manufacturer to make sure they're available. Access permission, ownership rights, privacy, data sharing and integrating with other sensor platforms may be additional data considerations for your project.

Display/visualisation: Decide whether you require a data display on the device itself and be aware not all models offer this. More typically, you'll also have the option (or be required) to visit a website or use an app to view the data. Some manufacturers offer advanced web-based data visualisation services, typically for a subscription fee. For models with storage on the device, from where data is downloaded manually, manufacturers may supply software to visualise the data.

Consider ease of use

Useability is a key factor. Before you buy, determine the expertise required to operate the LCS device and its software. Find out if you'll need tools, computers or software. Check how easy it is to determine whether the device is continuing to operate properly, providing uninterrupted data over time. Consider factors like device size and weight, especially for portable models.

Installation: Is the device easy to install? Does it have flexible options to ensure its installation is compatible with your proposed location, and that installation doesn't become difficult or expensive? Models that reduce the complexity and technical expertise required for installation may be the best bet. Also consider whether the device must be resistant to theft or vandalism.

Power options: An LCS device should suit your needs in terms of power availability. Plug-in devices are the best option for stationary monitoring, but you'll need to ensure power is accessible. Some models have batteries or USB power supplies, useful for short-term or mobile data collection. Solar power is an option for some models, but requires attention paid to orientation and battery size.

Operation and maintenance: Make sure the device is robust enough. Will it tolerate expected wear and tear, such as shipping, or being dropped if it's a portable unit? If it's outdoors, is its enclosure durable enough to withstand extremes of heat, cold or moisture and dust?

Determine whether special expertise will be needed to perform necessary maintenance. Does the model have a warranty, a good-quality manual and online support? Some manufacturers offer a fee-based technical support plan, and in some cases, this support can extend to assistance with the design and implementation of your project.

All air pollution sensors have limited lifespans and may become less accurate over time (see above). Check your manufacturer's information to see how long the unit's sensors typically operate before they require servicing and replacement.

Resources

Independent LCS evaluations

- Airlab
- AQ-SPEC Air Quality Sensor Performance Evaluation Center of California's South Coast Air Quality Management District (AQMD). Due to geo-blocking, you may need a VPN to access South Coast AQMD web pages.
- Evaluation of emerging sensor performance (US EPA)

Guidance on how to plan and run LCS projects

- Community in action: A comprehensive guidebook on low-cost sensor (South Coast AQMD)
- The enhanced air sensor guidebook (US EPA)
- How to evaluate low-cost sensor by colocation with federal reference monitors (US EPA)
- Performance Testing Protocols, Metrics, and Target Values for Fine Particulate Matter Air Sensors (US EPA)
- Forum Sensor.Community