Public investment, private innovation:

The global market for air quality monitoring

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Foreword

by Claudia Sheinbaum, Mayor of Mexico City

Everyone deserves to breathe clean air, and yet communities around the world continue to struggle with the local impacts of air pollution. Too often, the health effects are not distributed equally, and where you live determines how likely pollution is to worsen your health or shorten your life.

The global pandemic put these longtime inequities into sharp focus as new evidence shows that the same people who lived with polluted air for decades are also at increased risk for severe illness from COVID-19. These findings underscore the need to clean the air we breathe and protect vulnerable populations.

Public pressure to better understand personal exposure to air pollutants and toxics is at an all-time high. And as leaders devise plans for building healthier, more resilient communities in a post-pandemic world, clean air needs to be made a priority. Fortunately, even before the pandemic, leading cities around have been showing bold leadership on tackling the global air pollution crisis. Cities that effectively and consistently implement comprehensive air quality management plans can significantly reduce air pollution to protect their residents' health while also addressing the climate crisis. However, a serious local, regional and global problem remains and much more needs to get done.

Recently, Mexico City joined 38 other cities across the globe in signing C40's statement of principles, pledging "to build a better, more sustainable and fairer society out of the recovery from the COVID-19 crisis". But while the commitment from cities to tackle the air pollution crisis is more powerful than ever before – that alone is not enough. To devise truly effective solutions that drive down pollution levels, leaders need access to more accurate and more localized data.

Because at the end of the day, we cannot fix what we cannot measure: enhanced air quality monitoring is key to maintain continued support for mitigation efforts.

As momentum grows to tackle the global air pollution crisis, city leaders can work collaboratively with the private sector and the civil society to accelerate clean air action by shining a light on air quality at a scale and scope never seen before.

New, cost-effective sensing technologies and data analytics can identify areas of dirty air that a sparse network of traditional monitors might miss, filling in gaps where modeled data isn't available and painting a more holistic picture of air pollution sources and impacts. Knowing where pollution is coming from, who's impacted by it and who's responsible for it makes for highly actionable information that policymakers can use to improve transparency and public health.

In Mexico City, being part of one of the largest metropolitan regions in the world with over 21 million inhabitants, we've struggled with our own suite of air pollution challenges over the last three decades. From being labeled as the "most polluted city in the world" in the early nineties, air quality significantly improved along the years as a result of a continuous efforts involving the local and federal government, the private sector and the citizens. The regulatory-grade Mexico City's air quality monitoring network has been key for this progress, by continuously providing data to assess air pollution, support the implementation of air quality goals and evaluate the effectiveness of emissions control strategies.

Monitoring has also informed us that air pollution ceased to decline around six years ago and it even started to increase again in the Valley of Mexico. Therefore, we recently launched a new set of high impact, science-based measures focused at key emission sources, aiming to bring back air pollution towards a downwards trend.

Technology innovation for improving air quality is one of those measures. Among other efforts, we are working together with Environmental Defense Fund and other local, national and international partners to harness the transformative power of new technologies to give people the knowledge to take action and scaling the clean air solutions we need to tackle air pollution.

We are starting to work on a new age of air quality monitoring, building upon our current capacities to enhance the identification and assessment of our air pollution concerns, while building public support for the development of tailored air quality policies, determining the effectiveness of our mitigation solutions, and holding polluters accountable.

In the short term, we will be taking advantage from the best information and experience around the world for developing technical guidelines for investing in effective, lower-cost sensors and advanced analytics so that these technologies can be adopted not just in Mexico City, but scaled to communities across the globe.

Only by measuring air pollution in the places where people live, work and play can policymakers truly create more effective, targeted solutions, increased local support and - ultimately - cleaner air. We look forward to working with innovators to try out new solutions, clean the air and recover stronger than ever.

"Sensing technologies are the new eyes and ears for cities to understand air quality, as well as the sources and health risks from pollution. We have a unique opportunity to work with the technology innovators, the academia and the private sector to connect health and technology to truly clean the air we breathe".

CLAUDIA SHEINBAUM, MAYOR OF MEXICO CITY

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Executive Summary

Ambient air quality monitoring is a fundamental element of a sound air quality management system. The systematic measurement of the quantity and types of air pollutants in the outdoor air enables air pollution control agencies to assess the extent of pollution, provide air pollution data to the general public in a timely manner, support implementation of air quality goals or standards, provide information on air quality trends, provide data for the evaluation of air quality models, support research — such as long-term studies of the health effects of air pollution — and evaluate the effectiveness of emissions control strategies.

Recent air quality monitoring technology developments are revolutionizing the ability to measure air pollutants. New, cost-effective sensor technologies, data analytics and modelling tools are boosting the capacity to gather, analyze, interpret and communicate unprecedented amounts of information on air pollution and its sources. These technologies also help identify local, tailored options to improve air quality.

As a result, air quality agencies across the globe are assessing whether these technologies can supplement current conventional monitoring systems. Agencies are also considering how to efficiently monitor and process increasingly large amounts of data. Demand is growing for sensor technologies and advanced analytics that can be scaled, and opportunities exist for further investment and innovation in this space.

This report serves as a primer on public and multilateral funding mechanisms and investments in air quality monitoring and key air quality policies for five regions from 2010-2020: the United States and Canada, the European Union, Latin America, India, and China. The analysis evaluates public funding for compliance-based conventional monitoring as well as lower-cost mobile monitors and sensors. The regional survey was limited to outdoor air quality, with a predominant focus on oxides of nitrogen (NOx), particulate matter (PM) and volatile organic compounds (VOCs).

For technology providers

This report provides a landscape of regional demand drivers, public funding opportunities and air quality policy contexts in key markets for air quality monitoring. Technology providers must learn the particular policy and technical context for the areas in which they work. As highlighted in the regional assessments, governments develop air quality policies and air quality monitoring networks that respond to unique national, regional and local concerns.

For regional and local governments

This report serves as a resource on funding, launching and scaling various types of air quality monitoring systems. Local agencies can find various best practices in the regional case studies, highlighting innovative monitoring systems in Los Angeles, United States; Berlin, Germany; Santiago, Chile; and Ahmedabad, India.

Executive Summary: Key Findings

While approaches to air quality mitigation and monitoring are varied and specific to regional policies and concerns, the following key findings emerge as trends across the five global regions in this analysis.

National air quality standards drive air quality monitoring programs and investments in regulatory-grade equipment.

The majority of public spending on air quality is currently directed at buying and maintaining regulatory-grade monitoring equipment — particularly reference equipment requiring more capital investment — to ensure regional and local compliance with national ambient air quality standards. Technology providers can look to pollution standards to indicate where governments might be expanding their monitoring efforts.

Regional and local agencies are the primary funders and implementers of air quality monitoring networks.

While ambient air quality standards are set at the national level, regional and local agencies are primarily responsible for funding and implementing regulatory-grade monitoring with support from national government agencies or — in the U.S., Canada and the European Union — international investors.

Monitoring is undertaken for "beyond compliance" purposes.

A growing number of cities and local jurisdictions across the globe are monitoring air pollution at the hyper-local level — collecting data, for example, on benzene emissions from oil refineries or nitrogen dioxide (NO_2) emissions from congested streets. This targeted approach may be required by law, but it also may be undertaken to respond to public pressure, or as a scientific campaign. Some regional and local agencies are funding pilot initiatives that use lower-cost sensor networks as educational and communication tools. In many cases, these networks also inform air pollution mitigation actions, especially as these networks are able to identify local pollution hotspots.

Public demand for lower-cost sensors has increased significantly in the past decade.

The demand for lower-cost sensors is expected to continue to increase as a result of pressure from environmental advocates and the public's desire to better understand personal exposure to air pollutants and toxics. Air quality agencies are responding to the increased demand by evaluating and calibrating new technologies in labs, launching community education programs and citizen science initiatives, and piloting local programs. Regional and local government agencies are the primary investors deploying lower-cost sensor networks, while national governments are investing in research and development efforts to validate lower-cost sensors.

Agencies view lower-cost sensors as complementary to regulatory-grade monitoring.

Data from regulatory-grade monitors are usually necessary for demonstrating compliance with national standards and regulations. Regulators and researchers remain skeptical of data produced by lower-cost sensors; therefore, government agencies and academic institutions across the five global regions presented in this report are evaluating how lower-cost sensors can complement — but not replace — existing networks.

As countries, regions and cities expand their air pollution monitoring networks, the need for data validation and analysis will also grow, especially due to regional and local governments' lack of capacity.

Data collected by monitoring technologies must be carefully validated and analyzed if it is to inform public policy decisions. As countries and cities expand monitoring networks in response to policy and public demands, there is an opportunity for technology providers to support government agencies in drawing informative insights from the data generated from these monitors, as well as to improve reference monitoring sites. Regional and local government agencies face a shortage of technical personnel to analyze and interpret data from the growing number of monitoring stations that generate significant amounts of data.

Effective communication of air quality data is a critical component of air quality management systems.

Agencies want to — or are compelled to — share air pollution data with their constituencies. For this reason, services that ensure real-time data is accurate and placed into an appropriate context for public viewers are critical to agencies that currently lack this communicative capacity. There is also growing interest from the public on how air pollution monitoring data can be interpreted for health outcomes.

Multilateral agencies are important sources of funding for beginning air quality monitoring efforts in locales where none exists and for building capacity for nascent efforts.

Notable funders, such as the World Bank and the United Nations Development Programme, are investing in better monitoring and management capacities across the globe. In countries where monitoring efforts are either in the early stages or scaling up, public spending on air quality monitoring consists of regulatory-grade monitoring equipment. Bilateral and multilateral funding opportunities will increase where a tangible link can be made between air quality data, measures to reduce emissions, health outcomes and climate outcomes. Connecting air quality improvements with greenhouse gas emissions reduction will also likely increase multilateral or bilateral funding for local air quality monitoring programs, notably in megacities.

Air pollution is not yet a priority government issue in some countries.

Some programs are underfunded and understaffed -- with growth opportunities in the areas of quality assurance and quality control. In many cities, conventional air monitoring is defective or non-existent, particularly in developing countries. This limits the availability of reference air quality data at a local scale, which might delay deployment of lower-cost sensors.

Regional Takeaways

The following regional findings distill high-level takeaways for each of the five gobal regions studied in this report. Additional information can be found in the individual regional assessments.

United States and Canada

- Federal agencies provide key funding support for air quality monitoring networks, but subnational entities provide a higher portion of overall costs to operate and maintain equipment.
- Funding for air quality monitoring at federal levels has been consistent over the past 10 years.

European Union

- Across the EU, air quality is a priority environmental issue, and funding air quality monitoring is considered a key component of air pollution mitigation.
- The EU has innovative funding methods for advancing new air quality monitoring technologies and analysis.

Latin America

- High concentrations of urban populations present opportunities for emerging technologies.
- Multilateral organizations provide critical support for national government agencies to establish ground-level and regulatory-grade monitors.

India

- National targets are driving the expansion of the national ambient air quality monitoring network and investments in alternative monitoring technologies, such as lower-cost sensors.
- Technology providers can support equipment calibration and data analysis.

China

- China’s “battle for blue skies” plan has resulted in significant investments in air quality monitoring.
- Air quality monitoring is limited in certain regions — alternative monitoring technologies are helping to fill that gap.

United States and Canada

Key Takeaways for Technology Providers

Federal agencies provide key funding support for air quality monitoring networks, but subnational entities provide a higher portion of overall costs to operate and maintain equipment.

State, local and tribal agencies in the U.S. and provinces and territories in Canada control the bulk of funding for air quality monitoring. Regional and local agencies also have broad discretion on the design of monitoring networks and disbursement of associated funding from federal and regional sources. In response to the growing interest for lower-cost sensors and other alternative monitoring equipment, federal, regional and local governments are investing in research and pilot initiatives to better understand how lower-cost sensors can complement the existing regulatory-grade networks.

Funding for air quality monitoring at federal levels has been consistent over the past 10 years.

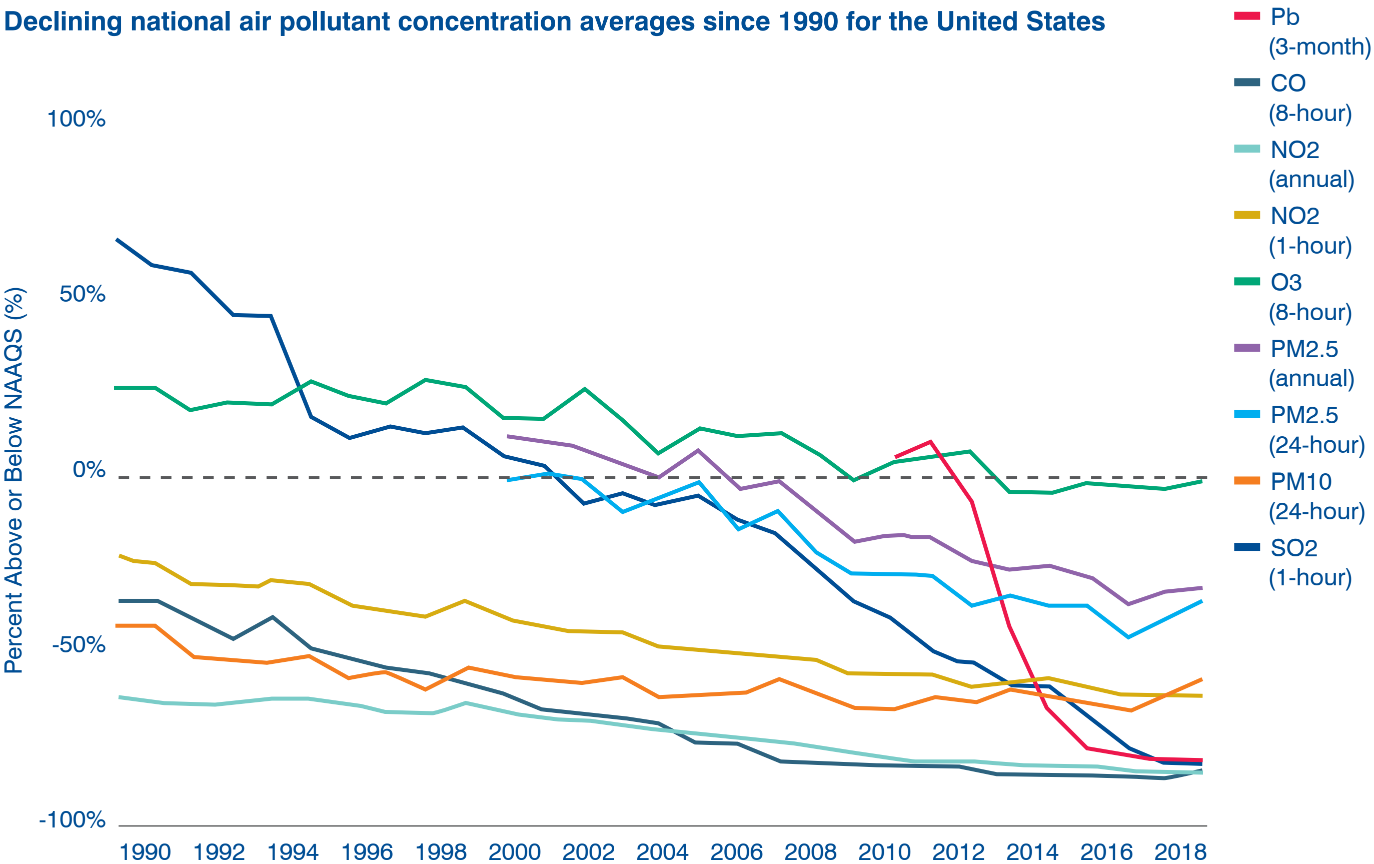
Based on an analysis of expenditures in the past 10 years, the United States Environmental Protection Agency (U.S. EPA) allocated over $111.7 million in grants involving air quality monitoring. Environment and Climate Change Canada's spending on the country's national air monitoring network totaled CA $59.9 million. Annual allocations have remained consistent, according to interviews with agency staff, consequently weakening agencies' purchasing power. There is interest in expanding the U.S. monitoring network and allocating more resources for it in an effort to improve the way the U.S. does monitoring.

Air Quality Policy in the U.S. and Canada

Since 1990, the United States and Canada have observed national declines in air pollutant concentration averages (See Figure 1 for U.S. trends).[1,2] In both countries, a collaborative system between federal government agencies and regional government agencies have driven improvements in air quality at national, regional and local levels.

Figure 1.

Declining national air pollutant concentration averages since 1990 for the United States



Source: U.S. EPA Air Quality System

In the United States, the U.S. EPA collaborates with state, local and tribal governments to implement the National Ambient Air Quality Standards (NAAQS) under the Clean Air Act. Similarly, Environment and Climate Change Canada (ECCC), also known as the Department of the Environment, implements an Air Quality Management System (AQMS) — formed in 2012 as an agreement between federal, provincial and territorial governments — to implement a comprehensive and collaborative approach for reducing air pollution.

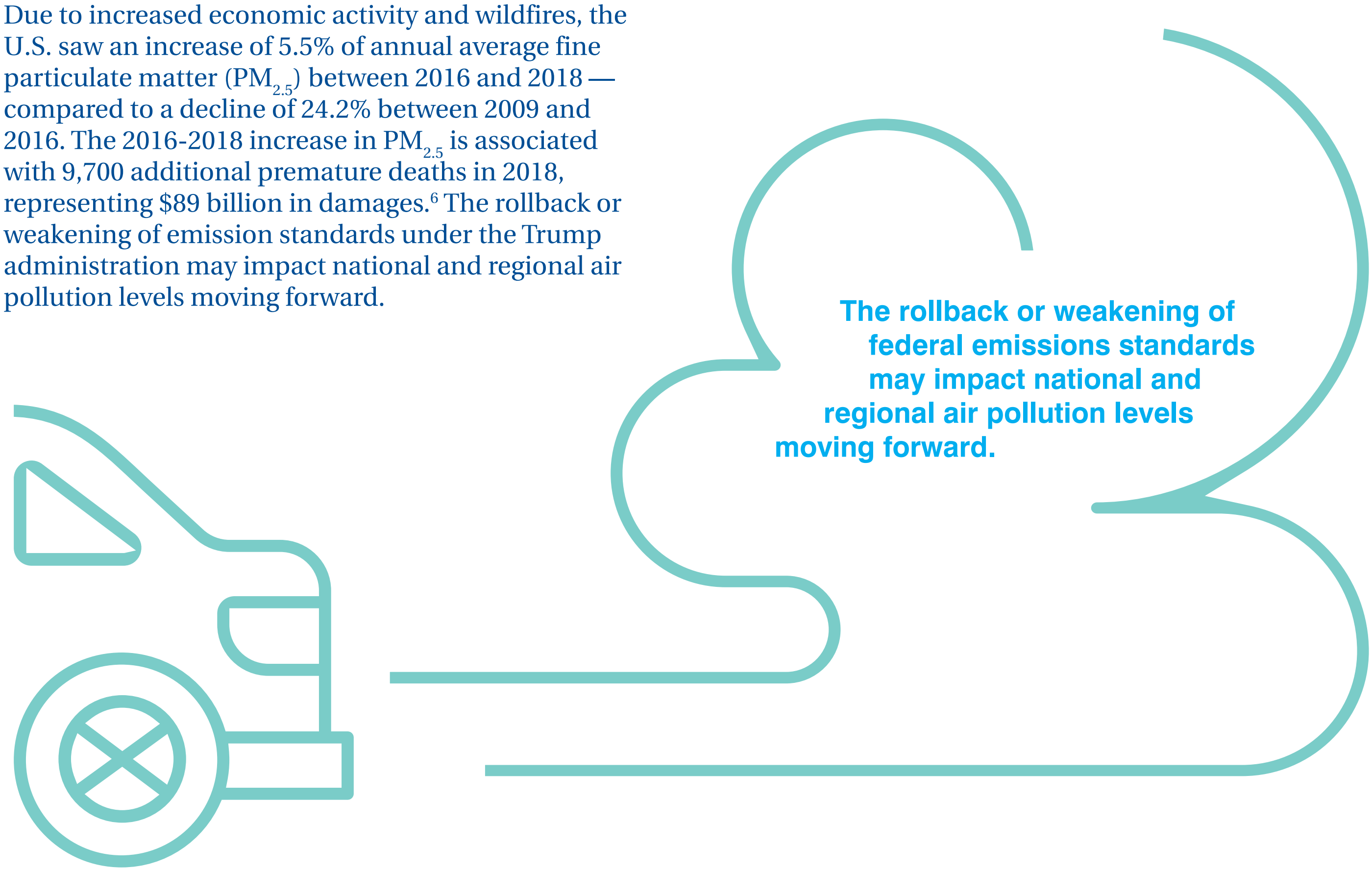
Priorities for AQMS include enforcement of the new Canadian Ambient Air Quality Standards (established in 2013) and assessing the contribution of different industrial sectors to air pollution and resulting health risks.[3] To ensure attainment of national ambient air quality standards, both countries have invested in an extensive network of air quality monitors, and regional and local governments serve as the primary funders and implementers with support from federal government agencies.

Given the profound impact of air quality on health outcomes and economic activity, mitigating air pollution emissions and monitoring progress have remained prominent issues across political administrations. The primary emission sources of air pollution for both countries are the following: stationary fuel combustion sources, industrial and other processes, highway vehicles and non-road mobile sources.[4] Sulfur dioxide (SO_2) emissions in the U.S. primarily originate from coal-fired combustion for electricity and industrial boilers. In contrast, electric power generation in Canada has a lower relative contribution to SO_2 emissions due to the country's large hydroelectric and nuclear capacity, as well as differences in population and demand. Primary sources of SO_2 emissions in Canada include nonferrous smelting and refining industry, upstream petroleum industry and electric power generation utilities. Meanwhile, non-road and on-road vehicle emissions account for the greatest portion of oxides of nitrogen (NOx) emissions for both countries. Compared to the U.S., the industrial sector in Canada contributes a higher percentage of volatile organic compounds (VOCs) due to oil and gas production. In the U.S., solvent utilization, agricultural livestock waste and field burning, prescribed burns, and petroleum storage and transport make up the majority of VOCs.[5]

Due to increased economic activity and wildfires, the U.S. saw an increase of 5.5% of annual average fine particulate matter ($PM_{2.5}$) between 2016 and 2018 — compared to a decline of 24.2% between 2009 and 2016. The 2016-2018 increase in $PM_{2.5}$ is associated with 9,700 additional premature deaths in 2018, representing $89 billion in damages.[6] The rollback or weakening of emission standards under the Trump administration may impact national and regional air pollution levels moving forward.

For FY 2020, the Trump administration proposed a $2.7 billion reduction in the U.S. EPA's budget (from $8.8 billion for FY 2019 to $6.1 billion for FY 2020). The budget includes $425.3 million for air pollution control programs in FY 2020. The programs include: $111.1 million for National Ambient Air Quality Standards implementation; $17.3 million for the Federal Stationary Source Regulations Program (also known as Air Toxics); and $160.9 million for grants for state, local and tribal air quality management.[7] Notably, the administration proposed a 30% reduction of grant funding for state, local and tribal air quality management — a key funding mechanism for air quality monitoring. Meanwhile, ECCC's budget increased by 19% between 2013-14 and 2017-18 and is planned to increase by 25.5% by 2021-22.[8] ECCC's air quality management budget has also remained consistent in the past 10 years.[9]

For both the U.S. EPA and ECCC, budgets for air pollution monitoring — embedded within larger air quality management budgets — have largely remained consistent in the past 10 years. The lack of budget increases has consequently reduced agencies' purchasing power.



Public Funding for Air Quality Monitoring

This overview assesses federal funding mechanisms and trends between 2010 and 2020. Implementation partners are primarily state, local and tribal agencies that control the bulk of funding for air quality monitoring.

United States: A Partnership Between the U.S. EPA and States, Local and Tribal Governments

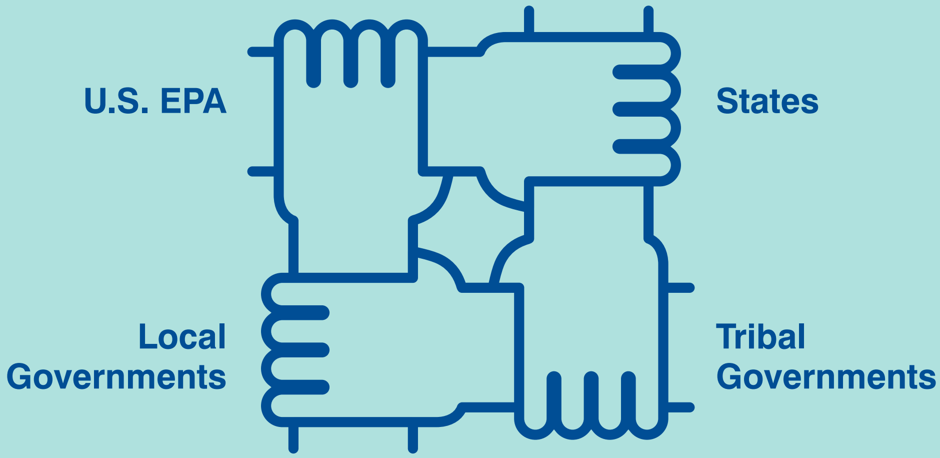
In the U.S., the National Ambient Air Quality Standards (NAAQS), under the Clean Air Act, led to the establishment of a national ambient air quality monitoring network. The national ambient air quality monitoring network monitors six air pollutants (criteria pollutants): particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and lead.[10] The national ambient air quality monitoring network is a partnership between the U.S. EPA and states, local and tribal agencies formed over 40 years ago. Funding has remained consistent with the exception of the introduction of the Fine Particle Standard in 1997, which expanded the monitoring network to include $PM_{2.5}$, increasing expenditures and technological investment.[11]

Under this partnership, states, local and tribal governments are responsible for the design, data quality assurance and operation of four major air quality monitoring networks:[12]

1. State and Local Air Monitoring Stations (SLAMS): Monitor criteria pollutants under NAAQS, consisting of 3,000 monitoring sites;
2. Photochemical Assessment and Monitoring Stations (PAMS): Provide enhanced monitoring of ozone, oxides of nitrogen (NOx) and VOCs, consisting of 75 monitoring sites;[13]
3. $PM_{2.5}$ Chemical Speciation Network (CSN): Established in 1997 as a component of the National $PM_{2.5}$ Monitoring Network, consisting of 75 monitoring sites;[14] and
4. Air Toxics Monitoring Network: Supports reduction of 187 air toxics, or hazardous air pollutants.[15]

These monitoring networks are primarily funded under Sections 103 and 105 of the Clean Air Act under Congressional budgets for the U.S. EPA, approved every fiscal year. Clean Air Act Section 103 includes funding specific to air quality monitoring whereas Section 105 funding are general "Air Program Grants." Given that the ambient air quality monitoring networks have

National Ambient Air Quality Monitoring Network



been established, a significant portion of expenditures are for operation and maintenance costs, rather than purchasing new equipment. For Air Program Grants, state, local and tribal governments have flexibility on how they are going to meet their obligations with the EPA, allowing state, local and tribal governments to address specific concerns which could include air quality monitoring.[16] Title V operating permits, under the Clean Air Act, are also another source of funding for states, enabling states to generate revenue to fund monitoring programs.[17]

Based on an analysis of expenditures between 2010 and 2019, the EPA allocated over $111.7 million in grants involving air quality monitoring. Within the U.S. EPA, the Office of Air and Radiation (OAR) is the primary source of funding, directly disbursing over $87 million (in 2016 USD) to grantees, followed by the U.S. EPA regional offices.

For-profit organizations, which include technology and service providers, are the primary recipients of the U.S. EPA's air quality monitoring expenditures, followed by government agencies, academic institutions and non-profit organizations. Between 2010-2020, for-profit organizations received over $103 million (in 2016 USD) to perform a wide range of services such as:

1. Supplying monitoring equipment to the U.S. EPA and other public agencies;
2. Spatial and temporal analysis of air pollutant data;
3. Operation and maintenance of monitoring sites; and
4. Software support and technical assistance.

State, local and tribal governments also have broad authority to design air quality monitoring networks, with the U.S. EPA playing an oversight role limited to monitoring networks that evaluate NAAQS attainment. Every five years, states conduct in-depth assessments of their regulatory-grade monitoring networks to determine if their networks meet the U.S. EPA's objectives and if they are responding to changes in health, technology and emissions trends. The next assessment is due in 2020. While these assessments are focused on NAAQS, states may include monitoring networks beyond evaluating NAAQS attainment, e.g., air toxics monitoring and piloting lower-cost sensor networks. Additionally, states publish annual monitoring plans, which highlight distinct regional or local drivers for air quality monitoring, such as Industrial Source Rules.

Regional governments play a larger role in the implementation of lower-cost sensor networks. Cities in the United States have piloted use of lower-cost sensors to identify emission sources and to engage and educate the public.[18] In Juneau, Alaska, the State Division of Air Quality established 21 lower-cost sensors installed around downtown Juneau in 2019 to monitor the impacts of cruise ships and other emission sources.[19] In Denver, Colorado, the expansion of a 10-mile stretch of I-70 led to scrutiny of potential impacts to children attending nearby schools, leading to the installation of a lower-cost sensor network at the public schools.[20] These pilot initiatives are largely funded by states and cities. In California, the Community Air Protection Program addresses the disproportionate impacts of air pollution in environmental justice communities, requiring selected communities to develop community air monitoring plans, which includes the use of lower-cost sensor networks in complement with research and regulatory grade monitors.[21]

Research Funding

The U.S. EPA awards various research grants to advance air pollution monitoring. These grants are primarily provided to research and academic institutions, which then purchase equipment or utilize the services of technology providers. The U.S. EPA retains considerable discretion in selecting recipients, determining amounts of awards and approving work plans.[22] For example, in 2014, the Science to Achieve Results (STAR) program funded a total of approximately $4.5 million for six research organizations to work with local communities to explore data quality, durability and uses of lower-cost sensors.[23] The Regional Applied Research Effort (RARE) program is another funding source under the U.S. EPA through the Office of Air and Radiation (OAR) and Office of Research and Development (ORD), which disburse RARE grants across the U.S. EPA regions to further examine emerging monitoring technologies.[24,25]

Federal, state and local agencies are conducting various research and pilot initiatives on emerging monitoring technologies, particularly lower-cost sensors. At the federal level, OAR is focused on better understanding the quality of data produced by sensors, how to interpret data produced by sensors and helping the public understand differences in monitoring data. For example, in collaboration with state, local and tribal governments, the U.S. EPA is evaluating how lower-cost sensors perform compared to regulatory-grade monitoring stations.[26]

Canada: A Collaboration Between Environment and Climate Change Canada and Provinces and Territories

Established in 1969, the National Air Pollution Surveillance (NAPS) network serves as the primary monitoring initiative to determine compliance with the CAAQS, which are largely consistent with U.S. standards. The joint federal, provincial, territorial and municipal monitoring initiative includes continuous analyzers for sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3) and fine particulate matter ($PM_{2.5}$ and PM_{10}) that are used to provide continuous air quality measurements and includes monitoring stations for toxic substances such as polycyclic aromatic hydrocarbons, dioxins and furans, and heavy metals analyzed over an iterative 24-hour cycle. Today the NAPS network consists of 286 sites in 203 communities located in every province and territory. Distinct from NAPS, the Canadian Air and Precipitation Monitoring Network (CAPMoN) also monitors rural and remote areas for research purposes.[27]

In the past 10 years, notable investments in air quality monitoring for Canada include: ensuring monitoring instruments are properly maintained and replacing instruments that have reached their end of life; investing in the Canadian Air Health Index and real-time mapping websites; and expanding laboratories and analytical equipment for detailed chemical analysis, e.g., VOC and $PM_{2.5}$ speciation.[28] Beyond regulatory-grade, or reference, monitors, ECCC is collaborating with the U.S. EPA on testing lower-cost sensors. ECCC staff indicated that the agency's engagement with lower-cost sensors is currently at an "exploratory" stage.[29]

According to a survey by ECCC staff, provinces and territories contribute approximately CA $32 million, while ECCC contributes CA $7.7 million annually to the NAPS network. In the past 10 years, ECCC's expenditures for the NAPS network total CA $59.9 million ($55.6 million in 2016 USD) with spending spread across provinces and territories. Since the establishment of the Canada-United States Air Quality Agreement in 2000, budgets and expenditures for the NAPS program have been consistent. Annual fluctuations in total expenditures are due to capital investments in the form of new monitoring equipment and laboratory equipment for analysis. However, the consistency of the agency's budget for the NAPS program has consequently weakened the agency's purchasing power, especially since ECCC purchases the majority of its monitoring equipment from the U.S. where the value of the Canadian dollar has declined.[30]

Provinces and territories assume most of the costs in monitoring networks, such as providing infrastructure and collecting the data. A memorandum of understanding between ECCC and the provinces and territories of Canada was signed in October 2019. ECCC's responsibilities include collaborating with the provinces and territories in overall management of the NAPS program, locating NAPS sites, and coordinating a national quality assurance and audit program. Meanwhile, provinces and territories' responsibilities include providing land and infrastructure and associated costs for each NAPS site and collecting, processing, managing, analyzing and reporting continuous air quality monitoring data.[31]

Beyond the NAPS program, provinces and territories are independently funding air pollution monitoring to address regional or local issues. For example, the province of Nova Scotia uses revenue generated from its pollution tax to fund air quality monitoring programs. Similarly, in the province of Alberta, revenue generated from pollution pricing fund monitoring programs led by nonprofit organizations in the province's airsheds.[32]

For an example of funding for air quality monitoring programs in the U.S. and Canada, read the case study on Los Angeles: Community Air Monitoring for Environmental Justice.

Case Study

Los Angeles - Community Air Monitoring for Environmental Justice

Location	Sections of the cities of Wilmington, Carson and West Long Beach in California, USA
Total Area Monitored	71.86 square miles (186.1 km^2)
Implementing Agencies	South Coast Air Quality Management District (SCAQMD) and the California Air Resources Board (CARB)
Project Timeline	October 2019 - present
Targeted Source(s) of Emissions	Port and goods movement activities, petroleum refineries, oil wells
Targeted Pollutants for Measurement	VOCs (benzene), diesel particulate matter
Driver of Monitoring Program	Air quality mitigation policy enacted by the California legislature in 2018
Funding Source(s)	California state budget

Assembly Bill 617 was passed by the California legislature in 2018 to address the disproportionate impacts of air pollution in environmental justice communities. The measure requires local air districts, in partnership with a community steering committee, to develop community emission reduction plans to reduce air pollution and toxic air contaminants from commercial and industrial sources. Priority sources identified by the community are the target of the Community Air Monitoring Plan (CAMP),[33] which are developed and implemented by the air district. The analysis of the data collected from community air monitoring programs is intended to inform future community emissions reduction plans and will be used to track progress.

In Wilmington, Carson and West Long Beach, multiple monitoring programs were active prior to the CAMP. The Ports of Long Beach and Los Angeles have voluntarily provided real-time regulatory grade monitoring from six stations since 2007. South Coast Air Quality Management District (SCAQMD) — responsible for regulating stationary sources of air pollution in Southern California's South Coast Air Basin — has three active regulatory monitoring stations for documenting compliance with U.S. air quality standards in the community. SCAQMD also requires real-time facility stack monitoring as well as real-time fence-line and community air monitoring at refineries. While there were on-going programs in the area, the development of the Wilmington, Carson and West Long Beach monitoring program or CAMP provided an opportunity to design a program that went beyond air quality standards and addressed toxics, such as benzene and diesel PM.

SCAQMD received $20 million from the state to implement year 1 of the AB 617 to develop a CAMP and a community emission reduction plan for three separate communities of which Wilmington, Carson and West Long Beach is one. A SCAQMD representative estimated the following staffing to scale and implement programs: monitoring (~20 FTE); public affairs (~10 FTE); enforcement (~10FTE); and planning (~30 FTE).

Monitoring Technology and Data Management

The CAMP uses a combination of existing and new air monitoring equipment to address community concerns. This includes EPA-approved methods for measuring particle and gaseous pollutants (i.e. Federal Reference Methods and Federal Equivalent Methods or FRM and FEM, respectively), air monitoring instruments and equipment used for EPA-funded national programs for air toxic measurements, or other appropriate technology if FRM/FEM equipment for measuring a particular pollutant (or set of pollutants) do not exist (e.g. optical remote sensing and other state-of-the-art technologies). Specific details are summarized below.[34]

Three mobile platforms

a. Platform 1: Equipped with FRM and FEM research-grade instruments to measure mass and number concentrations of PM of various sizes, BC, CO, NO2, NO3 and Methane. Includes anemometer and GPS.

b. Platform 2: Multiple advanced remote optical sensing (ORS) monitors that can measure a wide range of gaseous pollutants, including air toxics. Especially valuable for identifying leaks from fugitive emission sources.

c. Platform 3: Proton Transfer Reaction–Mass Spectrometer (PTR-MS) capable of simultaneous real-time monitoring of hundreds of VOCs present in ambient air.

Two fixed air monitoring trailers (all equipped with FRM and FEM research-grade instruments)

Network of air quality sensors

a. SCAQMD has partnered with Aclima to install a dense network of sensors to support an update to the MATES program, an Environmental Justice initiative that provides information on air toxics monitoring at about 10 sites throughout the South Coast Air Basin for a one- to two-year period. Over 30 air pollutants are measured at each fixed station, including gaseous and particulate air toxics. For the purposes of the CAMP, sensors are primarily used to complement and augment the capabilities of fixed monitoring locations.

Process for Selecting Technology Providers

SCAQMD has an extensive vetting process for monitoring technologies, including the Air Quality Sensor Performance Evaluation Center, or AQ-SPEC, the most comprehensive sensor evaluation program in the United States, which aims to provide citizen scientists and other sensor users with unbiased information on sensor performance based on rigorous field and laboratory testing.

SCAQMD releases requests for proposals for monitoring technologies and services. SCAQMD can also pursue sole source contracts for specific monitoring technologies with approval from its Governing Board.

SCAQMD looks for opportunities to partner with technology providers to vet and learn about new technologies and services. SCAQMD prefers to build long-term relationships with technology providers that can begin with a proof of concept and grow into a contract and long-term relationship.[35]

Data Management and Sharing

Under law, the data collected under the CAMP must be transferred to a data management system run by the California Air Resources Board in near real time and available publicly. This platform is still under development so SCAQMD has provided public access to an online data display tool that only shares fixed regulatory monitoring data in the short term. As of now, there are no plans for real-time display of mobile measurements given the needed analysis to place measurements in context.

Generally, SCAQMD prefers to receive raw data and run its own modeling analysis and QA/QC of data for FRM and FEM instruments. SCAQMD has begun to partner with technology providers to provide data analytics for lower-cost sensor networks which produce massive amounts of data and also contract with website designers to create publicly accessible online data display tools.[36]

Impact and Next Steps

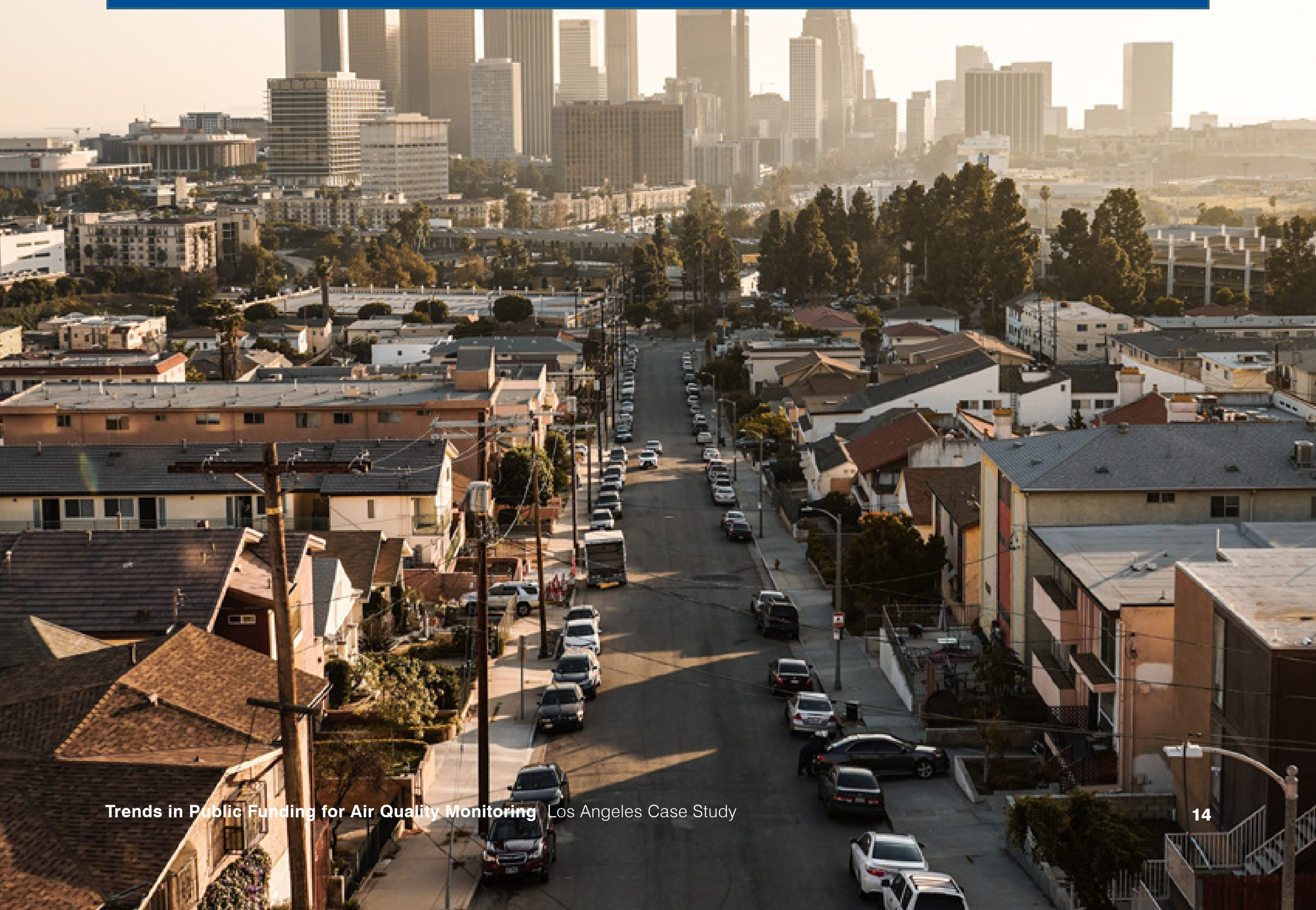
SCAQMD will use updated data to assess the communities most affected, identify key sources of pollution and develop targeted emissions reduction plans to reduce community exposures to air pollution. The program is in the first stages of being implemented and the air district has just begun to present the preliminary results.
Next steps include fully implementing the monitoring program in 2020 and determining priority mitigation measures that were included in the community emission reduction plan. Specific actions under consideration include:

1. Improve refinery flare notifications.
2. Conduct surveillance and air measurements to identify potential leaking vessels.
3. Evaluate designated truck routes.
4. Prioritize oil drilling and production wells and conduct mobile air measurements to identify leaks.
5. Develop emission reduction regulation on railyards.

Lessons Learned

For many air quality agencies facing pressure to do community-focused monitoring, effective air quality monitoring technology isn't enough on its own. Communication and trust are central elements to effective community air monitoring programs. It is challenging to communicate air quality data because numbers and readings have little significance without context. Given the complexities and nuances of the information for the majority of the public who is not familiar with air quality monitoring, trust and open lines of communication are central to building credibility in data. Strategies for building trust include:

1. **Provide adequate time for outreach. Go out into the communities to hold public meetings after work hours.**
2. **Listen to stakeholders who know their communities and problems through first-hand experience.**
3. **Provide transparent, easily accessible data on a user-friendly platform.**
4. **Staff a responsive enforcement and compliance team that can respond to community complaints in a timely manner.**
5. **Always include the next actionable step when presenting data findings.**



European Union

Key Takeaways for Technology Providers

Across the European Union (EU), air quality is a priority environmental issue. Funding air quality monitoring is considered a key component of air pollution mitigation.

Monitoring is typically integrated into most grants towards air quality mitigations programs in the EU and plays an important role in ensuring the effectiveness of mitigation measures. The largest source of funding for air quality comes from individual country budgets. Other sources of public funding for air quality measures and monitoring include municipal budgets and EU funding programs.

Europe has innovative funding methods for advancing new air quality monitoring technologies and analysis.

The EU, more than other regions, is evaluating the use of lower-cost sensors and advanced data processing to support existing policies. Government agencies are looking for strategies to use citizen science and lower-cost sensors as a complement to regulatory monitoring systems. Substantial funding exists for technology providers or local governments partnering with technology providers.

Air Quality Policy in the European Union

Air quality is a priority environmental concern in the EU. The European Environmental Agency (EEA) estimates 90% of citizens living in cities are exposed to pollutants at higher concentrations than the air quality levels deemed "harmful to health."[37] At the same time, the public expects authorities to implement effective measures to reduce air pollution and it's impacts.[38]

Government agencies (city, country, regional) are looking at new ways to monitor and evaluate impact from air quality mitigation activities as a result of growing public pressure and engagement around air quality. One example is a new regional citizen science campaign, CleanAir@School, which launched in 2018 and is a joint initiative of the European Network of the Heads of Environmental Protection Agencies (EPA) and the EEA. Under the initiative, citizens are monitoring nitrogen dioxide around schools across Europe using a common approach. A goal for the program is to evaluate whether "in the light of this knowledge, parents shift away from bringing their children by car to school."[39] As shown in this program, the European Commission is looking to "promote the wider use of citizen science to complement environmental reporting."[40] These initiatives and other local activities supplement regulatory monitoring required under the EU's clean air policy framework.

Since the late 1970s, the EU has worked to improve air quality with some of the first air quality standards established in 1980 for sulphur dioxide (SO_2) and particulate matter (PM).[41] While significant progress has been made, air quality remains poor in many areas despite reductions in emissions and ambient concentrations.

The EU's clean air policy is based around four central policies:[42]

1. The United Nations Economic Commission for Europe (UNECE) Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under the Convention on Long-range Transboundary Air Pollution (LRTAP), which set national emission ceilings for 2010 to 2020 for four pollutants: SO_2, nitrogen oxides (NO_x), volatile organic compounds (VOCs) and ammonia (NH_3);
2. National Emission Ceilings (NEC) Directive (EU, 2016) which codified the Gothenburg Protocol for the EU and established ceilings for the total national emissions for SO_2, NO_x, non-methane VOCs, NH_3 and fine particulate matter ($PM_{2.5}$);
3. Ambient air quality standards set out in the Ambient Air Quality Directives (2004, 2008), which established health-based standards for a range of pollutants including ozone (O_3), PM_{10} and $PM_{2.5}$ and nitrogen dioxide (NO_2); and
4. Emission and energy efficiency standards for key sources of air pollution (vehicle emissions, production and industry), which are developed through EU legislation.

EU member countries develop plans and implement national and local measures to comply with both the Ambient Air Quality Directives as well as the NEC Directive. The major sources of air pollution include transportation (on-road and off-road); commercial, institutional and household; as well as energy production and distribution. An EEA report evaluating city-level implementation of air quality plans from 10 European cities concluded that the majority of mitigation measures target road traffic (lowering speed limits, congestion charges). Additional local measures included expanding district heating, using cleaner fuels for heating, introduction of low-emission transport zones and switching to cleaner buses or trams.[43]

In 2018, the European Court of Auditors issued a report evaluating the effectiveness of EU actions to protect human health from air quality. Given the level of investment, one of the recommendations emphasized the need for more result-oriented air quality plans.[44] As cities in the EU look to make the case for new air quality measures, they are looking for new tools and methods to quantify the impacts of proposed measures.

Monitoring Initiatives in the European Union

The Convention on LRTAP led by UNECE established the European Monitoring and Evaluation Programme (EMEP) to track progress towards air quality directives established under the Gothenburg Protocol.[45] To ensure information on emissions reported by member states, the NEC Directive requires member states to use the EMEP/EEA air pollutant inventory guidebook.[46] Across the EU, reporting to the European Commission is the responsibility of the national level and leverages local air quality databases for reporting to demonstrate progress towards Ambient Air Quality Directives and NEC Directives. Monitoring is typically operated at the regional level by some type of central administrative agency in each country. According to the EEA, for the 29 countries with available data, there are close to 5,000 urban/local sites, and more than 800 regional sites.[47] The majority of EU countries utilize standard or advanced/state-of-the-art methods for compounds measures, with some countries in Eastern Europe using non-standard methods. There are no standardized quality assurance/quality control (QA/QC) procedures across all monitors.[48]

Additionally, the EU funds Copernicus Atmosphere Monitoring Service (CAMS), which provides consistent and quality-controlled information related to air pollution and health, solar energy and greenhouse gases. CAMs uses satellite Earth observation, in situ (non-satellite) data and modeling. CAMS is the primary source of data for the EEA-run European Air Quality Index which provides hourly air quality updates.[49]

Public Funding for Air Quality Monitoring

Significant funds have been directed towards air quality across the EU and vary by region. While EU-wide data are not available on total investments for air quality, the EU's Cohesion Policy Funds, which include European Regional Development Fund (ERDF), European Social Fund (ESF) and Cohesion Fund (CF)), provide aid and financing for regions that have a GDP per capita below 75% of the EU average. Based on a 2019 analysis, over 4.5 billion euros (USD 4.95 billion) of Cohesion Policy Funds were invested in air quality from 2000-2020.[50]

The largest source of funding for air quality comes from individual country budgets. For example, Poland, which has some of the worst air quality in the EU, rolled out a 25 billion euros ($29.6 billion in USD) program in 2018, which hoped to leverage financing from the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) to provide grants and loans to renovate 4 million homes and buildings with better insulation and more efficient heating systems.[51]

England, which has one of the most robust air quality monitoring programs in the EU, invested 2.454 billion GBP ($3.16 billion in USD) in commitments on air quality and cleaner transport from 2015-2020.[52] From 2016-2020, England invested 18.7 million GBP ($24.1 million in USD) in its monitoring networks, or .075% of total spending on air quality and cleaner transport.[53]

For the purpose of this analysis, we have focused on public funding for air quality monitoring through EU initiatives. The bulk of funding for air quality monitoring exists at the country, regional and city levels; given the breadth of countries in the EU, range of detailed publicly available data, diverse approaches to air quality monitoring and multitudes of languages, access to these sub-regional levels of information is limited and challenging.

The EU funds Copernicus Atmosphere Monitoring Service (CAMS), the primary source of data for the EEA-run European Air Quality Index, which provides hourly air quality updates.

Key Public Funders and Funding Mechanisms

Sources of public funding for air quality measures and monitoring include municipal budgets, national/regional budgets, fiscal incentives and EU funds.[54] The European Investment Advisory Hub, released "Financing Air Quality Plans: Guidance for Cities and Local Authorities" in 2019 and identified the following sources of funding for air quality plans.

Table 1:

Main funding and financing sources for air quality measures[55]

Source	Most Common Form of Financial Support
European Investment Bank	Investment loans, framework loans, intermediated loans, equity, guarantees
European Bank for Reconstruction and Development–Green Economy Transition (GET)	Guaranteed loans, direct equity, equity funds, and credit lines in the context of individual green projects
World Bank	Mostly loans and guarantees
European Regional Development Fund	Grants, financial instruments
Cohesion Fund	Grants, financial instruments
LIFE Programme 2014-2020	Grants, financial instruments
Connecting Europe Facility (CEF)	Grants, financial instruments
Urban Innovative Actions	Grants
European Economic Agreement (EEA)	Grants

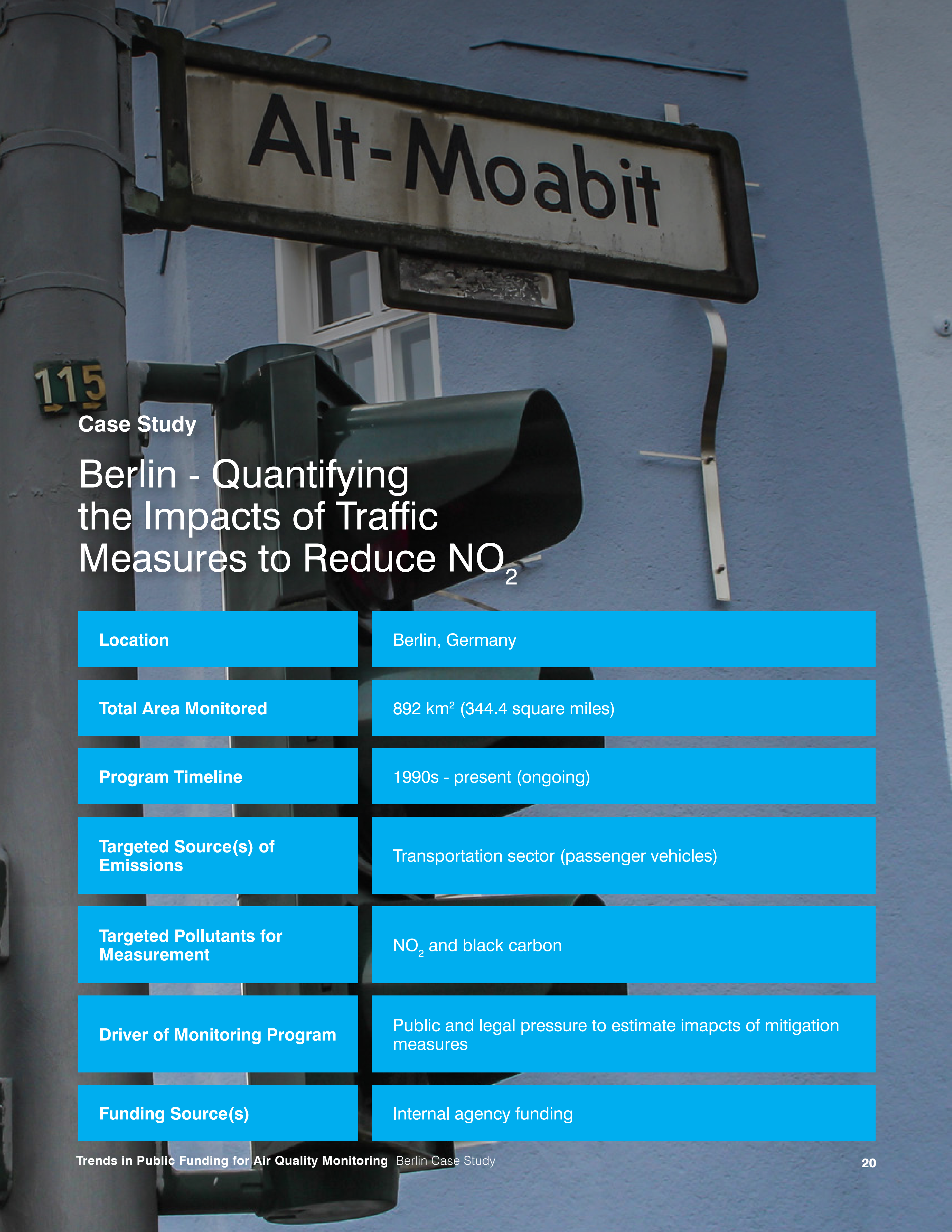
Monitoring tends to be part of most major grants towards air quality programming in the EU. However, it is quite challenging to extricate what portion of each project budget is allocated directly to monitoring, analysis and communication of data. The primary sources of funding outside of country-level budgets are: the LIFE Programme, Horizon 2020 and Urban Innovative Actions.

The LIFE Programme is the European Commission's funding instrument for environment and climate action. For the 2018-2020 LIFE Multiannual Work Program, 1.24 billion euros was committed to the sub-programme for the environment and 97 million euros was made available to Integrated Projects for Environment. Eligible projects included helping member states and regional/local authorities in the implementation of Air Quality Plans and national air pollution control programs and includes funding for "monitoring implementation of and compliance with the targeted measure; sharing best practices; employing effective methods for the preparation, revision and environmental assessment of the targeted measures; and increased monitoring capacity through e.g., highly dispersed and real-time monitoring techniques established coherently in multiple localities, increasing the opportunities and information-base not only for the assessment of plans but also for creating new, dynamic plans."[56] A similar call for projects will be released in 2020. Integrated Project funding is typically 10 million euros and allows co-financing with other programs such as the ERDF.

Horizon 2020 is the largest EU research and innovation program, and has directed over 89 million euros in funds to improving air quality monitoring modeling and technologies.[57] As an example, in 2016, the University of Ireland coordinated a 5.8 million euros project with cities, technology providers and other research institutions to "deploy a network of air quality and meteorological sensors (both stationary and mobile) and evaluate through analysis and a suite of up-to-date numerical modelling the benefits expected from the interventions on a neighbourhood and city-wide scale for several aspects ranging from quantification of pollutant concentration to exposure."[58]

Urban Innovative Actions (UIA) is an initiative of the EU that provides urban areas throughout the EU with resources to test new and unproven solutions to address urban challenges.[59] The UIA program has released two calls for proposals directed at air quality, the most recent of which closed in December 2019 and included proposed projects for citizen science and the use of indicative air quality measurements to complement official air quality monitoring stations. Previous grants include a $5 million (USD) grant in 2018 to the Aix Marseille Provence to launch Digital Alliance for Marseille Sustainability (DIAMS), a program focused on providing high quality data collected by leveraging microsensors and advanced data-processing.[60]

For an example of funding for air quality monitoring programs in Europe, read the case study on Berlin: Quantifying the Impacts of Traffic Measures to Reduce NO_2.



Case Study

Berlin - Quantifying the Impacts of Traffic Measures to Reduce NO_2

Location	Berlin, Germany
Total Area Monitored	892 km^2 (344.4 square miles)
Program Timeline	1990s - present (ongoing)
Targeted Source(s) of Emissions	Transportation sector (passenger vehicles)
Targeted Pollutants for Measurement	NO_2 and black carbon
Driver of Monitoring Program	Public and legal pressure to estimate imapcts of mitigation measures
Funding Source(s)	Internal agency funding

Case Study: Berlin - Quantifying the Impacts of Traffic Measures to Reduce NO_2

The Senate of Berlin, as an entity controlling both the city and federal state of Berlin, is tasked with compliance monitoring for EU air quality directives as well as Berlin's local clean air plans. The Senate of Berlin relies on internal funding for air quality monitoring and analysis. EU regional funding opportunities like the European Regional Development Fund (ERDF) have been used to implement local mitigation measures, such as retrofitting Berlin's buses with particulate filters, but the agency has not yet applied for any monitoring-specific funds.

Berlin has monitored a wide variety of pollutants since the 1980s. Berlin's Senate Department for Environment, Transport, and Climate Protection engages with a wide range of monitoring efforts tied to their local mitigation policies. In recent years, monitoring efforts have redoubled as the result of a Berlin court order calling for more stringent measures to meet the nitrogen dioxide (NO_2) limit values — for example, by introducing driving bans for diesel vehicles along portions of eight different roads throughout the city. The court order included the requirement that the city monitor the effectiveness of the driving bans and the trends for other polluted roads to evaluate whether additional bans — or other measures, like speed limits — should be introduced. This has emphasized the government's need to carefully monitor NO_2 along main roads throughout the city.

The Senate Department for Environment, Transport, and Climate Protection is implementing a set of strategies dedicated to limiting particulate matter and NO_2. Two critical strategies are a ban on heavily NO_X polluting diesel cars and the introduction of a 30-kilometers-per-hour speed limit on certain popular highways. Speed limits have been in effect since around 2011, after public discontent with the loud noise and heavy traffic from highways convinced the traffic management agency to enforce a strict speed limit on a few key roads. Since then, the air quality managers in Berlin have looked for opportunities to scale speed limits on roads where NO_2 thresholds are exceeded. To monitor the effects of speed limits after they have been put into place, the Department mainly uses passive samplers strategically placed at hotspots to evaluate the impacts of the measure. The passive samplers were initially implemented as a voluntary program in the 1990s, however, the court order requiring increased monitoring is driving a scaled-up implementation of the program.

Monitoring Technology and Data Management

The monitoring technologies utilized by the Senate Department for Environment, Transport, and Climate Protection to evaluate impacts from reduced speed-limits and banning of specific diesel vehicles include:

- **Sixteen regulatory-grade reference monitoring stations:**

  The monitors are located at traffic-orientated sites, in the urban background and in the outskirts of the city. These monitors are used primarily for ensuring compliance with European air quality standards. Since 1975, air quality in Berlin has been monitored continuously by Berlin's air quality monitoring network (BLUME).

- **A measuring vehicle fully equipped for automatic measurements.**

- **A supplementary network of small and lower-cost samplers (RUBIS and passive samplers):**

  These measurements have supplemented BLUME since 1997. RUBIS samplers are installed at lampposts on main roads. The miniaturized devices each contain a particle sampler for the analysis of soot (tracing black carbon, initially accompanied by an adsorption cartridge for the tracing of benzene). The RUBIS devices are collocated with NO_2-passive samplers. As of the passage of Berlin's 2018 annual report on air quality, the RUBIS and passive sampler network is comprised of 30 sites, though this number is increasing for NO_2 by at least an additional 13 sites. Two of the sites equipped with RUBIS and six sites with NO_2 passive samplers are collocated with reference monitoring stations to ensure the data can be compared with the automatic measurements.

The costs of operating Berlin's air quality network of 16 automatic stations, one mobile station, and the supplementary network of small and lower-cost samplers totals between 300,000 euros and 400,000 euros annually for maintenance, plus 250,000-350,000 euros for new investments (excluding staff costs).[61] The NO_2 passive sampler measurements add approximately 60,000 euros, excluding staff costs, to the department's annual expenditures. The Department for Environment, Transport, and Climate Protection also allocates funds for specific assessments, such as its special equipment for measuring black carbon.

Hotspots were specifically chosen based on where the city is enforcing its diesel ban as well as the speed limit. The agency originally had around 20 such samplers in place, but the number of passive samplers has now more than doubled.

The passive sampler tubes are collected every two weeks and analyzed in a lab to produce two-week averages, from which annual averages are calculated to assess the compliance with the current limits. However, due to increased public interest, the agency now publishes biweekly numbers, despite their variable and less reliable nature. The agency's laboratory must work efficiently to validate the data soon after it is collected in two-week intervals in order to publish it as quickly as possible.

In-house researchers continuously validate the air quality models with monitored data to understand variations and explain them. A detailed list of the models used by the department, including which models are used in what cases, can be found in the agency's Air Quality Plan for Berlin 2011-2017.[62] The Plan has recently been updated and will soon be published in English as well. The results of the air quality modelling — as well as an archive of all air quality data measured by the Department — is published in Berlin's Environmental Atlas.[63]

Impact and Next Steps

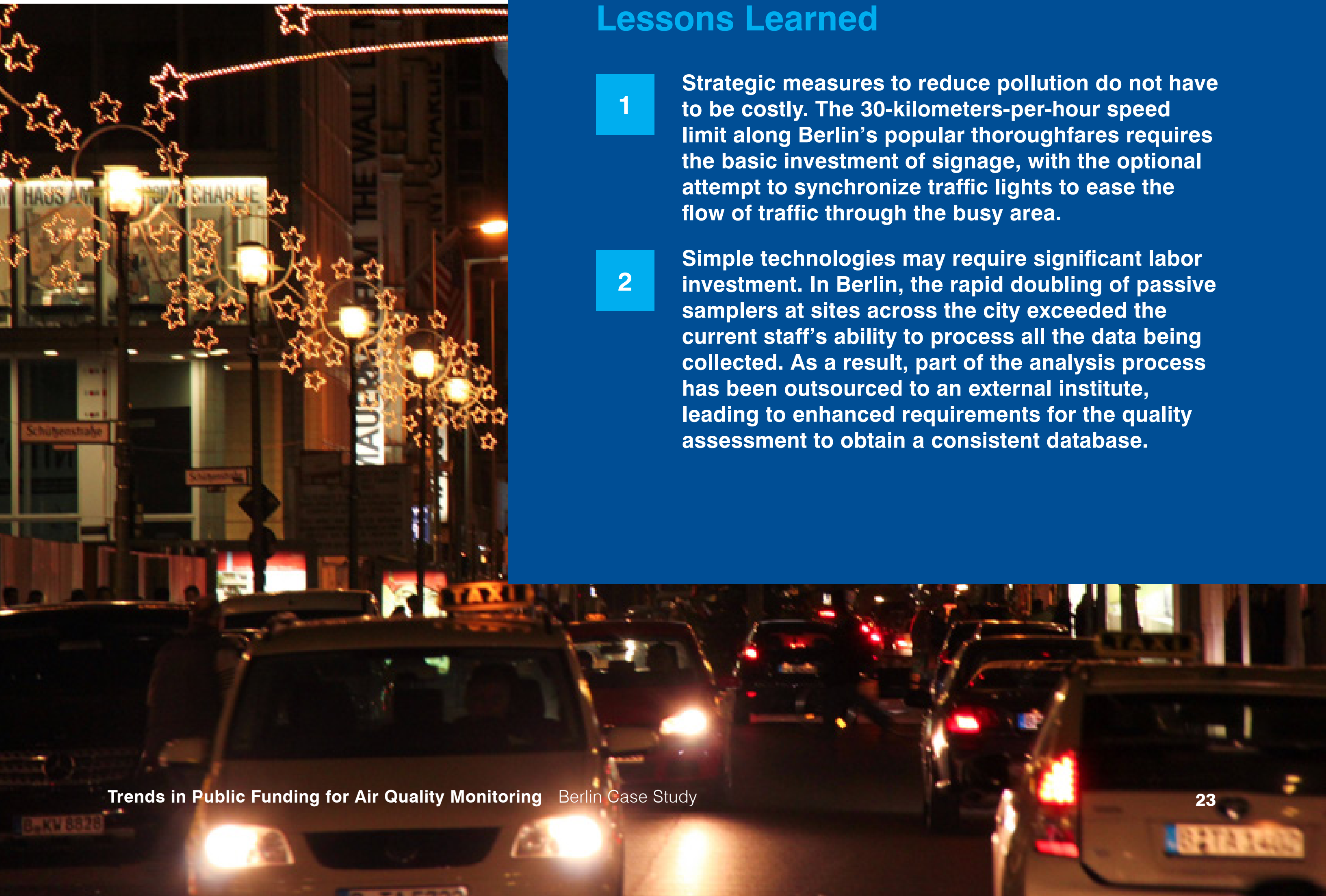
Although the speed limit in particular was contentious when it was implemented in Berlin, the Department has been able to demonstrate that the 30-kilometers-per-hour limit is a useful measure in limiting pollution from vehicles. The department can point to data from 15 years ago that tracked pollution from approximately 40,000 vehicles per day and indicates concentrations of NO_2 have been reduced by roughly 10% and PM_{10} by between 5%-10%. The Senate of Berlin continues to collect data at multiple sites along heavily trafficked roads to validate these results and account for any discrepancies in the data.

Community pressure and litigation have required decision makers and regulators to make the case for mitigation measures that might otherwise not be so popular. Now, there is additional pressure to see real-time, advanced monitoring for the agency to prove the impact of their stated approach. As the pressure mounts, it can be challenging for local agencies to communicate the complex data and its impacts with the general public. Leaders at the air quality management department have been looking into how to work with communications professionals to better communicate the monitoring results with the general public.

Lessons Learned

1. **Strategic measures to reduce pollution do not have to be costly. The 30-kilometers-per-hour speed limit along Berlin's popular thoroughfares requires the basic investment of signage, with the optional attempt to synchronize traffic lights to ease the flow of traffic through the busy area.**

2. **Simple technologies may require significant labor investment. In Berlin, the rapid doubling of passive samplers at sites across the city exceeded the current staff's ability to process all the data being collected. As a result, part of the analysis process has been outsourced to an external institute, leading to enhanced requirements for the quality assessment to obtain a consistent database.**



Latin America

Key Takeaways for Technology Providers

High concentrations of urban populations present opportunities for emerging technologies.

Many cities in Latin America — Mexico City and São Paulo are two examples — have inspired their federal governments to expand the strategies modeled by the cities to other parts of the country. However, resources are scarce in developing countries, resulting in limited monitoring capacities and practices. Properly operated air monitoring networks are still the exception — reliability of air quality data from conventional monitoring remains a challenge. Due to the lack of conventional monitoring equipment in many countries, agencies may be particularly interested in implementing lower-cost sensors to provide data in the absence of regulatory networks.

Multilateral organizations provide critical support for national government agencies to establish ground-level and regulatory-grade monitors.

Agencies at the national level oversee many countrywide monitoring efforts across the region. Although subnational leaders have paved the way in many cases, the recent decade has shown significant interest from central government agencies to invest in air quality monitoring in support of regional and local agencies. Loans from external funders such as the World Bank and the United Nations Development Programme (UNDP) have supported the expansion of monitoring networks.

Air Quality Policy in Latin America

Latin America is characterized by swift population growth, urban expansion and economic development leading to increased energy consumption and resource use, making air quality a formidable challenge, especially in larger cities.[64, 65] The key drivers of pollution are from the transportation sector, with industrial and agricultural emissions also serving as leading factors for poor air quality across the region.[66]

National agencies and a few prominent cities have taken the lead in the region to fund air quality monitoring efforts. The most common policy driver for air quality monitoring in the region is the adoption of national standards set for each pollutant, though most countries' standards have thresholds higher than the guidelines put forward for the region by the World Health Organization (WHO). In recent years, particulate matter (PM) has become a focus due to its severe public health impacts, but countries have been slower to adopt standards for both PM_{10} and $PM_{2.5}$. For example, Bolivia, Guatemala and Peru have adopted WHO's Air Quality Guidelines for PM_{10}, but only Guatemala had done so for $PM_{2.5}$ up until 2016. It may be the case that countries have been slow to adopt guidelines due to the rapid pace of growth in the region's urban centers in recent decades.[67] Even the regions with well-established networks have added $PM_{2.5}$ to their monitoring efforts many years after initial monitoring efforts — in Santiago, for example, where air quality monitoring has taken place since 1988, $PM_{2.5}$ has been measured only since 2000, and standards were introduced by the central government in 2016.[68]

Although in Latin America there are some excellent examples of monitoring, data availability and regular reporting, this is not common across the region. A lack of transparency around data and reporting raises issues, such as allowing public access to important information. The data itself is also of variable quality. There are no standardized monitoring techniques, data collection methods or averaging protocols across the region. There is also limited evidence for quality control or assurance activities that could ensure optimum data. It is clear that the region would benefit from capacity building and training activities on these topics.[69]

Environmental agencies across the region have pursued a wide range of monitoring initiatives, at times partnering with multilateral organizations interested in expanding air quality monitoring and management efforts in the region. Just as air quality standards and regulations vary across Latin America, so do the countries' approaches for funding for air quality monitoring. One study conducted in 2016 found 17 countries across Latin America and the Caribbean with air quality monitoring stations, with the main pollutants monitored being PM10, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Robust monitoring networks were found in Brazil, Chile, Colombia and Mexico.[70] In these countries, early leadership from a major metropolitan region in the late 20th century became a model for the central governments' environmental agencies to roll out monitoring efforts across the respective nations.

Many of the robust networks have relied on significant contributions from subnational entities, as with the state of São Paulo in Brazil, where the majority of the country's monitoring stations are located. In other cases, countries include specific budget line items at the national level with funds dedicated toward air quality monitoring. For example, Chile's air quality monitoring network receives about 1% of annual funding allocated to Ministry of Environment programs in recent years, on the order of $130,000 annually for air quality forecast modeling. Monitoring may not comprise a significant percentage of expenditures, but this demonstrates regularly allocated funding specifically geared toward monitoring capacities.

The majority of air pollution mitigation activities undertaken by Latin American countries address emissions that stem from the transportation sector. Since the region's cities are growing rapidly, so too are their cumulative mobile source emissions. Between 1990 and 2005, some countries in the region saw their total vehicle fleets more than double, with most of a country's fleet concentrated in a single, populous city. For example, the total number of registered vehicles in Mexico went from 10.2 million in 1990 to 21.5 million in 2005, and Brazil's total skyrocketed to 42 million up from 18.3 million over the same period.[71] Several local agencies have introduced Bus Rapid Transit (BRT) systems as a means of mitigating the high emissions from vehicles. Vehicle circulation restrictions have attempted to cap on-road congestion, such as Mexico City's *Hoy No Circula* program — started in the late 1980s — which originally aimed to reduce weekday vehicle congestion by 20% through on-road scheduling based on a vehicle's license plate. Nowadays, *Hoy No Circula* and the Inspection and Maintenance programs are used to incentivize fleet renewal with cleaner cars by means of differentiated traffic restrictions and inspection requirements.

In São Paulo, where air pollution has been a concern and monitoring has been undertaken since the second half of the 20th century, the state's PROCONVE program (Programa de Controle de Poluição do Ar por Veículos Automotores), is a multi-stage program to introduce alternative fuel types, mandate oxygen sensors, or focus on the reduction of hydrocarbons and NO_x.[72] With the population concentrated heavily in urban centers, the role of shaping air quality mitigation programs is usually undertaken by urban municipalities across Latin America.
Recognizing the importance of regional collaboration, the United Nations Environment Programme (UNEP) has periodically convened a Forum of Ministers of Environment of Latin America and the Caribbean since 1982. Over the past decade, these meetings have resulted in collaborative action on air quality among the many other environmental issues under discussion in the region. Most recently, the Forum adopted a Regional Plan of Action on Atmospheric Pollution in 2016 with the goal of fostering much-needed collaboration at the regional and national levels.[73]

Given that a regional mechanism for funding air quality monitoring to support the region has not yet been established, air quality monitoring efforts are showcased by voluntary actions and key partnerships. Latin American cities are key representatives in global campaigns to reduce air pollution, such as the BreatheLife campaign, a collaborative communications effort between WHO, the World Bank, UNEP, and the Climate and Clean Air Coalition (CCAC). Eighteen cities throughout the region have become partners in the BreatheLife campaign, demonstrating the extent to which subnational entities are taking part in tackling poor air quality. Regional organizations, such as the Pan-American Health Organization (PAHO), have provided support in the region for air quality monitoring efforts, though not with direct funding.

Public Funding for Air Quality Monitoring

Many countries centralize funding for their air quality monitoring efforts in a federal Ministry of Environment — this is the case in Colombia, Chile, Mexico and Peru, for example. Money is usually disbursed from the national level to the regional and municipal agencies for program execution. In Colombia, this is the exact model: the national government sets national standards for pollutants and the regional environmental authorities are responsible for execution.[74] For Brazil, one of the region's most well-known monitoring systems, funding has historically been a state-level responsibility. However, in 2019, the country announced an effort to establish a countrywide system of monitors with the allocation of $7.8 million (USD) from the Ministry of the Environment.[75]

Similarly, Mexico City demonstrated sub-national leadership when it faced some of the worst air quality in the world toward the end of the 20th century. The city has maintained a continuous focus on air quality monitoring in the metropolitan area and is now well known in the world of air quality management for its forceful efforts to tackle pollution. Mexico City's ProAire[76] program, now in its fourth stage, is a multifaceted program to monitor and improve air quality, and other states have followed suit — there are now 37 ProAire Programs across Mexico.[77] Through the Environmental Commission for the Megalopolis, the Mexican government recently granted $7.5 million (USD) to six state members for enhancing their air monitoring infrastructure and capacities.[78] At the federal level and as a neighbor of the United States, Mexico has also invested in partnerships with the U.S. EPA to study emissions control areas, monitor air quality along the U.S.-Mexico border, and share data and best practices among federal, state and local governments in both countries.[79] Broad efforts such as these are critical to replicate across the region, as coverage of monitoring networks is currently believed to reach around 146 million people — only 1/3 of the region's population.[80]

There are innovative ways in which leading cities have put their regulatory grade networks to good use. Santiago has developed a unique policy addressing the short-term health impacts from air pollution by announcing "Critical Environmental Episodes" when models predict particularly poor air quality. On the day of the alert, these announcements have led to as much as a 20% reduction in ambient concentrations of PM.[81] This program is just one small piece of a larger puzzle of programming under the Santiago Metropolitan Area's regional Air Pollution Control and Prevention Plan — Plan De Prevención y Descontaminación Ambiental, or PPDA. Each region in Chile develops a PPDA in conjunction with the centralized government with the aim of achieving pollution reductions to get closer to Chile's national standards.

There are also examples of lower-cost strategies being implemented to monitor air quality in the absence of — or as a means of corroborating — regulatory-grade data. Whether or not a country has established its regulatory-grade network, there are opportunities to partner with local agencies on lower-cost strategies for monitoring, since air quality is a pervasive problem for the majority of the population. In the federal district of Brasilia, lower-cost sensors were deployed in a 2014 pilot program to validate data collection methods; the idea being that reliable lower-cost sensor data can present an opportunity to avoid maintenance and operations costs associated with regulatory-grade monitoring stations.[82] In the Aburrá Valley, Colombia, where Medellín is located, the regional environmental agency funded a citizen science effort to pilot lower-cost sensors by distributing them to families throughout the valley and collecting regular readings to inform government equipment readings.[83] Chile's government department responsible for enforcing compliance with environmental policy, la Superintendencia Del Medio Ambiente (SMA) conducted its own study calibrating lower-cost PM sensors alongside their automatic reference monitors to understand the relative use of novel technologies for assisting with enforcement or informing public policy.[84]

Key Public Funding in Region (2010-2020)

For Latin America, a common funding mechanism for the establishment of ground-level regulatory-grade monitors is a loan or grant from a multilateral organization. Looking from 2010 to 2020, partnerships between the World Bank and Peru, UNDP and Argentina, and the Swiss Agency for Development and Cooperation (SDC) and Bolivia rise to the forefront as examples of these large-scale investments to provide a country with the capacity for monitoring air and other environmental pollutants. Data from the Organisation for Economic Co-operation and Development's Creditor Reporting System (OECD CRS) revealed additional funding in smaller grant amounts for added capacity, research initiatives and cross-country collaboration. Additionally, some national budgets list clearly defined expenditures for air quality monitoring, which are helpful for identifying recurring sources of funding that may be more consistent than one-time, multi-million dollar partnerships.

A prominent funding opportunity in Latin America is a partnership between the World Bank and the Government of Peru for a loan of $40 million (USD) across five years to establish a countrywide monitoring network.[85] The five-year loan (2017-2021) to Peru's Ministry of Environment (MINAM) and Agency for Environmental Assessment and Enforcement (OEFA) will go "to generate and share information for environmental quality control at the national level, by supporting the Government of Peru to improve its environmental monitoring and analytical capacity, increase public access to environmental quality information and promote informed public participation in environmental quality management."[86] The World Bank is financing air quality management projects in other regions of the world — in Pakistan and Vietnam, for example — that provide technical assistance on pollution management in developing countries.[87] Latin American nations are likely recipients of additional funding from this project portfolio, though specific recipients or project purposes can be challenging to identify. It may be the case that project titles are left intentionally broad so as to build out a wide scope of opportunities and allow for flexibility and innovation within each project.

Other multilateral agencies have partnered with countries in the region to establish a ground-level monitoring network. In Bolivia, the SDC collaborated with Bolivia's Ministry of Environment and Water (Ministerio de Medio Ambiente y Agua, or MMAYA) and invested $3.8 million (USD) from 2014 to 2017 on a program called the Clean Air Project, of which monitoring was a core component. In Argentina, the Ministry of Environment and Sustainable Development worked with UNDP and committed $1.24 million (USD) from 2016 to 2019 to implement a federal network of environmental monitoring, which includes stations to monitor water, air and land.[88]

Countries such as Mexico and Chile, with their capital investment in air quality monitoring equipment taking place in the 1980s and 1990s, maintain funding for specific programs but are not necessarily investing in any more regulatory-grade monitoring equipment. On the other hand, Peru, Bolivia and others stand to benefit greatly from multi-year projects to begin the process of continuous monitoring. Whether or not countries have long-established monitoring networks, there is an opportunity at the national level for service providers to aid in the process of collecting and working with data, whether by providing services directly or training agency staff to do so.

International partners have demonstrated an interest in building the capacity for Latin America to monitor air quality. For example, the U.S. State Department has invested in the region through a trade agreement with Central American and Caribbean nations, and it recently embarked upon a 36-month partnership under the U.S. Air Quality Capacity Building Fellowship to "enhance developing country capacity in air quality management through placement of U.S. air quality experts with national and subnational governments."[89] Chile's SMA undertook its research on calibrating lower-cost sensors in part to support the efforts of institutions such as the U.S. EPA in exploring so-called "Next Generation Compliance and Enforcement" technologies, though the research was internally funded.[90]

In countries with a robust air quality monitoring network such as Mexico, there are examples of continued public and multilateral funding to support data analysis or regional studies. For example, the United Kingdom's Foreign & Commonwealth Office reported an $84,000 (USD) single-year grant to support Mexico's Ministry of Environment (SEMARNAT) to develop collection, verification, validation, quality control and quality assurance of data for greenhouse gas and air pollutant inventories for the country. In fact, setting aside or securing funding to establish a monitoring network has been demonstrated in the region to be only the beginning of a city or country's monitoring effort. Training for staff, data validation efforts, quality assurance and quality control, and effective communication strategies have all surfaced as barriers for agencies collecting and communicating air quality data.

For an example of funding for air quality monitoring programs in the Latin American region, read the case study on Santiago: Monitoring and Enforcement through Public and Private Networks.

Examples and Details of Major Grants/Loans

Table 2:

Top Five Funding Organizations by Total Amount, 2010–2020

Name of Funding Organization	Recipient(s)	Total Amount (USD)	Project Description(s)
The World Bank (International Bank for Reconstruction and Development)	Peru	$32 million loan	Establish ground-level monitoring network throughout Peru (project scoped for a total of $40M committed 2017-2021).
Swiss Agency for Development and Cooperation	Bolivia	$3.8 million loan	Establish ground-level monitoring network throughout Bolivia.
Germany Federal Ministry of Education and Research	Brazil	$0.99 million	KLIMAPOLIS program to establish cooperation between Germany and Brazil on issues including air pollution in urban areas.
Chile Federal Ministry of Environment	Chile (Internal Funding)	$0.94 million	Annual budget allocation for air quality forecast modeling
Argentina Federal Ministry of Environment and Sustainable Development	Argentina (Internal Funding)	$0.81 million	Investment under a UNDP program to setup an automatic monitoring network.

Case Study

Santiago - Monitoring and Enforcement through Public and Private Networks

Location	Santiago, Chile
Total Area Monitored	15,403.2 km^2 (5947.2 square miles)
Program Timeline	2012–present (ongoing)
Targeted Source(s) of Emissions	Mobile sources, fixed sources and burning
Targeted Pollutants for Measurement	Particulate Matter (PM_{10} and $PM_{2.5}$)
Driver of Monitoring Program	National environmental regulations
Funding Source(s)	Public funding allocated through Ministerio del Medio Ambiente (MMA) and Superintendence of Environment (SMA)

Chile has one of the most robust air quality monitoring systems in Latin America and has had monitoring in place since the 1960s. The Chilean central government, through the Ministry of Environment (MMA), has taken the lead in designing and funding air quality monitoring programs throughout the country with input from individual metropolitan regions. Through these collaborations, MMA developed robust monitoring systems in several regions and 13 Atmospheric Prevention and Decontamination Plans (Planes de prevención y/o descontaminación atmosférica, or PPDA) throughout Chile. The Ministry of Environment is integrating as much monitoring data as possible into its national network, el Sistema de Información Nacional de Calidad del Aire (SINCA). This top-down approach was first established by the country's public health agency, before transitioning to the then-newly created MMA in 2012. In recent years, MMA works closely with the Chilean Superintendence of Environment (SMA), the chief environmental enforcement agency, to monitor pollutants and to better enforce national environmental regulations.

The monitoring efforts in Santiago are particularly well-developed. While other cities in Chile face poor air quality resulting from the burning of wood-based fuels or from high-emitting factories, most of Santiago's pollution mitigation efforts have centered on the transportation sector.[91] Santiago's PPDA has more than 100 measures aimed at improving air quality. For example, a specific management plan ("Plan operacional de gestión de episodios críticos" in Spanish) was introduced as one component of Santiago's greater PPDA.[92] The Plan lays out a procedure for critical episodes of air pollution from $PM_{2.5}$ and PM_{10} by introducing specific restrictions on activities such as driving, parking and woodburning, which have particularly devastating effects during the winter.

Monitoring Technology and Data Management

Santiago draws on two types of monitors:

- Santiago uses a **public monitoring network** with 11 stationary, continuous, regulatory-grade monitors—all 11 monitor particulate matter, and nine additionally track ozone, sulfur dioxide, nitrogen dioxide and carbon monoxide. The MMA is responsible for all public monitoring networks throughout Chile, including those in Santiago.
- Santiago also has **private monitoring networks** that have been installed due to requirements for environmental permitting for private projects. Current environmental laws in Chile require large companies with high-emitting activities to track their activity. Companies report their data to SMA at regular intervals as a means of measuring compliance with environmental laws.

SINCA, Chile's national monitoring network, integrates the majority of its air quality monitoring data from publicly owned equipment. Data from the publicly owned monitoring equipment are fed automatically into MMA's lab, where they can be validated and integrated into the real-time website available online.[93] The MMA and SMA are working to automate integration of the private networks into the SINCA network, an effort that could more than triple the number of monitors across the country that send data to the website and make data available for analysis and public use.[94]

Impact and Next Steps

Air quality remains one of the most pressing environmental problems in Santiago. Major air quality issues have been historically linked to high concentrations of respirable particulate matter, both PM10 and PM2.5. This heightened public awareness drives much of the government's activities, such as the creation of SINCA and its publicly available data. The published data in turn inform the community, giving citizens a better understanding of the severity of the problem. Media coverage has also played a role, publicizing pollution forecasts and intensifying the conversations around air quality. In response, the Chilean agencies continue to broaden their efforts. In 2019, SMA conducted a study that introduced lower-cost sensors at 22 locations to test their potential to supplement readings from regulatory-grade stations. The findings indicated that such equipment may be helpful for gathering nimble measurements in areas lacking a permanent station, but the readings cannot be validated to the extent necessary for measuring regulatory compliance. This pilot study nonetheless revealed helpful insight regarding the opportunity for lower-cost and mobile monitors to support monitoring for the sake of regulatory compliance.[95]

Lessons Learned

1. **The strength of Chile's central environmental agencies, including MMA and SMA, result in robust monitoring efforts that are replicated throughout the country. Santiago, an early leader in air quality monitoring in Chile, has made huge strides in improving its air quality problem through careful transportation-related efforts and particularly stringent requirements during the smoggy winter season.**

2. **Funding at these agencies are a key source of opportunity for technology providers to collaborate on new pilot projects, improvement of data collection and validation, and other efforts related to air quality monitoring. Because air quality is seen by the Chilean community as a key public health issue, decision makers at all levels of government are keenly interested in growing the environmental agencies' capacity to combat the pervasive problem of air pollution.**

India

Key Takeaways for Technology Providers

National targets are driving the expansion of the national ambient air quality monitoring network and investments in alternative monitoring technologies, such as lower-cost sensors.

The National Clean Air Programme (NCAP) aims to reduce particulate matter pollution ($PM_{2.5}$ and PM_{10}) by 20%-30% by 2024 (using 2017 as baseline) and requires action plans from 122 non-attainment cities. As a core part of this effort, the central government is making investments to expand monitoring stations by 2024 to the following totals: 1,500 manual monitoring stations and 150 Continuous Ambient Air Quality Monitoring Stations (CAAQMS) as part of the National Air Monitoring Programme (NAMP). The National Green Tribunal has also released orders to expand the number of CAAQMS. NCAP has also set a target of 1,000 real-time monitoring stations (with a focus on lower-cost sensors) by 2024. While lower-cost sensor networks are not currently recognized as a monitoring and enforcement tool, the National Physical Laboratory is working to create standards and certify lower-cost sensors. At regional and local levels, State Pollution Control Boards (SPCBs) and municipalities are piloting lower-cost sensor networks outside of the national monitoring network.

Technology providers can support equipment calibration and data analysis.

The combination of the growing number of air quality monitoring stations and the transition from manual monitoring stations to continuous ambient air quality monitoring stations has resulted in significant increases in air pollution data. Agencies often lack trained personnel to manage and analyze the data. Technology providers can play a key role in providing additional capacity to analyze and interpret daily data to enforce air quality standards.

Air Quality Policy in India

In January 2019, India adopted its landmark National Clean Air Programme (NCAP) as a five-year action plan to reduce particulate matter pollution ($PM_{2.5}$ and PM_{10}) by 20%-30% by 2024 (using 2017 as baseline).[96] This plan required 102 non-attainment cities to develop action plans and earmarked Three billion rupees (approximately $42 million USD) to implement the program for the 2018-20 period.[97]

To ensure progress, the NCAP aims to expand India's national air quality monitoring network and to pilot emerging monitoring technologies such as lower-cost sensors in select cities.[98] Beyond central government-led initiatives, India's air pollution crisis has put an international spotlight on air pollution monitoring. Demand is increasing for air pollution monitoring equipment and data from a broad swath of stakeholders: regional and local government agencies, research institutions, civil society and the general public.

Air pollution data is now being recorded and reported more frequently with varying levels of data quality as a result of the shift from manual stations to CAAQMS. Technology providers and government agencies have the opportunity to collaboratively translate growing air pollution data into meaningful mitigation actions, particularly leveraging the modernization of India's manual monitoring stations and the growing prominence of lower-cost sensors. Translating data to action is critical as dangerously high air pollution levels persist among major Indian cities with deadly consequences: air pollution is responsible for 12.5% of all deaths in India.[99,100] If India does not drastically change its trajectory, deaths resulting from air pollution will reach 1.7 million deaths annually by 2030 and 3.6 million deaths annually by 2050 — compared to 1.1 million in 2015, according to an analysis by the Health Effects Institute.[101]

According to the World Health Organization, out of the 12 cities globally with the highest levels of fine particulate matter, or $PM_{2.5}$, 11 were located in India in March 2018.[102] Coarse dust particles, or PM_{10}, in India primarily originate from windblown dust and construction.[103] Vehicles, power plants, industry, waste burning, agricultural burning and cooking with solid fuels contribute to $PM_{2.5}$, levels.[104] In 2019, dangerous air pollution levels in Delhi led to multi-day closures of schools and industrial facilities, largely caused by intentional burning to clear agricultural residue and forests in neighboring states.[105]

Tackling air pollution is a core priority for central and regional or local government agencies, as well as the general public who have made it a key issue to address the public health emergency.[106] Beyond NCAP, central government agencies have further empowered regional and local government agencies to tackle air pollution. In the Delhi region, or the National Capital Region, the Supreme Court empowered the Environment Pollution (Prevention and Control) Authority (EPCA) to implement the Graded Response Action Plan (GRAP) to address key pollution sources.[107]

Under the Air (Prevention and Control of Pollution) Act of 1986, the Central Pollution Control Board (CPCB) serves as the central body for air pollution mitigation and monitoring efforts. CPCB has identified 122 non-attainment cities under India's National Ambient Air Quality Standards (NAAQS), using ambient air quality data from 2011 to 2015.[108] However, based on an independent analysis by Greenpeace of 2017 air quality data, their analysis identified 241 cities or towns (out of 313 cities) that had PM10 levels beyond the NAAQS prescribed by CPCB — more than double the 102 non-attainment cities identified.[109] As a result, the National Green Tribunal (NGT), a specialized forum to address violations of environmental laws, directed CPCB to expand the number of non-attainment cities — potentially to over 200 — demonstrating the impact of publicly accessible air quality monitoring data.[110]

Public Funding for Air Quality Monitoring

The NAMP serves as the nationwide program for ambient air quality monitoring, implemented by the CPCB, State Pollution Control Boards (SPCBs), Pollution Control Committees, National Environmental Engineering Research Institute (CSIR NEERI) and various monitoring agencies.[111] The network consists of 793 manual monitoring stations covering 344 cities or towns in 29 states and nine union territories. The four pollutants monitored using manual monitoring stations are sulphur dioxide (SO_2), nitrogen dioxide (NO_2), PM_{10}, and, for 275 stations, $PM_{2.5}$. Additionally, the network consists of 208 real-time CAAQMS in 71 cities across 17 states, monitoring eight pollutants: PM_{10}, $PM_{2.5}$, SO_2, NO_x (oxides of nitrogen), ammonia (NH_3), CO, ozone and benzene.[112,113]

The NCAP set targets for expanding monitoring stations by 2024 to the following totals: 1,500 manual monitoring stations and 150 CAAQMS. For CAAQMS expansion, NCAP is setting a target of two to three stations in each city, prioritizing the Indo-Gangetic plain.[114] In December 2019, the NGT directed all SPCBs to install CAAQMS and publicly display the air quality index in real time within a year. SPCBs must also submit quarterly progress reports to the CPCB, and SPCBs that fail to comply with the order must pay a monthly penalty of 5 lakh (approximately $7,000 USD).[115]

For 2019-20, CPCB saw a 16% budget increase, from 2,683 crore ($375 million USD) for 2018-19 to 3,175 crore ($444 million USD) for 2019-20 to fund NCAP implementation, as well as other pollution control activities.[116] As of November 2019, 90 out of the 102 nonattainment cities have received funding for NCAP activities. The 28 priority cities — with million-plus population and PM_{10} levels exceeding 90μg/m³ — received a total of 10 crore ($1.4 million USD) in 2019 from the Ministry of Environment, Forest and Climate Change (MoEFCC) for NCAP implementation activities, including installation of CAAQMS. The 74 remaining nonattainment cities have each received 10 lakh ($14,000 USD) or 20 lakh ($28,000 USD) each, depending on population.[117]

At the central government level, expansion and operation of the NAMP is funded by CPCB, which receives annual allocations from MoEFCC. Additionally, CPCB generates significant funds through fines on agencies and industries that fail to comply with environmental targets.[118] Between 2009 and 2019, MoEFFCC provided over 118 crores, or over $16 million (USD), to 36 monitoring agencies in 29 states and six union territories to expand and maintain the NAMP. In 2018-2019 alone, MoEFCC provided Rs 11.12 crores, or over $1.5 million (USD).[119] CPCB annual budgets and annual action plans illustrate a funding stream from CPCB's national office to its regional offices to implement the national monitoring network. For example, CPCB's Bengaluru office received over 70 million Indian Rupees or over $1.2 million (in 2016 USD). Funding for the implementation and expansion of NAMP includes modeling and analysis and purchase of new equipment.

Foreign governments (such as the United States, Norway and Sweden) have also provided funding to research institutions, government agencies and NGOs to build capacity on air quality management efforts broadly, funding over $10 million (in 2016 USD) in the past 10 years, based on grants that have been identified in the Organisation for Economic Co-operation and Development's Creditor Reporting System (OECD CRS).

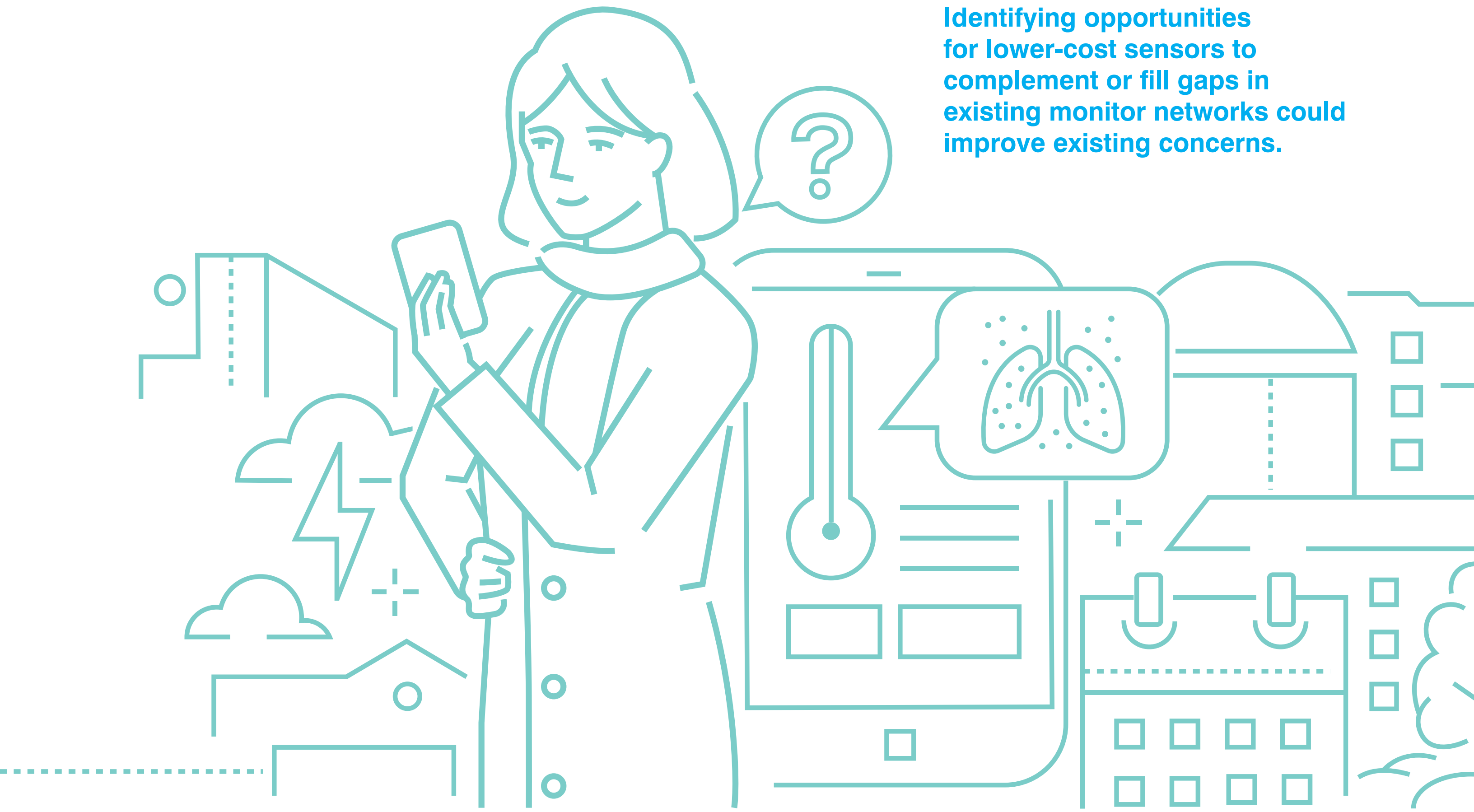
Despite the central government's investments in the NAMP, there is an opportunity to address significant gaps in air pollution monitoring. Approximately 300 out of 5,000 cities and towns in India have air quality monitoring. Cities with higher pollution levels like Varanasi and Kanpur presently have limited air pollution monitoring stations. Most monitoring stations are concentrated in northern India, with monitoring stations in western and southern states. There is no real-time data reporting from central states (Chhattisgarh, Jharkhand and Odisha) and northeastern states, which face a heavy burden of polluting industries.[120,121]

While CPCB continues to increase the number of its monitoring stations, there is also a gap in calibration of the monitoring equipment and quality assurance of the data generated. This gap presents an opportunity for technology and service providers to ensure proper calibration of equipment, improving the quality of the data generated from the monitoring stations.[122] The continued reliance on manual monitoring stations also remains a challenge in ensuring data quality.[123] On the flipside, the growing number of online or continuous monitoring stations, which generate massive amounts of data, has further highlighted capacity challenges. An expert interviewee indicated that there is a significant shortage of technical capacity to analyze the data, which includes preparation of action plans, inventory of air pollutants, source apportionment and modeling. Addressing the gap in technical capacity would improve the effectiveness of air pollution mitigation efforts, e.g., source apportionment would enable regulatory agencies and civil society to better leverage resources.[124]

Beyond the NAMP, some air quality monitoring initiatives using emerging monitoring technologies are being funded by state pollution control boards and cities. The drivers for these different monitoring initiatives vary. For example, Gujarat's State Pollution Control Board is investing in lower-cost sensors due to its "research-based" and "tech-savvy" leadership, according to an expert interviewee.[125] Civil society and research institutions are using lower-cost sensors to educate communities and identify areas of concern for further investigation, driving investment for lower-cost sensors.[126] Additionally, the NCAP includes targets for increasing lower-cost sensor networks in cities. However, there remains significant concerns from the CPCB around the quality of data generated from lower-cost sensors. Identifying opportunities for lower-cost sensors to complement or fill gaps in existing monitor networks could improve existing concerns. Research efforts on utilizing satellite-based monitoring are underway. Satellite-based monitoring would be able to monitor rural areas and areas that are not presently covered by the existing national monitoring network.[127, 128]

For an example of funding for air quality monitoring programs in India, read the case study on Ahmedabad: City Leadership in Communicating Air Pollution Monitoring Data.

Identifying opportunities for lower-cost sensors to complement or fill gaps in existing monitor networks could improve existing concerns.



Case Study

Ahmedabad - City Leadership in Communicating Air Pollution Monitoring Data

Location	Ahmedabad, India
Total Area Monitored	464.1 km^2 (179.2 square miles) (average AQI taken from 10 monitors)
Implementing Agencies	Ahmedabad Municipal Corporation (AMC) Health Department leads implementation of AIR Plan; plan was developed in collaboration with: Gujarat State Pollution Control Board, Indian Institute of Public Health Gandhinagar, Natural Resources Defense Council, Indian Institute of Tropical Meteorology, and various local researchers and civil society groups
Project Timeline	May 2017 - present; AIR Plan and AQI launched in May 2017; updated AIR Plan published in December 2018
Targeted Source(s) of Emissions	Transportation and industry
Targeted Pollutants for Measurement	Key pollutants under NAAQS: PM_{10}, $PM_{2.5}$, O_3, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2); volatile organic compounds (monitored by Gujarat Industrial Development Corridor)
Driver of Monitoring Program	Voluntary city-led initiative
Funding Source(s)	AIR Plan implementation funded by city of Ahmedabad; monitors funded by IITM-SAFAR

Case Study: Ahmedabad - City Leadership in Communicating Air Pollution Monitoring Data

In May 2017, the city of Ahmedabad launched the Air Information and Response (AIR) Plan to provide publicly accessible air quality reports and to establish an early-warning pollution forecasting system to alert residents about poor air quality. Implemented by the Ahmedabad Municipal Corporation (AMC), the AIR Plan leverages the Air Quality Index (AQI) and corresponding monitoring stations developed and managed by the Indian Institute of Tropical Meteorology's System for Air Quality and Weather Forecasting and Research (IITM-SAFAR). The AIR Plan builds on the city's leadership on extreme heat preparedness. In response to a 2010 heat wave that resulted in hundreds of deaths, the city developed the Ahmedabad Heat Action Plan (HAP) and associated early warning heat alert system.[129]

Ahmedabad's AIR Plan focuses on addressing the public health impacts of air pollution and serves as a model for other cities on communicating air pollution monitoring data to the public. The AIR Plan builds on five key pillars:

1. Interagency coordination, i.e., bringing different city departments together to implement the plan;
2. Public awareness and community outreach;
3. Capacity building among medical professionals;
4. Focused activities for vulnerable groups, e.g., children attending schools; and
5. Identification of key pollution sources to inform mitigation actions.

The city of Ahmedabad already had over 20 monitoring stations from various programs by 2016, but data from the monitoring network was not easily accessible to the public. For example, seven monitors are part of the National Air Monitoring Programme and are operated by the Gujarat Pollution Control Board; these monitors manually collect air pollution data only twice a week and have encountered technical issues in sharing results online. The gaps in the monitoring network and emissions data led to the joint launch of Ahmedabad's AIR Plan and AQI in May 2016.

IITM-SAFAR invested RS 20 crore (approximately $2.8 million USD) for the installation of 10 continuous air quality monitors in and around Ahmedabad as part of the AQI. The AMC provided land for the monitors free of cost to SAFAR, and, to cover implementation costs of the AIR Plan, the AMC set aside RS 30 Lakh (approximately $42,500 USD) for maintenance of screens, ongoing public advisories and public awareness programs.

Monitoring Technology and Data Management

Ahmedabad's AIR Plan and AQI rely on 10 continuous air quality monitors in and around Ahmedabad established by IITM-SAFAR with support from government agencies and civil society. The system was developed based on best practices for communicating AQI systems from megacities in India and around the world. The cities of Delhi, Mumbai and Pune already had AQI systems before the launch of Ahmedabad's AQI system, and the city of Ahmedabad examined best practices on outreach efforts around existing AQI systems. The AIR Plan also relies on lessons learned from cities around the world (Beijing, Los Angeles and Mexico City), where AQI systems provide air quality alerts through different communication mediums, such as hourly online reports and smartphone applications.

Process for Selecting Technology Providers

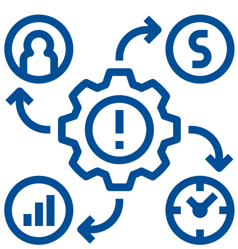
In 2015, IITM posted a tender notice, or request for bids, for equipment and digital display system for the establishment of Ahmedabad's AQI. The scope of services in the tender notice included the establishment of 10 monitoring stations, acquisition of data remotely and locally, and processing and conversion of air quality data to the air quality index. Preference was given to manufacturers with previous experience operating and maintaining ambient air quality monitors, previous experience designing ambient air quality monitoring systems that minimize equipment maintenance and calibration, and with ISO9000, ISO9001, ISO17025 and NATA accreditations. IITM selected the France-based Environment SA as the technology provider, providing U.S. EPA-certified equipment for PM_{10} and $PM_{2.5}$ sampling.

Data Management and Sharing

IITM-SAFAR monitors collect data at five minute intervals that feed into Ahmedabad's AQI system. The equipment follows standards and procedures established by the Central Pollution Control Board, the U.S. EPA and World Meteorological Conditions. IITM-SAFAR calculates site-level AQI for each monitor and also calculates a city-wide AQI based on site-level AQI findings. The city-led AIR Plan streamlines interagency coordination to document and communicate the city-wide AQI to the public.

AQI values are associated with health messages and outreach actions. For example, "Very Poor" city-wide AQI (300-400) forecast triggers a Health Alert. An appointed Nodal Officer within AMC's Health Department leads coordination efforts, which include monitoring daily AQI; disseminating public health messages to local departments, community service providers and the Gujarat State Pollution Control Board; and working with press offices to increase media coverage of dangerous air pollution levels. This outreach system also ensures that health alerts are shared with vulnerable groups, leveraging Urban Health Centers to disseminate information to at-risk populations and Ahmedabad's school flag program to reduce personal exposure to students using color-coded flags to communicate daily AQI forecasts.

Impact and Next Steps



Data generated from the continuous air pollution monitoring stations are used to develop a more comprehensive emissions inventory for the city of Ahmedabad. The inventory identified the transportation and industry sectors as the primary contributors for $PM_{2.5}$, accounting for more than two-thirds of emissions. The AMC and other agencies are drawing on the data and collaborative processes from the AIR Plan and AQI to guide the city's mitigation activities.

Case Study: Ahmedabad - City Leadership in Communicating Air Pollution Monitoring Data

Lessons Learned

NRDC, one of the knowledge partners for the AIR Plan, considers the program as a model for other cities in India to disseminate air pollution data and to inform mitigation actions. NRDC is working to replicate the AIR Plan in Pune, the second largest city in the state of Maharashtra, using lessons learned from Ahmedabad.

1. **Focus activities on vulnerable groups: NRDC is seeking to replicate Ahmedabad's school flags program, which reaches approximately 140,000 students in 90 schools, in the city of Pune.**

2. **Involvement of medical and public health professionals: There is growing scientific literature on the significant public health impacts of India's air pollution crisis. Medical and public health professionals play important roles in communicating and preventing negative health impacts. Like Ahmedabad, the city of Pune has an active civil society and the medical community. NRDC and other stakeholders are looking to leverage efforts from existing groups, as well as lessons learned from Ahmedabad.**

3. **Cross-sector working group: The AIR Plan was championed by city leadership and it incorporates feedback from a wide range of stakeholders, including various city departments, community service providers, research institutions and civil society. The AIR Plan's collaborative development process is a model for other cities in India and beyond.**

China

Relevant Takeaways and Opportunities

China's "battle for blue skies" plan has resulted in significant investments in air quality monitoring.

Air quality is a key issue across China, resulting in tens of billions of dollars in spending over the last decade. According to official reports, China has committed to spending over $56 billion for air pollution mitigation efforts. Air pollution monitoring has played an important role in measuring and tracking progress. China's rapid expansion of its national ambient air quality monitoring network has primarily relied on central government funding with support from cities. Cities are responsible for funding localized monitoring networks and demonstrating progress on city-specific plans.

Air quality monitoring is limited in certain regions — alternative monitoring technologies are helping to fill that gap.

Given the country's vast geographic scale, various research initiatives have been funded to further expand air quality monitoring in China using emerging technologies, such as sensor-based fixed and mobile air quality monitors (vehicle-mounted and aerial) and satellite monitors. The Chinese government — in partnership with researchers, for-profit organizations, and civil society, including EDF — is working to improve the accuracy of data generated from lower-cost sensors and other alternative monitoring technologies. The Chinese government has made significant strides in this effort, and opportunities remain to further examine and validate the reliability of alternative monitoring technologies.

Air Quality Policy in China

The year 2012 was a turning point for China's air quality policy. Heightened public concern over air pollution across China led to the development of new air quality standards and two sequential air pollution control action plans (2013-2017, 2018-2020) to improve air quality. The new environmental protection laws and the amended air pollution prevention and control laws lay the legal foundations for ambitious air pollution mitigation measures and corresponding investments in air pollution monitoring.

Since 2012, the Chinese government has made significant investments in its "battle for blue skies." China's landmark Air Pollution Prevention and Control Action Plan, released in 2013, led to a commitment of spending RMB 350 billion ($56 billion USD) by 2015 for air pollution mitigation efforts in major cities, with local governments funding most of the programs aimed at improving air quality.[130] Funding focused on the key regions of Beijing-Tianjin-Hebei (BTH), the Yangtze River Delta (YRD) and the Pearl River Delta (PRD).[131] Specific targets include a 10% reduction in PM_{10} concentration compared to 2012 levels for all towns and cities and 25%, 20% and 15% reduction in $PM_{2.5}$ concentration for BTH, YRD and PRD, respectively. It specifically required the city of Beijing to achieve annual average $PM_{2.5}$ concentration of no more than 60 $\mu g/m^3$.

In 2015, the amendment of the Atmospheric Pollution Prevention and Control Law of the People's Republic of China legislated the institutional measures proposed in the Action Plan. The Three-Year Action Plan for Winning the Blue Sky War, released in 2018, demonstrates the Chinese government's continued commitment to addressing air pollution challenges, mandating at least an 18% reduction of $PM_{2.5}$ levels by 2020 for cities that failed to meet national standards (35 $\mu g/m^3$).[132]

The key actions that have led to significant decreases in various types of air pollution include desulfurization and closure of coal-fired power plants, increased efficiency of polluting power plants, shifts toward cleaner fuels and electricity for cooking and heating, installation of NO_x filtering systems on power plants and new emission standards for vehicles.[133]

At a regional level, between 2013 and 2016, RMB 100 billion ($16 billion USD) was spent to address Beijing's air pollution alone.[134] Beijing continues to invest in air pollution mitigation activities; in 2017, officials announced they would invest RMB 18 billion ($2.6 billion USD).[135] From 2013-2019, Beijing reduced its $PM_{2.5}$ emissions by 52.8% by implementing ambitious structural approaches to air pollution mitigation — including closing its coal-fired power stations and banning people in surrounding areas from burning coal for heat.

Across all of these investments, air pollution monitoring has played an important role in measuring and tracking progress. China's pivot to aggressive air pollution mitigation activities in the late 2000s came with a rapid expansion of national, regional and local air quality monitoring networks. Central, state and local government agencies are investing in a growing network of air quality monitors, which span from regulatory-grade reference equipment to emerging lower-cost sensors. Air pollution monitoring stations, particularly stations within China's national ambient air quality monitoring network, have enabled government officials to ensure continued progress on key air quality targets. Notably, states and cities that fail to meet air pollution targets are penalized by the central government.

The combination of aggressive air pollution mitigation policies and air pollution monitoring to track and validate progress has been largely successful. As the major focus of air pollution control policy and evaluation, national particulate matter (PM) concentration has been significantly reduced. By the end of 2018, annual concentration in 121 of 338 cities had met the national standard of 35 $\mu g/m^3$, and the percentage of days with excellent and good air quality was 79.3%. The annual average concentration for $PM_{2.5}$ was at 39 $\mu g/m^3$ and the annual concentration of PM_{10} at 71 $\mu g/m^3$.[136]

Regional control of PM concentration has also achieved significant results. Under the Air Pollution Action Plan, in 2017, the $PM_{2.5}$ concentration in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region and the Pearl River Delta region decreased 39.6%, 34.3% and 27.7%, respectively, compared to 2013 levels. PRD had met the national $PM_{2.5}$ standard. In Beijing, the 2013 plan led to the reduction of $PM_{2.5}$ levels from 89.5$\mu g/m^3$ to 58 $\mu g/m^3$. Recent research has found that China's ambitious air pollution mitigation policies have led to life-saving benefits.[137,138]


PM2.5:
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Public Funding for Air Quality Monitoring

In 2012, the new ambient air quality standards were released, which included the expansion of participating cities under the national air quality monitoring network and increased the frequency of releasing air quality data to the public. Under the national ambient air quality standards, particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) are considered "basic" pollutants and are required to be monitored under the national air quality monitoring network.[139]

Prior to 2012, the national air quality monitoring network only covered 113 cities with 661 state-controlled monitoring sites for three pollutants (PM_{10}, SO_2 and NO_2). To meet the requirement of new air quality standards, the Ministry of Environmental Protection (now Ministry of Ecology and Environment [MEE]) released the Plan for National Ambient Air Monitoring Network Establishment in 2012, expanding the state-controlled monitoring network to 338 cities. By 2017, 1,436 state-controlled monitoring sites had been established. By the end of 2020, the number of state monitoring stations will reach 1800. This expansion has been primarily funded by the central government while local governments have provided supporting funds. Local governments applied for special funds from the central government for the construction of monitoring sites and local governments were required to solve any remaining funding gaps to expand the monitoring network.[140] Between 2013 and 2017, the central government invested RMB 1.13 billion ($161 million USD) and local governments contributed RMB 690 million ($98 million USD) to expand the air quality monitoring network.[141]

Beyond the state-controlled monitoring network, local government agencies (province, city, district, county and town levels) have also funded, set up and managed local monitoring networks, independent from state government funding (this was driven by a 2013 mandate that requires air quality monitoring as an environmental protection standard in cities). By 2019, over 3,500 local ambient air quality monitoring sites had been established.[142,143]

To strengthen supervision over local monitoring initiatives and to provide further information for local governments on inspection and pollution control measures to achieve national targets, various research initiatives have been funded using emerging monitoring technologies, such as sensor-based fixed and mobile air quality monitors (vehicle-mounted and aerial) and satellite monitors. Using a "grid management system," the MEE is applying satellite remote sensing technology to better target and monitor air pollution for 28 cities in the Beijing-Tianjin-Hebei region and neighboring area and 11 cities in the Feiwei area.[144]

China has made significant strides to expand real-time reporting of air quality data to the public. As of now, all of the state-controlled monitoring stations provide real-time data, publicly available through the China National Environmental Monitoring Center (CNEMC).[145] The Chinese government has also introduced stringent controls to maintain the quality of monitoring data. For example, the CNEMC supervises and imposes strict punishments against any potential interference of monitoring sites by local governments and commercial third-party service providers. Further, CNEMC maintains a blacklist and mechanisms that block violating companies from participating in the Chinese market.[146]

Foreign governments and multilaterals also play smaller but important supporting roles. For example, the U.K. has provided funding to the city of Guangzhou to evaluate lower-cost sensors for street air pollution monitoring, linking air pollution with the modeling of pollutant exposure.[147,148]

The Organisation for Economic Co-operation and Development's Creditor Reporting System (OECD CRS) identifies over $24.6 million (in 2016 USD) in funding to China from foreign governments and multilateral agencies. These grants primarily fund air quality management activities and knowledge transfer between China and the United States, as well as between China and the United Kingdom. The following table summarizes the key funding mechanisms for air quality monitoring in China. In total, our analysis identified over $281 million (USD) invested in air quality monitoring from 2010-2020. These figures do not include the significant levels of local investments in lower-cost sensors and micro stations.

Table 3:

Key Public Funding Mechanisms for Air Quality Monitoring in Region (2010-2020)

Name of Public Funding Mechanism or Program	Funding Agency	Amount Provided Between 2010-2020	Overview of Public Funding Mechanism
Central Government	Ministry of Ecology and Environment	RMB 1.13 billion ($161 million USD) between 2013 and 2017	Expansion of national ambient air quality monitoring network
Local and Regional Governments	Various local and regional agencies	RMB 690 million ($98 million USD) between 2013 and 2017	Support for expansion of national ambient air quality network; funding local monitoring networks
International and Multilateral agencies	Example: UN Environment	$24.6 million (in 2016 USD) between 2010 and 2019	Focused broadly on capacity-building initiatives for air pollution control measures

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Research Methodology

CEA Consulting took the following approach to identify trends and mechanisms for public funding of air quality monitoring:

Conducted targeted primary research.

- Interviewed more than twenty regional experts including government representatives and non-profit organizations.
- Reviewed statutory requirements for air quality monitoring across regions.
- Identified country level expenditures for air quality and monitoring, where budget information was accessible online.
- Reviewed tens of thousands of grants from the Organisation for Economic Co-Operation and Development's Credit Reporting System:

  https://stats.oecd.org/Index.aspx?DataSetCode=CRS1.
- Reviewed hundreds of grants from publicly available databases supported by the European Union.

  2014-2020 project data for LIFE:

  https://life.easme-web.eu/

  2010-2020 Horizon 2020:

  https://cordis.europa.eu/projects/en

Conducted extensive secondary research and analysis across air quality policy and air quality monitoring sectors.

- Reviewed over 100 primary analysis and research papers addressing air quality and monitoring policy across the globe.

Topics outside the scope of this analysis include funding for indoor air quality monitoring and methane.

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