

WHAT THE AIR TOLD US

Stories behind **four decades**
of **air quality monitoring,**
management, and climate
change in México



Ruth Wouters
Carlos Sánchez Rivas

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Air Quality, Climate, and Commitment

When I was invited to contribute with this foreword, I felt both honored and hopeful. Honored, because I have had the privilege of contributing —at different times and in different roles, as a researcher, government officer, and as a civil society advocate— to Mexico’s long and complex journey to understand and improve its air quality. Hopeful, because this book gives voice and visibility to many of the people who have made that journey possible. Their work remains a standard that will continue to inspire new generations of scientists, decision-makers, and advocates.

This book brings together decades of effort. Not just scientific progress, but the human stories behind it. Through interviews with pioneers, visionaries, and professionals who laid the foundations for Mexico’s air quality monitoring systems, this work recovers the legacy of those who worked quietly but persistently to gather data, maintain instruments, and push for better emissions and air quality standards, often under challenging conditions.

Air Quality and Climate Change: One Challenge, Shared Roots

One of the most valuable contributions of this publication is to remind us that air pollution and climate change are deeply intertwined. For many years they were treated as separate issues, but we now understand that they share the same sources: transport, industry, and energy production. The use of cleaner fuels, stricter regulations, and an energy transition towards renewable sources benefits both urban health and the planet’s climate stability. In this context, air quality monitoring plays a dual role: it protects lives in the short term and provides essential information for climate mitigation in the mid and long term.

Among the recurring lessons in these pages, the fundamental importance of air pollution monitoring stands out. Without reliable, continuous, and publicly available data, air pollution remains invisible to the public eye and to policymakers. Measurements transform suspicion into evidence, and evidence into action. In Mexico City, it was only when systematic monitoring began in the late 1980s that we came to grasp the true extent of the problem. That insight triggered the launching of effective measures to control some of the atmospheric pollutants such as lead, sulfur dioxide, and carbon monoxide, and to strengthen international collaboration.

From Data to Decision: The Power of Monitoring

Monitoring is essential for building public trust and demanding institutional accountability. It informs citizens, empowers journalists, and supports health professionals revealing long-term trends, both in emissions and in the political will to address them. Thanks to monitoring, Mexico was able to take decisive steps in the 1990s, such as removing lead from gasoline, reducing sulfur in fuels and introducing catalytic converters in vehicles. These policy breakthroughs were not accidental; they were the result of sustained scientific work, political advocacy, and courageous decisions at the highest level.

Progress, however, has not been linear. As several contributors in this book observe, Mexico has often been slow to adopt international air quality and vehicle emission standards, not because of scientific limitations, but due to industrial and administrative delays. Even so, there are also examples of innovation: the adaptation of exposure assessment methodologies to identify vulnerable populations and improve assessment of health impacts, the use of bioindicators in regions with limited infrastructure and the creation of regional alliances and innovative management structures to improve environmental coordination across jurisdictions.

Progress, Resistance, and Innovation

The connection between air quality and climate change has become increasingly important in recent decades. The concept of ‘co-benefits’ has matured, as we now understand that reducing methane helps to curb global warming while also lowering ground-level ozone. This dual impact strengthens the case for integrated policies, but to design them, we need robust, high-quality data, which only monitoring systems can provide.

Shifting Standards and Definitions

Another key theme raised in this book is the role of public participation. In Mexico’s environmental history, it has often been the pressure exerted by citizens, academics, and civil society that has prompted governments to act. Air quality standards continue

to evolve, driven not only by scientific advances but also by growing social demand. As science progresses and acceptable limits become stricter, pollution levels once deemed safe now require immediate intervention. This shift can generate confusion, but it represents progress redefining what it means to breathe clean air based on deeper and more accurate knowledge.

Finally, this book fulfills an essential function: preserving institutional memory. In a country where policies and administrations change frequently, it is easy to forget the long, complex process of building air quality systems, or to repeat past mistakes. The interviews and reflections collected here form a living archive, and invaluable resource for students, researchers and policymakers, and also as a small tribute to those who kept working when political support was scarce and public attention faded.

A Legacy that Continues

For those entering this field: your work matters. Whether you design instruments, analyze data, advise governments, or raise awareness in your community, you are continuing an intergenerational legacy. You are not just inheriting a problem; you are becoming an active part of its solution.

The voices gathered in this publication represent only a small sample of a much larger universe of dedicated professionals, policymakers and advocates who have contributed to improve the air quality in Mexico. I hope this work inspires further research, publications and many more stories that are worth to be recognized and known widely.

May this work serve as a foundation for deeper commitment, broader collaboration, and more determined action. The air we breathe links us all and the fight to clean it must be shared.

Adrián **Fernández** Bremauntz, PhD

INTRODUCTION

This book brings together a series of in-depth interviews with individuals who made significant contributions to the development of air quality monitoring systems in Mexico. Scientists, engineers, and public officials share how this issue became a political priority, how these systems were structured, and how science, health, and public policy have influenced one another over time. Their stories highlight, for instance, the use of plants as bioindicators, the creation of national monitoring networks, and efforts to make data more accessible. These conversations offer a personal and uncommon perspective on four decades of building environmental knowledge.

A Shared Conviction

The project began with a shared belief: the history of air quality monitoring systems in Mexico cannot be told solely through formal reports. Behind the compiled data are people who challenged the status quo, designed new methods, negotiated with officials from various government departments, trained students, and fought to keep environmental concerns on the public agenda. Through their voices, this book reconstructs a complex story of innovation, resilience, conflict, and learning. Sadly, some key figures could not be included, either because they are no longer with us or could not be reached.

The book is intended for a broad and diverse audience. Students and researchers in environmental science, public health, or environmental law will find valuable insights on how knowledge is produced and shared. For government professionals, civil society members, journalists, and educators, these interviews offer lessons about what it takes to build lasting institutions —and how fragile environmental progress can be.

Above all, this book is for those who care about clean air and environmental management, for those who want to understand how data and scientific knowledge are transformed into public policies —or why, at times, they are not.

Learning from the Past

We hope this book serves several purposes. First, to document a national history that remains underrepresented in both national

and international literature. Mexico's environmental efforts have drawn global attention, particularly for its early air quality monitoring initiatives. Yet the personal and institutional dynamics behind these efforts have seldom been thoroughly documented. This work seeks to fill that gap.

Second, to offer a critical reflection on the complex relationship between air quality and public policy. Many interviews reveal moments of alignment —when scientific evidence led directly to action— but also moments of disconnection, delay, or political interference. The implementation of international standards, the adoption of new monitoring technologies, and the development of regional strategies were rarely straightforward processes. Even so, many interviewees express cautious optimism regarding the new generations of scientists, the growing visibility of environmental health, and the increasing integration of climate and air quality agendas.

The intersection of air pollution and climate change weaves a common thread throughout these conversations. Several interviewees emphasize how early urban monitoring efforts laid the groundwork for more ambitious climate strategies. Others highlight the need to update standards, ensure data transparency, and improve coordination between the environmental and energy sectors. The shared message is clear: air quality is a central public health concern and also a pillar of climate resilience.

A Mosaic of Perspectives

Throughout the book, recurring themes emerge: the crucial role of access to air quality data; the ethical dilemmas inherent in environmental decision-making; the unequal distribution of pollution and health burdens; and the fragility of institutions in the face of political change. Some interviews focus on scientific advances, others on regulatory milestones or social pressure. Together, they offer a mosaic of perspectives —sometimes complementary, sometimes in tension— that reflect the complexity of environmental management in Mexico.

We are deeply grateful for the generous collaboration of all the people interviewed for this book. Their willingness to share their experiences and testimonies made it possible to document these stories that are rarely told in a format like the one chosen for the book.

We also extend our gratitude to Adrián Fernández Bremauntz and the team at Iniciativa Climática Mexico, whose support and partnership made this work possible.

We hope this book informs, provokes, and inspires. May it serve as a foundation for future research, a teaching tool, a resource for public policy, and a reminder that cleaner air is not only a scientific challenge, but also a social and political one.

Ruth **Wouters**
Carlos **Sánchez** Rivas

Behind the Story

- » In the 1990s, Mexico began developing systematic air pollution control policies informed by health data, comprehensive emission inventories, and international guidelines.
- » Automated monitoring networks and long-term programs such as ProAire became possible thanks to improvements in data infrastructure.
- » Collaboration between Mexican and international experts and research institutions increased, helping to base air quality standards on complex risk analyses.
- » Regional cooperation in Latin America supported the exchange of knowledge and strategies for air quality management.
- » International organizations such as the OECD and the World Bank began integrating Mexico's experiences into broader environmental frameworks.

Cooperation, Innovation and Persistence: An Effective Approach to Air Quality

On clear days, the outlines of the volcanoes surrounding Mexico City become visible. Environmental engineer Rodolfo Lacy refers to this rare clarity with a phrase by Alfonso Reyes: “the most transparent region of air”—a description Carlos Fuentes would later use with ironic weight. With no more than three such days a year, that irony now seems well justified. For Lacy, this shift in visibility reflects broader transformations in urban development, climate, and public health policy.

Engineering as a Response to a Public Health Challenge

Lacy began studying environmental engineering in the 1970s, when air pollution in Mexico City was largely unrecognized as a political or health issue. Nevertheless, it was a visible and harmful phenomenon. Dust storms carried pollutants from dried lakebeds, informal brick kilns, and heavy industry. Lacy recalls that this dust contained lead, organic matter, and other harmful substances, though the public did not always recognize them as such.

Driven by the urgency of these issues, Lacy decided to specialize in air quality—an unusual choice at the time, given the lack of institutional infrastructure. In 1989, he joined Mexico City's government and developed its first formal air quality management program. He would later lead landmark initiatives, such as the Programa Integral de Control de la Contaminación Atmosférica (PICCA), the contingency plan for high-pollution days, and later, the broader ProAire strategy. Despite the absence of budget, guidelines, or even a defined job description, Lacy and a small team managed to establish the systems needed to address air pollution.

Their work produced the first comprehensive strategies that combined emissions monitoring, vehicle restrictions, urban planning, and public health campaigns. These strategies became a

Figure 7. Six decades of collaboration among institutions and organizations leading to the development of the current air quality monitoring policies in Mexico.

reference for other Latin American cities and contributed to the creation of broader national regulatory frameworks.

Early Policy Steps and Strategic Measures

Initial measures included a citywide vehicle restriction program and the closure of highly polluting facilities. In some cases, enforcement required coordination with police or federal authorities. Epidemiological data was used to link pollution to respiratory illnesses and mortality.

Some changes occurred through coincidence. Lead was removed from gasoline after the children of the U.S. ambassador suffered lead poisoning, prompting executive action. Similarly, clandestine smelters and the last illegal brick

Lead was removed from gasoline after the children of the U.S. ambassador suffered lead poisoning

-making kilns within the city –near the densely populated Tlatelolco neighborhood–were shut down through coordinated operations.

Catalytic converters were introduced, and new fuel standards were negotiated. Lacy's team also developed public alert systems and redefined air quality indexes, which helped raise awareness and influence behavior. Notably, the Índice Metropolitano de la Calidad del Aire (IMECA index) was developed to track pollution levels and communicate risks to the public.

In parallel, programs were established to promote cleaner industry. Lacy achieved agreements with state-owned and private to adopt cleaner technologies or shut down outdated facilities. These included the closure of a refinery, including cleaning of the site, that later became a green park and changes in power plant operations.

Institutional and International Cooperation

Lacy worked across institutions and borders to strengthen air quality management. International partnerships with experts from the United States, Germany, Japan, Canada, and France supported air monitoring, reforestation, and the development of industrial emissions standards.

A key milestone was his collaboration with Nobel laureate Mario Molina, who in 1991 chaired an advisory group providing scientific guidance for long-term decisions. These partnerships helped Mexico build credibility and access funding through organizations such as the World Bank and the United Nations.

Lacy believes that such cooperation was vital at a time when national capacity was still emerging. Shared experiences and international examples strengthened local policymaking. The city also participated in broader research efforts, including the Milagro Project, which examined how pollutants from Mexico City affect global atmospheric conditions.

Managing Complexity and Resistance

Lacy emphasizes that environmental policy requires a balance between science, politics, and society. Programs like “Hoy No Circula” (a vehicle restriction program based on license plate numbers) required both technical justification and public communication. In fact, he recalls that the launch of that program was viewed internally as a referendum on the government's credibility.

Even naming the programs was strategic—a misleading title could undermine public trust. His team emphasized transparency, publishing real-time data and engaging directly with the public. Resistance came from multiple sectors, but open dialogue helped build credibility. He recalls a long evening at his children's school explaining air pollution policy. “One parent told me, ‘I don't know if I'm convinced, but I admire your patience,’” Lacy recalls.

To support institutional development, Lacy also contributed to the creation of laboratories for fuel analysis, vehicle emissions testing, and air quality monitoring. These facilities played a crucial role in ensuring data reliability and public accountability.

Recent Setbacks and Ongoing Concerns

In recent years, Lacy has warned of setbacks in both monitoring and environmental policy. Laboratories have been closed, monitoring stations lost funding, and technical capacity has weakened. These changes, he argues, have reduced Mexico City's ability

to assess key pollutants or evaluate fuel quality. At its peak, the city's network had 25 stations measuring a wide range of pollutants. Today, few operate at full capacity. According to Lacy, this decline reflects a shift in political priorities, where long-term investments are often sacrificed for short-term gains.

Figure 1. Methodological and regulatory changes in the monitoring of pollution levels. Lacy's team played a key role in most of them.

“We built infrastructure not only in equipment but in trust and collaboration,” he says. “Without maintenance, it all begins to erode.” He also warns of the dangers of political interference and the loss of technical independence, both essential to maintaining credible environmental data.

Key Principles for Future Professionals

“We built infrastructure not only in equipment but in trust and collaboration”

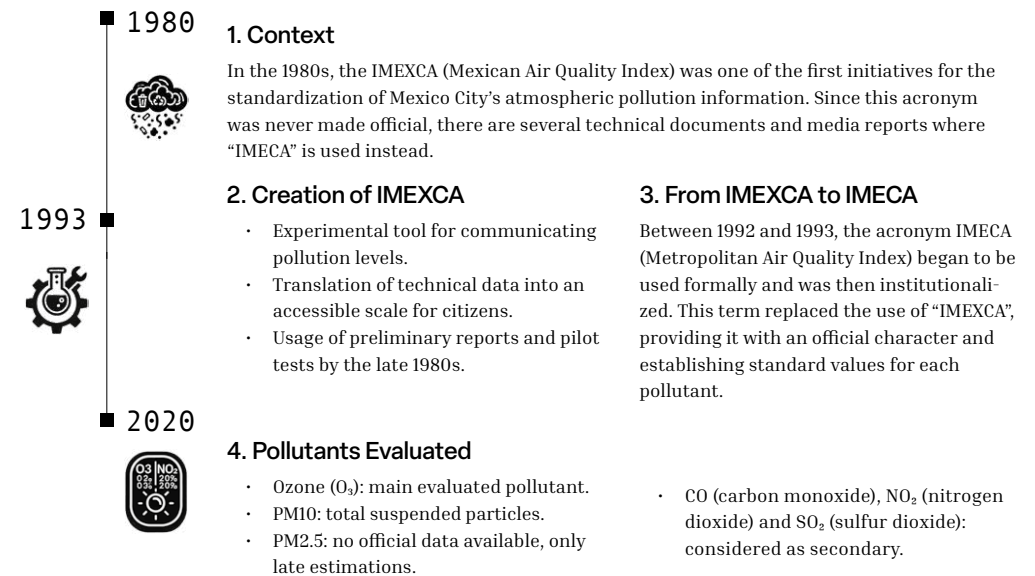
For future professionals, Lacy highlights a few essentials: consistency, patience, and adaptability. Policymaking rarely follows a linear path. It demands vision, but also the ability to respond to shifting political and social contexts.

His experience has taught him the importance of continuous learning and staying connected to the scientific community. Technical expertise, he argues, must go hand in hand with the ability to build coalitions and communicate clearly.

Finally, he underlines the power of listening. “Sometimes progress doesn’t come from convincing others, but from truly taking their concerns seriously.”

Lacy’s career demonstrates that meaningful air quality improvements are possible, but only through persistent attention to science, society, and the complex dynamics between them. For him, environmental work is never static: “You begin with a screwdriver,” he says, “but over time, you’ll need a drill, and eventually a hammer. Each stage demands new tools and a deeper commitment.”

The evolution of IMEXCA index in Mexico City



5. Comparative chart

Pollutant	IMEXCA (80-90s)	IMECA (1995-2019)	Air and Health Index (2020-)
Ozone (O ₃)	≈ 330 days/year with excesses	≈ 220 days/year	≈ 230 days/year
PM10	≈ 340 days/year	≈ 150 days/year	≈ 180 days/year
PM2.5	≈ 200 days/year (unofficial)	≈ 180 days/year	≈ 90 days/year
Comment	PM2.5 unofficially measured		

Figure 1. Evolution of the first air quality reports in Mexico City based on official reports by the IMEXCA AND IMECA initiatives.

Behind the Story

- » Air quality monitoring in the 1970s relied on manual networks. Most measurements in Mexico were carried out through filter sampling; automated stations were scarce and often unreliable.
- » Field technicians were the backbone of the first monitoring efforts. Ángeles and his colleagues installed, maintained, and collected air samples in both urban and rural areas.
- » Detailed pollution profiles depended on manual sampling. The identification of particle types and heavy metals was only possible through physical sample collection, not automated systems.
- » The expansion of monitoring coverage began with technician-driven initiatives. The nationwide deployment of new stations in the early 1980s was made possible thanks to the creative use of available resources.
- » Health research often relied on manually collected data. Critical cases of lead pollution near industrial facilities were confirmed through direct sampling in places such as Chihuahua and Torreón.

The Impact of a Technician's Work

When Felipe Ángeles García began working for the federal government in 1975, he had no idea he would become one of the pioneers of air quality monitoring in Mexico. In 1976, he joined the technical department, and by 1977, he was already working in the manual atmospheric monitoring network in Mexico City. "Everything was new to me," Ángeles recalls. "I didn't know the subject, but I immersed myself in it."

As he became more familiar with the field, Ángeles noticed the limitations of the techniques used at the time. Although a modern automated network was being established during those years, mainly with Dutch equipment, Ángeles noticed that the technology was fragile: "Communication relied on the telephone network, and stations often failed. On top of that, there was a lack of well-trained technicians."

Ángeles specialized in the manual collection of air samples. Using simple equipment, similar to a vacuum cleaner, he gathered particles on filters that were later analyzed in laboratories. He discovered that manual sampling provided unique insights: "You could identify the type of particles –biological, organic, volcanic– and determine the presence of heavy metals. Automated stations couldn't do that; they only produced a single number."

Awareness and Collaboration

In the early years, public awareness of air pollution was still very limited. "People didn't even know pollution existed, let alone that it could affect their health." Ángeles collaborated with the Health Department to install air monitoring stations at healthcare centers, helping lay the groundwork for future environmental policies.

His dedication led to significant contributions. He was the one who selected the location for the Pedregal monitoring station in Mexico City, a site that remains active to this day. While working in Pedregal de San Ángel, one of the most affluent areas of the city, he found a public elementary school, a rare sight in that

neighborhood. “What struck me was finding a public elementary school right in the middle of such a wealthy neighborhood.”

Thanks to cooperation between the school principal and his supervisors, the station was successfully established. Ángeles emphasizes that, although he selected the site, he was not involved in the technical installation of the automated network. “At that time, I was still working only with the manual network, but I was the one who found the site,” he explains.

Expansion of the National Network

Ángeles’ curiosity and initiative soon allowed him to play a key role in expanding Mexico’s manual monitoring networks. When he noticed dozens of unused high-volume samplers sitting idle in a warehouse, he proposed putting them to use. His idea led to the installation of new monitoring stations in cities like Querétaro, Puebla, and Saltillo.

Although Ángeles describes himself as “an ordinary soldier,” he gradually took on greater responsibility until he managed to coordinate a team responsible for collecting manual air samples across the country. Maintaining

high standards became one of his trademarks: he closely supervised quality control and developed internal protocols based on international guidelines. “I realized that careful preparation and fast delivery to the laboratory were crucial”.

Attitude Matters

For Ángeles, attitude was just as important as technical skills. “The first thing I always made clear to young technicians was that they needed the right attitude,” he says. He recalls how some technicians refused to adapt to working conditions in the field, while others showed great dedication, willing to work long hours to complete their tasks properly.

During this period, Ángeles traveled extensively across the country, helping to set up networks often under difficult conditions. “The work was tough. We drove for days over bad roads and sometimes had to improvise to install the equipment safely,” he recalls.

Yet he found these years highly valuable: “I saw the importance of what we were doing, we were really making a contribution.”

He also took pride in reviewing and evaluating the technical work of different networks. “It gave me satisfaction to identify and point out mistakes. Not technical malfunctions, but things like keeping the sampling inlets clean were essential and often neglected.”

Manual vs. Automated Networks

Ángeles always remained a firm advocate of manual monitoring. “Automated stations provided quick data, but they lacked detail about the composition of the air,” he explains. His work showed the ongoing importance of studying fine particles, heavy metals, and biological material through manual methods, especially in contexts with potential health risks.

In cities such as Chihuahua and Torreón, Ángeles carried out key investigations into lead pollution near industrial facilities. In Chihuahua, he installed a high-volume sampler near the Ávalos steel factory despite the extreme heat. “We installed there because at a nearby health center, babies were being born with lead in their blood”, he says.

“We installed there because at a nearby health center, babies were being born with lead in their blood”

Physicians linked the contamination to the nearby factory, prompting the installation of a manual network and, later, automated equipment. It soon became evident that automated equipment couldn’t detect lead levels; only manual sampling provided that critical information. In Torreón, government sampling became necessary because private monitoring by the Peñoles company lacked independence. “The Ministry of Health arrived in the conflict area dressed in white suits, like astronauts,” Ángeles recalls. “The local population panicked. Looking back, it probably wasn’t the best approach.

During these operations, Ángeles and his team collected samples from rooftops, inside homes, technical rooms, and even within the industrial facilities themselves. Their findings confirmed widespread mismanagement and serious negligence.

Training the Next Generation

Later in his career, Ángeles dedicated himself to training new technicians. Through programs such as the Mexico Environmental Program and CENICA (Centro Nacional de Investigación y Capacitación Ambiental de México), he provided practical, hands-on training in air quality monitoring techniques. Under his mentorship, young technicians became specialists managing networks in states like Morelos, Puebla, and Guanajuato. “Many graduates came with plenty of theoretical knowledge but lacked practical skills like properly collecting and handling samples.”

If he could start over, Ángeles says he would place even more emphasis on selecting committed personnel. “Many technicians just wanted to climb higher without mastering the basics. It is essential to build real experience and develop a genuine love for the work.”

A Long Career in the Service of Air Quality

“Many technicians just wanted to climb higher without mastering the basics” After more than four decades devoted to air quality monitoring, Felipe Ángeles García warns that progress requires more than just advanced technology. Although Mexico City has excellent automated networks, he observes that much of the data remains underused and that public engagement is lacking. He hopes that the new generation will continue to value accurate and independent monitoring, not just for managing pollution, but for protecting people’s lives.

Air pollution, 1978

Air Quality Index in the Valley of Mexico

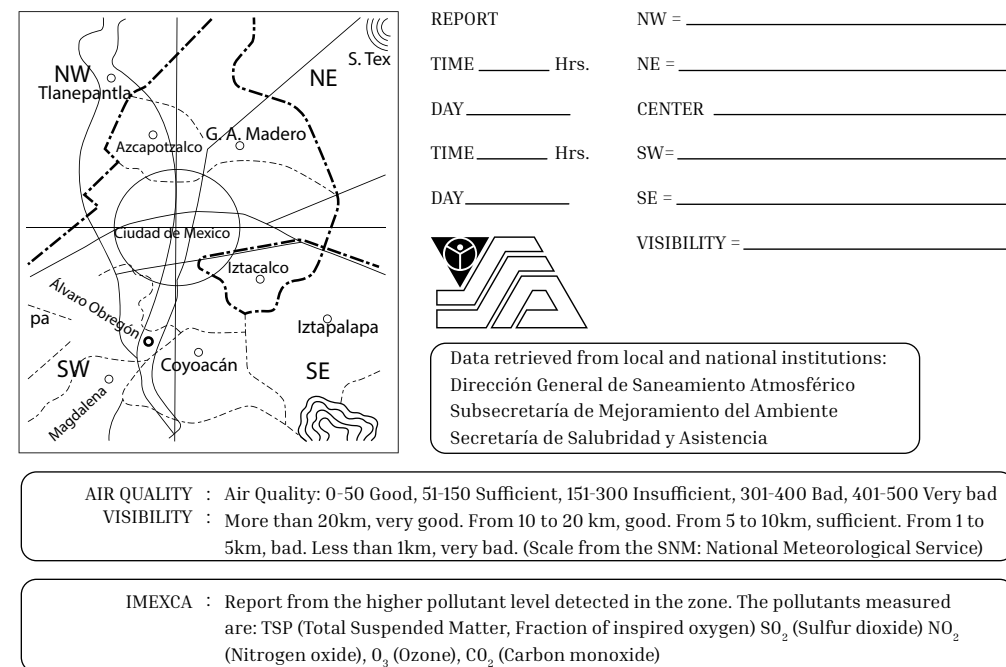


Figure 2. Technical map of air pollution
 Retrieved from: Mexican Air Quality Index (IMEXCA). Technical memorandum SMA/DGS AT/02-78.

Behind the Story

- » By the late 1980s, Mexico City was one of the most polluted cities in the world, with ozone and lead levels far above WHO thresholds.
- » International studies showed links between air pollution and health problems such as respiratory and cardiovascular diseases, leading to calls for action in Mexico.
- » Young environmental professionals, such as Carlos Sánchez Rivas, initiated pollution mapping efforts and applied land-use analysis techniques at the local level for the installation of monitoring stations.
- » The first formal air quality standards in Mexico were issued in 1982, but systematic enforcement began much later.
- » Early monitoring relied heavily on manual readings and incomplete networks: automated stations only began to expand significantly in the 1990s.

Not Just Numbers: Memories from the Front Lines of Air Quality Monitoring

Between 1982 and 1996, Carlos Sánchez Rivas worked in Mexico, contributing to the development of a reliable infrastructure for measuring and analyzing air pollution. As a geographer, he integrated the spatial and temporal dimensions into the study of air quality, combining fieldwork, technological innovation, and collaboration with national and international institutions. His work not only provided essential data for scientific research but also offered reliable information to policymakers and raised public awareness. Throughout his career, he has upheld the belief that clean air is a right, driven by the conviction that knowledge inspires change.

Sánchez began his career in the early 1980s as an air pollution data analyst at the Federal Environmental Agency. In 1986, he started a master's program in Toluca, where he participated in some of the first efforts to monitor and map air quality.

The First Measurements: Craftsmanship and Urgency

His early work combined manual sampling tools with data from existing automatic networks, though the quality of that data was often inconsistent. In some cases, mobile measurements were enabled in targeted areas. Nevertheless, the results quickly painted a worrying picture: high concentrations of particulate matter, sulfur and nitrogen oxides, and lead – primarily from traffic. The data he and his team collected were later used in policy debates on the gradual elimination of lead gasoline and the introduction of vehicles equipped with catalytic converters.

Building on that experience, Sánchez became involved in regional measurement projects in northern Mexico, studying differences in air quality on both sides of the Mexico-United States border. Collaboration with U.S. institutions, such as the Environmental Protection Agency (EPA) and universities from both countries, allowed him to compare measurement methods and interpret

Figure 11. Illustrative representation inspired by Sánchez's work with meteorological balloons to create atmospheric vertical profiles in Toluca.

the data within a broader context. He emphasized the importance of standardized protocols but also the need for flexibility and adaptability to local conditions.

New Perspectives

In 1990, Sánchez was granted a scholarship for a postgraduate degree in Environmental Management in Italy. There, he learned to use geographic information systems (GIS), modeling, and policy-oriented data analysis. The program gave him new insights into how environmental data can be made useful for policy. In Italy, he saw how maps and visualizations could play a powerful role in communication with both policymakers and citizens. He brought this knowledge back to Mexico, where he improved data processing and presentation on his projects.

During a brief stay in a desertic region of North Africa, he gained experience with natural air pollution, such as dust from desert areas. He was fascinated by how local populations naturally responded to changes in air quality. This cultural dimension of atmospheric perception reinforced his conviction that environmental problems are always embedded in social contexts.

From Raw Data to Policy Impact in Mexico City

Upon his return, Sánchez coordinated a team that was responsible for analyzing air quality in Mexico City, within the National Institute of Ecology. He assembled multidisciplinary teams, collaborated on the design and installation of monitoring networks, and experimented with innovative methods —among them, the use of tobacco and alfalfa plants as bioindicators, an approach that would later be explored by Mónica Alegre González. The plant's leaves showed visible damage at increased concentrations of ozone and nitrogen oxides. His experience in Italy helped him structure data and improve communication with policy bodies.

During this period, collaboration with medical and health institutions was also strengthened. Sánchez's department shared air quality data with the Instituto Nacional de Salud Pública and other entities. These data were used in studies on the relationship between air pollution and respiratory problems in children. He

viewed it as a shared responsibility: his job was providing reliable data that others could translate into medical insights. "We provided the numbers, they drew the conclusions," he later said.

The Network in Toluca as a Model

In 1993, he returned to Toluca to lead a team responsible for operating and automated monitoring network. Assigning Sánchez to this role was an obvious choice, given his earlier involvement in designing and planning the installation of the network.

His knowledge of the city and prior experience allowed him to identify the most effective monitoring locations and envision the expansion of the network to a regional scale. In addition to standard measurement equipment, he used meteorological balloons, provided through a collaboration with a nuclear power facility, to create vertical air profiles. The network he set up in Toluca became a model for the urban monitoring systems in Mexico.

Between Technology and Policy: A Connecting Role

Sánchez did not consider himself a traditional researcher but rather a key facilitator in the management of geographic and environmental knowledge. His work integrated spatial and temporal data to support researchers and decision-makers, ensuring reliable information for the intersectoral management of air quality. His efforts were instrumental in institutionalizing air quality monitoring in Mexico and in promoting actions aimed at prevention and risk mitigation.

In his later reflections, Sánchez emphasized the importance of cross-sector collaboration. He pointed out the need for affordable sensors for citizens, promote transparent data exchange, and strengthen communication between healthcare, environment, and policy sectors. His experience taught him that technical solutions only succeed when they are linked to public engagement and education.

"We provided the numbers, they drew the conclusions"

Looking Ahead: Challenges and Recommendations

Sánchez has expressed concern about the slow pace of progress. Although more knowledge is available than ever before, he observes that political will and institutional collaboration often lag behind. He warns against technocratic thinking detached from social realities and advocates for an approach that actively involves citizens. His work in the 1980s and 1990s remains a reference point in regional air quality reports.

His core message is powerful in its simplicity: clean air is not a privilege. It is a right that belongs to everyone. He believes that if people understand what they are breathing, they will be more willing to demand change. This conviction ran throughout his career and remains deeply relevant today amid global environmental issues.

The contribution of Carlos Sánchez Rivas to the development of air quality policies in Mexico exemplifies how technical expertise, practical experience, and social involvement can come

together to create sustainable change. His story underscores the value of interdisciplinary collaboration and shows how geographic fieldwork can contribute to health, inform policymaking, and, above all, raise awareness about the impact of air quality on the quality of life.

Timeline of Air Quality Measurements in the Valley of Toluca

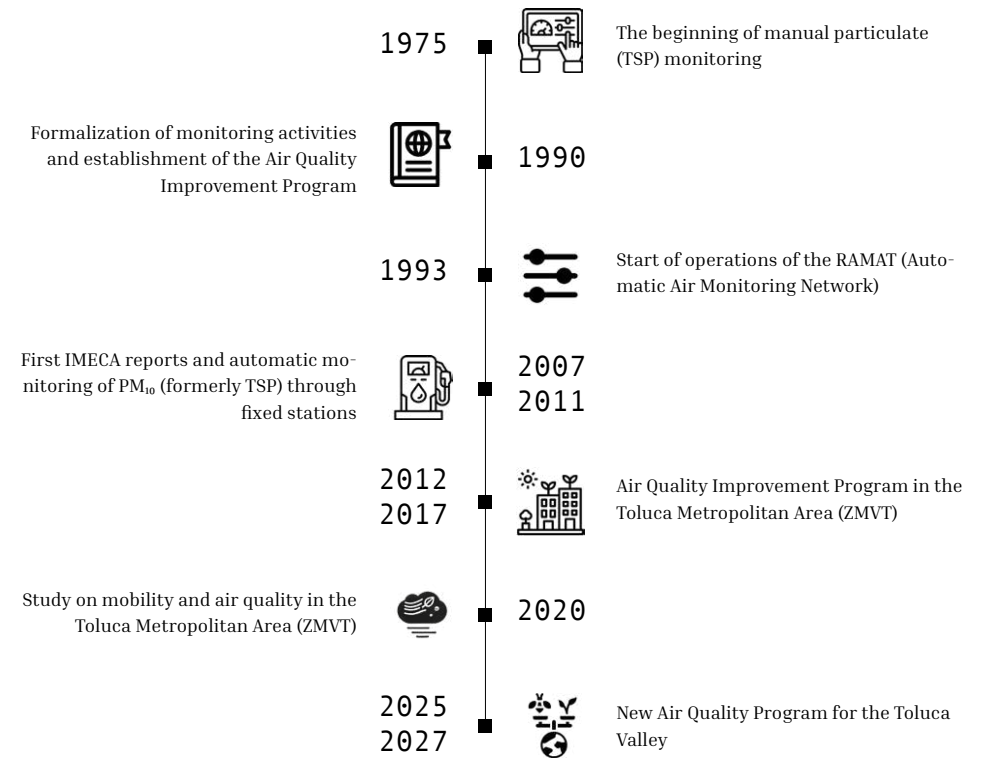


Figure 3. Illustrative timeline of air quality monitoring work in the Valley of Toluca.

Retrieved from: official documents published by the Government of the State of Mexico

Behind the Story

- » In the 1970s, scientific links between air pollution and health effects (such as respiratory diseases and child mortality) were already well established internationally. Mexican health officials began exploring to what extent these issues could be attributed to poor air quality in Mexico.
- » International collaboration –especially with the U.S. Environmental Protection Agency (EPA) and the Panamerican Health Organization, a branch of the World Health Organization (WHO)– became essential for developing the first health-based air quality standards in Mexico.
- » The Secretaría de Desarrollo Urbano y Ecología (SEDUE) –now SEMARNAT– launched one of its first efforts to build automatic air monitoring networks during the early 1980s.
- » Early measurements focused on pollutants like ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide and suspended particulates, but linking them to health outcomes required new methodologies.
- » Once air quality metrics became reliable and accessible, subsequent studies provided strong epidemiological and causal evidence that chronic urban air pollution profoundly impacts children’s respiratory health.

Diagnosing a City’s Breath: The Role of Air Quality Monitoring in Mexico City’s Environmental and Public Health Policy

In the 1980s, Mexico City was one of the most polluted cities in the world. Every day, millions of residents were exposed to air that posed serious risks to their health. During this period, Pablo Cicero Fernández led the team that installed the automatic air quality monitoring system at the Mexican Secretariat of Urban Development and Ecology. This citywide network of stations was instrumental in enabling data-driven environmental policies and public health research.

Cicero was born into a medical family. His mother was a medical anthropologist and his father a thoracic surgeon and pulmonologist. Inspired by his early exposure to respiratory health issues and environmental impact, Cicero pursued a degree in environmental engineering at the Universidad Autónoma Metropolitana de Azcapotzalco (UAM) in 1976.

In 1980, Cicero joined the public sector as a junior engineer. Initially focused on water pollution, he later transitioned to air quality management when he was invited to help install and launch an air quality monitoring network in Mexico City. *Despite technical limitations, the network began delivering critical air quality data.*

He contributed to the installation of 25 monitoring stations across the capital. These early efforts relied on analog technology and telephone lines. Despite technical limitations, the network began delivering critical air quality data.

Advanced Training and Scientific Collaboration

To achieve better understanding of the data, Cicero moved to the United States in 1988 to study Environmental Health at University of California, Los Angeles (UCLA). There, he earned a master’s degree and later a doctoral degree in Environmental Science and Engineering. His education covered biostatistics, toxicology,

exposure assessment, and epidemiology —essential fields to link air quality with public health outcomes.

Even while based in California, Cicero remained actively involved in Mexico's environmental issues. He collaborated with researchers such as Carlos Sánchez, Victor Hugo Páramo, and Rodolfo Lacy on studies demonstrating the measurable health benefits of improved air quality. This work helped frame pollution not only as an environmental problem but also as a public health crisis.

Health Implications and Public Communication

Between 1984 and 1988, air quality policy in Mexico lacked a clear health focus. Although epidemiological data already showed increased mortality during high-pollution episodes —similar to trends observed elsewhere— these findings were rarely shared with the public. Vulnerable groups, such as children, the elderly, pregnant women, and outdoor workers were disproportionately affected.

Pollution levels varied across the city: particulate matter concentrations were higher in poorer northern districts, while ozone concentrations were higher in affluent southern neighborhoods. Public concern emerged mainly when air quality problems affected influential communities.

Visualization and Public Awareness

Cicero and his coworkers were pioneers in the visualization of air pollution data through maps, mosaics, and color-coded indexes. These tools made complex data accessible to non-specialists and helped raise public awareness. Meteorological data were also integrated to illustrate pollutants dispersed across the city.

Mexico City's geography—a high-altitude basin prone to temperature inversions—made it particularly vulnerable to pollution. Major sources included traffic, industrial activity, a cement plant, and a power station. The monitoring system made it possible to understand these dynamics with much greater precision.

Scientific Infrastructure and Policy Development

During this period, Mexico's scientific infrastructure expanded. Universities such as Universidad Autónoma de México (UNAM) and Universidad Autónoma Metropolitana (UAM) established additional monitoring stations and launched their own research programs. A key catalyst for cross-sector collaboration was Nobel Prize-winning chemist Mario Molina, who promoted cooperation among academia, policy-makers, and health authorities.

These efforts led to significant changes: cement plants were closed, power stations switched to cleaner fuels, and emission standards for industry and vehicles became more stringent. Cicero emphasized that data played a critical role: without reliable measurements, there would have been no foundation for action.

Air Pollution and Health Risks

Scientific evidence highlighted the health effects of pollutants such as ozone and PM_{2.5} (particulate matter smaller than 2.5 micrometers in diameter), which were linked to respiratory, cardiovascular diseases as well as premature deaths. Cicero compared chronic exposure to air pollution with smoking—a gradual yet serious health threat.

He also contributed to a World Bank study estimating the potential number of lives that could be saved if Mexico met international air quality standards. These findings provided strong evidence for continued investment in air quality improvements.

Career in the United States

By 1993, Cicero settled permanently in the United States. He joined the California Air Resources Board (CARB), where he focused on mobile emissions research and the development of emissions inventories. He played a central role in the investigation that uncovered the Volkswagen emissions scandal (Dieselgate). In parallel, he served as an adjunct professor at UCLA, teaching courses on air quality and public health.

Cicero and his coworkers pioneered the visualization of air pollution data through maps, mosaics, and color-coded indexes

Figure 7. The evolution of interinstitutional measures from 1986 to 1997, in which Cicero and his collaborators participated.

Figure 12. Historical mosaics of the Air and Health Index published by the Ministry of Environment of Mexico City, reflecting the hourly concentrations recorded per day for the years 1990, 2000, and 2004 to 2025, respectively. Páramo's work was fundamental to this initiative.

Outlook and Impact

Cicero considers his time in Mexico fundamental both to his professional career and to the country's environmental management. He advocates for the continuous strengthening of air quality monitoring systems and for broader public education on environmental health. His use of tools such as pollutant roses—used to trace pollution sources—underscores the value of data in formulating targeted policies.

Cicero considers his time in Mexico fundamental both to his professional career and to the country's environmental management

His work illustrates how early efforts to collect environmental data evolved into the foundation for evidence-based environmental and health policy. Today, his message remains clear: clean air is not a luxury, but a basic human need.

Timeline of Air Quality Standards and Control in Mexico (1950-2020)

Decade/Year	Main event	Type (Law, Standard, Network, Institution)
1950	First studies on visibility, air acidity and particles in Mexico City.	Technical public health studies
1971	Federal Law for the Prevention and Control of Environmental Pollution (LFPC) – DOF, March 23, 1971.	Federal Law
1972	Foundation of the Subsecretariat for Environmental Improvement (SSA).	Agency
1976	The SSA establishes the first technical standards (SO ₂ , CO, PST, O ₃).	Technical standards (pre-NOM)
1982	Federal Environmental Protection Law – DOF, January 11, 1982.	Federal Law
1987	Presidential decree creates the Urban Development and Ecology Secretariat (SEUDE).	Agency
1988	General Law of Ecological Balance and Environmental Protection (LGEEPA) – DOF, January 28, 1988	Framework environmental law
1993–94	DOF publication of the first Air Quality Official Mexican Standards (NOM): CO, SO ₂ , O ₃ , NO ₂ , PST/PM ₁₀ , Pb.	NOMs
2000	2000: Standards are updated: PM _{2.5} , tropospheric ozone, and volatile organic compounds measurement is incorporated.	Updated NOMs
2023	NOM-172-SEMARNAT-2023 (Air and Health Index).	NOM

Figure 4. Timeline of air quality standards and control measures in Mexico.

Behind the Story

- » The biological effects of air pollution were still poorly understood in Mexico during the 1980s and early 1990s; most attention focused on human health and urban smog.
- » Plants were increasingly studied as “silent witnesses” to pollution exposure, showing visible damage (e.g., chlorosis, leaf deformation) that could indicate local air quality problems.
- » Native and cultivated species such as tobacco and alfalfa were among the first used in experimental studies to detect pollutant stress in urban environments. Interest in biological indicators grew as technological monitoring remained expensive and sparse, making plant-based methods a low-cost alternative in Mexico City.
- » Subsequent research focused on estimating biogenic emissions —especially isoprene and monoterpenes— from vegetation around Mexico City, as these compounds contribute to ozone formation. A USEPA model was adapted to estimate these emissions under local conditions, improving understanding of their role in urban atmospheric chemistry.
- » Mexican biological research in this field was often isolated, with few interdisciplinary links between ecology, geography, and atmospheric science.

From the Use of Tobacco Plants as Bioindicators to Air Quality Public Policies: Biology as a Bridge to Environmental Policy

In the 1990s, Mexico City faced growing concerns about air pollution, while technical infrastructure for air quality monitoring was still limited in many areas. In search of complementary methods, researchers and policymakers explored the use of biological indicators —plant species that visibly respond to specific pollutants. This approach led to the development of a biomonitoring program that used tobacco and alfalfa plants to track ozone and sulfur dioxide levels across the city.

Biologist Mónica Alegre González played a key role in establishing this program, adapting international methods to local conditions and ensuring that the results were linked to official air quality data. Over time, her work expanded to include modelling of biogenic emissions and contributions to public policy development, capacity building, and international cooperation.

Air Quality as a Field of Work

Alegre studied biology at the Universidad Autónoma de México (UNAM) and combined her education with a career in the government. At the age of twenty, she had the opportunity to choose among several areas at the Ministry of Urban Development and Ecology. She recalls that, at the moment of deciding, she looked out the window and saw pollution hanging over the city. That visible presence was the reason she chose to focus on air quality.

In her early years, her work centered on the technical aspects of air quality monitoring, analyzing measurement data and supporting the understanding of environmental pollution behavior in Mexico City. Over time, her interest shifted toward biological monitoring, which involves using plants as alternative methods to obtain information about air quality.

That visible presence was the reason she chose to focus on air quality

Biomonitoring with Tobacco Plants

In collaboration with other researchers and colleagues, Alegre worked on a biomonitoring method based on international experiences with tobacco plants. Certain varieties of these plants show leaf damage (in the form of white spots) when exposed to elevated ozone concentrations.

For the Mexican program, the plants were cultivated in the Colegio de Postgraduados de Chapingo, an agricultural school and research institute at Texcoco. They were placed at various locations in Mexico City, alongside existing automatic monitoring stations. Each exposure cycle lasted about fifteen days. Afterwards, the plants were collected, the leaves were analyzed, and new plants were placed.

The leaf damage was then compared with the measured ozone concentrations. This approach yielded a clear correlation between ozone exposure and visible damage, demonstrating the method to be a valuable tool, particularly in areas lacking technical infrastructure.

Beyond Tobacco Plants: Additional Indicators and Broader Biological Research

Figures 9 and 10.
Biomonitoring of tobacco plants to determine the effects of air pollution on vegetation.

After working with tobacco plants, the program was expanded to include alfalfa, a species found to be sensitive to other pollutants, particularly sulfur dioxide. In this case, researchers observed not only leaf damage, but also pollutant concentrations in the roots. A correlation was again established with the official automatic network's measurement data.

Later, while working in other roles, she joined a team that adapted a model from the Environmental Protection Agency (EPA) from the United States, to fit the conditions in Mexico City. This model, the Biogenic Emission Inventory System (PC-BEIS), estimates natural emissions of volatile organic compounds from vegetation, such as isoprene and monoterpenes, which can contribute to ozone formation when they react with nitrogen oxides in the atmosphere.

To implement the model, Alegre used the official vegetation map of Mexico City. She divided the map into 10-by-10-kilometre grids, manually estimating vegetation types in each square and building a database as input for the model. As geographic information systems became more accessible, vegetation data were enhanced with satellite images, analyzed with the support of the Centre for Atmospheric Sciences at UNAM. The model's results were later incorporated into public policy documents and used in air quality forecasting.

The model's results were later incorporated into public policy documents and used in air quality forecasting.

Collaboration and Dissemination

The results of the biomonitoring project, along with the biogenic emission estimates, were presented at national and international conferences. In the early 2000s, as part of the air quality project led by Nobel Prize laureate Mario Molina, Alegre collaborated with researchers from Fraunhofer Institute in Germany to refine biogenic emission calculations. She also promoted and supported the training of new staff who continued developing emissions inventory.

From Data to Public Policy

While the research was scientifically grounded, the implementation of data into public policy often depended on both technical evidence and timing. The use of the plants as bioindicators offered a cost-effective and straightforward method, but policy-makers first had to recognize its value. Eventually, the biomonitoring program and later the biogenic emissions inventory were included in Mexico City's air quality policies. Meanwhile, the biomonitoring initiative was complemented by other efforts, such as acid rain monitoring.

Interdisciplinary Development

Engagement in air quality issues profoundly influenced Alegre's professional development. Her interdisciplinary approach, which involved collaboration with experts in chemistry, meteorology, environmental engineering, geography, and later environmental law enforcement, inspired her to address environmental challenges from multiple perspectives. At one point, she considered switch-

ing to the environmental engineering area, but she ultimately remained loyal to biology. This broad outlook became essential in shaping her understanding of environmental problems.

Later, she worked on environmental law enforcement, particularly on advancing recognition of the human right to a healthy environment. She currently heads the Environmental and Land Management Prosecutor's Office, a pioneering institution that defends Mexico City residents' right to a healthy environment and well-ordered territory — a role whose foundations were laid in the Air Quality Program

Relevance Today

Although the tobacco plant program was eventually discontinued, Alegre continues to see opportunities for biomonitoring, particularly in rural or isolated areas where automatic measurement equipment is unavailable. She also points to recent ozone peaks in Mexico City as reminders of the ongoing urgency of the issue and the need to keep people informed and connected to the current state of air quality monitoring.

The invisible nature of air pollution is a significant reason why the issue quickly fades from view. "As long as people don't feel it directly, it disappears from the agenda. That's why it's important to continue finding ways to make the impact of air pollution visible and understandable."

Final Reflection and Advice to the New Generations

Collaboration, effective communication, and perseverance in research and public policy processes remains essential for ongoing work. Much of the progress achieved was made possible thanks to the support of colleagues, institutions, and supervisors, who provided a space for experimentation.

Alegre advises young researchers to invest in communication and translating scientific data into understandable messages for decision-makers and the general public. She also highlights the importance of biology in addressing environmental

challenges. Biologists bring systems thinking and long-term perspectives, allowing them to connect atmospheric chemical processes with their effects on ecosystems and human health.

Monica Alegre González was a pioneer in using plants as bioindicators for air pollution in Mexico City and in developing the first biogenic emissions inventories. Her work not only laid a practical foundation for environmental public policy but also demonstrates how biology can help to address specific environmental issues. "It taught me, through application of science, I can make a concrete contribution, even with something seemingly simple like the information that you can get from a tobacco plant."

"It taught me, through application of science, I can make a concrete contribution, even with something seemingly simple like the information that you can get from a tobacco plant."

Behind the Story

- » In the 1980s, the Federal Environmental Agency created a team of meteorologists, and for the first time, air pollution forecasts were developed based on meteorological parameters.
- » Early forecasts relied on radiosondes and manual analysis, with meteorologists working under basic conditions and limited resources.
- » Forecasting efforts helped shape emergency measures such as the program “Hoy No Circula”, aimed at reducing pollution during critical episodes.
- » In Toluca, local emissions studies revealed the influence of seasonal patterns and cultural practices such as fireworks and open burning.
- » Linking air pollution to climate change impacts became increasingly important, highlighting the need for integrated early warning systems as part of environmental management policies.

An Unfamiliar Profession with Environmental Impact

In the early 1980s, meteorology was still a little-known profession in Mexico. Pablo Escamilla Báez decided to study it in Veracruz, drawn by its scientific nature and the involvement of institutions like UNAM. After the 1985 earthquake in Mexico City, meteorology began to play a new role in protecting public health. Escamilla joined a new initiative focused on air quality forecasting.

Working in a small office in Río Elba, he became part of the first team to use meteorological data to predict pollution levels. Using radiosondes, balloons that measure atmospheric conditions, they provided early forecasts of how air pollution might spread. These forecasts informed decisions on emergency measures, such as restrictions on vehicle use during high-pollution days.

Developing Air Quality Forecasting Under Basic Conditions

At the time, there were no official guidelines or digital tools. The team developed its own methods. Every morning, data from radiosondes was collected and analyzed manually. Based on this, the team produced daily forecasts. Pollution levels were often high, and meteorologists relied on a mix of data and expertise to judge how weather patterns would influence air quality.

Eventually, international models were added to the process, but expert judgment remained essential. The team’s forecasts contributed to the launch of “Hoy No Circula”, a vehicle restriction policy aimed at reducing pollution during critical episodes. These early efforts not only influenced policy but also marked the beginning of meteorology as a practical environmental tool in the country.

Meteorologists relied on a mix of data and expertise to judge how weather patterns would influence air quality.

Escamilla and his team demonstrated that technical knowledge could be translated into real-world decisions. Although they

worked with limited resources, their ability to interpret data and explain its implications for urban life helped legitimize meteorology within environmental planning.

Focus on Regional Emissions in Toluca

Figure 5. Greenhouse gas emissions inventory data in the State of Mexico, with active participation by Escamilla.

In 1994, Escamilla moved to the State of Mexico and focused on Toluca. There, pollution sources differed: less traffic, but more dust and open burning. Seasonal changes also influence air quality during colder months, concentrations of fine particles increased. Escamilla studied local emissions, including those from cultural practices such as fireworks and agricultural waste burning. He also mapped greenhouse gas emissions —methane and CO₂— from sources like landfills and wastewater treatment plants. He emphasized that policy must be based on reliable data.

As part of the “Programa para el Mejoramiento de la Calidad del Aire” in the state of Mexico, Escamilla helped compile emission inventories that included both traditional air pollutants and climate related gases like nitrous oxide. His work provided a foundation for local authorities to identify high-risk areas, evaluate sources of pollution, and prioritize mitigation strategies.

For many years, he has been the only meteorologist employed by the state. “To this day, there still isn’t a meteorologist working for the State of Mexico” he notes. From Toluca, he also works with authorities in Mexico City, as both areas are part of the same metropolitan region. This cooperation ensures that measures implemented on one side of the regional border are informed by atmospheric conditions across the whole valley.

“To this day, there still isn’t a meteorologist working for the State of Mexico”

Linking Air Quality and Climate Impacts

Escamilla highlights the close connection between air pollution and climate change. He contributes to studies on the impacts of heatwaves, droughts, and floods, and identified vulnerable communities using public health data. He emphasized the need for timely public warnings and more effective early-warning systems, especially in the Valley of Mexico.

He also supports cross-sectoral approaches, integrating air quality management with urban planning and public health efforts. By comparing environmental data with epidemiological trends, his work helps explain why certain populations experience more exposure-related health effects.

Results over Time

In the 1990s, ozone concentrations at the Plateros monitoring station reached 398 IMECA points, a very high level on Mexico’s air quality index. Today, alerts are issued at just 150 points. In Toluca, where PM2.5 (fine particles that penetrate deep into the lungs) is the main concern, improvements are also evident. Still, cultural factors such as fireworks and bonfires contribute to spikes in pollution.

Escamilla believes that public awareness must continue. “People often assume the problem is solved, but that’s not the case.” Local events and seasonal activities can still cause dangerous peaks. He sees communication as a key aspect of prevention, especially for communities that may not understand how weather and air quality interact.

Lessons for Policy and Practice

Escamilla calls for continuous investment in air quality monitoring, data analysis, and education. He sees a missed opportunity in the large amount of data is available that is not yet fully used for early action. He argues for a daily alert system linking forecasts to public communication.

He finds value in scientific work that leads to concrete outputs. “Finishing an emissions inventory based on real data: that made me feel good about the work.” He adds that his background in academia helped him remain focused on research throughout his career.

“Finishing an emissions inventory based on real data: that made me feel good about the work.”

Escamilla’s career shows how expert knowledge, institutional continuity, and local collaboration can generate lasting impact. He encourages institutions to invest in expertise and in long-term capacity building so that data can be translated into action across multiple sectors.

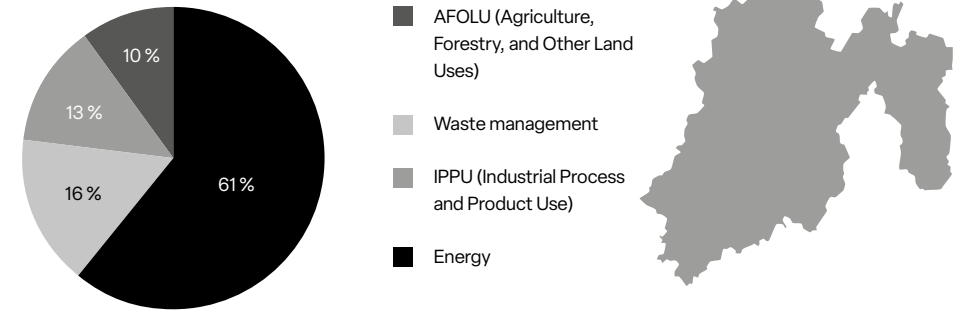
Recommendations for Young Professionals

To young meteorologists, Escamilla offers a clear message: keep learning, combine technical work with research, and value experience. He cites American hurricane expert William Gray as a figure whose deep knowledge sparked meaningful discussions.

Finally, he stresses that pollution and climate change must be addressed together. Changes to local geography, such as valley development, can influence heat, wind patterns, and air quality. “Everything is connected,” he says. More than a technical issue, Escamilla sees air quality as a public responsibility that requires both scientific and civic engagement.

Greenhouse emissions inventory in the State of Mexico

1. Emissions by Sector



2. Challenges for Mitigation

- Transition to clean energy and improvement of public transportation.
- Management of waste, traffic, and energy consumption.
- Appropriate land use practices

3. High Emission Zones

- Valley of Toluca: High industrial and vehicular density.
- Mexico City Metropolitan Area: High density in municipalities such as Naucalpan, Tlalnepantla, Ecatepec, and Nezahualc6yotl.
- Lerma River: High density and methane emissions in agricultural and livestock areas

Figure 5. State inventory of greenhouse gas and compound emissions in the State of Mexico, 2022. Retrieved from: State Institute of Energy and Climate Change (IEECC) (2022)

Behind the Story

- » Early air quality measurements in Mexico were manual and limited in scope; automation only improved monitoring in the late 1980s and early 1990s.
- » In the mid-1990s, health data were systematically linked to pollution levels through epidemiological studies.
- » Regional air quality management plans, such as ProAire, became possible once sufficient monitoring data and modeling tools were available. The first ProAire programs started in the early 1990s.
- » Household emissions from cleaning products, liquefied petroleum gas (LPG), and wood burning are an underestimated source of urban air pollution in Mexico.
- » Mexico's progress in air quality has benefited from political continuity and the long-term commitment of professionals who began their careers in early air quality programs.

From Refineries to Cleaning Products: The Changing Sources of Air Pollution

Over the past four decades, the focus of air quality policy in Mexico has shifted significantly. Where pollution once came largely from industrial facilities, it is now increasingly linked to consumer behavior and household products. This evolution in pollution sources has required continuous adjustment in policy, technology, and governance.

Air quality has moved from being a marginal concern to a strategic issue embedded into national and urban policymaking. As sources, climate and technology evolve, air quality management must adapt accordingly.

Tunnels and Turning Points

Victor Hugo Páramo Figueroa, a key figure in Mexico's air quality initiatives, earned his degree as a chemical engineer in the city of Guanajuato. During his studies, he and his classmates began measuring pollution levels inside the city's tunnels—an early experience that sparked his interest in environmental sciences.

In 1976, he moved to France to study cross-border air pollution and acidification, earning a master's and PhD at the University of Pau. There, he became interested in Europe's coordinated response to transboundary pollution problems, like acid rain. The importance of data exchange and international cooperation would remain a guiding principle in his work.

The importance of data exchange and international cooperation would remain a guiding principle in his work.

Upon returning to Mexico in the early 1980s, Páramo joined the Ecology Commission of Mexico City, one of the few bodies dedicated to air quality at the time. He helped establish chemical laboratories and laid the groundwork for routine environmental monitoring.

Air Quality as Uncharted Territory

At that time, Mexico City was just beginning to conduct detailed environmental monitoring and to develop a clear policy framework. Initial efforts focused on identifying pollutants and understanding their behavior across seasons and over the years.

While data collection was essential, policies could not rely solely on information gathering. Some measures, such as reducing fuels with high sulfur content, could be implemented without complex models, but more comprehensive and lasting strategies required solid and sustained data.

Policy in Motion

Since the 1990s, Páramo has participated in nearly every major air quality initiative, working on emissions inventories, modeling, and regulatory design. He describes the process as a continuous exchange between scientific understanding and policymaking: measuring, analyzing, proposing, evaluating and revising.

Ozone data from the 1990s show that established limits exceeded almost daily. Over the years, the number of days meeting health standards has increased, reflecting the cumulative effect of various interventions. These have included relocating heavy industry, phasing out leaded gasoline and implementing catalytic converter requirements and new fuel standards.

Programs like “Hoy No Circula”, which restricts vehicle circulation on certain days, and mandatory smog checks have also played key roles. However, as exemptions and circumvention increased, their impact diminished. The government is currently revising these programs to refocus on real emissions reductions.

New Sources, New Concerns

Air pollution sources have become more diffuse. Volatile organic compounds found in everyday household products—such as perfumes, air fresheners, and cleaning agents—now contribute

significantly to pollution. These sources are harder to regulate due to their ubiquity and the individual behaviors involved.

Addressing them requires detailed behavior-oriented policies, often coordinated with public health communication. New regulations on solvent content in consumer products are being developed, an effort that clearly demands cross-sector collaboration.

Climate and Continuity

Rising temperatures and changing weather patterns complicate air pollution dynamics. Predictive models must now account for more variables, requiring increasingly refined approaches.

Despite frequent political turnover, air quality policy in Mexico has benefited from consistent support. Successive administrations have continued existing programs, maintaining momentum in long-term environmental management.

Volatile organic compounds found in everyday household products—such as perfumes, air fresheners, and cleaning agents—now contribute significantly to pollution

Regional Cooperation in Action

Páramo currently coordinates the Comisión Ambiental de la Megalópolis (CAME), a coalition of seven states and four federal ministries. Originally formed to harmonize vehicle regulations, CAME now supports a broader agenda of environmental coordination.

Mexico City effectively operates as a low-emission zone, and CAME’s policies influence vehicle standards across participating states. Common regulations allow for broader enforcement and greater regional impact.

CAME also incorporates input from scientists, NGOs, and industry groups. While this enriches policy development, it adds complexity, as participating regions differ in geography, economic focus, and environmental priorities.

Figure 12.
The mosaic from 1990 to 2025 period reflects the progress and advances made in reducing ozone levels, an effort in which Páramo played a key role.

Monitoring as a Compass

Monitoring is essential both for diagnosis and for response. Reliable, consistent data enables governments to track pollution sources, measure policy effects, and assess health impacts.

In cities like Monterrey, limited monitoring has hindered progress. The lack of accountability for pollution control and ineffective interventions can be traced, in part, to inadequate measurement systems. Páramo cites this as a cautionary example of what happens when reliable data are lacking.

The Role of Adaptation and Political Continuity

Environmental challenges evolve and policies that were once effective can become outdated. Flexibility is essential—programs must be re-evaluated and redesigned in response to new data, behaviors, and environmental conditions.

Páramo emphasizes the importance of continuity, but also of willingness to change. Successful policy depends on both political support and adaptability. He notes that the strength of Mexico's air quality policy lies in its ongoing commitment to both.

A lasting legacy, he suggests, is not just in programs or regulations, but in the professionals who sustain them

A lasting legacy, he suggests, is not just in programs or regulations, but in the professionals who sustain them. Many of today's air quality leaders in Mexico began their careers in his teams, evidence that institutional knowledge and commitment can persist and evolve across generations.

Cleaning Products that Generate More Air Pollution than Vehicle Emissions

Emissions of volatile organic compounds (VOCs) from cleaning products contribute more to air pollution than transportation.

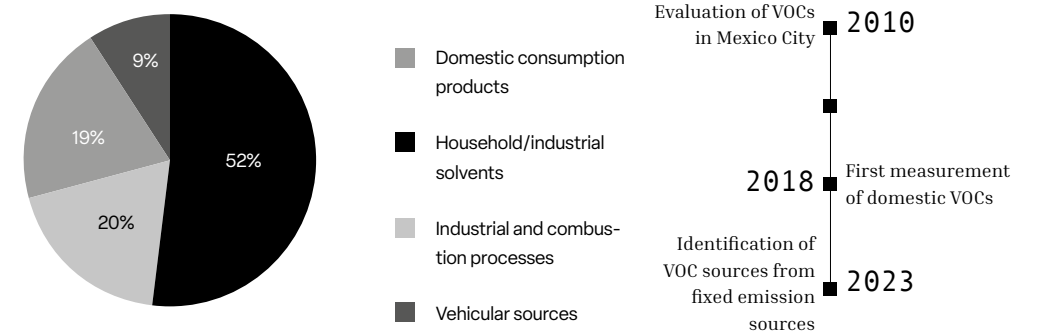


Figure 6. Informative chart showing the polluting impact of cleaning products—which often exceeds vehicular emissions—based on information shared by UNAM and INECC. Retrieved from: (UNAM DGCS 736 / 2021, INECC 2018, SEDEMA-CDMX 2020).

Behind the Story

- » Air pollution in Mexico City began in colonial times, when Spanish conquerors altered the basin's hydrology, creating dry zones that increased the dispersion of particulate matter across the valley.
- » The chemical composition of air pollution in Mexico includes not only ozone and particulates but also solvents, heavy metals, and acids.
- » Atmospheric deposition has spread toxic substances across urban surfaces, soils, and ecosystems for decades.
- » Mexico lacks a systematic approach to monitor long-term chemical contamination through rainfall and dust.
- » Air pollution is frequently framed as a technical challenge, but this perspective obscures the ethical and public health dimensions that deserve equal attention. While monitoring is a critical first step, it must be accompanied by sustained and equitable action; without it, the fundamental right to clean air remains unrealized for many.

Evolving Air Chemistry: Understanding Pollution and Its Consequences

As explained by Rodolfo Sosa Echeverría, head of the Environmental Pollution Section at the Instituto de Ciencias de la Atmósfera y Cambio Climático (ICAYCC) at UNAM, the problem in Mexico City is the result of centuries of urban, industrial, and political decisions.

The city's very location has contributed to its persistent air quality challenges. Built in the middle of a former lake basin and surrounded by mountains, it lies at over 2,240 meters above sea level. This topography traps pollutants, limits air circulation, and increases ultraviolet radiation—all of which intensify ozone formation.

The transformation of the landscape began during the colonial era, when Spanish conquerors expanded the city upon Aztec foundations, draining lakes and channeling rivers. Today's air pollution cannot be fully understood without acknowledging these historical developments. According to Sosa, environmental planning must consider not only emissions data, but also geographical vulnerability and social inequality.

Atmospheric Data through Wet Atmospheric Deposition

Sosa's team has monitored atmospheric pollutants for years using a method known as wet atmospheric deposition, which consists of analyzing the chemical substances in rainfall. These measurements help identify compounds that accumulate in the atmosphere and descend upon the urban environment.

The data show that, despite improvements in sulfur dioxide concentrations in ambient air, sulfur compounds remain dominant in rainwater samples. This apparent contradiction is due to pollution transported from external industrial areas, such as Tula-Vito-Asasco in the states of Mexico and Hidalgo, where high-sulfur fuel oil is still used for power generation and industrial processes.

Figure 8. Research on the evolution of air pollution conducted by Sosa in 2025.

These emissions are carried by wind into the Mexico City basin, contributing to acid rain. “Regional air quality cannot be managed by city policies alone,” Sosa notes. “Cross-jurisdictional cooperation is necessary.”

“Regional air quality cannot be managed by city policies alone” The government of Mexico City currently operates a robust network of monitoring wet atmospheric deposition stations in collaboration with UNAM. Weekly rain samples are collected and analyzed at the university laboratories. However, similar systems are not yet fully developed in neighboring states, creating disparities in data collection and environmental management.

The Overlooked Impact of Toxic Compounds

While most of the regulatory policies focus on the so-called criteria pollutants —ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide, particulate matter, and lead—, Sosa emphasizes the health and environmental risks of toxic substances such as benzene, toluene, and other volatile organic compounds (VOCs), heavy metals, among others. Unlike criteria pollutants, which have specific threshold values in air quality standards, these toxic compounds are harmful even at low concentrations. Moreover, many VOCs, together with nitrogen oxides, act as precursors to ozone and contribute to its formation.

“Several volatile organic compounds are chemically reactive and toxic,” Sosa explains. “They pose a dual threat: they damage human health directly and also contribute to secondary pollution.” Despite their relevance, these substances often remain outside the scope of current air quality policies. Sosa argues that a more inclusive regulatory framework is needed —one that recognizes both the chemical complexity and the cumulative effects of various pollutants.

Pollution as a Social and Economic Issue

Air pollution in Mexico City is not only a scientific matter, but also a social and economic one. Many daily practices expose workers and residents to toxic air. These include auto body painting on the street without protective gear, cooking with leaking LPG tanks in

open-air markets, and fueling cars at gas stations lacking evaporative recovery systems.

“These are not isolated incidents, they’re part of an economic reality,” says Sosa. “People depend on these jobs, even if they come with health risks.” For example, gas station attendants may work long hours exposed to benzene vapors and other toxic compounds, often relying on customer tips instead of salaries. Regulating these practices without considering their economic impact would be unrealistic. Sosa calls for integrated strategies that combine environmental protection with social support and labor alternatives for this informal but real economy.

Lessons from the COVID-19 Lockdown

The COVID-19 pandemic provided an unexpected case study for air pollution management. During the lockdown, vehicle traffic dropped drastically, leading to significant reductions in primary pollutants such as nitrogen oxides. However, secondary pollutants, especially ozone, did not decline accordingly and increased in some cases. “This showed us that traffic reduction alone is not a silver bullet,” Sosa explains.

“Ozone is formed through complex interactions between VOCs, nitrogen oxides, sunlight, and meteorology. Effective strategies need to address all these factors simultaneously.”

The Role of Ethics in Environmental Science

One of the strongest themes in Sosa’s work is ethical responsibility. For him, monitoring is not just a technical task, it is a moral obligation. Environmental professionals, especially those working in consultancy or public service, must report truthfully and base their recommendations on evidence.

Sosa recalls how his former supervisor, Humberto Bravo, once personally funded an air quality report to ensure honest results. “You don’t produce reports to make clients feel good,” says Sosa. “You provide a diagnosis, like a doctor. Only by presenting the truth can we act effectively.”

This principle also applies to the training of new scientists at UNAM, where students learn not only technical skills but also the ethical consequences of their work. Environmental reports influence public health policy, regulatory action, and public trust. Accuracy and transparency are therefore essential.

Strengthening National and Regional Systems

Mexico City's monitoring network is considered one of the most advanced in Latin America. It includes automatic stations, manual sampling, meteorological sensors, and a growing system for measuring atmospheric deposition. This infrastructure, built over decades, demands constant maintenance, calibration, and investment.

Neighboring states such as Mexico State, Hidalgo, Queretaro, Puebla and Morelos are in the early stages of building similar systems, with support from national experts like Víctor Hugo Páramo. However, many challenges remain. Expanding reliable monitoring infrastructure outside the capital is crucial for developing coordinated regional policies.

Priorities for Future Action

To reduce pollution in a meaningful way, Sosa identifies three key priorities:

1. Improve control of evaporative emissions, particularly at gas stations, auto paint shops and LPG facilities, and reduce or control leaks in domestic and industrial settings.
2. Include toxic pollutants in national emissions inventories and establish legal reporting requirements.
3. Shift from temporary restrictions to structural reforms, replacing short-term restrictions, such as temporary driving bans, to long-term structural reforms that target fuel quality, vehicle maintenance, industrial processes, and urban design. Current programs like "Hoy No Circula" may reduce traffic, but do not address the underlying sources of emissions. Instead, policy should target fuel quality vehicle maintenance, industrial processes, and urban design.

Recommendations for the Next Generation

For students and young professionals, Sosa emphasizes three guiding principles: scientific knowledge, diligence, and ethics. Environmental science is not only about measuring pollutants but also about understanding the human and political systems that produce them. Being willing to confront inconvenient data is essential to building effective policy.

"Measurement is not just a technical matter," Sosa concludes. "It's a responsibility to science, to decision-makers, and above all, to the people who breathe this air every day."

Behind the Story

- » The deployment of automatic monitoring networks began in the late 1980s to generate data that would help address air pollution problems and respond to growing international concern.
- » Policies such as “Hoy No Circula” were initially emergency measures but were later integrated into long-term planning.
- » The closure of polluting industries, under the command-and-control model, highly effective in making companies understand the seriousness of the issue –sometimes following demands from civil society.
- » Scientists played a key role in policy development but generally operated outside formal decision-making structures.
- » The creation of the National Institute of Ecology marked a shift toward more effective environmental management, emphasizing regulatory frameworks and data-driven approaches.

The Architecture of Agreement

Sergio Reyes Luján studied Physics at Universidad Autónoma de México (UNAM) in the early 1960s, during a period of rapid urban growth and increasing air pollution in Mexico City. He later became a teacher and researcher, and participated in the foundation of the Universidad Autónoma Metropolitana (UAM). Over the years, his focus shifted from academic work to the intersection of science and policy. Today, he works across institutions and disciplines, moving between theory and application. In his own words: “You can’t remove the chaos. But you can help people find clarity within it.”

During the 1980s and 1990s, Reyes played a key role in Mexico’s early responses to urban air pollution. He did not approach the problem as an activist or researcher, but as a builder of institutions. He served as Subsecretary of Ecology and later as the founding president of the National Institute of Ecology (INE), where he contributed to the development of the country’s environmental governance.

“I wasn’t a scientist or a researcher. I was someone who could reach agreements.”

From these positions, Reyes helped facilitate some of the most impactful air quality decisions of the time, including vehicle restriction programs and the closure of major industrial sources of pollution. He characterizes his contribution with modesty: “I wasn’t a scientist or a researcher. I was someone who could reach agreements.”

Institutions Before Action

When Reyes took on leadership positions, Mexico’s environmental policy landscape was still fragmented. Although public concern about pollution was increasing, there were few coordinated structures. Reyes focused on strengthening those structures. During his tenure at the Ministry of Urban Development and Ecology, he helped to develop long-term air quality plans, expand monitoring systems, and define the legal mandates of environmental institutions.

He also promoted visible policy decisions, such as the closure of a cement plant and a refinery in the Valley of Mexico —both considered major sources of particulate pollution. These measures marked a turning point: air pollution ceased to be just a background issue and became a recognized matter of public policy.

Reyes does not claim ownership over these measures. “Let’s say I was involved,” he says. His aim was not recognition, but to create conditions for coordinated action.

Alongside these national efforts, Reyes engaged with emerging international environmental issues. Through his connections at UNAM, he met Dr. Mario Molina, who would later receive the Nobel Prize in Chemistry. Before that recognition, Molina advised Mexican policymakers, including Reyes, on the need to reduce the use of chlorofluorocarbons (CFCs) in aerosols and refrigeration systems. Following these discussions, Mexico became the first country in the world to ratify both the Vienna Convention and the Montreal Protocol.

Negotiation as a Method

Reyes works constantly at the interface of knowledge and decision-making. Rather than pushing a particular ideology, he advocates negotiation as a tool for progress. For him, reaching agreement involves identifying what different actors can accept, not just what they demand. This approach aims to build common ground and ensure that all participants have a voice in the outcome.

“If people don’t feel included,” he says, “they won’t support what comes out of it.” He supports coordination across ministries, promotes the use of scientific data in policymaking, and facilitates communication among institutions. He believes that inclusive processes are just as important as results. “If people don’t feel included,” he says, “they won’t support what comes out of it.”

This emphasis on negotiating proved crucial at a time when Mexico’s environmental policy was still emerging, and institutional support was limited. By promoting consensus, Reyes helped ensure the continuity of key measures across political cycles.

“Hoy No Circula” and Public Space

One of the most visible policies from this period was “Hoy No Circula”, a vehicle restriction program based on license plate numbers. The measure sparked mixed reactions when first implemented. While some supported its goals, others questioned its fairness or effectiveness. Reyes views the program not only as a technical intervention but also as a tool for public engagement. “When people lose access to something, they start asking why,” he explains. “That opens space for broader discussion.”

He emphasizes the policy’s social dimension. It brought pollution into the public conversation and places responsibility not just on industry but also on individuals. In doing so, it helped normalize environmental regulation as part of everyday life.

Years later, Reyes continues to view “Hoy No Circula” as a sign that public institutions can take action and that citizens are capable of adapting.

Policy Through Knowledge

Reyes argues that effective policy requires more than data; it depends on a public that understands what the data means. He frequently emphasizes the importance of journalism and education. “I look at the source,” he says, referring to how he reads news reports. “That’s what people need to learn: how to go to the source.”

In his view, environmental change is rooted in orientation, helping people interpret information and assess its credibility. “There are videos about almost everything now,” he notes. “That’s not the problem. The problem is that people don’t know how to tell what matters.”

He expresses concern about a generation growing up without the habit of verification. The ability to check claims, trace sources, and understand policies, he argues, is essential to public support for environmental actions. Without this ability, even well-designed policies may fail.

International Experience as a Tool

Reyes also encourages young professionals to study abroad and return with expanded skills and networks. In his experience, that strengthens their position in national policy discussions, lends credibility, helps them articulate complex ideas, and enables long-term professional relationships.

He sees this international connection not as a luxury but as a necessity. In rapidly evolving fields such as air quality management, the ability to draw on global knowledge and systems is a key component of national progress.

The Structure of a Legacy

For the past twelve years, Reyes has worked in the private sector. Today, many of the programs and institutions he helped establish continue to operate. Their persistence, he suggests, matters more than individual credit.

He is also aware of how easily progress can be lost. Monitoring programs can be dismantled; agencies can be restructured or absorbed. Still, he remains convinced that knowledge, once established, has a capacity to move, adapt and find new stewards. “There’s always more to do,” he says. “But there is much more that we can lose.”

Figure 7. Evolution of institutional coordination on air quality, which—since the foundational efforts of Reyes Luján—has ensured the continuity of public actions to this day.

That knowledge, once established, has a capacity to move, adapt and find new stewards.

Looking Back, Moving Forward

Lessons and Actions for Clean Air in Mexico

The story of air quality monitoring in Mexico is one of persistence, innovation, and gradual change. This epilogue looks back on the lessons of past decades, but it also looks ahead to the actions needed to secure cleaner air for future generations.

In the 1980s and early 1990s, Mexico City faced one of the worst urban air pollution crises globally. Episodes of high ozone (O₃), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and particulate matter (PM₁₀) frequently exceeded international safety thresholds. Factors such as population growth, industrial expansion, and traffic congestion were central to the problem. Air quality norms were formally issued as early as 1982, but systematic enforcement came much later.

Early air monitoring relied on manual readings and fragmented networks. Automated stations began expanding meaningfully only in the 1990s, supported by increasing public pressure and international attention. Field technicians played a key role in installing and maintaining this first generation of stations, gathering critical data that uncovered industrial hotspots and lead exposure near refineries and smelters.

Building a Foundation for Action

These early efforts were shaped by a combination of scientific initiative and citizen activism. Field technicians formed the backbone of early monitoring efforts, working across different locations to install rudimentary devices, collect filters, and analyze samples. Their work revealed local hotspots of lead contamination near industrial facilities and uncovered the extent of particulate pollution in the metropolitan area.

Programs like PICCA and ProAire marked the first coordinated responses to severe urban smog. Policies like “Hoy No Circula” were initially emergency measures but later became part of long-term planning, and the closure of polluting industries often

happened only after sustained pressure from science and civil society. The creation of the National Institute of Ecology marked a shift toward more independent, data-driven environmental governance. Over time, air quality became a national issue, with monitoring networks expanding beyond Mexico City to other regions.

During the 1980s and early 1990s, the biological effects of air pollution were still poorly understood in Mexico. Plants served as ‘silent witnesses’ to pollution, displaying visible damage such as chlorosis and leaf deformation. Species like tobacco and alfalfa were among the first used in experimental studies to detect pollutant stress in urban environments. These low-cost methods complemented the manual data collection carried out by early field technicians. The use of biological indicators also encouraged interdisciplinary collaboration, linking biology, geography, and atmospheric science in new ways.

The Challenges Ahead

The interviews presented in this book make clear that monitoring remains essential for understanding air quality and guiding decisions, but progress is still fragile and incomplete. Monitoring systems have expanded and improved, yet on their own they cannot achieve the level of clean air that citizens deserve. Reaching this standard requires concrete action based on the knowledge these systems produce.

Mexico’s air quality efforts were never the result of a single plan or agency. They evolved through trial and error, social pressure, collaboration, and evidence-building –driven as much by urgency as by innovation. From the manual field campaigns of the 1970s to the sophisticated emission models of the 2020s, the trajectory has involved generational shifts in how we understand, manage, and live with air pollution. The path forward must honor that legacy. Not through nostalgia, but by recognizing that governance systems are fragile, reversible and constantly evolving.

Key Steps for the Future

- **Deepen integration of health and climate policies.**

Air pollution, climate change, and public health are closely connected. Policies should align air quality standards with health data and climate adaptation strategies, and early warning systems must combine meteorological and biological indicators. Emerging pollutants, such as ultrafine particles and indoor VOCs need greater regulatory attention.

- **Move from data collection to policy enforcement.**

Mexico has built a robust monitoring infrastructure, but enforcement has not always matched technical capabilities. Real-time data must translate into action, supported by legal frameworks and institutional independence for agencies like INECC and SEMARNAT. Data should serve people, not just regulatory compliance.

- **Acknowledge and regulate domestic and informal sources.**

Household emissions from cleaning products, LPG, and wood burning are an underestimated source of air pollution in Mexican cities. Indoor air quality must be treated as a public health concern through cleaner technologies and public education. Informal emissions should be addressed with the same seriousness as industrial ones.

- **Build a new generation of environmental leaders.**

Progress has always relied on dedicated technicians, scientists, and policymakers. Today, underfunding, talent drain, and weak links between research and decision-making threaten that legacy. Investment in training, mentorship, and interdisciplinary education is vital for the future.

- **Embed ethics and equity in policy.**

Environmental risks are often framed as technical issues, while ethical and health concerns remain underrepresented in public debate. Communities with limited resources still bear the heaviest burden. Air quality policy must prioritize justice, accountability, and inclusion.

- **Lead regional and global collaboration.**

With decades of learning, scientific capacity, and innovation, Mexico can lead by example in Latin America, sharing best practices, supporting partnerships with other megacities, and contributing to regional environmental agreements.

A Collective Responsibility

The people featured in this book represent decades of dedication and courage. Their stories show that progress happens step by step, often driven by individuals working outside formal structures who insisted on evidence-based action. The scientific advances, policy innovations, and institutional changes achieved over the past four decades demonstrate that even the most severe pollution crises can be addressed with persistence and collaboration.

Some important pioneers are not featured in this book because they have passed away or were unreachable. We would like to acknowledge a few of them here to honor their contributions: Dr. Mario Molina Pasquel y Henríquez, Dr. Humberto Bravo Alvarez, Dr. Ernesto Jaúregui Ostos, Dr. Matilde Espinosa Rubio, M. A Yolanda Falcón Briseno, Met. Ernesto Sandoval Jimenez, Eng. Enrique Tolivia Meléndez, Dr. Margarita Castillejos Salazar, Dr. María de Lourdes de la I. de Bauer, Eng. Rogelio González García, Arch. René Altamirano Pérez. Their research, technical work and policy efforts laid important groundwork, and their legacy remains part of the foundations of Mexico's air quality efforts.

Mexico now has the chance to build on this legacy. With its accumulated knowledge, institutional memory, and technical infrastructure, the country can lead by example in Latin America. The next chapter will depend on decisions made today, about investment, enforcement, education, and collaboration. Protecting the independence of scientific institutions, maintaining long-term programs like ProAire, and fostering international partnerships will be key to achieving lasting improvements.

This epilogue is not a conclusion. It is a recognition that the air we breathe is the outcome of countless technological, political, economic and personal decisions. The story of Mexico's air quality is far from over, but it stands as proof that change is possible when evidence meets action, and when people remain at the center of policy.

Inter-Institutional Measures Agreed upon for Air Quality in Mexico (1960–2025)

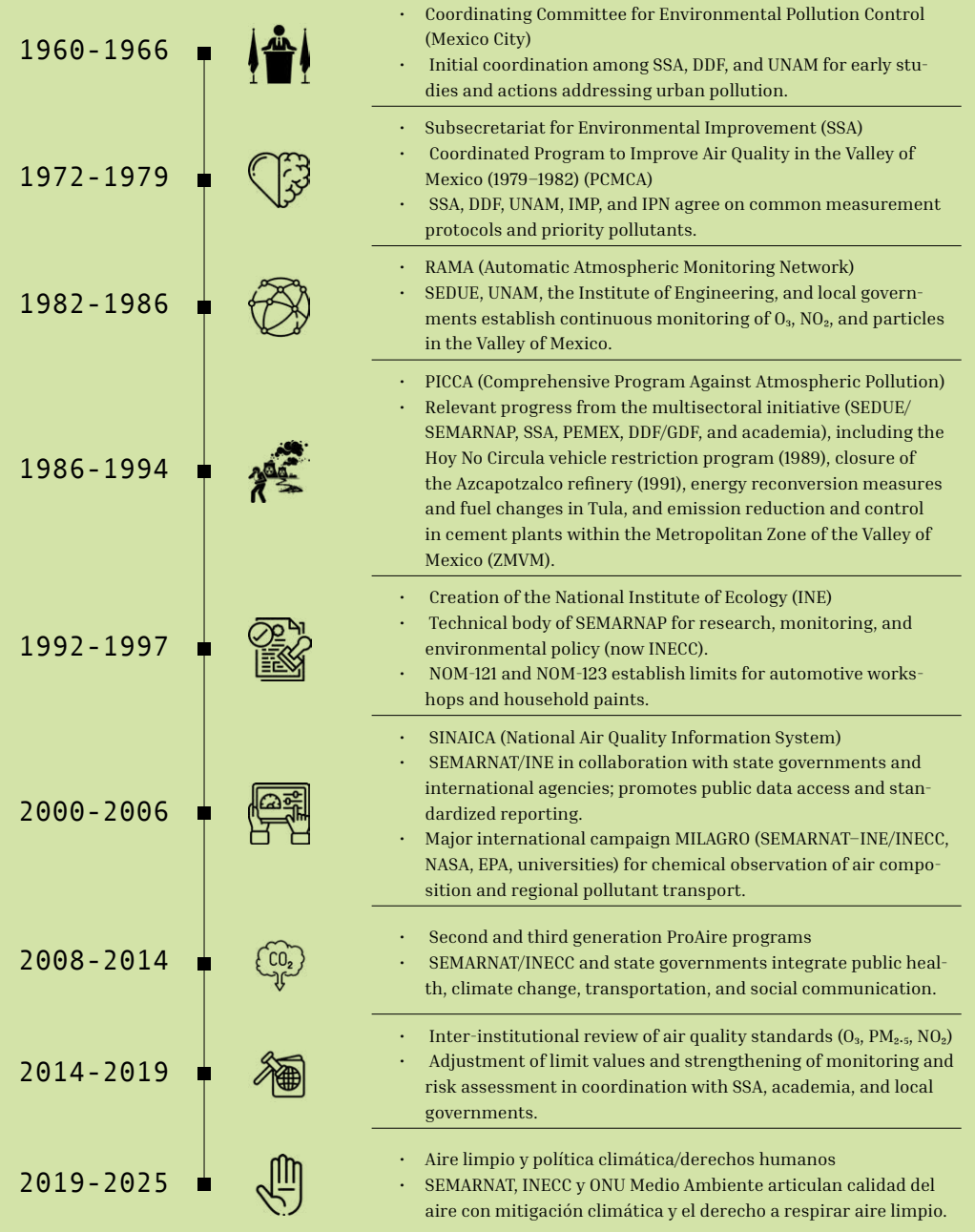


Figure 7. Timeline of inter-institutional agreements and measures for air pollution control in Mexico (1960–2025).

Campaña MILAGRO 2002. *Iniciativa de una Megaciudad: Observaciones científicas locales y globales (Megacity Initiative: Local and Global Research Observations) (MILAGRO)*. (2002).

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Programa Integral Contra la Contaminación Atmosférica (PICCA). (1990–1995).

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Soto Colobaltes, N. V. (2015). *El aire de cada día: Política y medición de la contaminación atmosférica en la Ciudad de México (1960–2015)*.

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Voria-Aburto, V. H., Castillejos, M., et al. (1998, December). Mortality and ambient fine particles in Southwest Mexico City, 1993–1995. *Environmental Health Perspectives, 106(12)*.

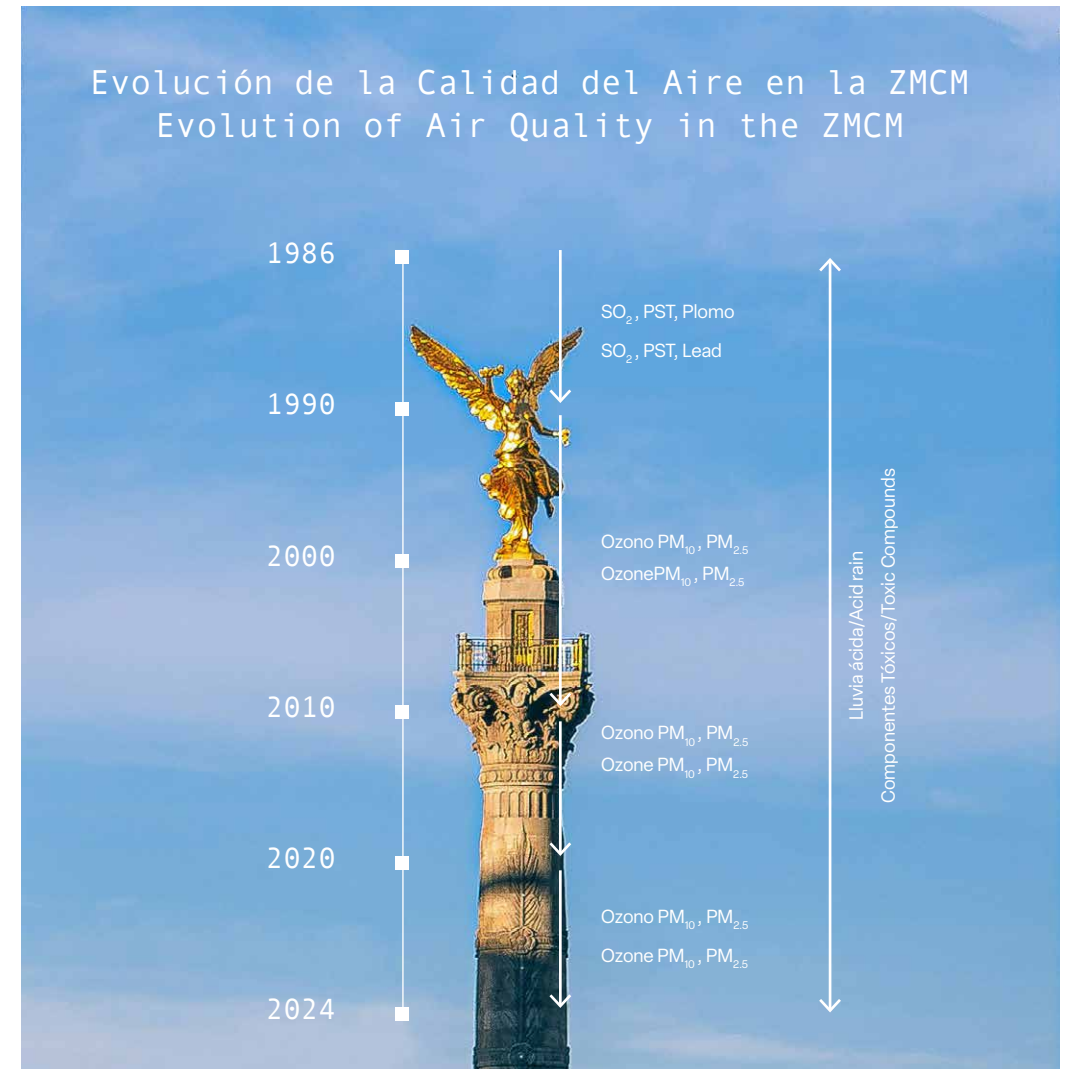


Figura 8. Línea del tiempo de la evolución de la contaminación atmosférica en la ZMCM.

Fuente: SEMINARIO INSTITUCIONAL DEL ICAYCC UNAM. Estado actual y futuro de la investigación sobre contaminación atmosférica. Dr. Rodolfo Sosa Echeverría

Figure 8. Timeline of the evolution of air pollution in the Mexico City Metropolitan Area.

Retrieved from Institutional Seminar of ICAYCC UNAM. Current Status and Future of Research on Air Pollution. Dr. Rodolfo Sosa Echeverría



Figura 11. Representación ilustrativa inspirada en las mediciones pioneras de meteorología en en Valle de Toluca

Figure 11. Illustrative representation inspired by the first meteorological measurements in the Valley of Toluca.

Figura 9. Hoja de tabaco con 80% de daño por ozono.

Figure 9. Tobacco leaf with 80% ozone damage.



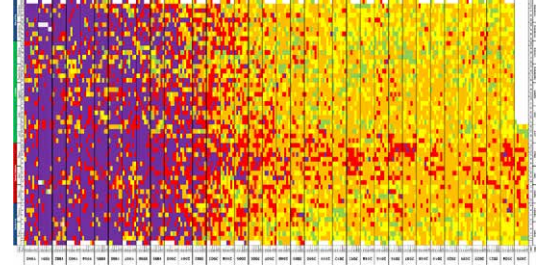
Figura 10. Exposición de plantas de tabaco en la Estación Pedregal.

Figure 10. Exposure of tobacco plants at the Pedregal Station.



MOSAICOS HISTÓRICOS DEL ÍNDICE AIRE Y SALUD

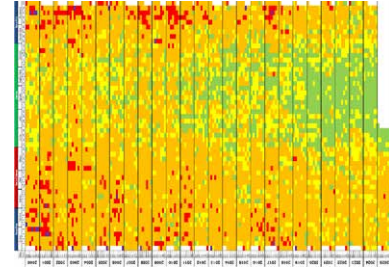
(NOM-172-SEMARNAT-2023) DE O₃ EN LA ZONA METROPOLITANA DE LA CIUDAD DE MÉXICO (1990-2025)



Mosaico de ozono, cada celda corresponde a la concentración horaria máxima registrada por día entre 1990 y 2025. De acuerdo con la NOM-172SE-MARNAT-2023. Para fines comparativos, el color de la celda indica la calidad del aire de acuerdo con los rangos del índice Aire y Salud vigentes a 2025.

LEYENDA	
Categoría de la Calidad del Aire	Color
Buena	Verde
Regular	Amarillo
Mala	Naranja
Muy Mala	Rojo
Extremadamente Mala	Púrpura

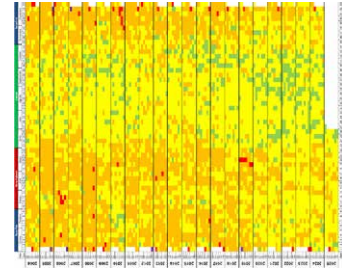
(NOM-172-SEMARNAT-2023) DE PM10 EN LA ZONA METROPOLITANA DE LA CIUDAD DE MÉXICO (2000-2025)



Mosaico de PM10, cada celda corresponde a la concentración del valor máximo del promedio de 24 horas de acuerdo con la NOM-025SSAI-2021 y NOM-172-SEMARNAT-2023, registrado por día entre 2000 y 2025. Para fines comparativos, el color de la celda indica la calidad del aire de acuerdo con los rangos del índice Aire y Salud vigentes a 2025.

LEYENDA	
Categoría de la Calidad del Aire (µg/m³)	Color
Buena	Verde
Regular	Amarillo
Mala	Naranja
Muy Mala	Rojo
Extremadamente Mala	Púrpura

(NOM-172-SEMARNAT-2023) DE PM2.5 EN LA ZONA METROPOLITANA DE LA CIUDAD DE MÉXICO (2004-2025)



Mosaico de PM_{2.5}, cada celda corresponde a la concentración del valor máximo del promedio de 24 horas de acuerdo con la NOM-025SSAI-2021 y NOM-172-SEMARNAT-2023, registrado por día entre 2004 y 2025. Para fines comparativos, el color de la celda indica la calidad del aire de acuerdo con los rangos del índice Aire y Salud vigentes a 2025.

LEYENDA	
Categoría de la Calidad del Aire (µg/m³)	Color
Buena	Verde
Regular	Amarillo
Mala	Naranja
Muy Mala	Rojo
Extremadamente Mala	Púrpura

Figura 12. Conjunto de Mosaicos históricos del índice de aire y salud en la Zona metropolitana de la Ciudad de México, publicados por la Secretaría del Medio Ambiente de la Ciudad de México.

Figure 12. Set of historical mosaics of the Air and Health Index in the Mexico City Metropolitan Area, published by the Secretaría del Medio Ambiente of Mexico City.