Selecting low-cost sensors for air quality monitoring

Sustainable Communities and Waste
National Environmental Science Program

Guidance for community groups

About this fact sheet

Low-cost sensors to monitor air pollution are developing rapidly. Community groups taking part in air quality monitoring projects can now choose from dozens of models available to the Australian market.

Given their wide-ranging prices and capabilities, it can be time-consuming to select a suitable monitor for your air quality monitoring project. This fact sheet provides guidance for community and environment groups seeking acquire these devices. It describes key features or concerns to consider, and complements our online low-cost sensor selection tool: monitors.cleanairstars.com

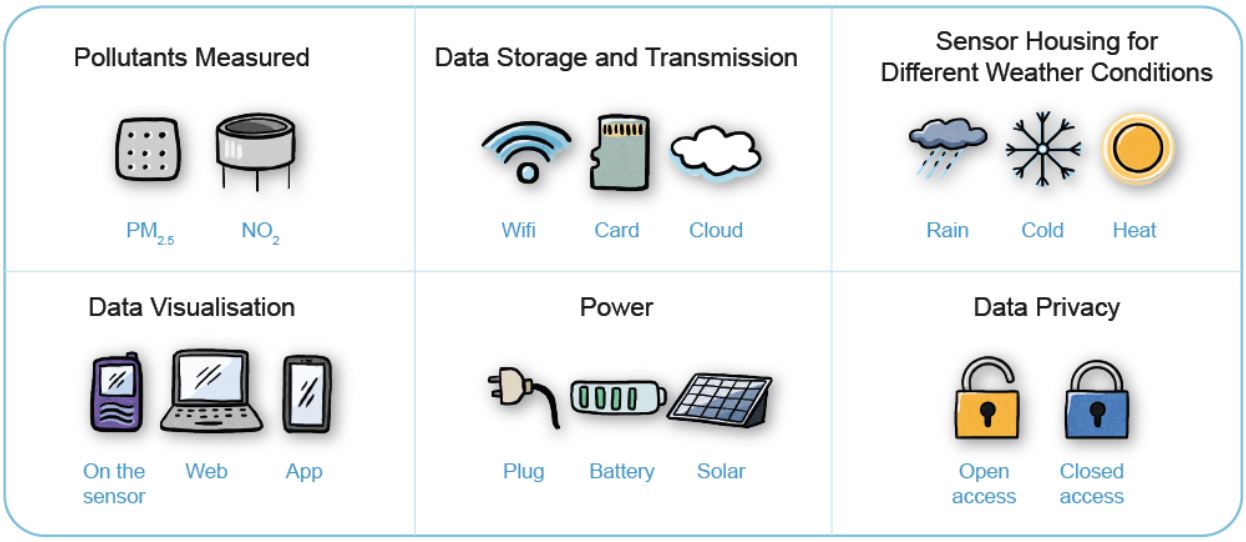
This guidance covers low-cost sensor devices that measure particulate matter (PM), polluting gases, and volatile organic compounds (VOCs). It does not cover carbon dioxide (CO_2) monitors, such as the Aranet4, commonly used to check whether indoor ventilation is adequate.

Match the device with your project goals

When community groups monitor air quality, it's often in response to perceived air pollution risks to people or the environment. Monitoring projects can serve environmental justice causes to ensure no group disproportionately bears the burden of policies or operations that lead to pollution.

Low-cost sensors can help community groups 'ground truth' pollution data from other agencies, reveal pollution sources and improve understanding of how pollution varies in time and space. These devices can also help community groups shape how people perceive and respond to air quality information. By increasing environmental health literacy, they can increase the effectiveness of efforts to improve community health.

Correctly matching the model of a low-cost sensor device with your monitoring project's goals is a crucial step.



Key things to consider when selecting low-cost sensors

Here we cover some key user concerns when making the important choice of a device for your project.

Device costs & related expenses

Different models of air quality sensor devices vary greatly in price. This fact sheet and associated online tool define low-cost sensors as devices costing less than AUD$10,000. Community groups will likely seek devices at the lower end of this range.

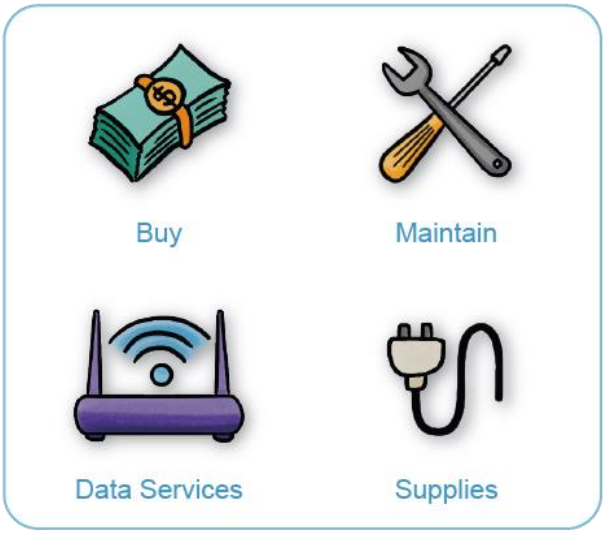
Device costs generally increase with the number of pollutants measured and the degree of sensor accuracy and sensitivity.

The majority of manufacturers offer units for a one-off purchase price, but some offer them on a subscription basis. Some 'plug and play' models also provide the option to easily replace individual sensors on the device, a feature worth considering for longer-term monitoring projects. Many manufacturers offer discounts if buyers purchase multiple units.

When costing a device for your project, be sure to consider the total cost of ownership.

This includes not only purchase costs or subscription fee for the unit, but related and long-term operating costs as well. These may include:

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



Select a device that measures pollutants you're concerned about

Low-cost sensors only detect the specific pollutants they're designed to monitor. Be sure your chosen device measures the pollutants you're concerned about. The types and number or pollutants a device measures affect its cost.

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

1. **Particulate matter** are particles from burning fuels. These include PM_1 (extremely fine particles with a diameter 1 micron or less, or 100 times smaller than a millimetre), $PM2_{.5}$ (fine particles of 2.5 microns or less), and PM_{10} (particles of 10 microns or less). These small particles pose a health hazard because they can travel deep into lungs, some even into your bloodstream Most PM sensors measure $PM_{2.5}$ with reasonable accuracy, but typically do a poor job of measuring PM_{10}. The lifetime of PM sensors varies, but generally ranges from 1 to 4 years.
2. **Gases**: Nitrogen dioxide (NO_2) or ozone (O_3) are polluting gases released by burning fuels. Low-cost sensors generally measure gases with less accuracy than PM sensors. It can be quite expensive to buy a device that measures these gases accurately. Gas sensor lifetimes range from 6 months to 2 years.
3. **Volatile organic compounds (VOCs):** This is a broad class of polluting particles, many of them produced by humans. Some VOCs have short- or long-term adverse health effects. Most low-cost sensors do a poor job of measuring VOC pollutants accurately and can be very costly.

Weather data

If you wish to collect data on temperature, humidity, barometric pressure or wind, be sure the device you select measures these meteorological variables. Though most base models measure temperature and humidity, some only measure internal temperature and humidity to improve their calibration, making them unsuitable for collecting weather data. If meteorological datasets are crucial to your project, and accuracy is an issue with the model you select, consider buying a separate weather station.

Consider sensor attributes that affect data quality

Accuracy: Depending on your project's goals, accuracy may be very important. Accuracy varies greatly among different models of low-cost sensor devices, and even within a model for the different pollutants it detects. Investigate the device's accuracy for each pollutant you wish to measure.

Accuracy refers to how well a sensor's pollution measurements agree, or correlate, with measurements of a highly accurate reference instrument, such as those operated by state regulatory agencies. Accuracy is often expressed as an R^2 value, a statistical term. The closer the R^2 value to 1, the stronger the correlation and the greater the accuracy, with 1 being perfect correlation.

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

There is no Australian standard for R^2 values, but the US Environmental Protection Agency gives a target value of $R^2 \geq 0.70$ in its evaluations of $PM_{2.5}$ sensors.

Reliable manufacturer information about accuracy may be lacking. Independent evaluations, available for some models, can offer insight into device accuracy and other aspects of performance (see 'Resources'). Fewer independent evaluations are available on sensor performance for gas-phase pollutants (NO_2 and O_3) and VOCs than for PM, but the number is increasing.

These independent evaluations can help you judge whether a device meets your needs, including how sensor readings may vary with humidity or temperature. Be aware, however, the field test conditions of independent evaluators may not match the conditions of your study area. These evaluations may also provide biased statistics for both gases and particles due to changing pollutant concentrations and 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 may be important if you wish to measure small differences in pollutant concentration.

Sampling rate (also called sampling interval or sampling frequency) is the rate or time interval at which a sensor can take measurements. Sampling rate may be important if your monitoring project needs to capture a pollutant plume that changes rapidly in concentration or is short-lived in time. Where air quality conditions are less variable, sampling rates of minutes or hours are likely to be adequate. Some devices reduce their sampling rate if their 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 interest in your environment, from highest to lowest concentrations. Check the manufacturer's technical specifications for the limit of detection, the lowest concentration of a pollutant the device can detect.

Calibration: For some monitoring projects, it's important to demonstrate the accuracy of sensor measurements. Calibration is a way to check and adjust sensor settings, to ensure measurements compare well with a known and certified standard. Some sensors are calibrated at the factory prior to sale. Manufacturers may also offer customers the option to return devices to the factory to be re-calibrated.

For some air quality monitoring projects, it's important to field calibrate a device by co-locating it with reference instrument. This may be necessary to account for the effects of weather and air pollution on sensor accuracy. Calibration also allows users to address drift, that is, the tendency for monitors in the field to gradually become less accurate.

If calibration is important to your project, investigate before buying. Ask the manufacturer how to calibrate the instrument. Factor in any extra costs related to calibration, co-location and correction services, as well as the time needed to complete these steps.

Consider how the device manages data

Data transmission: Check how the unit transmits data to ensure it is compatible with your project. Some models only offer Wi-Fi transmission. This may be a viable option if you have control over the settings for Wi-Fi and the low-cost sensor device. But dependable and adequately strong Wi-Fi transmission can be extremely difficult to obtain and sustain in government buildings including schools, and unsecured outdoor areas.

Fortunately, most manufacturers offer a range of transmission options, including Bluetooth, satellite, 4G and low-power wide-area network (LoRaWAN). A minority of more basic models simply store data on the device, for example, on an SD card, for manual retrieval.

Regardless, be sure to factor in any additional costs for data retrieval or transmission, such as mobile subscription services.

Data storage, handling and access: For some projects, a device's capacity for on-board data storage is important. 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 products store data on central servers, from where you can download it. For some, 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 calibration) or other 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 integration with other sensor platforms may be other important 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 web-based data visualisation that's useful for community monitoring projects.

Consider ease of use

Useability of low-cost sensors is likely to be important for community monitoring projects. Before you buy, learn what expertise is required to operate the low-cost sensor device. Find out if you'll need to purchase and make available tools, computers or software. Confirm whether it will be easy to check that the device is continuing to operate properly, providing uninterrupted data. 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 location, and 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 needs to be resistant to theft or vandalism.

Power options: A low-cost sensor device must 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. Models with batteries or USB power supplies are useful for short-term or mobile data collection. Solar power is available for some models, but requires attention paid to orientation and battery size.

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

Determine whether you'll need special expertise to maintain the device over time. Does it have a warranty and a good-quality manual? Check the manufacturer's reputation for responsive customer service, such as online help and a dedicated support team. Some manufacturers offer a fee-based technical support plan, and in some cases,

this support can also extend to design and implementation of your project.

All air pollution monitors have limited lifespans and generally become less accurate over time. Check manufacturer information to see how long you can expect sensors to 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