clarity

Maximize Your Air Quality Budget in a Post-COVID World

A Guide to Leveraging Low-Cost Sensors for Air Quality Monitoring 2.0

2020 was a turbulent year for nearly every corner of the world, and the air quality management space is no exception. Due to the economic impacts of the COVID-19 pandemic, government agencies around the world are facing reduced budgets for 2021 and beyond. At the same time, COVID-19 and increased public awareness of the health risks of climate change have put air pollution in the global spotlight, culminating in increased public demand for local, real-time air quality monitoring.

Air Quality Monitoring 2.0: A new era for air quality management in the post-COVID world

While budget restrictions present a challenge for air quality managers looking to respond effectively to air pollution, COVID-19's impacts on the global economy had a silver lining: the pandemic served as a worldwide laboratory for how policies targeting pollution reduction and behavioral change can impact the air that citizens breathe.

The unique economic and behavioral conditions that came with COVID-19-induced lockdowns led to unprecedented improvements in air quality in many locations around the world. In Europe, the European Environment Agency (EEA) published their "Air quality in Europe — 2020 report[1]," showing reductions of up to 60% for certain air pollutants in many European countries since lockdowns were implemented in the spring of 2020. Meanwhile, in the United States, cities across the country saw air pollution reach unprecedented highs and lows in the span of a single year due to the unique economic conditions associated with COVID-19 and a record-breaking wildfire season in the West.

The pandemic showed the public how polluted their air was before lockdown and demonstrated how quickly air pollution can be reduced through changes in human activities.

Traditional air quality monitoring networks have served air quality managers well in the past, enabling remarkable achievements such as the reduction of ambient concentrations of many targeted air pollutants in the United States by more than 90 percent since 1970. But despite commendable improvements in air quality, air pollution continues to cause millions of premature deaths every year. As the science on air pollution progresses, the evidence is overwhelming that the human and economic costs of air pollution are greater than we ever realized.

> "Scientists, regulators, economists, and the general public have spoken: our air quality monitoring infrastructure needs to be modernized to address current air pollution issues."

Air pollution in the 21st century is a moving target characterized not by large point-source polluters, but by a constantly shifting landscape of point and mobile-source emissions. To effectively respond to air pollution in the 21st century, governments and communities need tools that can track air pollution at the neighborhood level.

Fortunately for air quality managers around the world, the technology is now available to modernize air quality monitoring networks in a way that not only addresses public demand for local data and delivers results, but also reduces costs. The U.S. Government Accountability Office (GAO) and U.S. Environmental Protection Agency (USEPA) recently published a report[2] recommending that environmental agencies across the U.S. assess low-cost sensors as a way to cost-effectively modernize their air quality monitoring networks.

Air quality monitoring in the 21st century will be characterized by the use of low-cost IoT sensors to supplement existing reference networks. This guide provides an overview of best practices for planning and implementing Air Quality Monitoring 2.0 networks for 21st-century air quality managers.

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21st-century air quality management challenges

With the diversity of perspectives on how air quality should be monitored and managed, it is hard to find an approach that meets the needs of all stakeholders. Regulatory requirements are typically set at the national level and are often outdated. Meanwhile, the communities most impacted by air pollution are holding air quality managers increasingly accountable for health impacts at the neighborhood level and have different ideas about how air quality should be managed.

Increased public accountability

Communities around the world are beginning to ask more questions about air quality. In 2019, the Court of Justice of the European Union (CJEU) ruled that citizens have the right to go to court to challenge how authorities monitor air pollution, and that compliance must be assessed at monitoring stations located where people's exposure to pollution is the greatest, not with a regional average. While increased awareness of air quality issues is undoubtedly a positive development, it comes with increased public accountability for air quality managers.

Expensive traditional equipment leads to blind spots

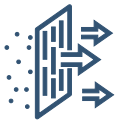
Traditional monitoring networks were designed to monitor air quality trends year-over-year, not to identify individual air pollution events or day-to-day exposures. Federal reference monitors (FRM) in the U.S. and many other countries are expensive, leading to networks with sparse coverage.

Air pollution hot spots that traditional networks miss have significant health impacts for surrounding communities, which can lead community members to take matters into their own hands and invest in low-cost sensor networks outside of the local air quality manager's jurisdiction.

Changing sources of air pollution

Air pollution develops from a complex mix of many different sources and activities, both natural and human-driven. Even as progress is made on traditional criteria pollutants, new sources of air pollution are constantly being identified.

Today's air quality threats tend to be more localized in nature, requiring higher-resolution monitoring infrastructure to address effectively. Modern air quality threats of high concern include toxic compounds and particulate matter from point and mobile sources, as well as natural hazards such as wildfires.



Aging equipment

Much of the air quality monitoring equipment used today is decades old and designed to monitor pollutants that no longer pose a major health threat. While FRMs are supposed to be the gold standard of monitoring equipment, a USEPA audit released in 2015 found that nearly half of U.S. FRMs did not meet federal standards for particulate matter[3].

These monitors do not provide the real-time information that air quality managers need to effectively respond to local air pollution, and working with aging equipment comes with its own challenges — there are reports of scientists purchasing FRM replacement parts on eBay because the manufacturer is no longer in business[2].

Outdated regulatory standards

Many air quality regulations are decades old and do not adequately address modern-day air pollution challenges. The US air quality monitoring program, for example, evolved from standards set in place by the 1970 Clean Air Act (CAA). At that time, acid rain, smog, and ozone pollution were of national concern.

Ambient levels of the criteria pollutants established by the CAA have declined significantly over the past decades, which is a testament to the success of the USEPA and air quality managers. However, the added cost and effort for state and local agencies to purchase expensive, specialized equipment to meet stringent USEPA requirements for criteria pollutants such as carbon monoxide, found at levels well below the National Ambient Air Quality Standards (NAAQS), provides little value from a public health standpoint.

Because regulations have not been updated to address modern-day criteria pollutants, it can be unclear to air quality managers what they should do to control these pollutants, or which technologies are acceptable to use for compliance purposes.

Restricted budgets

Air quality managers are facing restricted budgets in a post-COVID world. The recent GAO report found that in the U.S., annual federal funding for state and local air quality management grants has decreased by about 20 percent since 2004 after adjusting for inflation. These budgetary restrictions will only become more pronounced as the economic impacts of the pandemic limit government spending. Restricted budgets mean that air quality managers have to get creative in order to get the most value out of their limited resources.

Effectively responding to air pollution is no easy task!

Fortunately for air quality managers, low-cost sensors offer a cost-effective way to improve the reliability and resolution of air quality monitoring networks, improving agencies' ability to work within budget constraints and effectively respond to air pollution concerns at the local level.

Opportunities with low-cost air quality monitoring

Low-cost air pollution monitors have become widely available over the past decade. These technologies can be deployed in many locations without the need for a significant upfront capital investment, making them useful air quality monitoring tools for both government agencies and the public.

Air quality managers can deploy dozens of low-cost sensors for the equivalent cost of a single reference monitoring station, and with advances in modelling can leverage these high-density monitoring networks to understand air pollution resolution as high as 10 square meters.

In collaboration with the USEPA, the GAO recently published a list of use cases for indicative monitoring[4]. By supplementing reference monitoring networks with low-cost sensors, air quality managers can address these information needs.

The need for local, real-time air quality data[4]

Air pollution hotspots

Air pollution levels vary significantly from one location to another, and pollution hotspots may occur between existing monitoring sites. Air quality managers need information on a localized scale to get an accurate picture of the exposure that individuals face and the associated health effects.

Short-term changes in air quality

Air quality managers and the public need more frequent measurements that can be reported in real time. Real-time information helps air quality managers and the public understand short-term changes in air quality due to changes in weather patterns or events, such as natural disasters and industrial accidents.

Air quality data for rural areas

The distance between monitoring sites tends to be much greater in rural areas, and some rural areas may not have any monitoring sites at all. This makes it difficult to fully understand the acute effect on air quality in those areas from sources such as wildfires, oil and gas development, and wood smoke in mountain valleys.

Filling the gaps with low-cost sensors

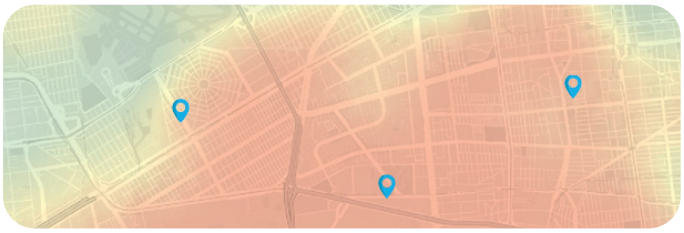
According to the EPA, two-thirds of counties (2,120 of 3,142) in the United States had no ambient air quality monitoring infrastructure associated with the national monitoring system in 2019[2].

Leveraging the strengths of legacy and new technologies

Traditional air quality monitoring equipment can cost anywhere from $10K to $100K per monitor in upfront capital expenditures. The true cost of traditional monitoring equipment, however, comes in the form of operating expenditures (OPEX). Operating a single FRM can often run in the hundreds of thousands of dollars per year, according to a review of publicly available budgetary information.

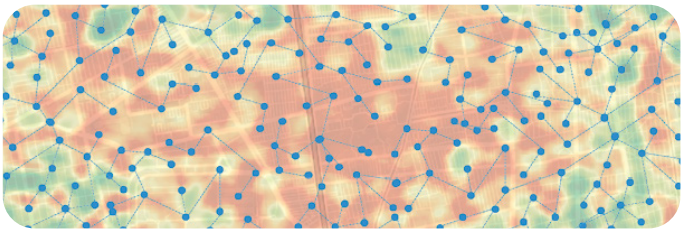
FRMs are incredibly useful for regulatory purposes, but it is not feasible to deploy them at the scale possible with low-cost sensors—the cost of a single reference station can be 10X or even 100X the cost of a low-cost sensor. By embracing Air Quality Monitoring 2.0, air quality managers can deploy dozens or hundreds of low-cost sensors for the cost of a single reference monitoring station. Advances in modeling allow air quality managers to leverage these high-density networks to understand air pollution at a resolution as high as 10 m².

Traditional FRM Network



In a traditional air quality monitoring network, a sparse network of FRMs collect highly accurate data in order to produce a regional average, often used for regulatory purposes.

Air Quality Monitoring 2.0



In Air Quality Monitoring 2.0, air quality managers leverage low-cost sensors to supplement existing FRM networks with high-resolution data that allows them to effectively respond to air pollution, when and where it strikes.

Despite the challenges that remain for low-cost sensors, such as lack of certification standards, governments and communities need tools that can track air pollution at the neighborhood level to effectively respond to air pollution in the 21st century. Air Quality Monitoring 2.0, characterized by the use of low-cost IoT sensors to supplement existing reference networks, is already being adopted by leading agencies around the world.

This guide provides an overview of best practices for planning and integrating low-cost sensor networks for 21st-century air quality managers.

Guide to leveraging low-cost sensors for Air Quality Monitoring 2.0

Cities including London, Paris, and Bangalore have embraced Air Quality Monitoring 2.0 by implementing indicative air quality monitoring networks to supplement existing regulatory networks. Here we present our lessons learned from these projects as a resource for other cities and air quality managers looking to install, manage, and calibrate a low-cost monitoring network as a way to save budget and modernize their air quality monitoring infrastructure.

Planning your low-cost network

Know your objectives

What is the primary goal of expanding your air quality monitoring infrastructure?

- What do you hope to learn about air quality? Are there specific questions to answer?
- What are your regulatory or non-regulatory performance targets (KPIs)?
- What spatial and temporal resolution will be necessary to achieve your goals?
- What pollutants must be monitored to support your goals? What are some typical concentration ranges (if known)?

Maximize public health benefits by directing limited resources toward the highest-value activities—most cities decide to focus on monitoring $PM_{2.5}$ and NO_2.

Determine your budget

Balance desired network performance with budget.

- Low-cost sensors can help you get the most spatial coverage for your budgetary spend.
- Consider allocating resources from other areas to allow you to maximize ROI.

Consider existing infrastructure

Conduct a gap analysis.

- What assets do you already have available?
- What gaps are the most important to fill?

Choose the right partners

Getting the right partners to the table and taking a collaborative approach during the planning phase helps secure buy-in and ensure all stakeholder needs are met.

- Technology partners who will provide the sensing technology.
- Community partners who can help identify siting priorities and communicate data findings.
- Air pollution or health scientists who can help analyze data and interpret health impacts.
- Deployment partners who have access to potential monitoring sites, such as parks or transportation departments, and can help with deploying devices.

Create a plan for how data will be used

It is important to think through how the data will be used at the beginning of a project.

- What decisions will be taken if readings are high? Will additional monitors or investigators be deployed?
- What quality assurance/quality qontrol (QA/QC) steps will be taken?
- What data quality objectives need to be met to ensure the data can serve the goals of the monitoring?

Validate the technology

Review third-party test reports, publications, and shared experiences from other agencies or cities

- Lab/chamber testing: most controlled but requires expensive equipment and technical team.
- Field testing via colocation: plan a colocation study if at all possible to facilitate accurate calibration of the data. Experts suggest allowing at least a month for optimal calibration performance.

Plan the scope and siting of your deployment

Based on agreed-upon goals, speak to partners to gather input for site selection.

- What sites are the highest priority for exposure assessment?
- What sites are available and suitable for monitors?
- How long will the devices be deployed?

Create community engagement strategy

This step is key to ensure that data from low-cost sensors is communicated appropriately to external stakeholders.

- How will you communicate the network to the community or other stakeholders?
- Will the data be publicly available on a website?
- Are any training or educational resources needed?

Choosing the right air quality monitoring technology partner

There are a wide range of low-cost sensors on the market, and finding the right solution may not be straightforward. Every tool has pros and cons and there are many considerations to be factored in before making a decision. The following table summarises the most important criteria that every team should take into account when evaluating a potential air quality monitoring partner.

Criteria	Why does it matter?	Key questions and considerations
Air quality measurements	Different sensors offer different pollutant profiles. Accuracy and precision also vary widely among low-cost sensors. **Choose a sensor that meets your needs.**	☐ What pollutants do you need to monitor, at what accuracy? Consider R^2, Root-Mean-Square Error (RMSE), and Mean Absolute Error (MAE). ☐ What sampling rate do you need for your desired temporal resolution? ☐ How precise are the sensors? High precision can save significant cost and labor when calibrating units.
Installation	If the sensors are not designed to operate self-sufficiently with flexible siting, installation can become an expensive and time-consuming process. **Opt for a solution that reduces complexity.**	☐ Will the monitors require access to other infrastructure such as electrical and WiFi? ☐ How much technical knowledge is required for installation? ☐ Will the site require special measures to prevent theft or vandalism?
Operation & maintenance	OPEX can be expensive with hidden maintenance costs. **Choose a solution that is robust and designed to operate with minimal maintenance.**	☐ Does the sensor demonstrate consistent and proven performance across different environments? ☐ Will the monitors be exposed to extreme weather conditions that may affect sensor readings? ☐ How much technical knowledge is required for maintenance? ☐ Does the company offer a warranty for its sensors?
Data quality, access & connectivity	How seamless and secure is the ability to access data from the monitors? **Opt for a solution that allows you to access data easily in order to draw conclusions and take action.**	☐ Will the company calibrate the sensor data, or would your team conduct its own calibration? ☐ How will you access data from the network? Does the provider offer a software dashboard or hardware only? ☐ Do you need on-board data storage? ☐ What data security does the company offer?
Customer service	Are you just purchasing a piece of technology, or will you have access to ongoing support? **Make sure you have the support you need for a successful network.**	☐ Does the company have a team dedicated to customer success? ☐ Is support for project design and implementation included in the price of the solution?
Third-party evaluations & references	A reputable air quality monitoring provider will be able to provide you with third-party verification reports and/or customer references. **Choose a provider you can trust.**	☐ Look for validation testing reports from testing centers such as AQ-SPEC, AirLab, and others. ☐ Before investing in a technology that will constitute a core part of your monitoring network, make sure to speak with other air quality managers that have used the technology.

Deploying and implementing your network

1

Establish your project team

Plan on having regular (bi-weekly) project meetings and planning with local partners to assess and resolve current and potential issues before they arise, to improve communication, and to increase cross-team transparency

Establish clear roles for both deployment and ongoing network management phases.

- Who owns the devices and data?
- Who will access the data?
- Who will install the devices and perform field maintenance?
- Who will handle Quality Assurance/Quality Control (QA/QC)?

2

Perform colocation

Colocate devices at a reference monitor to provide data for calibration.

- Choose a reference monitor that measures the concentration of the pollutant of interest (e.g., $PM_{2.5}$, NO_2) at least once per day and is representative of the area where sensors will be deployed (urban, roadside, park, etc.). Hourly measurements are the preferred and most common averaging period.
- Colocate sensors with government reference equipment for several weeks to a month before re-deploying in the field.

Look for sensors with very high precision to enable remote calibration

Remote Calibration lowers the cost, labor, and time requirements of traditional calibration. In this model (only possible with very high precision), a single sensor is colocated with the government reference equipment for the entire duration of the monitoring project, while the remaining sensors are concurrently deployed in the field.

3

Leverage local knowledge for installation

Work with local partners that have access to priority monitoring sites and can help deploy devices.

- Obtain permits to access and install monitors at the priority sites you selected.
- If using solar-powered monitors, ensure all devices are charged properly before installation and that all sites will receive sufficient sunlight.
- Take pictures of all deployment sites, this will come in handy when managing your network!

4

Perform initial calibration of data

Indicative sensors must be calibrated to output reliable absolute air quality readings that meet regulatory requirements in standardized units of measurement.

- Develop a calibration model for each indicative monitor based on the sensor readings from the colocation and any other applicable variables, such as temperature and relative humidity.
- Calibration requirements depend on the technology provider, but an accurate calibration model generally requires high variability in concentrations at the colocation site. If you observe very high values in the field but your calibration model was based on lower concentrations, the model may not be applicable and will need to be updated for the high-concentration situations.
- Some technology partners include calibration services as part of their service offering. Make sure to confirm if calibration services are offered by the provider you choose!

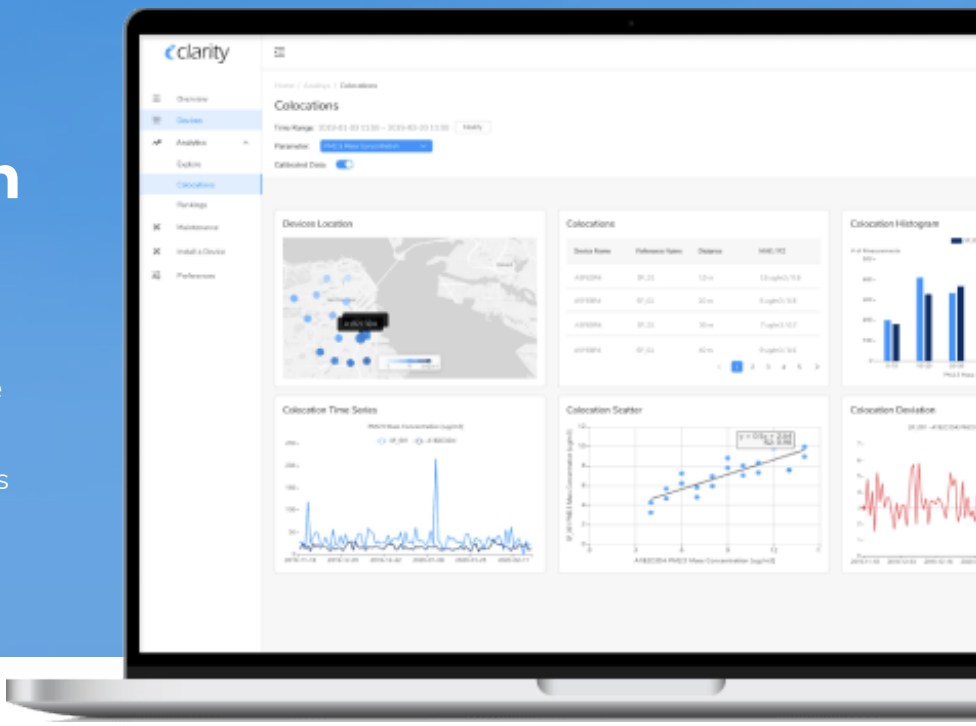
5

Monitor operational health of the network

If a monitor stops reporting data, how will you know?

Managing your network: moving from data to action

We can't manage what we can't measure, but measurement is just the first step to improving air quality with your network. The following steps can help you to ensure that your network is providing actionable insights for all stakeholders.



Review data regularly

Choose a solution that includes a web interface or API for easily and securely interacting with data.

Use your network as a screening tool

High readings on the indicative network can be used to prioritize where to send investigators or additional higher-cost monitoring equipment.

Create a decision matrix

Data from sensors can be used to make real-time decisions about whether to close facilities or move operations indoors to reduce unhealthy exposures.

Monitor and evaluate air quality interventions

Sensor networks can be used to assess whether policy interventions have created significant air pollution reductions.

Produce regular (e.g., quarterly) reports

Include community members and other stakeholders in this process to ensure all perspectives are reflected and updates are received by the appropriate groups.

Reports should include recommendations on policy and other measures that could be guided by observed trends. If you aim to use your network to influence policy, these reports will be a valuable resource to demonstrate both the data and the consensus of stakeholders involved with the process.

Air Quality Monitoring 2.0 has arrived

Save money while modernizing your air quality monitoring network

Air Quality Monitoring 2.0 is characterized by the use of indicative monitoring networks to supplement existing reference networks. Following the best practices laid out in this guide, this approach can be used to quickly and cost-effectively modernize your air quality monitoring network. Upfront research and preparation in planning your network will pay dividends, and finding the right technical partner for the job can help you you maximize the value of your network.

Clarity is here to empower you with local, real-time air quality data

Clarity Movement Co. was founded in 2014 to empower the world to reduce air pollution. The Clarity team leverages expertise in air sensing technology, IoT devices, and data analytics to provide the most reliable low-cost hardware + software air quality monitoring solution available on the market. Clarity's air quality sensing-as-a-service solution revolutionizes the way governments, businesses, and communities understand and respond to air pollution, and currently provides local, accurate, and scalable air quality monitoring to more than 85 cities across 40+ countries.

Want to speak with an Air Quality Expert?

We have helped over 85 cities in 50+ countries design and implement Air Quality Monitoring 2.0 networks.

Contact us for a free consultation on how to save money by modernizing your air quality monitoring network.

- √ Understand the impact of indicative monitoring for your stakeholders
- √ Learn about colocation, calibration, and moving from data to action
- √ Get short-term and long-term recommendations for modernizing your network

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4. Source: U.S. Government Accountability Office (GAO), Opportunities to Better Sustain and Modernize the National Air Quality Monitoring System, Appendix 3. Produced by the GAO via literature review and interviews with Environmental Protection Agency (USEPA) and state and local agency officials.