Improving Air Quality Monitoring Solution for Environmental Governance on Cities and Industries

APEC Policy Partnership on Science, Technology and Innovation

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1. Introduction to Air Quality Monitoring and Trends in Digital Governance

1.1 Overview of the Global Air Quality Situation

Air pollution has emerged as one of the most critical environmental and public health challenges in our interconnected world. Across the globe, mounting evidence indicates that over 99% of the world's population is exposed to air quality levels that significantly exceed the safety thresholds recommended by the World Health Organization (WHO). In many regions, nearly one-third of the global population resides areas where air pollution surpass even the least stringent of WHO's interim targets.

The stark realities of the global air quality situation are particularly evident in densely populated urban centers. Rapid urbanization, industrial expansion, and an increasing reliance on fossil fuels have contributed to heightened levels of airborne pollutants. Key sources include emissions from motor vehicles, industrial discharges, and biomass combustion. Moreover, climate-induced phenomena, such as wildfires exacerbated by prolonged droughts and heatwaves, further compound air pollution levels.

From a public health perspective, the ramifications of poor air quality are devastating. Between 1980 and 2020, more than 135 million premature deaths worldwide have been linked to air pollution. Urban centers experiencing rapid industrialization, particularly within the APEC region, face additional challenges as growing populations increase the demand for energy and transportation—factors that in turn elevate pollutant emissions.

Climate change further deepens these challenges. During the historical periods of August 2023 and August 2024, global measurements indicated that temperatures had surpassed the 1.5°C threshold for 14 consecutive months. This persistent warming is intricately linked to greenhouse gas emissions and is responsible for extended wildfire seasons and severe weather events. These events not only degrade air quality directly by emitting large quantities of particulate matter and toxic compounds, but they also create feedback loops that further disrupt climate stability. Consequently, the intersection between air pollution and climate change presents both a scientific and policy-driven imperative to enhance environmental monitoring and establish integrated governance frameworks capable of addressing these intertwined crises.

Within the APEC region, the challenges of air pollution are compounded by rapid economic growth and the accelerated pace of urban development. Member economies must now contend with the dual imperatives of sustaining economic development while simultaneously protecting public health and preserving environmental quality. The urgency of these challenges demands robust, data-driven responses—a transformation that hinges on the adoption of modern digital technologies in environmental governance.

1.2. Smart Air Quality Monitoring: Technologies and Applications

Modern air quality governance faces several persistent challenges that limit the effectiveness of pollution control and environmental protection. Key pain points include the difficulty of collecting accurate and timely pollution data, the complexity of managing heterogeneous environmental conditions across industrial zones, traffic corridors, construction sites, riverside areas, and residential neighborhoods, and the lack of scientifically validated data to support intelligent enforcement and governance decisions.

To address these challenges, the integration of smart technologies—including IoT (Internet of Things), artificial intelligence (AI), and unmanned aerial vehicles (UAVs)—has significantly transformed how air quality is monitored, managed, and maintained. By enabling real-time data collection, digital traceability, and automated analysis, these technologies are supporting a shift from equipment-based monitoring to fully integrated systems that enhance environmental transparency and governance efficiency.

Key innovations include the use of mobile sensor platforms, such as drone- or vehicle-mounted monitors, for dynamic and targeted data collection; blockchain applications that enable secure data transmission, verification, and regulatory transparency; and AI tools for identifying pollution hotspots, tracking emission sources, and supporting automated audits and inspections.

This digital evolution supports several core outcomes:

- Smart Sensing: Real-time detection of pollution hotspots, early warnings, and centralized air quality data management.
- Ubiquitous Monitoring: Immediate public access to air quality data, activity route recommendations based on outdoor air quality, and compliance oversight in high-risk zones.
- Instant Alerts and Response: Integration with automated response systems, such as pollution mitigation or energy efficiency controls triggered by pollution thresholds.

As governments transition from legacy systems, often marked by fragmented databases and manual workflows, to cloud and edge-enabled platforms, environmental agencies are increasingly able to consolidate diverse datasets, forecast pollution events, and execute rapid, localized responses. These new digital architectures facilitate not only scalability and responsiveness but also improved coordination across departments such as transportation, urban planning, and public health.

Looking forward, the global market for air quality monitoring technologies that incorporate sensors, system integration, and UAVs is expected to grow significantly by 2030. In parallel, legal and regulatory frameworks must evolve to support the use of real-time environmental data for enforcement, policy design, and public engagement.

In summary, the convergence of smart sensing, AI, blockchain, and integrated digital platforms represents a transformative opportunity for APEC economies to modernize air quality governance and deliver smarter, faster, and more inclusive environmental management solutions.

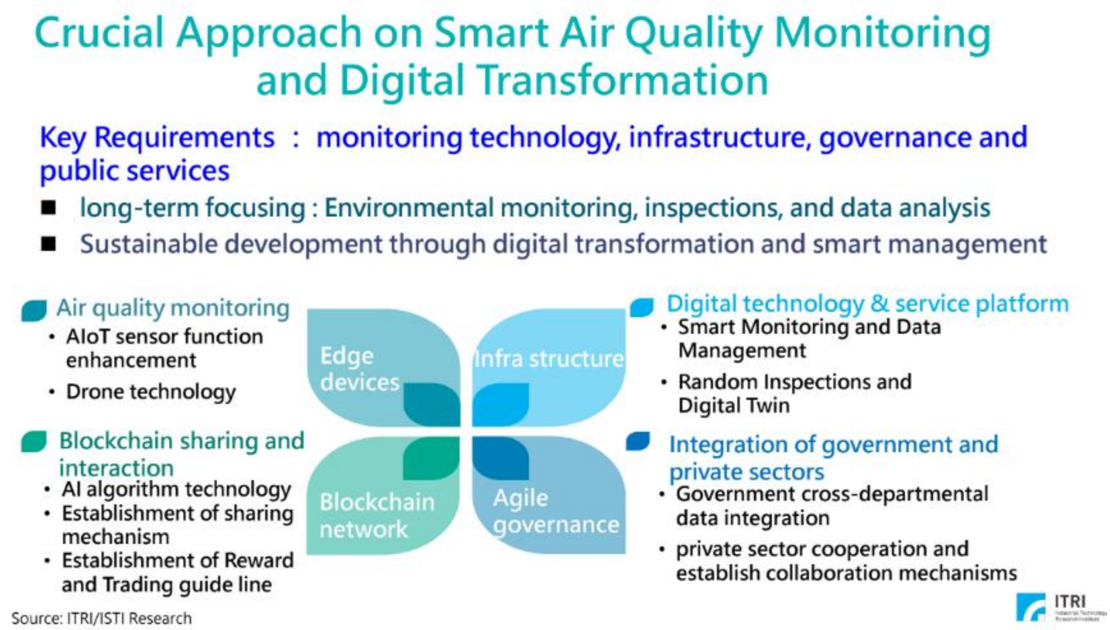

Figure 1. Smart Air Quality Monitoring and Digital Transformation

2. Research and Implementation of Air Quality Monitoring in APEC Region

2.1. Indonesia

Strengthening Urban Air Quality Monitoring: Lessons from Indonesia

The Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG) has progressively enhanced its air quality monitoring network to address both urban pollution and wildfire-related haze, particularly in major cities such as Jakarta. This initiative reflects over two decades of system development, policy support, and international cooperation.

Beginning in 2004 with the installation of PM10 analyzers in Bukit Kototabang, BMKG has gradually expanded its monitoring capacity across multiple regions. In recent years, the network was upgraded to include PM2.5 and black carbon monitoring in urban areas. This expansion was driven by worsening air pollution trends, especially during wildfire seasons and prolonged dry periods.

Jakarta remains a focal point due to its dense population, industrial activity, and coastal topography. Urban pollution in the city is exacerbated by transboundary emissions and limited atmospheric ventilation, resulting in prolonged episodes of poor air quality—especially during the dry months from June to September. Seasonal trends show air quality improving during the rainy season (January–February and December), with natural rainfall reducing airborne pollutants. Conversely, air quality declines sharply in the dry season due to stagnant meteorological conditions and increased emissions.

BMKG also highlights challenges related to limited monitoring coverage in Jakarta. Several urban and industrial areas remain underserved by existing monitoring infrastructure. The agency recommends expanding the air quality network through a combination of reference-grade and low-cost sensors to capture localized events more effectively. Integration of real-time data into public information platforms and city-level decision-making is also emphasized as a strategic priority.

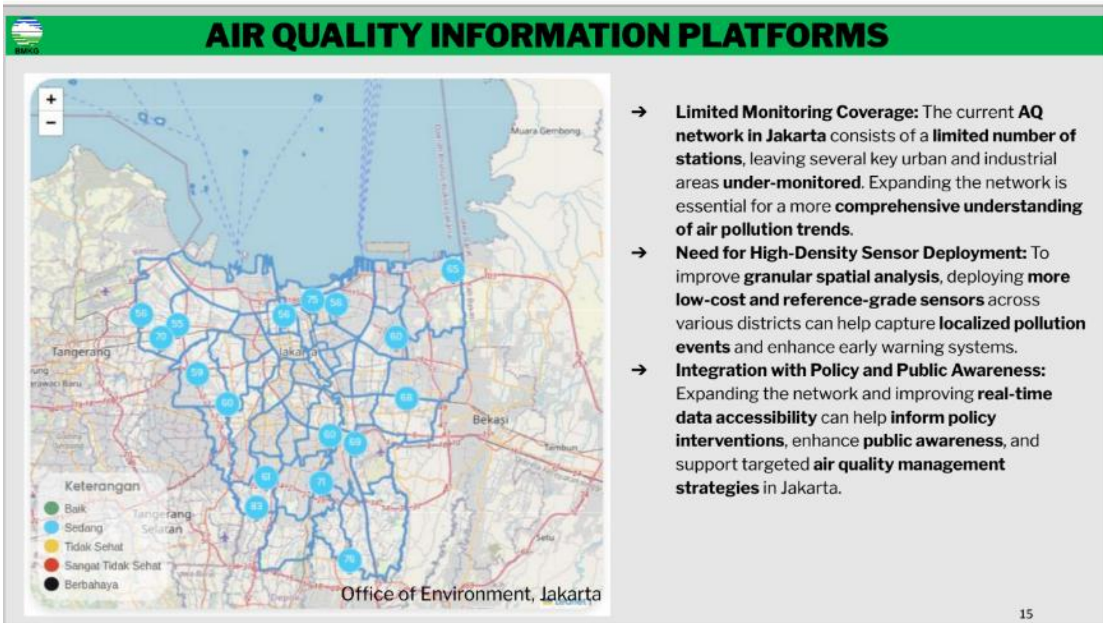

Figure 2. Air Quality Information Platform in Indonesia

2.2. Japan

Status and Future Development of Air Quality Monitoring in EANET, especially LCS Utilization in Asian Region

The Asia Center for Air Pollution Research (ACAP), serving as the Network Center of the Acid Deposition Monitoring Network in East Asia (EANET), has been leading regional efforts to expand air quality monitoring through the application of low-cost sensors (LCS) in combination with traditional reference systems. Recognizing the challenges faced by developing economies—such as high monitoring costs and limited technical capacity, ACAP has introduced a Hybrid Air Quality Monitoring Network (HAQMN) model to address these gaps.

This hybrid model enables broader monitoring coverage by integrating LCS with standard reference stations, targeting pollutants such as PM2.5 and ozone. ACAP launched HAQMN demonstration projects in selected Asian cities, including Ha Noi, Viet Nam and Yangon, Myanmar. In Yangon, LCS devices were relocated across five sites within the city for small-scale monitoring. Results showed that PM2.5 levels exceeded World Health Organization standards, especially during the dry season and nighttime periods when pollutants accumulated due to wind direction from the city center.

Looking ahead, EANET is working toward integrating satellite data and IoT technologies with LCS networks to improve pollutant tracking across urban and regional scales. The synergy of multi-point LCS data and remote sensing will contribute to better understanding of emission sources, pollution transport, and mitigation planning.

ACAP's approach offers a scalable and cost-effective framework for expanding air quality monitoring, particularly in resource-constrained environments. It provides a practical model for APEC economies seeking to enhance environmental governance through accessible technologies and regional collaboration.

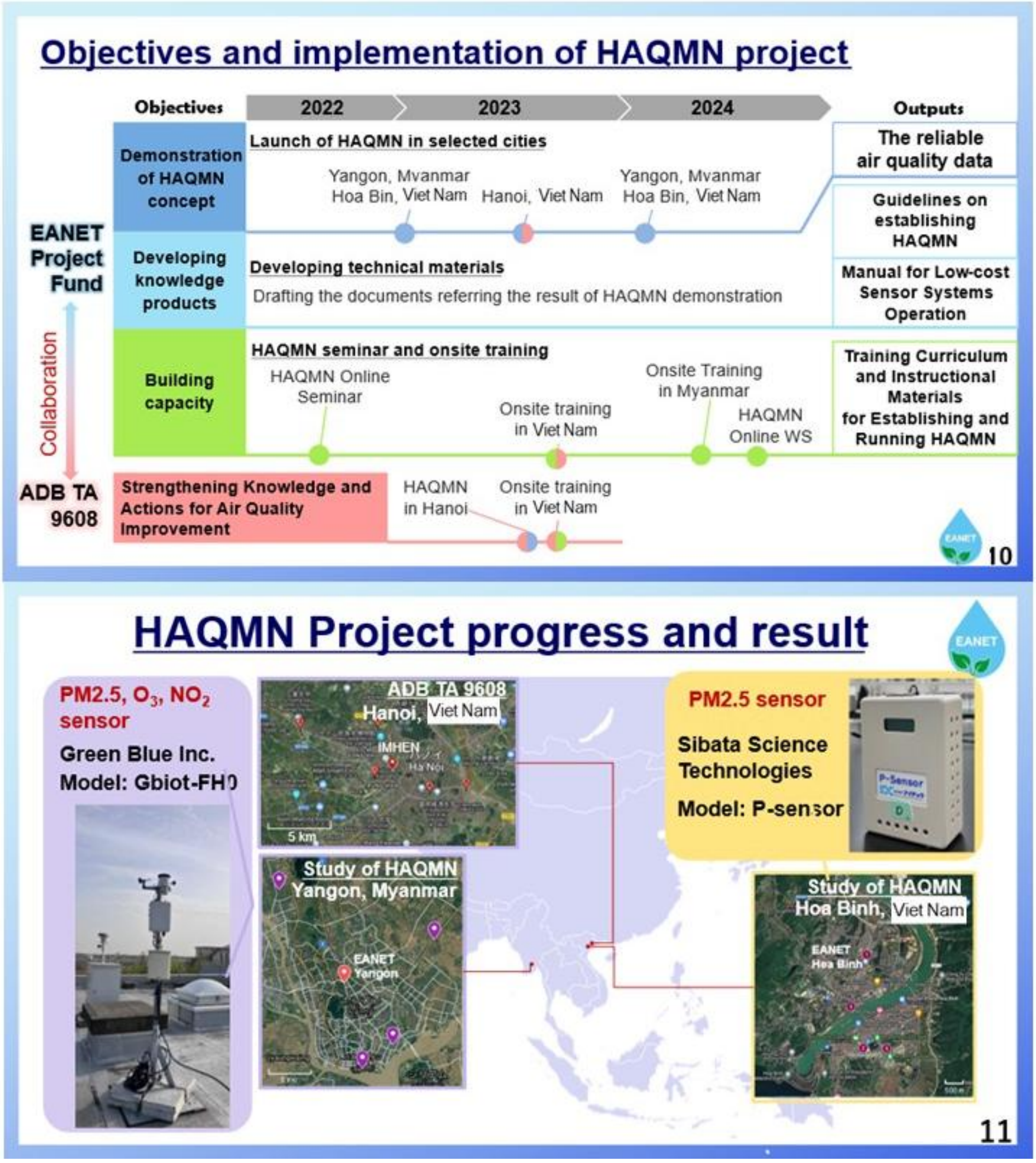

Figure 3. HAQMN Project: Goals and Achievements

2.3 Malaysia

Revolutionizing Air Quality Monitoring in Malaysia with Low-Cost Sensors: A Case from National University of Malaysia

The National University of Malaysia (UKM) has developed and deployed an innovative, low-cost air quality monitoring system called AiRBOXSense. Designed as an affordable and scalable alternative to conventional monitoring stations, AiRBOXSense enables real-time environmental sensing across various public, private, and community sectors in Malaysia.

AiRBOXSense integrates core sensor elements, power systems, cloud-based data processing, and connectivity via Wi-Fi or GPRS, providing live data access through mobile applications and online dashboards. This infrastructure supports applications such as roadside air quality mapping, disaster monitoring, school-based environmental education, and greenhouse gas tracking in industrial zones.

Beyond outdoor applications, the system has been adapted for indoor use in high-density facilities like hospitals and airports. For example, indoor air quality studies conducted at Sultan Abdul Aziz Shah Subang Airport revealed important insights about pollutant exposure in confined transport hubs. Additionally, a pilot study using the airborne sensing drone demonstrated the capability of mobile platforms to enhance pollution detection coverage and identify localized pollution sources in real-time.

2.4. The Philippines

Enhancing Air Quality Monitoring in the Philippines through the UP CARE Research Program

The University of the Philippines Diliman, through its UP CARE (Community-Accessible Real-Time Environmental) Research Program, has established a comprehensive, sensor-based air quality monitoring system aimed at improving data availability and public awareness across urban regions of the Philippines. The initiative integrates IoT-based sensor networks, big data platforms, and citizen engagement to support air quality assessment and policy development.

UP CARE consists of stationary sensor nodes deployed in strategic locations across Metro Manila and Baguio, including barangay halls, public markets, parks, and academic campuses. As of 2025, 24 sensors have been installed—21 in Metro Manila and 3 in Baguio/Benguet—designed to detect PM2.5, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), temperature, humidity, and traffic conditions.

An additional focus of the program is on indoor air quality (IAQ) monitoring. Using compact sensors, UP CARE tracks pollutant levels in closed environments such as offices and classrooms. The system links indoor data to outdoor conditions, supporting ventilation planning and health-focused decision-making.

To reach wider audiences and scale impact, the program maintains strategic partnerships with government agencies, NGOs, and academic institutions. The initiative also emphasizes education and citizen science by making data available through web portals and public dashboards, fostering transparency and community participation.

In conclusion, UP CARE offers a practical, multi-sector model for expanding air quality surveillance using low-cost, real-time monitoring systems. By combining technology with community engagement and academic rigor, the program enhances the Philippines' capacity for air quality governance—serving as a replicable framework for APEC economies seeking integrated, accessible environmental monitoring solutions.

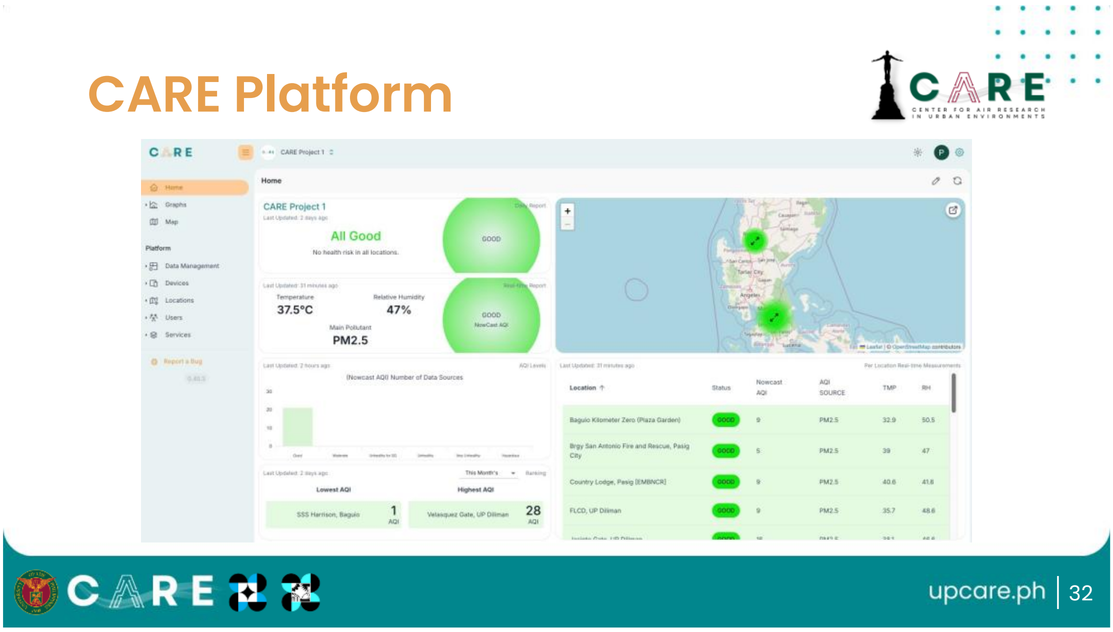

Figure 4. CARE Platform

2.5 Chinese Taipei

2.5.1 Smart Air Quality Sensor and AIoT Management System: A Case from ITRI

The Industrial Technology Research Institute (ITRI), through its Smart Sensing & Systems Technology Center, has developed an integrated system to enhance air quality monitoring and urban environmental governance in the context of smart cities. Recognizing the limitations of conventional, expensive, and sparsely deployed monitoring stations, ITRI has focused on low-cost, scalable, and networked solutions suitable for high-density deployment and real-time management.

The solution features a set of compact sensors capable of monitoring key air pollutants, including PM2.5, ozone (O_3), carbon monoxide (CO), and total volatile organic compounds (TVOCs). These sensors are integrated into an "air box," developed in collaboration with Vision Co., and designed for wide deployment in both urban and industrial zones. As of the report date, the air boxes have been deployed across five cities and seven commercial ports in Chinese Taipei. The compact design and wireless communication capability (via 4G LTE/NB-IoT) allow for real-time data collection, early warning notifications, and integration into centralized monitoring platforms.

Complementing the hardware is ITRI's Smart Air Quality Management System, which includes a user-friendly map-based interface. This system visualizes pollutant distribution, wind direction, and weather data in real time and issues automatic alerts when pollution events occur. The core of the platform is the Event Analysis AI Engine, which integrates data from various sources, including local sensors, central environmental monitoring systems, and global meteorological databases (e.g., NOAA)—to trace pollution sources and support timely decision-making.

In summary, ITRI's solution presents a replicable, technology-driven model for smart air quality management. By combining real-time monitoring, early warning, and cross-source data integration, the system enhances both public awareness and regulatory capacity—offering APEC economies a practical tool for advancing sustainable, data-informed environmental governance.

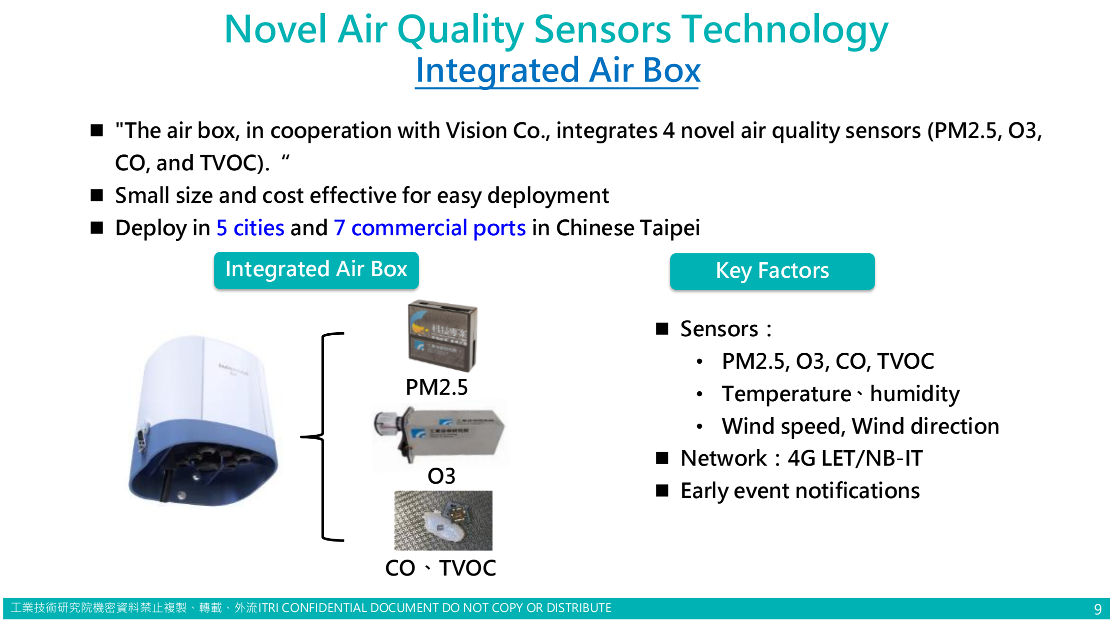

Figure 5. Integrated Air Box Featuring Novel Air Quality Sensing Technology

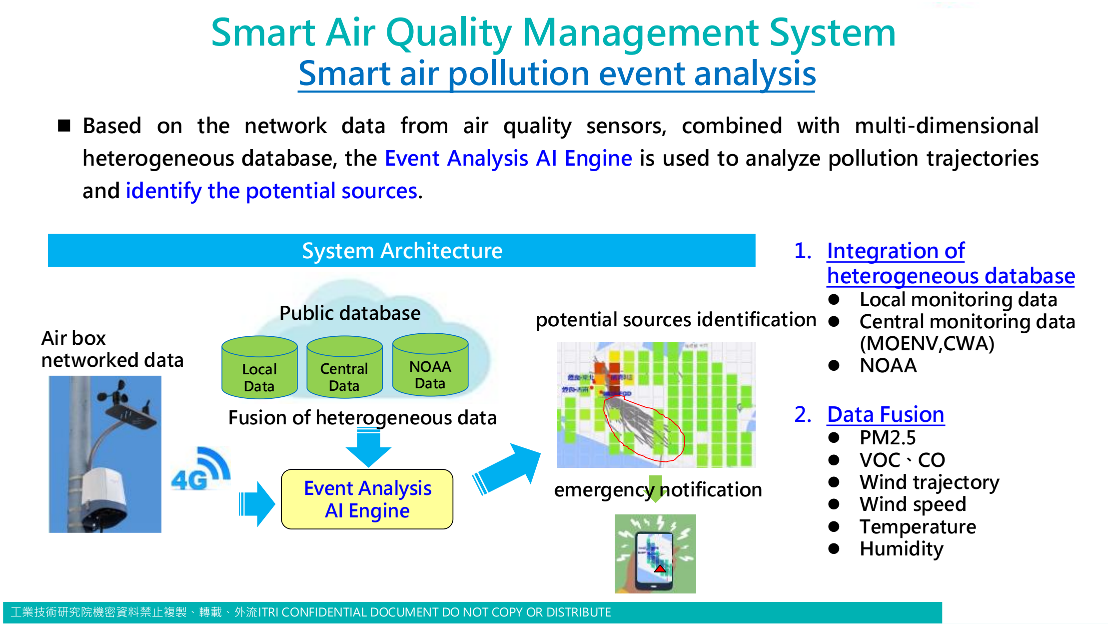

Figure 6. Smart Air Quality Management System

2.5.2 Application of a Cross-scale Atmospheric Chemical Transport Model for Air Quality Forecasting and Pollution Diagnosis over Chinese Taipei

The Air Quality Research Center in Chinese Taipei has developed a high-resolution forecasting and diagnostic system to improve the accuracy and responsiveness of air quality governance. This system addresses the challenge of determining whether air pollution in western Chinese Taipei originates from local sources or is transported from other regions. To support better decision-making, a centralized program has been initiated to strengthen forecasting capabilities at both regional and local levels.

The center's system is integrated with the existing air monitoring infrastructure with an expanded network of 75 stations and over 10,000 IoT-based micro-sensors. These sensors offer greater coverage and provide the localized data necessary for more accurate, real-time air quality assessments. Using this comprehensive data network, the forecasting system delivers 72-hour predictions at a fine spatial resolution (1 km x 1 km), enabling local authorities to issue timely public health alerts and plan responsive actions.

The Air Quality Research Center's integrated approach—linking ground sensors, regional models, and real-time forecasting—provides governments with a valuable tool for air quality planning. It enhances early warning capacity, helps distinguish local vs. external pollution sources, and supports informed, data-driven policy decisions. This model offers a practical reference for APEC economies aiming to modernize air quality management.

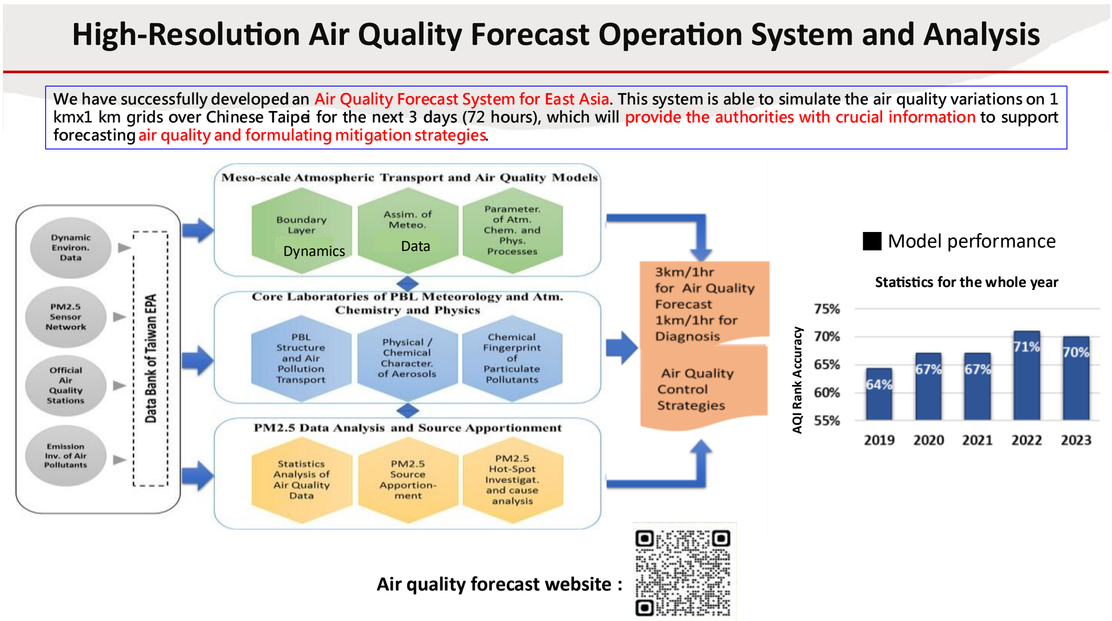

Figure 7. High- Resolution Air Quality Forecast Operation System and Analysis

2.5.3. Applying IoT for Air Quality Management: A Case from Green Ideas Synergy

Green Ideas Synergy Inc., based in Taichung, applies AIoT technologies to strengthen air quality governance across Chinese Taipei. From 2021 to 2024, the company deployed over 3,000 air quality sensors and supported six local governments in implementing smart law enforcement initiatives.

The core of Green Ideas' system is a real-time pollution alert platform integrated with the LINE messaging app. When sensors detect abnormal concentrations of pollutants—such as PM2.5, TVOCs, or odors from factories, construction, or open burning—the system triggers automated notifications and dispatches enforcement teams immediately. This 24/7 mechanism ensures rapid, data-driven response, replacing slower, manual complaint-based investigations.

Long-term sensor deployment is also used for hotspot diagnostics. In one case, 32 sensors positioned around an industrial park in central Chinese Taipei identified abnormal nighttime TVOC readings. Through wind direction analysis and heatmaps, the likely emission source was traced to a specific factory. On-site inspection confirmed unauthorized discharge points, resulting in a NTD650,000 fine. This method has proven effective for tracking pollution patterns and targeting inspections with precision.

In urban districts with recurring air pollution issues—such as busy markets and restaurant clusters, the company collaborated with local authorities to install sensors and implement mitigation measures. Across five sites, interventions such as traffic adjustments and exhaust control achieved an average PM2.5 reduction of 21.9%.

The company's systems also support emergency response during fire-related pollution incidents. Mobile air monitoring vehicles, equipped with sensors and cameras, provide real-time pollutant tracking and impact mapping. These tools deliver early warnings to local authorities and residents—often before official government alerts—enhancing public health protection and emergency coordination.

Through the integration of smart sensing, automated alert systems, and evidence-based enforcement, Green Ideas Synergy Inc. demonstrates a scalable, replicable model for modern air quality governance.

2.5.4. Enhancing Smart Management：The Case from ProBai Solution

ProBai Solution, a local company specializing in AIoT and big data environmental applications, has developed smart air quality monitoring solutions for various sectors, including construction, urban governance, and agriculture. Their technology enables real-time tracking, automated alerts, and data-driven compliance management across different operational environments.

In the construction sector, ProBai's Smart Construction Sensing System addresses common challenges such as dust, noise, regulatory compliance, and occupational safety. Sensors installed at construction sites detect PM2.5 and PM10 levels. When pollution exceeds safe thresholds, the system automatically activates dust suppression mechanisms, such as water spraying. Additionally, LED boards and alarm lights notify workers on-site to minimize exposure risks. The system also incorporates weather and safety data—such as wind speed, wind direction, temperature, and rainfall—to adjust construction activities accordingly and reduce the risk of heat stress or high-altitude work hazards.

The platform integrates a visualized AQI map, time-lapse cameras, and cloud-based data storage. This allows construction firms to remotely manage multiple sites on a unified interface and provide government regulators with access to historical records for audit and compliance purposes. This solution not only supports environmental monitoring but also improves transparency and accountability in construction operations.

In agriculture, ProBai has implemented air quality monitoring systems in pig farms to improve livestock health and operational efficiency. The sensors detect pollutants such as ammonia (NH_3), hydrogen sulfide (H_2S), ozone (O_3), CO_2, PM2.5, and PM10, which affect animal health and contribute to odor-related complaints from nearby residents. When harmful levels are detected, the system activates farm equipment to maintain sate conditions. This helps reduce disease outbreaks, ensures compliance with environmental regulations, and alleviates the burden on aging agricultural workforces.

Across all sectors, data collected by ProBai's systems is uploaded to the cloud, supporting long-term analysis, real-time alerts, and performance tracking. By combining expertise in big data, AI, and environmental sensing, ProBai Solution offers a practical model for integrating smart technologies into air quality governance. Their work demonstrates how real-time, localized data can enhance decision-making, operational safety, and compliance.

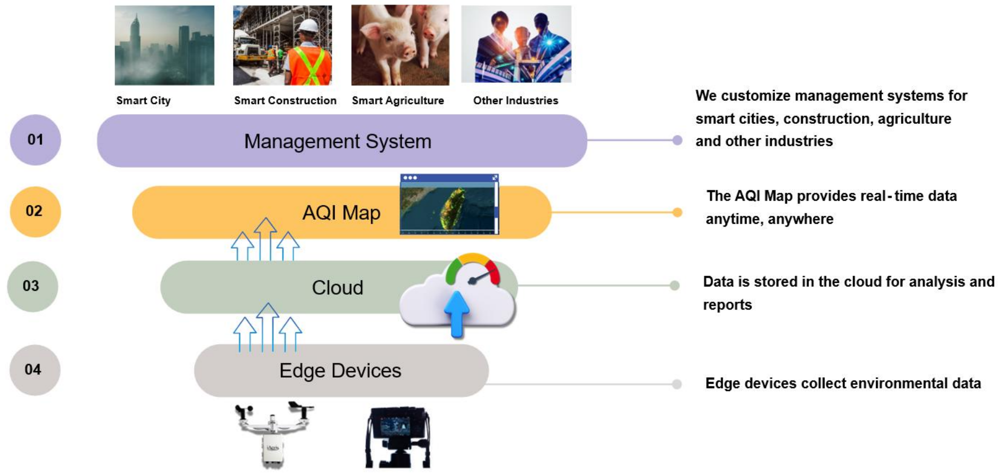

Figure 8. Solution Structure for Air Quality Monitoring

2.5.5. Low-cost air sensors IoT deployment and Applications: A Case from Ministry of Environment in Chinese Taipei

To enhance environmental oversight, the Ministry of Environment (MOENV) in Chinese Taipei has developed a layered air quality monitoring system combining traditional fixed stations with a growing network of low-cost smart sensors. This expanded infrastructure includes more than 78 standard monitoring stations and approximately 10,000 IoT-based sensors, improving spatial resolution and enabling near-time pollution assessment and response.

The MOENV utilizes five types of sensor deployment—such as mounting on streetlights—to form a dense network capable of monitoring PM2.5, PM10, ozone, and other major pollutants. This approach supports a more precise Air Quality Index (AQI) and aids in both forecasting and regulatory enforcement. In addition, the ministry has developed a smart platform for equipment monitoring, pollution tracking, and AI-based event detection. This platform integrates government datasets, wind field data, public complaints, and industrial records to trace pollution sources and issue proactive alerts.

Big data analytics have allowed the MOENV to identify over 1,500 cases of environmental violations, resulting in fines totaling more than NTD310 million. This demonstrates how sensor networks, when paired with intelligent data systems, can significantly enhance compliance efforts.

A key innovation is the “Mobile of Things” (MoT) system, which equips moving vehicles—such as taxis, buses, and scooters—with air quality sensors. These mobile units increase spatial coverage without requiring heavy infrastructure, enabling dynamic pollution mapping across urban areas and along roadsides. Applications have included identifying pollution hotspots near roads, responding to open burning, and adjusting street cleaning schedules based on real-time PM2.5 concentrations.

The MoT system has been deployed in collaboration with nine local Environmental Protection Bureaus, using 60 mobile sensors for practical operations. The data collected supports decisions on enforcement actions and environmental planning, providing a flexible and cost-effective extension to fixed monitoring infrastructure.

In parallel, the MOENV has launched the “Environment Info Push” mobile app, the first in Chinese Taipei to provide 12-hour air quality forecasts using AI and big data. The app helps both citizens and visitors access localized, real-time environmental information, increasing transparency and public engagement.

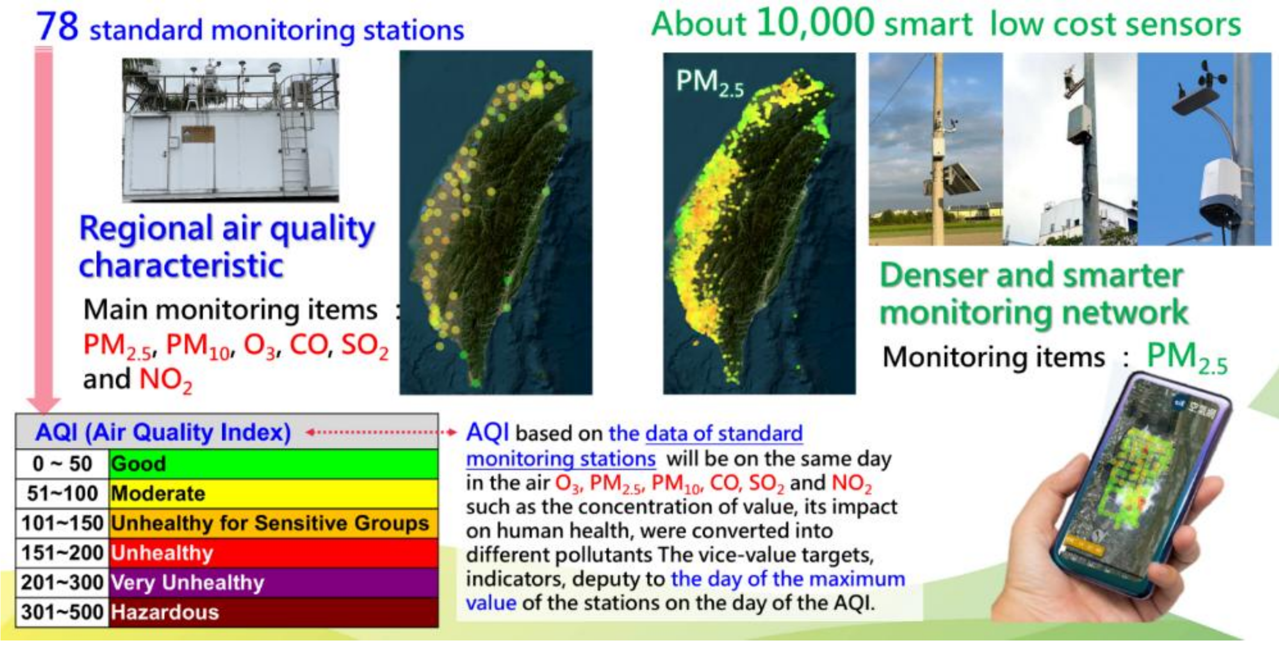

Figure 9. Air Quality Monitoring in Chinese Taipei

Figure 10. All-in-One Platform for Air Quality Monitoring in Chinese Taipei

2.5.6. Applying Artificial Intelligence and IoT in Environmental and Air Quality Management: A Case from Taichung City Government

The Environmental Protection Bureau of Taichung City Government has implemented a comprehensive suite of smart technologies to enhance the detection, enforcement, and management of air quality issues. This approach integrates artificial intelligence (AI), the Internet of Things (IoT), and mobile monitoring systems to improve both the efficiency and effectiveness of urban environmental governance.

One notable initiative is the application of AI-based image recognition systems to identify high-polluting scooters. These systems are installed at fixed roadside locations and on mobile platforms, including taxis through a partnership with local taxi company. The system automatically detects visible emissions and matches them with license plates, enabling around-the-clock enforcement without the need for manual inspection. In 2024, this initiative led to the issuance of NTD2.8 million in fines and the cancellation of 139 vehicle licenses due to non-compliance with inspection requirements.

In addition, the Bureau has extended AI-based smoke detection technologies to monitor emissions from both public and private facilities. Since its deployment in 2012, the system has been installed at 40 locations in industrial and high-risk zones across Taichung. Between May 2023 and January 2025, the system identified 15 violations, resulting in NTD2.2 million in fines. These systems provide 24-hour remote surveillance and serve as digital evidence to support regulatory enforcement.

The city's Intelligent Environmental Inspection Center has played a central role in integrating these technologies. The center operates 21 smart monitoring units across nine major industrial and pollution-prone areas. In a warehouse fire incident, the system detected elevated PM2.5 levels and issued alerts 13 minutes before the fire department, demonstrating its value in emergency response and public safety.

Overall, Taichung City's integrated use of AI, IoT, and automated enforcement systems offers a model for smart environmental governance, supporting early detection, efficient regulation, and public health protection.

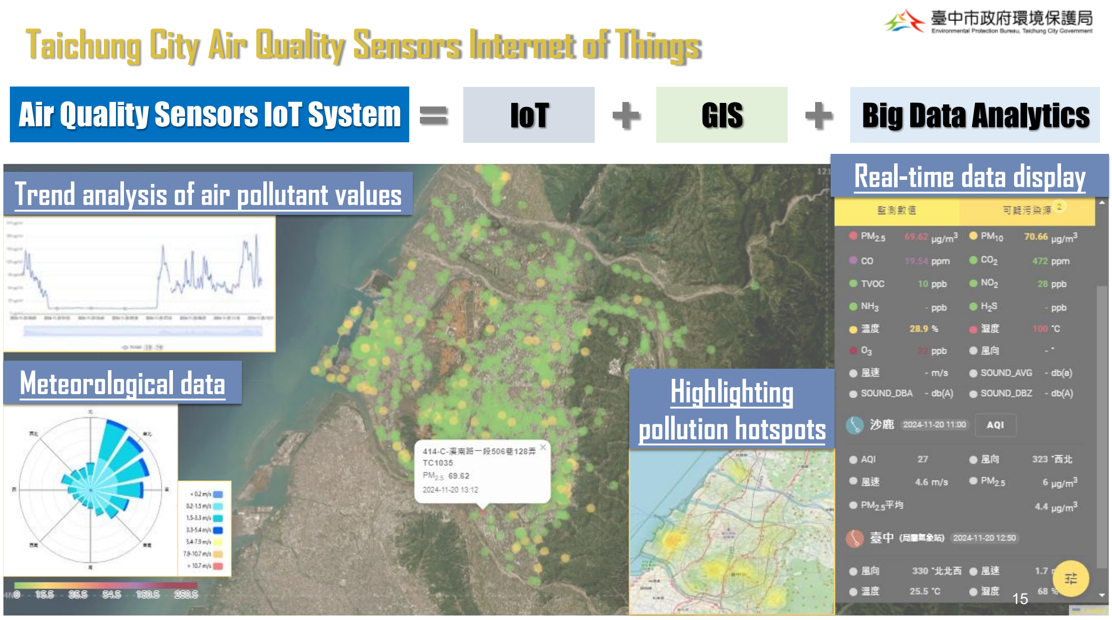

Figure 11. Integration of IoT, GIS, and Big Data in an Air Quality Sensor Platform

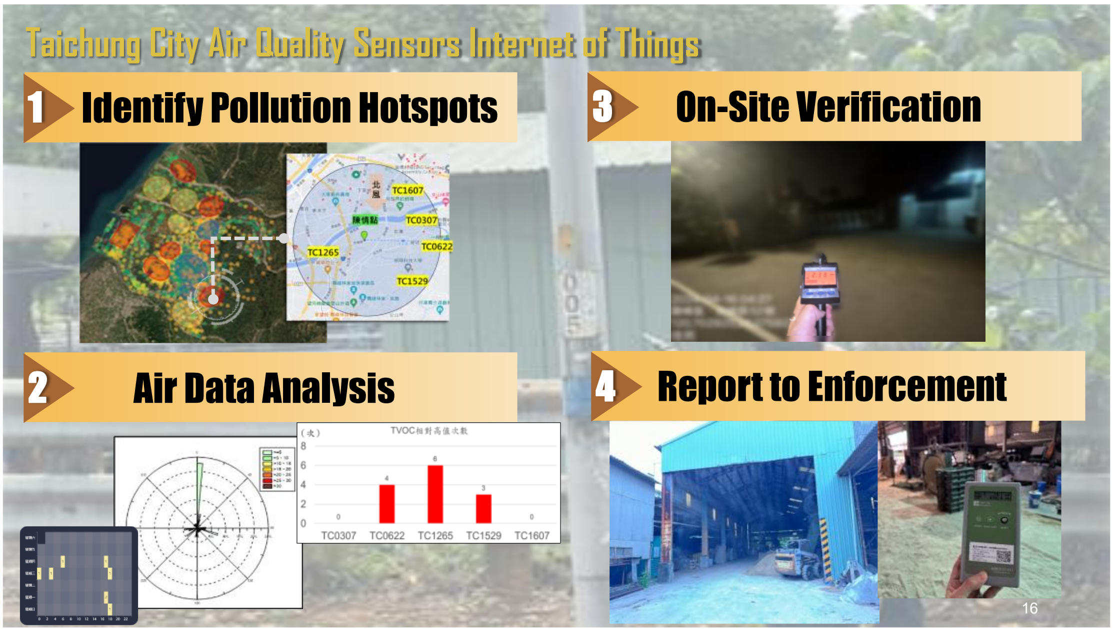

Figure 12. Case Study: Response to Public Air Quality Complaints

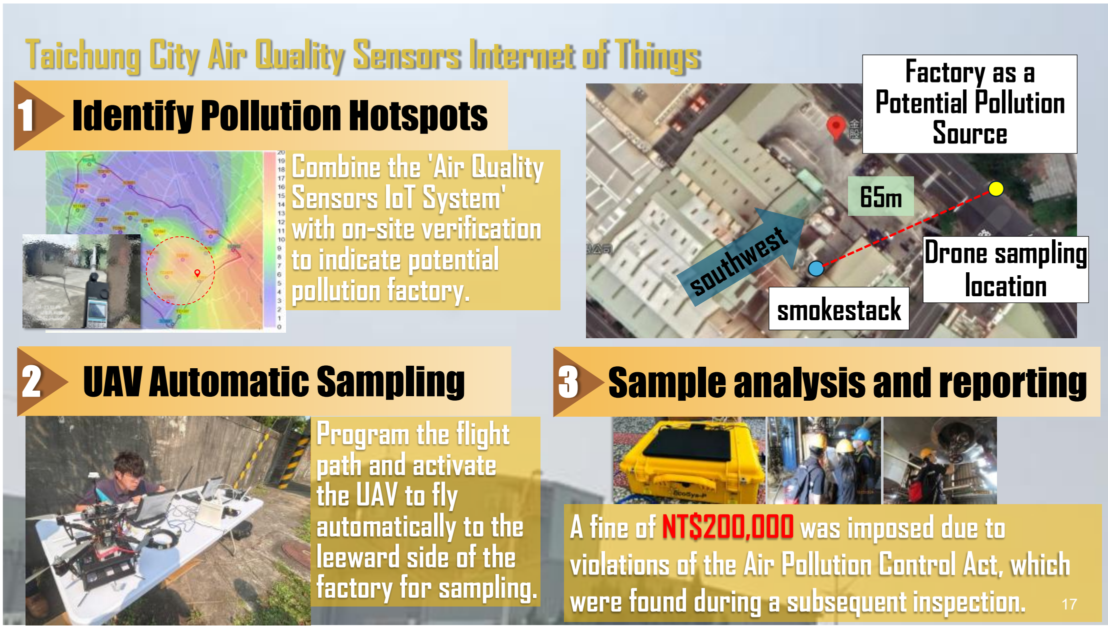

Figure 13. Case Study: Automated Drone-Assisted Air Sampling and Inspection

2.6. Thailand

Industrial IoT-Based Air Quality Monitoring in Thailand: A Case Study from Synergy Technology

Synergy Technology Co., Ltd., a leading private sector innovator in Thailand, has developed an Industrial IoT-based air quality monitoring platform aimed at enhancing environmental management across urban, industrial, and public spaces.

In partnership with stakeholders such as the Thailand Digital Economy Promotion Agency (depa), the Chulabhorn Research Institute (CDRI), and ProBai, Synergy has helped establish an Environmental Innovation Center in Bang Pakong. The initiative includes deployments in industrial estates, schools, and communities across seven eastern provinces of Thailand—providing localized monitoring for areas highly vulnerable to PM2.5 exposure.

By integrating real-time environmental sensing with scalable digital infrastructure, Synergy Technology enables government agencies and private sector clients to take proactive steps toward air pollution mitigation. The data supports early warnings, regulatory enforcement, and public health protection.

Figure 14. Dashboard of Synergy Solutions

2.7. Viet Nam

Enhancing Air Quality Monitoring in Viet Nam: Leveraging IoT and AI for Smarter Environmental Management

Air pollution in Viet Nam is a growing environmental concern, particularly in major cities like Ha Noi and Ho Chi Minh City. Effective air quality monitoring is essential for assessing pollution levels and implementing targeted mitigation strategies.

Traditional monitoring systems face challenges such as limited coverage, high operational costs, and delayed data reporting.

Viet Nam's current monitoring system includes central level and provincial networks managed by the Ministry of Natural Resources and Environment (MONRE), local Departments of Natural Resources and Environment (DONRE), and other organizations. These stations contribute data to the central level environmental database (Page 14). In Ha Noi, the network has grown to include 10 automatic stations and an additional 24 sensor-based monitoring sites donated by international partners such as THT Co., Ltd.

Viet Nam has been actively integrating smart technologies into its air quality management strategy to address the limitations of traditional monitoring systems. The Hanoi University of Science and Technology (HUST) highlighted several studies and applications demonstrating how Internet of Things (IoT) and Artificial Intelligence (AI) can modernize monitoring practices and support real-time environmental governance.

IoT-enabled systems have facilitated the deployment of dense, low-cost sensor networks capable of real-time data collection and wireless transmission to cloud platforms. These systems offer improved scalability, accessibility, and cost-efficiency compared to conventional fixed stations, allowing for wider coverage across cities and industrial zones.

AI technologies play a central role in processing the large volumes of data generated by these networks. Machine learning and deep learning algorithms are used to predict air pollution trends, identify anomalies, and analyze pollution hotspots. They can also integrate data from satellite imagery, meteorology, and traffic flows to generate more accurate and timely forecasts.

An example of this integration is the Fi-Mi system, developed by HUST. Fi-Mi uses AI to calibrate low-cost sensor data and generate high-resolution spatiotemporal air quality predictions. This reduces the need for widespread hardware deployment while maintaining data accuracy.

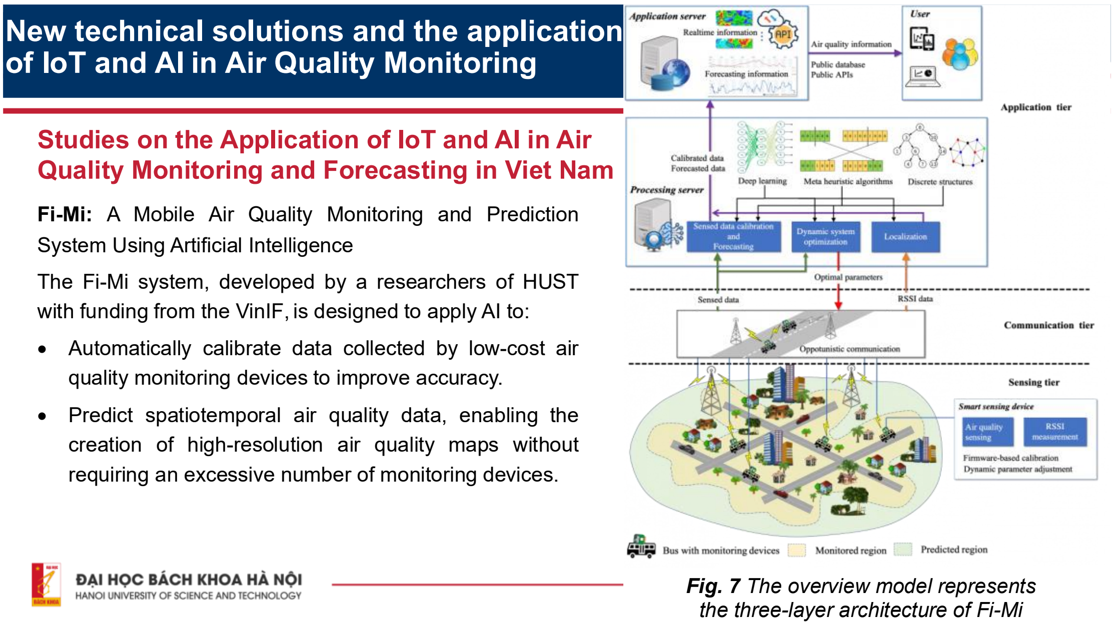

Figure 15. Air Quality Monitoring and Forecasting in Viet Nam

3. Air Quality Monitoring Solutions in Practice: Selected Case Studies

3.1 Air Quality Detector

The air quality detector, developed with technology transferred from ITRI, has been adopted by the Environmental Protection Administration's Air Quality Monitoring Network in Chinese Taipei. It is the only air quality monitor in the network that is both designed and manufactured in Chinese Taipei. With high-performance sensing capabilities, LTE transmission, GPS positioning, and remote maintenance functions, it ensures reliable and continuous monitoring. Its blue-and-white design integrates seamlessly with its surroundings, offering a distinctive alternative to conventional air quality monitors.

Figure 16. Air Quality Detector

3.2 Gas Sensor Module

The MOX gas sensor, independently developed by ITRI, is capable of detecting carbon monoxide (CO) and total volatile organic compounds (TVOC) in the environment. It features a proprietary micro heater, gas-sensing materials, and waterproof, dustproof packaging, ensuring high sensitivity and accuracy. The sensor has been deployed and validated at air quality monitoring stations operated by the Environmental Protection Administration, across six counties and cities, as well as in seven major commercial ports. Its miniaturized design enables broad and scalable deployment.

Figure 17. Gas Sensor Module

3.3 Air Quality Monitoring IoT System

The Smart Sensing & Systems Technology Center at ITRI has developed an Internet of Things (IoT)-based system designed to enhance the precision of outdoor air quality monitoring. This system leverages advanced sensing technologies to support real-time data collection and analysis across urban environments. It is applicable to a range of domains, including environmental monitoring, public health, and medical safety. The system also integrates third-party data sources—such as air quality indices, wind trajectories, and enforcement data—to enable comprehensive identification and tracking of pollution hotspots. These capabilities contribute to smart city initiatives by facilitating informed air quality analysis, regulatory inspections, and data-driven environmental governance. The system is intended to support the formulation of effective environmental policies and promote long-term public health benefits.

Figure 18. Air Quality Monitoring IoT System

3.4 Indoor and Outdoor Air Quality Solution

The demonstrated solution leverages advanced AIoT technology to unify various types of air quality sensors into a single integrated system. It has been successfully applied across multiple domains, including smart city infrastructure, indoor environmental management, and intelligent agricultural operations. By combining real-time data analytics with coordinated software and hardware integration, the system enables effective air quality monitoring and supports enhanced operational efficiency across diverse environments.

Figure 19. Indoor and Outdoor Air Quality Solution

3.5 Air Sensor Network, Ministry of Environment in Chinese Taipei

The Ministry of Environment has established a comprehensive air quality monitoring network that forms the foundation of its environmental management efforts. This network consists of 78 fixed stations and 10 portable stations, providing detailed monitoring across urban, industrial, traffic, background, and park environments. These stations support not only long-term trend analysis but also real-time data for pollution prevention and control planning. As of 2023, over 10,000 sensors have been installed and nearly 80,000 regulated factories are being monitored.

To enhance transparency and data accessibility, the Ministry developed an integrated online platform that displays real-time air quality information across administrative regions and industrial zones. The monitoring infrastructure undergoes rigorous maintenance, including daily calibrations, instrument checks, and quality assurance reviews, ensuring the accuracy and reliability of the data.

In recent years, the Ministry has adopted AI and Internet of Things (IoT) technologies to expand the system's spatial and temporal resolution. A smart monitoring platform has been introduced to integrate sensor data with environmental background information, improving predictive capabilities and early detection of air quality issues. IoT-based micro-sensors—deployed across urban neighborhoods, school campuses, and industrial zones—enable real-time monitoring down to the minute and at street level.

All sensor data is available to the public via the Ministry's online platforms, offering access to high-frequency readings, air quality forecasts, and real-time visualization tools. The system supports timely public communication and helps citizens plan outdoor activities while serving as a critical tool for localized environmental governance.

4. Results and Analysis of Pre-Seminar Survey

4.1 Purpose and Objectives

The rapid industrialization worldwide has significantly increased air pollution, posing serious health risks. One key focus of sustainable environmental development is real-time air quality monitoring in urban areas, which is essential for creating policies to address these challenges. This aligns with the priorities of APEC 2023, "Innovative: Enabling an Innovative Environment for a Sustainable Future."

Our project, "Improving Air Quality Monitoring Solutions for Environmental Governance in Cities and Industries," aims to enhance the accuracy of outdoor air quality monitoring and propose IoT-based governance solutions to support APEC economies in advancing air quality governance.

We are conducting a survey to assess the current state of air quality monitoring in APEC economies or regions, focusing on outdoor monitoring technologies. Through this survey, we seek to understand the requirements and practices in air quality monitoring, ultimately informing discussions on how IoT-based sensing systems and innovative solutions can improve air quality control in urban environments and industries. The results will inform the agenda of our upcoming international forum, where experts will discuss best practices and policy recommendations.

4.2 Scope and Methodology

The objective of this survey was to gather insights from key stakeholders of air quality monitoring within APEC economies. Invitations were distributed through the APEC Secretariat to all APEC economies, primarily targeting individuals from the following three categories:

- Policy makers and regulators in the field of air quality monitoring
- Researchers with expertise in air quality monitoring
- Representatives from industries regulated in air quality control

Based on the responses received, most participants were academic researchers and government officials. To ensure a more comprehensive perspective, we plan to enhance interaction with industry representatives in upcoming APEC forum in 2025 in Chinese Taipei, incorporating their feedback into the discussion.

The survey was conducted using an online Google Form, with most of the questions being multiple-choice (Appendix A). The survey was open to response from October to November 2024.

4.3 Result Analysis

4.3.1 Demographic Information

A total of 25 responses were received for this survey. Below is an explanation of the APEC economies of the respondents and their personal background information.

- Economies Represented in the Survey Responses: The survey responses covered six APEC economies, including: Japan; Republic of Korea; Peru; Chinese Taipei; Thailand; and the United States. The respondents represent a mix of advanced economies and emerging market and developing economies, based on the economic development classifications provided by the IMF (April 2023 Update). This classification highlights the diverse perspectives captured in the survey, representing economies at varying levels of development across the APEC regions (Table 1).

Table 1. List of Participating APEC Economies

Economic Development Classification	APEC Economy
Advanced Economy	Japan
	Republic of Korea
	Chinese Taipei
	the United States
Emerging Market and Developing Economy	Peru
	Thailand
Reference: https://www.imf.org/en/Publications/WEO/weo-database/2023/April/groups-and-aggregates	

- Background of Survey Respondents: The survey respondents primarily come from academic and research institutions (80%), with the remaining 20% representing government agencies. In terms of their specific areas of work, respondents are focused on three key domains: Research and Development (52%), Technology and Solutions Provision (28%), and Policy Development (20%). This distribution reflects a well-rounded representation of expertise in both theoretical research and policy-making perspectives. Moving forward, we plan to further enhance the diversity of perspectives by engaging more with the private sector through the APEC forum in 2025, encouraging greater collaboration and dialogue with industry stakeholders.

4.3.2. Environmental Policy and Regulation

The survey examined perceptions regarding the prioritization of environmental monitoring, including air quality and other environmental factors. About 90% of advanced economy respondents rated it as a very high or high priority, reflecting strong emphasis, while only 50% in emerging and developing economies did, indicating a lower focus on this issue.

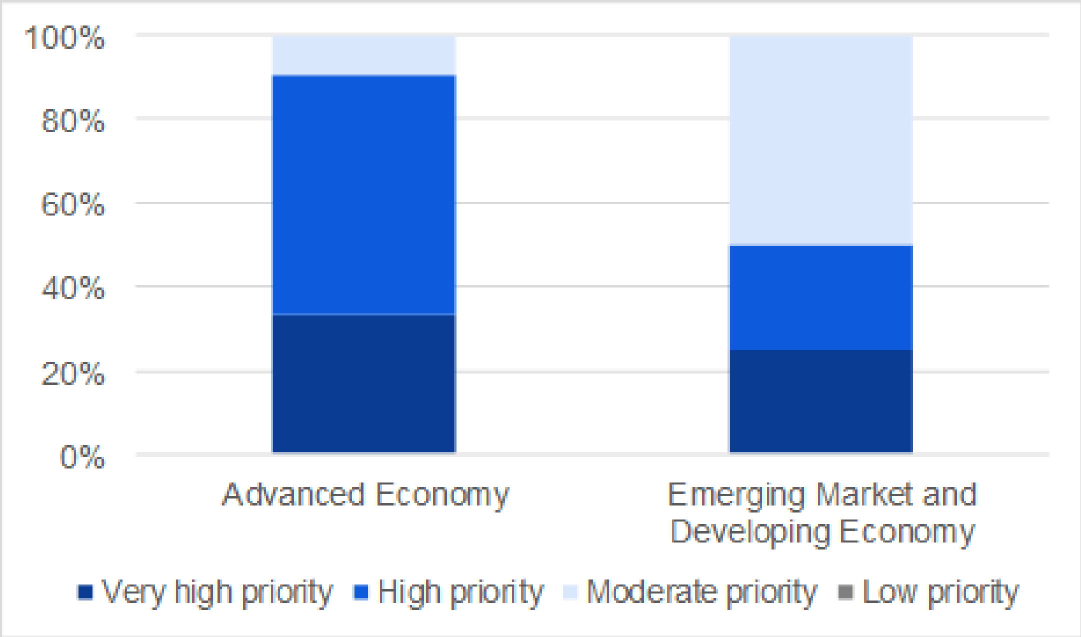

Figure 20. Degree of Prioritization of Environmental Monitoring

Table 2. Definition of Priority

Definition of Priority	
Very high priority	Environmental monitoring is a key focus of government policies and actions.
High priority	Environmental monitoring is important, but not always at the forefront of government efforts.
Moderate priority	Environmental monitoring receives some attention, but there are other higher priorities.
Low priority	Environmental monitoring is not a major focus and is often overlooked.

- Primary challenges in monitoring air quality
    - Respondents from advanced economies and emerging markets and developing economies exhibited differing perceptions regarding the primary challenges in air quality monitoring (Table 3). However, two challenges appeared in the top three concerns for both groups: 1) Inadequate technology or infrastructure, with limited coverage in rural or remote areas, and 2) Regulatory and policy challenges. These shared concerns align closely with the core themes of this survey and will serve as key focal points for future forums. Addressing these issues will be crucial for fostering effective and inclusive air quality monitoring solutions across diverse economies.

- It is worth noting that, in emerging markets and developing economies, regulatory and policy challenges are the main barriers to air quality monitoring, surpassing cost concerns. Addressing this requires prioritizing clearer regulations, stronger enforcement mechanisms, and cohesive policies to build effective monitoring systems. A strengthened regulatory framework will lay the foundation for tackling other challenges and achieving sustainable progress in air quality management.

Table 3. Ranking of Primary Challenges in Monitoring Air Quality

	Advanced Economy	**Emerging Market and Developing Economy**
1. Cost and resource constraints	1	5
2. Inadequate technology or infrastructure, with limited coverage especially in rural or remote areas.	2	3
3. Regulatory and policy challenges	3	1
4. Public awareness and engagement	4	2
5. Lack of continuous monitoring to capture fluctuations among different seasons	5	4
6. Limited technical and operational capacity among monitoring professionals	6	6

- Priorities for improvement in air quality monitoring: The consensus keywords for the priority directions in air quality management include: IoT-based monitoring systems, affordable and scalable sensors, advanced data analysis, and policy making.

Table 4. Priorities for Improvement in Air Quality Monitoring

Which areas do you think should be prioritized for improvement in air quality monitoring in your economy? Please select all that apply.	**Proportion of agreement**
IoT-based monitoring systems	72%
Policy making	72%
Affordable and scalable sensors that can be widely deployed	68%
Advanced data analysis and artificial intelligence tools to process data and predict trends	68%
Cloud data sharing platform	44%

- Entities targeted by air pollution regulations: In the responses from APEC economies, the most regulated industry in air quality control is industrial facilities (including manufacturing plants and power plants) (Table 5). These industries are typically major contributors to air pollution due to their high levels of emissions, making them a primary focus for air quality regulations. It is worth noting that in some agricultural economies, such as Thailand, agricultural production (open-air burning) is also included in air quality regulation industries.

Table 5. Entities Targeted by Air Pollution Regulations

Which entities are targeted by air pollution regulations in your economy? Please select all that apply.	Proportion of agreement
1. Industrial facilities（manufacturing plants and power plants）	96%
2. Commercial facilities	32%
3. Construction and infrastructure development	28%
4. Residential activities	24%
5. Agriculture	4%

- The influence of women in policymaking: The survey explored perceptions of women's roles in overcoming resistance to policy implementation. Notably, 76% of respondents strongly agreed or agreed with the statement, showing confidence in women's impact. To enhance women's influence in policymaking, the most common suggestion was to promote a friendly work environment and work-life balance (Table 6), emphasizing the importance of supportive conditions for women to thrive and lead effectively.
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Table 6. Proposed Measures to Enhance the Influence of Women in Policymaking

Proposed measures to enhance the influence of women in policymaking	Proportion of agreement
Promote a friendly work environment and strive for a balance between work and family life.	80%
Establish concrete, transparent, and measurable mechanisms for recruitment and talent retention.	60%
Enhance gender consciousness within the company and the responsibility of supervisors.	56%
Organize gender-related advocacy and training activities to enhance gender equality awareness in the workplace.	52%
Leadership commitment and support from the company.	32%

4.3.3 Air Quality Reference Stations

A remarkable 92% of respondents reported that their economies currently utilize reference stations to monitor air quality. Almost 100% of these respondents strongly agreed or agreed that the use of these reference stations has contributed to improving air quality. This highlights that air quality reference stations have become a standard and integral tool in global air quality monitoring, playing a key role in advancing environmental management and public health.

- Monitoring parameters: The most widely monitored parameter used by air quality reference stations is PM2.5, followed by CO/CO2 and NOX (Table 7).

Table 7. Monitoring Parameters (Reference Stations)

The proportion mentioned among monitoring parameters	
PM2.5	95%
CO/CO2	77%
NOX	73%
Ozone	59%
SOX	55%
Methane	32%
Other	14%

- Number of existing reference stations: The number of reference stations varies significantly across each economy, as shown in table 8.

Table 8. Number of Existing Reference Stations

How many reference stations are there in your economy?	
Less than 20	18%
21-50	12%
51-100	29%
101-200	6%
201 or more	35%

4.3.4 Air Quality Sensing Devices

Like the responses regarding reference stations, 92% of respondents indicated that their economies already use sensors for air quality monitoring. Additionally, nearly 100% of respondents agreed that the use of sensing devices has contributed to improving air quality. This underscores the growing reliance on sensors as an effective and widely adopted tool for enhancing air quality management globally.

- Monitoring parameters: The most widely monitored parameter used by air quality monitoring sensors is PM2.5, followed by CO/CO2 (Table 9).

Table 9. Monitoring Parameters (Sensing Devices)

The proportion mentioned among monitoring parameters	
PM2.5	68%
CO/CO2	14%
SOX	5%
Ozone	5%
Other	9%
NOX	0%
Methane	0%

- Number of existing sensing devices used in air quality monitoring: The number of sensors varies significantly across each economy, as shown in table 10.

Table 10. Number of Existing Sensing Devices

How many air quality monitoring sensors are there in your economy?	
Less than 20	24%
21-50	6%
51-100	18%
101-200	12%
201 or more	41%

- The most valued benefit of air quality monitoring sensing devices: When asked about the most important benefits of air quality sensing devices, 64% of respondents identified real-time data availability as the top advantage. This benefit enables timely responses to pollution events and allows for more dynamic and adaptive monitoring of air quality, highlighting the critical role of real-time information in effective air quality management and decision-making.

Table 11. Benefits of the Sensing Devices

What is the most important benefit of air quality sensing devices for you?	
1. Real-time data availability enabling timely responses to pollution events and more dynamic monitoring of air quality.	64%
2. Increased coverage and more localized data.	24%
3. Scalability enabled by affordability and ease of installation.	12%

- Future optimization expectations: Regarding the desired improvements for air quality monitoring sensing devices, the top three priorities identified were: sensor network coverage and density (68%), additional features to monitor a wider range of air pollutants (48%), and measurement accuracy (44%).

Table 12. Future optimization expectations for sensing devices

What improvements do you want in air quality monitoring sensing devices?	
1. Sensor network coverage and density	68%
2. Additional desired features, such as the capability to monitor a wider range of air pollutants	48%
3. Measurement accuracy	44%
4. Size and portability in various locations	32%
5. Air quality sensing devices are not yet available in my city or region.	8%
6. Data availability	4%

- Key barriers: When asked about the key barriers to adopting sensors, the top two reasons cited were budget constraints (45%) and frequent maintenance (32%). For the most significant factor, budget constraints, a follow-up question on acceptable price ranges revealed that approximately 40% of respondents preferred sensors priced at less than USD100, while around 36% selected the USD101-500 range. This indicates a strong need for cost-effective sensor solutions to enhance adoption.

Table 13. Major Reasons Hindering the Adoption of Air Quality Sensing Devices

The top reason hindering the adoption of air quality sensors	
Budget constraints	45%
Frequent maintenance	32%
No perceived need	14%
Lack of policy or guidance	5%
Already adopted	5%

If budget constraints are a concern, what price range is acceptable for adopting an air quality sensing device within your organization?	
Less than USD 100	40%
USD101-500	36%
USD501-1000	20%
More than USD1000	4%

4.4 Key Findings and Conclusions

The survey aimed to assess the current state of air quality monitoring in APEC economies, with a focus on IoT-based sensing systems. The results highlight that 92% of respondents from diverse economies already use reference stations and sensors for monitoring air quality, underscoring the growing reliance on these tools globally.

The responses indicate a shared emphasis on addressing key challenges such as inadequate infrastructure and regulatory policy barriers, both of which are critical for enhancing monitoring systems.

Given the growing importance of air quality monitoring sensors, we further explored the key benefits, optimization priorities, and barriers to adoption.

- The most valued benefit, identified by 64% of respondents, is real-time data availability, which allows for timely responses to pollution events and more dynamic air quality monitoring.
- Looking ahead, respondents identified key areas for future optimization of air quality sensors. The top priorities are improving sensor network coverage (68%), expanding the ability to monitor a wider range of pollutants (48%), and enhancing measurement accuracy (44%).
- Budget constraints (45%) and frequent maintenance (32%) were identified as key adoption barriers, with a strong preference for cost-effective sensors, particularly those under USD100.

The survey's findings will be vital in shaping the agenda for the upcoming international forum, where experts will explore how technological solutions like IoT can support better air quality control, particularly in urban environments and industries.

- To address the challenges identified, a clear focus should be placed on improving regulatory frameworks. Strengthening policies and enforcement mechanisms will create a conducive environment for adopting air quality monitoring technologies.
- Additionally, efforts should be made to improve sensor network coverage and density, ensuring comprehensive monitoring in both urban and rural areas.
- With budget constraints being a key barrier, cost-effective solutions should be prioritized, with an emphasis on affordable sensors.
- Finally, fostering collaborations with private sector stakeholders will help bridge gaps in technology deployment and ensure that air quality monitoring becomes a priority across the APEC region.

5. Policy Recommendations

- **Develop Integrated Digital Air Quality Governance Frameworks.** Governments should move beyond standalone monitoring systems and adopt integrated digital governance frameworks that combine IoT, AI, mobile sensing, and cloud-edge computing. This framework should consolidate real-time environmental data across multiple sources (e.g., ground stations, mobile platforms, and satellite inputs) and link with regulatory, transportation, and public health systems. Such integration enables accurate forecasting, rapid enforcement, and proactive urban environmental management.
- **Ensure Regulatory Readiness and Institutional Acceptance of Sensor-Based Evidence.** To harness the full potential of smart sensing technologies, governments must modernize environmental regulatory frameworks to acknowledge data from certified low-cost sensors, AI surveillance, and automated monitoring as reliable inputs to support air quality governance. Such data can play a vital role in pollution hotspot identification, trend analysis, early warning, and decision support. Regulations should include quality control protocols, data security standards (e.g., blockchain), and guidelines for integrating real time sensing technology into environmental planning and risk communication strategies.
- **Increase Investment in Scalable, Low-Cost Sensor Networks.** To address gaps in rural and industrial areas, policymakers should invest in the deployment of affordable, scalable air quality sensors. These deployments should follow a hybrid model, pairing reference-grade stations with widespread sensor nodes—including mobile and community-based units. Incentives, subsidies, or public-private partnerships may be necessary to lower costs and support long-term maintenance.
- **Institutionalize Public Access to Real-Time Air Quality Data.** APEC economies should adopt policies that require the real-time disclosure of air quality data via open platforms and mobile apps. This transparency promotes public health awareness, strengthens citizen participation, and supports data-driven community decision-making. Governments should collaborate with educational institutions and NGOs to expand environmental literacy and civic engagement through sensor deployment and data-sharing initiatives.
- **Strengthen Regional Collaboration on Standards, Training, and Innovation.** Given the cross-boundary nature of air pollution, APEC should foster regional collaboration through shared data platforms, joint research, and harmonized standards for sensor quality, AI algorithms, and data governance. Capacity-building programs should be supported to train environmental

professionals, particularly in developing economies, in deploying and managing modern air quality technologies.

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