Policy Brief

# Ten Essential Air Quality Research Areas That Need Support

Sarath Guttikunda

**SIM-air Working Papers**

**No. 62-2025**

URBAN emissions .info

## About UrbanEmissions.Info

UrbanEmissions.info (UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution and focusing on four key objectives:

- Sharing knowledge on air pollution
- Providing science-based air quality analysis
- Promoting advocacy and raising awareness on air quality management
- Building partnerships among local, national, and international airheads

## About SIM-air Working Papers

The working-papers describe case studies where we applied the SIM-air family of tools, document general notes on emissions and pollution modeling, and present our reviews on topics related to air pollution analysis @ https://urbanemissions.info/publications

Last 5 working papers


## Suggested Citation

Guttikunda, S.K. (2025) "10 Essential Air Quality Research Areas That Need Support". SIM-air working paper series #62-2025. Published by UrbanEmissions.Info, New Delhi, India

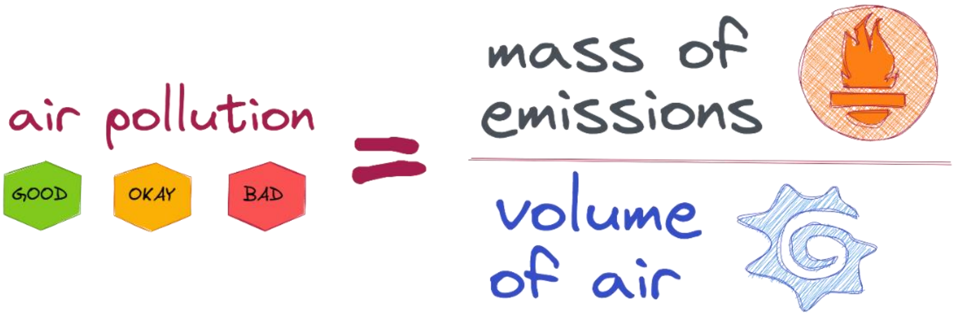
## Disclaimer

Policy Brief

# 10 Essential Air Quality Research Areas That Need Support

Beyond being a policy goal, clean air is an essential component of our overall well-being with an atmosphere free of harmful pollutants -- the ultimate objective of air quality management.

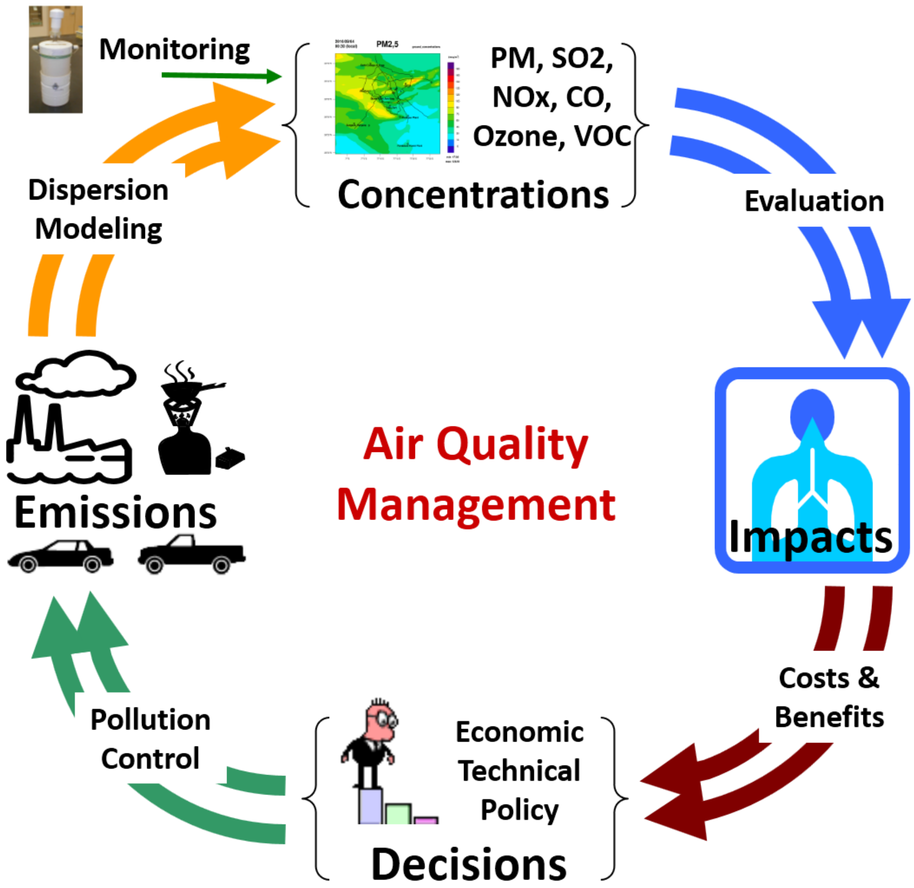
Air pollution is a pressing public health issue, with a list of associated health impacts that continue to grow, with short-term ailments like eyes, nose, and throat irritations and long-term ailments like respiratory illnesses, cardiovascular diseases, and neurological and developmental issues, affecting multiple bodily systems and some leading to premature mortality [1,2]. This problem is not isolated; it is intricately linked to various aspects of our lives. For example, our travel habits relying on personal vehicles and the resulting traffic congestion, contribute directly to the emission of pollutants; our consumption habits, from the production of goods to their transport and eventual disposal, create emissions at every stage of the supply chain.




The work in air quality management is not about managing pollution, but about managing emissions at their source -- systematically cutting down emissions or at least limiting them as much as possible. Achieving clean air for all requires a fundamental shift in how we manage emissions from all sources. This includes controlling the burning of gas, petrol, diesel, biomass, and waste, along with dust. A comprehensive strategy must also consider how to mitigate the effects of meteorological impacts on pollution levels.

Air pollution is a dynamic entity that is difficult to control once pollutants are released into the atmosphere. We can predict the direction of the wind, the timing of precipitation, or how emissions will behave chemically once they are airborne, because we know the atmospheric chemistry and physics, but it doesn’t solve the problem of air pollution. The only element we can effectively control is the emissions that enter the atmosphere from their source. Therefore, methods that attempt to manage pollution after the emissions are already in the air, such as mist fountains, smog towers, or air purifiers, only provide a “false hope” compared to a strategy focused on emissions control [3].

We understand the fundamental need to control emissions for clean air. If an intervention has the potential to control emissions, then it should be implemented. However, research is essential for determining how much to implement in a cost-effective manner without a large financial burden. This requires detailed information on where emissions originate, how pollution moves, and the strength of the sources contributing to the problem. Research provides a foundational platform, giving us the knowledge to plan and direct resources effectively.




Despite advancements in computational power, atmospheric research still faces significant challenges. While a lot of discussion now is focused on how AI can accelerate this research, it overlooks a fundamental prerequisite for success -- vast quantities of accurate information. Without this crucial input, AI models cannot produce reliable results[1].

[1] https://www.newyorker.com/culture/open-questions/what-if-ai-doesnt-get-much-better-than-this

We are neglecting the basics. Today, there is strong emphasis on expanding ground-based monitoring and using satellite data to understand air quality. However, air quality management involves more than monitoring. While monitoring provides some of the necessary data, a complete approach requires a deeper understanding of atmospheric science and how it relates to long-term trends. We need a comprehensive analysis of the costs and benefits of pollution to develop and implement an effective clean air action plan. We need a clear communication strategy to inform the public about air quality conditions, whether good or bad.

Our responsibility is to prioritize research to address this information gap through quality data generation, rigorous ground-truthing, and hands-on interpretation. This challenge is particularly difficult (and deep) in low- and middle-income countries, where the gaps in information and technological infrastructure are wide. This is not to say that high-income countries are exempt; everyone is still in a learning phase, with some being at an advanced stage of development than others.

For all this, we need to build foundational work on all the components of air quality management. Here are the TEN essential air quality research areas that need support.

1. Data collation and open data access
2. Ambient and emissions monitoring
3. Air Quality Modeling
4. Emission inventories
5. Epidemiological and health impact studies
6. Source apportionment studies
7. Managing emissions at source
8. What-if scenario “cost-benefit” analysis
9. Capacity building
10. Communications and connections

The objective of this document is to provide an overview of the key components of air quality management that require a deeper understanding. If a city decides to embark on an air quality management plan, research on these components is essential to better grasp the problem. It is not necessary to address all of them from the outset; instead, a city can build on each component progressively, learning from examples in other countries. **The point is to ensure that science is not ignored in the policy-making process, as robust research is the key to creating effective and lasting solutions.**

## 1 Data Collation and Open Data Access

**Research questions: How to improve data collection via monitoring and surveys? How to make the data accessible and usable?**

Air quality management is fundamentally an exercise in data management. Good data tells a good story and common proverb is, “garbage in, garbage out”. We need support for data management.

We require data from every component that goes into understanding and addressing the air pollution problem. For instance, we need data on emissions from every sector to build a comprehensive inventory, along with emissions monitoring for inputs. We also require data to model pollution, including information on its movement (meteorology), chemical transformation (chemistry), and deposition (physics), along with ambient monitoring for validation. We need information from epidemiological and cohort studies to understand the health impacts of different pollutants and use that to model future scenarios. To find cost-effective solutions, we need data on the performance, cost, and constraints of various control equipment. Additionally, we need information on institutional, logistical, legislative, judicial, and social factors, as all these influences how interventions are implemented.

At the national level, a primary source of macro-level data is the census, which authorities conduct approximately every 10 years. This effort is complemented by several other surveys, including those on households, livelihoods, labor, health, economics, education, and environment. These surveys provide specific and timely information to support a wide range of general statistics. Together, these data collection efforts provide a foundational understanding of national trends and are used to inform policy and track socio-economic progress. Several of these databases become key inputs for emissions analysis. For example, population census with details on socio-economic status is used for assessing household energy consumption and related emissions.

At the sub-national, regional, and airshed levels, data collation is required at a more granular scale to support detailed energy and emissions analysis. This allows for a localized and accurate understanding of pollution sources, moving beyond the broad assumptions that accompany national-level data. For instance, this requires information on vehicle fleets and their usage patterns within a city, not just national averages [4]. It also involves collecting data on energy consumption and fuel types at the household or neighborhood level, rather than relying on aggregated residential statistics from the national census. Similarly, for industries, a granular approach means getting information on specific fuel consumption rates, processes (combustion and controls), and locations of individual facilities within a region. This level of detail is necessary to develop accurate emissions inventories and implement effective, targeted policies for a specific area.

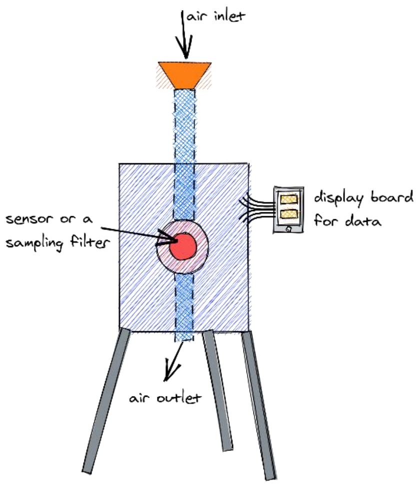
Collecting this granular data often involves a combination of short-term and long-term surveys that are designed to support quantitative analysis. Short-term surveys can be used to capture a snapshot of time-sensitive information, such as daily vehicle usage characteristics or fuel consumption during a specific season. In contrast, long-term surveys (conducted on a repetitive basis) are essential for establishing baselines and understanding broader trends over extended periods.

***Collecting data is not enough, it needs to openly accessible***, in a format that various stakeholders can use. While the public needs simple formats, such as a CSV file that can be opened on a basic device, more complex formats may be necessary for analytical groups due to the large volumes of data being processed. The important thing is that the data must be open so anyone can access, scrutinize, and study it. This public scrutiny is essential for determining whether the data is of a quality sufficient for use in air quality management studies.

## 2 Ambient and Emissions Monitoring

**Research questions: What is the best available technology to scale up ambient and emissions monitoring? How to use emerging data analytics to support air quality management?**

The basic principle of monitoring involves using equipment to measure pollutants at a specific location to understand their presence (in short -- buy it, put it, get data, plot, and present). We need more of this to happen. This includes foundational ambient monitoring, which provides long-term baselines [5]; emissions monitoring, which tracks pollutants at their source [6-8]; and mobile monitoring, which offers a dynamic view of pollution hotspots [9,10].




Ambient air quality monitors, while providing high-quality data, have limited spatial coverage. The traditional monitors are expensive to purchase, install, and maintain, which limits their number that can be deployed within a city or region [11,12]. As a result, large gaps often exist between monitoring stations, and as the data they collect represents the air quality only at that specific location[2]. Additionally, we live in a

[2] Thumb rule for a reference grade monitor is that it represents an area with a radius of 2 km in an open or uniform area. However, this assumption does not hold true in dense urban centres. The presence of obstacles

multi-pollutant environment[3], requiring information on how all the pollutants interact, move, and affect health, which makes monitoring an involved exercise. When dealing with a large area, the need for more monitoring stations is higher.

To address the need to scale up monitoring, new advancements are coming from low-cost sensors[4] that can supplement traditional reference-grade systems. However, these sensors require extensive calibration and maintenance, much like their expensive counterparts. The more we deploy them, the more we learn about their behavior and improve their accuracy [13,14].

Satellite data provides valuable supplementary information, serving as a proxy rather than a direct measurement of ground-level pollution [15]. The data's utility varies by satellite type, with geostationary satellites offering continuous temporal trends and orbital ones providing a snapshot [16]. This capacity to cover vast areas makes satellite data a valuable resource for regions that lack ground-level monitoring. When combined with modeling advancements and other forms of monitoring, this information can help reveal a complete story about pollution, from its sources to its movement [17,18].

Emissions monitoring concentrates on the sources of pollution, measuring the amount of a pollutant emitted per unit of activity, such as per kilometer of vehicle driven, per ton of fossil fuel burned, or per kilo of waste incinerated. This data is an essential component for building accurate emission inventories. While technology and fuels may be standardized, operational differences from one location to another can alter these numbers. For example, factors such as road conditions, overloaded vehicles, and constant traffic congestion mean that emission factors should be customized. Ideally, every city and country would conduct these tests under their specific conditions to localize their inventories. When this is not feasible, borrowed numbers from other regions can serve as a first and best guess.

The goal is to build a foundation of data. We need consistent research support for all forms of monitoring, to develop and to optimize each of these methods, ensuring that the data is of sufficient quality and quantity to feed a data-driven system.

---

such as tall buildings and varied street layouts can significantly alter local air flow and pollutant concentrations. Buildings can create street-level canyons that trap emissions, while a mix of land uses, like a busy road next to a residential zone, causes pollution levels to vary dramatically over short distances.

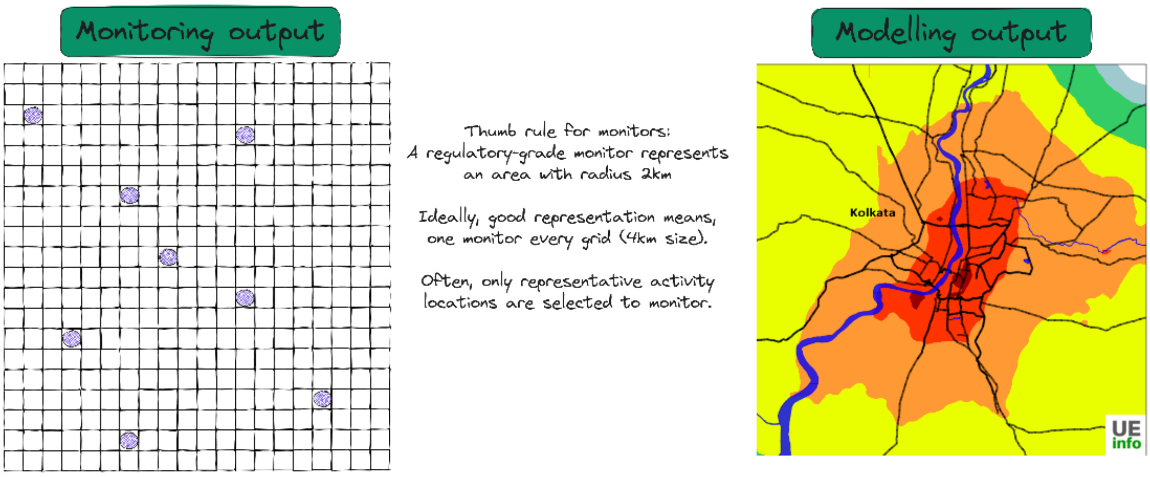
[3] Common pollutants which must be covered are $PM_{2.5}$, $PM_{10}$, $SO_2$, $NO_2$, CO, and Ozone

[4] These sensors, often optical particle counters, use a laser or LED to shine light through a small air sample. They measure the amount of light scattered by particles in the air, on which an algorithm is used to convert the scattered light signal into a particle count and concentration. A change in the chemical composition of the particle can alter the way it scatters light, which in turn affects the accuracy of the calibration used to convert the signal into a concentration. As a result, the calibration curves for these sensors are sensitive to a location's specific emission mix and can also vary with time and season.

## Air Quality Modeling

**Research questions: Which model best suits the data available? How to validate the model results against measurements and recycle lessons learnt? How to interpret model results? How to integrate emerging big data analytics into traditional modeling?**

Effective air quality management begins with measurement, as we cannot manage what we cannot measure. Ambient air pollution monitoring is the cornerstone of this effort, providing critical information on the levels and trends of pollution. However, **since it is not feasible to monitor everywhere, air quality modeling becomes essential**. Modeling not only fills the spatial and temporal data gaps left by monitoring but also expands our understanding of the science behind air pollution by using equations to perform scenario-based analysis.




Air quality models range from simple box model calculations to complex three dimensional Eulerian systems[5]. The simplicity of box models is only in their design, as they can provide significant insights into pollution trends before a user applies more complex models[6]. The models exist, and if we assume that emissions inventories are available, a primary bottleneck is often a lack of computational power. In low- and middle-income countries, this problem is compounded by a lack of both computational power and skilled operational personnel. A larger obstacle is often a fear of the models, fear of the numbers, and fear of the computers, which prevents this work from scaling up. ***We need operational mentors to train the next generation of atmospheric scientists***.

There is a growing push to automate air quality models by using artificial intelligence and machine learning to build algorithms and regression models. However, this focus often overlooks the fundamental need for high-quality data to build these

[5] Most used Eulerian models are WRF, WRF-chem, CAMx, CMAQ, CAM-Chem, CHIMERE, SILAM, CAMS, and GEOS-Chem; Most used Guassian-Lagrangian models are AERMOD, ISC3, and UAM

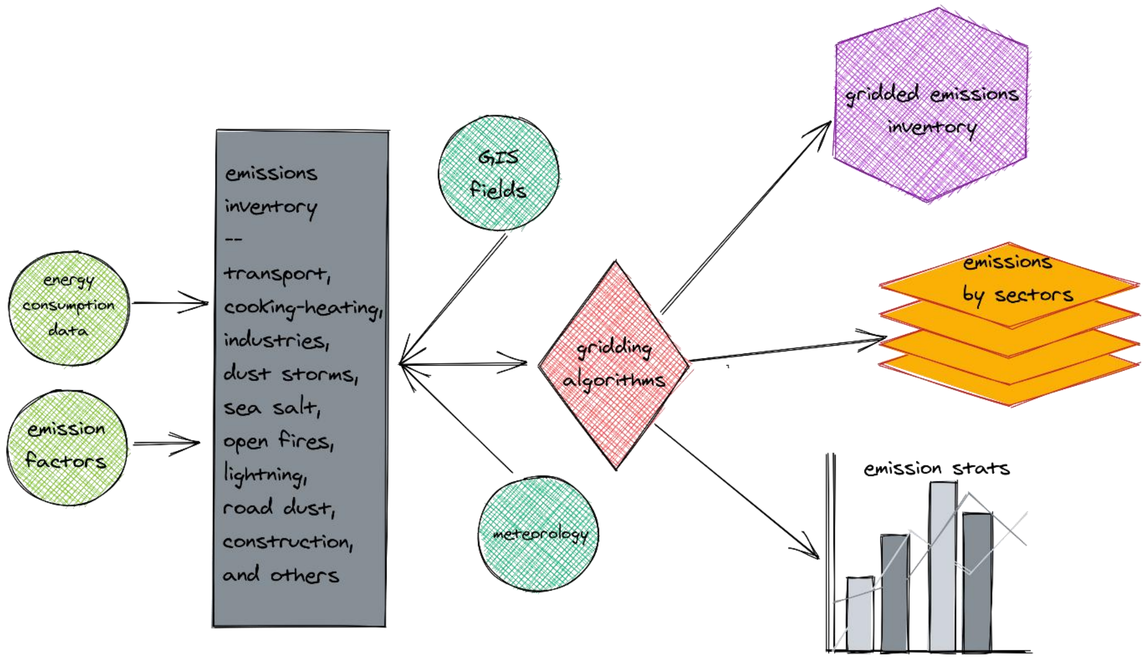
[6] Example applications and tools are available @ https://www.urbanemissions.info/tools

regressions, which can only come from direct measurements or from tested and calibrated deterministic models. When that data becomes available, the capacity for interpretation is still necessary, and that can only be developed through an understanding of traditional equations. While we are still in the learning phase of these new applications, research support is needed to build both the technical infrastructure and human capacity to run air quality models.

## 4 Emission inventories

**Research questions: Can a global emissions inventory be used for this airshed? Is there local activity and emission factors information to construct a customized emissions inventory for this airshed? How to conduct surveys to establish activity profiles? How to conduct experiments to ascertain emission factors?**

This section is extracted from Beginners Handbook (SIM-series #52) [19].




Emission inventories are the foundation of air pollution modeling, serving as a critical component in understanding air quality dynamics. These inventories provide detailed information on the magnitude and sources of pollutants released into the atmosphere, from anthropogenic (vehicles, industries, cooking, heating, waste burning), agricultural, and natural (dust, lightning, and biogenic) sources. By offering this essential baseline data, emission inventories allow researchers and policymakers to assess current air quality, track changes and trends over time, and evaluate the effectiveness of air pollution control measures. They also play a key role in identifying priority areas for regulatory action and ensuring that models reflect real-world conditions. Without inventories, it would be nearly impossible to develop effective strategies for reducing pollution and protecting public health.

Creating an emissions inventory is a complex and detailed process that requires the collection and analysis of various types of data. ***Key inputs include emissions factors, which represent the average emission rate of a pollutant for a given source, and activity levels, which describe how often and to what extent the emission-producing activities occur***. The process also requires precise information on the spatial and temporal distribution of emissions -- where the emissions are released geographically and when they occur -- so that the inventory can reflect real-world conditions. While airshed specific emission inventories at highest spatial and temporal resolution are preferred, often the global emission inventories are used as a substitute, which are integrated as pre-processors in most of the global and regional chemical transport models[7].

In the absence of local data, emission factors can be borrowed from established libraries or databases that provide standardized factors based on studies from similar regions or industries[8]. While these representative factors are not as precise as locally measured data, they offer a reliable starting point and can be refined over time as more specific and local data becomes available. Over time, emissions inventories can be improved by conducting field studies for better emissions factors, and continuous surveys with localized, sector-specific activity data.

Satellite feeds are increasingly used to enhance the spatial allocation of emissions. Satellite-derived data, such as land cover, vegetation, and even $NO_2$ or $CO_2$ concentrations (for example), can be incorporated into GIS models to nudge and refine spatial patterns. This is particularly useful for large areas or regions where ground-based monitoring or local information on the sources is sparse [20-23].

Given the constant evolution of technology, consumer behavior, and the urban and regional landscape, emissions profiles are continuously changing. Consequently, the research required to build an accurate emissions inventory is a perpetual process that demands a significant investment of patience, time, and financial support.

[7] Most used global and regional emission inventories in air pollution modeling are: GEIA (Global and regional repository); EDGAR, CEDS, CAMS, HTAP (Global – gridded - anthropogenic); SMOG-India (India – gridded - anthropogenic); MIX, REAS (Asia – gridded – anthropogenic); DICE, DACCIWA (Africa – gridded – anthropogenic); MEGAN (Global – gridded – biogenic); FINN, GFED (Global – gridded – open fires); and GAINS (Regional, Global – anthropogenic)

[8] These libraries, like the one available at (https://urbanemissions.info/tools) provide pre-determined emission factors for various sources, which can be used to estimate total emissions, when localized data is unavailable.

## 5 Epidemiological and health impact studies

**Research questions: What is the impact of air pollution on human health in my airshed? Is there access to local epidemiological parameters to quantify the health impacts? Is it necessary to conduct more epidemiological studies to reach a better assessment?**

A key development in evaluating health impacts has been the evolution of new methodologies over the past few decades [24,25]. The most recent advancement is the creation of Integrated Exposure-Response (IER) functions, which connect varying levels of air pollution exposure to specific health outcomes in different populations. This body of work, part of the Global Burden of Disease (GBD) study, was developed by the Health Effects Institute (HEI) and a group of leading research institutions [1,2]. This methodology has become a global best practice and a benchmark for the health impacts analysis of air pollution. Health endpoints most commonly included in the assessments are -- ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, Lower respiratory infections, dementia, diabetes, and obesity. All of them established IER functions.

**IER Health Impacts Calculator**

$$HI_i = Y \times AF \times PoP_i$$

$$AF = 1 - \frac{1}{RR}$$

$$RR(z) = 1 \quad \text{for } z < z_{cf}$$

$$RR(z) = 1 + \alpha\left[1 - e^{-\gamma (z - z_{cf})^{\delta}}\right] \quad \text{for } z > z_{cf}$$

HI = estimated health endpoint impacts in zone i
POP = population exposed in zone i
$Y_o$ = incidence/prevalence rate of health endpoint
AF = attributable fraction
RR = relative risk of the health endpoint
z = PM2.5 concentration
$z_{cf}$ = counterfactual concentration
$\alpha$ $\delta$ $\gamma$ = IER parameters for calculating RR

While the concept of health impact assessment is clear, the implementation should not be done blindly. ***Localized impact assessments require localized data***. Although the core impacts equations are same everywhere, key variables such as prevalence rates, which are dependent on local health conditions and wealth, must be customized. The risk function, which assumes that air pollution affects organs like the lungs and heart similarly everywhere, can be borrowed from existing studies. Some countries are reluctant to accept impact calculations, citing that the risk functions are not derived from local cohort studies, undertaking of which is both time-consuming and costly.

**A key localized input for health impact assessments is the prevalence rate**. Once the prevalence rate is known, risk functions can be applied to determine the portion of a health outcome that is specifically associated with air pollution. Prevalence rates can be measured for various health conditions as -- the percentage of a population with a particular disease at a specific time (e.g., the prevalence of asthma and other lower respiratory disorders in a city); the number of new cases of a disease within a given period (e.g., the incidence of lung cancer or heart attacks per 100,000 people per year); and the percentage of the population with a specific health risk factor, like obesity or high blood pressure.

Estimating prevalence rates can be challenging due to several factors, including the lack of complete and centralized hospital records, a lack of public health surveillance systems, scattered, inconsistent and unformatted data, and healthcare providers using varying diagnostic criteria, which can hinder systematic monitoring, reporting, and archiving. Socioeconomic factors also play a role, as populations with limited financial resources may not be able to afford a diagnosis, leading to an underestimation of the true prevalence. This is the core research required to conduct health impact analysis and localize the assessments.

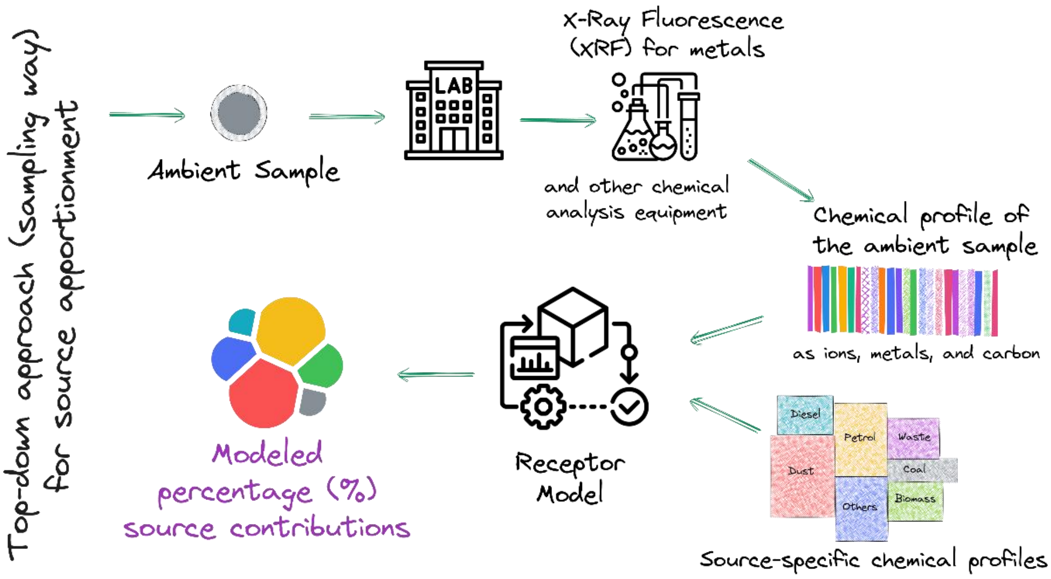
## 6 Source apportionment studies

**Research questions: What is the best methodology and equipment available for this study? Is more modeling necessary to conclude source contributions?**

For air quality management, source apportionment studies are a key tool, which helps determine the contribution of different sources to air pollution in a specific area. The analysis considers both the spatial origin and the type of source. For any designated region or airshed, this involves understanding how much pollution is coming from sources inside the area and how much is coming from outside. In addition to this spatial breakdown, the analysis identifies which specific sectors are contributing to the pollution share. These sectors include transport, industries, household activities like cooking and heating, dust from road and construction, and open waste burning. Knowing the contribution from sources inside a designated airshed allows for targeted local action, while addressing pollution from outside the airshed requires regional coordination.

In short, source apportionment studies help in not only identifying which sources are contributing significantly to the pollution problem but also prioritizing sectors to target for interventions in cost-effective ways to reach clean air goals. This is the basic necessary information to build an air quality management plan, and **every city and every region must conduct this research, as a first step** [26].

There are two main methods for conducting source apportionment studies [27]. The first is a top-down approach, also known as receptor modeling. This method involves collecting a physical air sample at a specific location, conducting a chemical analysis in a laboratory, and then using statistical models to match the sample's chemical signature to known source profiles. This process effectively determines how much of the measured pollution is coming from different sources, which are often linked to the distinct chemical signatures of various fuels.




The second method is a more involved bottom-up approach, also called an emissions inventory method (discussed in the earlier points). This process begins by building a detailed emissions inventory for a given area. This inventory is then processed through a chemical transport model, which uses meteorological data to simulate how pollution moves and transforms. The model provides a pollution map and estimates the contribution of each sector to pollution levels.

Both methods have their strengths[9], and they provide a more complete picture when used together. The top-down method offers a direct look at reality on the ground, while the bottom-up approach provides a more granular understanding of source contributions in both space and time. To better understand how pollution sources are affecting an area, we need to emphasize and support more of these combined source apportionment studies.

The methods, models, and best practices for source apportionment are well-documented, with decades of research from groups in the United States and Europe establishing a solid foundation [26]. While these applications are becoming more frequent in Asia, Africa, and Latin America, a gap exists in scaling up research opportunities to meet the demand in a wider range of locations and contexts.

[9] https://urbanemissions.info/publications/primer-on-pollution-source-apportionment

## Managing emissions at source

**Research questions: Is there an understanding of contributing sources? What are the institutional capabilities of the city or the region to implement emission control measures? What is the primary goal – better air quality or greenhouse gas reductions?**

Managing air quality ultimately means controlling emissions at their source. To achieve this, it's essential to understand the strength and intensity of all pollution sources. This research allows us to determine how these emissions contribute to air pollution and enables us to create a cost-effective plan to implement control measures before pollutants enter the atmosphere.

There is a range of control measures available for different pollution sectors, and a significant amount of research is required to customize them for a specific city or region. While these interventions generally follow a standard framework, they must be adapted to local conditions to be effective.

For example, public transportation is a well-known and effective control measure. It reduces emissions by encouraging the use of mass transit, which carries more passengers per kilometer than individual cars or motorcycles. This strategy helps decrease the number of private vehicles on the road, contributing to lower overall emissions. However, implementing such a measure isn't as simple as adding many buses (say 10,000 or just 100) to the roads. A thorough study must be conducted to assess the city's specific mobility needs, the projected public transport ridership, and how the operational costs of the system will be covered. This research ensures that the solution is both practical and financially viable, tailored to the unique demands of the city.

There is also a growing need to connect air quality and climate research, as many actions to address one can provide co-benefits for the other. First step is to gain an understanding of local needs and policies (or national/regional, depending on the airshed in concern), considering the opinions of various stakeholders to help set the course for research. For example, if a primary policy push is for climate action, such as reducing greenhouse gas emissions, improved air quality can be a co-benefit. Conversely, if the main objective is to achieve better air quality by controlling local pollutants, a reduction in carbon dioxide emissions can be a co-benefit.

***There is no single solution or path or "silver bullet" for managing emissions; any effort to cut and manage emissions at the source is a win***.

Here is a list of common emissions management measures adapted worldwide. Some or all of them can be adapted to support a clean air action plan.

For road transport:

- Promoting public transportation.
- Encouraging walking and cycling through better infrastructure.
- Implementing vehicle efficiency standards and introducing cleaner fuels like gas and cleaner technology like electric vehicles.
- Implementing green fleet management practices, such as anti-idling policies and regular maintenance, to ensure maximum fuel efficiency.
- Managing traffic congestion with strategies like smart signals, congestion pricing, carpooling, and ride sharing.
- Optimizing urban planning to reduce the need for long-distance travel.
- Improving driver behavior through eco-driving education.
- Optimizing freight logistics and routing using technology to consolidate shipments and reduce empty trips.
- Encouraging a modal shift, moving freight from roads to more energy-efficient options like rail and waterways, particularly for long-distance transport.
- Developing multi-modal hubs and improving urban delivery systems to streamline freight movement, especially within cities, by using smaller, cleaner vehicles for the last mile.

For power plants that use coal, gas, and diesel

- Combustion modifications, which involves using techniques like low-NOx burners to prevent the formation of pollutants during the burning process.
- Improving plant efficiency through modernization and the use of advanced turbines.
- Use of post-combustion control technologies, such as flue-gas desulfurization (FGD) to remove $SO_2$ and selective catalytic reduction (SCR) to control NOx.
- Fuel shift, transitioning from polluting fuels like coal and diesel to cleaner alternatives such as natural gas.

In general, for all industries, small, medium, and large

- Improving energy efficiency, which means using less energy to produce the same amount of output by upgrading equipment and optimizing processes.
- Transitioning to cleaner energy sources, like solar or wind power and switching to cleaner fuels.
- Optimizing the use of materials and resources to increase energy savings and lower emissions by reducing waste.

For open waste burning

- Improving waste segregation at the source, encouraging households and businesses to separate organic, recyclable, and non-recyclable materials.
- Waste diversion, which involves redirecting organic waste away from landfills to be processed through composting or anaerobic digestion.
- Broader focus on the circular economy, which promotes waste prevention, reuse, and recycling, is necessary to reduce the overall amount of waste generated and reduce the need for disposal through burning.

For household energy demand for cooking

- Encouraging the shift from traditional biomass and solid fuels to cleaner options like liquified petroleum gas, natural gas, or electricity.
- Distributing and promoting advanced biomass stoves that burn more cleanly and efficiently than traditional open fires.
- Improving home insulation and kitchen ventilation.
- Raising awareness about simple behavioral changes that can reduce energy consumption, such as using lids on pots to retain heat, soaking legumes before cooking, and turning off stoves promptly after use.

For dust on the roads and at the construction sites

- Applying water through water trucks, sprinklers, or misting systems is a straightforward and effective way to suppress dust. This is a useful temporary or short-term fix.
- Chemical suppressants (polymers and salts) on unpaved surfaces and stockpiles that bind dust particles together, are a longer-term fix which prevents dust from becoming airborne.
- Using physical barriers such as fences, tarps, and vegetation can help contain dust.

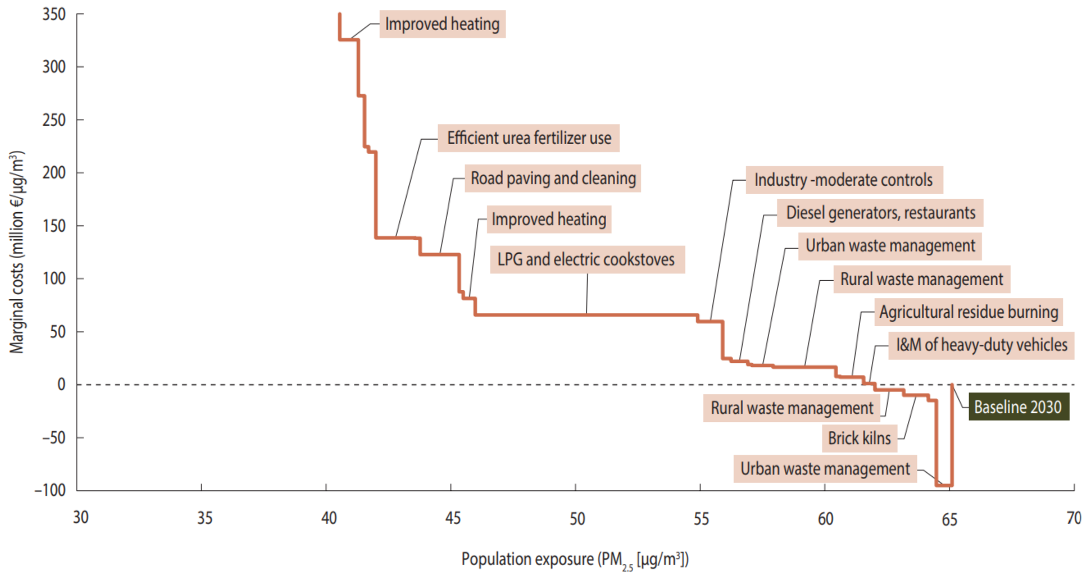
## 8 What-if scenario "cost-benefit" analysis

**Research questions: Is there an understanding of contributing sources? Is there a list of interventions that are suitable for the airshed? What is the cost to benefits ratio of these interventions? Is there institutional capacity to implement all or some of the interventions?**

Given a range of potential interventions, it is crucial to recognize that not all can or should be implemented, as they will not yield equal reductions in emissions and pollution. Therefore, a key step in the policy-making process is to assess the potential reductions of each intervention against a baseline. This baseline, or "business as usual" scenario, is a trend line of emissions and pollution that is drawn from a careful analysis of existing data (discussed in the previous sections). By comparing the potential impact of different interventions to this baseline, we can effectively guide the real policy-making process, ensuring that efforts are focused on the measures that will provide the most significant results – reaching the national standard or the WHO guideline.

Financial costs are associated with implementing emission control interventions, while the benefits, in the form of improved public health, are derived from emissions and pollution modeling. By comparing these metrics for various interventions, it is possible to identify a suitable set of options. This process helps to select those interventions that are cost-effective, provide the most significant health benefits, and effectively achieve the desired targets. This process is called "what-if" scenario analysis or "cost-benefit" analysis.

FIGURE 5.2 **Marginal Costs for Additional Measures in Uttar Pradesh, India, 2030**




**Illustrated figure extracted from "Striving for Clean Air: Air Pollution and Public Health in South Asia" by the World Bank (Washington DC) and IIASA (Austria) - https://www.worldbank.org/en/region/sar/publication/striving-for-clean-air**

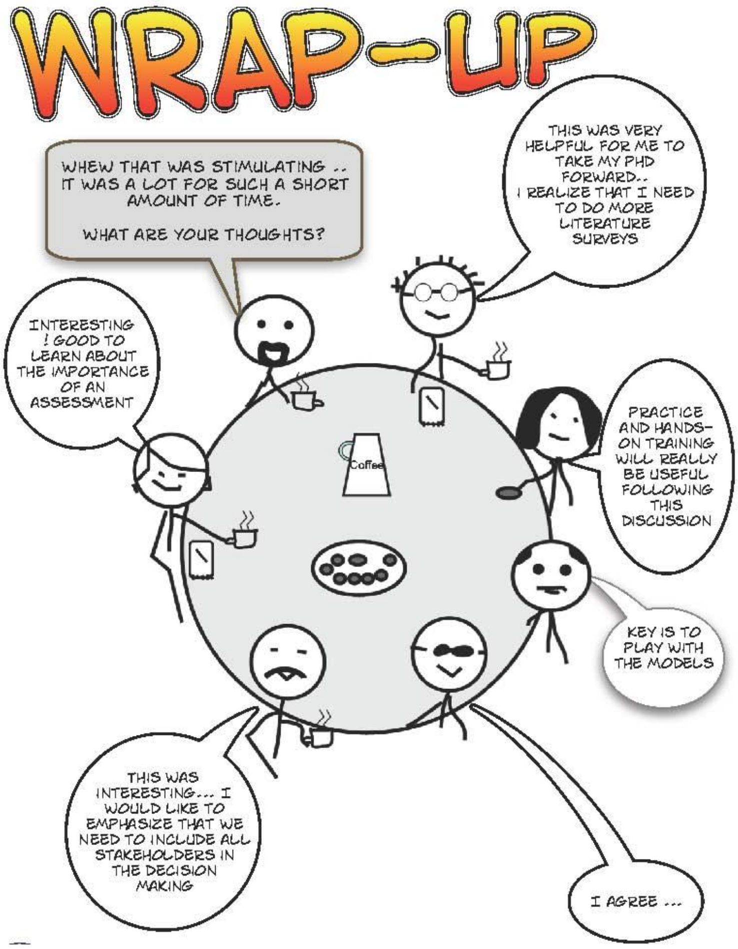
To fully assess the feasibility and benefits of interventions, research is needed to determine the costs of implementation, customized to the local socio-economic conditions. Similarly, research is required to monetize the health benefits of avoided emissions and pollution [28]. ***This dual research agenda allows for a comprehensive cost-benefit evaluation, providing a clear picture of which interventions are the most effective***.

## 9 Capacity building

**Research questions: Who is the audience requiring training? Is there training courses customized for various stakeholders?**

***The more people understand the language, the more buy-in we will have for clean air***.

In simple terms, capacity building is the process of improving an individual's or an organization's ability to understand, analyze, and act effectively. In the context of air quality management, capacity building is about strengthening knowledge on what pollution is, upgrading skills to analyze the emission trends, and having access to resources to support a policy dialogue more competently.




Capacity building means providing people with the foundational knowledge and tools needed to grasp complex information, such as data or technical jargon [29]. It's about learning how to identify patterns, ability to interpret data, evaluate information, understand basic science, and draw logical conclusions. These skills are crucial for making informed decisions and contributing meaningfully to a policy dialogue.

Effective air quality management is a multi-faceted endeavor that cannot be addressed by a single topic, course, or department. The various components, as previously discussed, require a diverse set of skills and knowledge. Because no single individual is an expert in all these areas, people's contributions will be focused on their specific backgrounds and skills. Despite this specialization, the goal remains the same: clean air. ***This collaborative approach, where everyone contributes their part, necessitates tailoring the process to the specific needs of the practitioners involved***.

When building the capacity of a **decision-maker**, the goal is not to turn them into a subject matter expert. Instead, the focus is on enabling them to make informed choices based on a comprehensive understanding of the problem and the available solutions. While a decision-maker needs access to all the raw data for ground truthing and transparency, they don't have to wade through every technical detail. Their training should equip them to effectively engage with experts, allowing them to rely on expert opinions without getting lost in the weeds. This means they need the capacity to interpret and understand the scientific findings and specialized language of experts. The training should focus on helping them evaluate expert consensus, weigh different recommendations, and ask the right questions to the final decision. For example, what will be the impact of promoting walking and cycling on air quality in my city; what is the most cost-effective air quality management strategy to implement by addressing all the known emission sources in my city?

A **community leader, or a representative from a non-governmental organization**, often serves as a crucial link between a project and the public. This group may lack a strong scientific background, making it essential that their capacity building is focused on communication rather than technical expertise. Their training should equip them to explain a project's benefits in a clear and compelling way. While they also need access to data for their work, this information should be presented in a format designed for public communication – using clear explanations and understandable visuals. The goal is to give them the tools to translate complex information into simple language so they can effectively explain a situation and build support within their community. For example, an excel tool can help a community leader illustrate a scenario of having more buses instead of private vehicles on the road, and what it means to public health[10].

To effectively address the problem of air quality, we must cultivate the **next generation of scientists**. For every component of air quality management discussed in the earlier sections, multiple people need to think through the challenges and find solutions. It is vital that every region and city in the world has a dedicated group of scientists responsible for generating, analyzing, and communicating the relevant

[10] Example MS Excel based tools on various sectors to estimate emissions and pollution are illustrated with instructions to operate @ https://www.urbanemissions.info/tools

data. This necessitates providing operational training to these emerging experts in all key areas, including emissions, pollution, health, and scenario analysis. Finally, it is essential to have experienced mentors ready to pass on their knowledge to the next generation who are exploring new science and new analytical techniques.

To achieve long-term success, air quality management cannot ignore **the public**. Public perception and buy-in are essential for the success of any policy. This requires engaging the public as an active partner in the process, not just a passive recipient of information. Therefore, effective strategies must include clear and consistent communication that helps the public understand the challenges, the proposed solutions, and their role in achieving a common goal of clean air.

Teaching and engaging with various stakeholders is a skill that is crucial for building a successful research area. The potential for this research segment is significant precisely because it requires a nuanced approach to communication. Tailored strategies ensures that the scientific findings are not just delivered, but are also understood and acted upon by many, maximizing the impact of the research.

10

## Communications and connections

**Research questions: Is there an understanding of the problem and the solutions that need to be communicated? Who is the audience? Can we simplify the science for common messaging?**

[11]Simplifying complex information is essential for effective communication about air pollution to the public, policymakers, and practitioners, and make environmental, health, and market connections. While advanced analytical systems, clear WHO guidelines, and national standards exist, progress on air quality often stalls, particularly in low- and middle-income countries, largely due to the "fear of the unknown," which stems from a lack of data, misconceptions, and the perceived complexity of the information systems [30].

A multi-faceted approach is needed to eliminate the fear of the unknown. This can be achieved through regular "show and tell" events, operational training for practitioners, and creative expressions like visualizations and public art installations. These efforts help bridge the knowledge gap, build trust in science, encouraging more people to engage in air quality conversation and advocacy.

Videos, photos, comics, and even simple Excel files can be used to great effect for mass communication. For example, the 2015 documentary "Under the Dome" in

[11] This section is extracted from SIM-series #51: Fear of the unknown: Communicating air quality information to public and practitioners

China used pollution data to spark a shift in public discourse. The "View from My Window" calendar in Beijing paired daily photos with real-time pollution readings, making the data relatable. The expansion of US Embassy monitoring networks and projects like the "Breathe London" initiative have also demonstrated how open data can drive public awareness and policy changes, such as the Ultra Low Emission Zone (ULEZ). The emergence of low-cost sensors is breaking down barriers to self-monitoring and is increasingly used in citizen science initiatives to fill data gaps. Beyond traditional media, hand-drawn visuals like doodles and comics are gaining momentum as communication tools. They simplify complex topics and offer a personal touch, making information more approachable for grassroots campaigns and educational settings.

Creative installations and public practices also play a vital role in encouraging behavioral change. Bogotá's Ciclovía, which closes over 100 kilometers of roads to motor vehicles every Sunday, promotes cycling and community engagement while also raising environmental awareness. Indian organizations have used "Lungs Billboard" installations to demonstrate the health impacts of air pollution, with the lungs turning black after a short period of exposure. The Air Quality Index (AQI) balloon in Paris, which changes color to provide a visual representation of real-time air quality. These creative installations help bring the message to a broader audience, making the complex issue of air pollution more relatable and understandable.

**It is crucial to recognize that the air pollution problem extends beyond scientific and technical limitations**. While models and data are essential, their effectiveness is amplified by clear communication. Simplifying complex information is key to building public awareness, securing political will, and empowering individuals to make informed decisions. This requires sustained support for research, most importantly, the development of human resources capable of translating scientific insights into actionable narratives. Only then can we bridge the gap between scientific understanding and practical solutions, leading to meaningful progress toward cleaner air.

## Reflections

We have the methods, models, and minds to address air quality issues. We need access to localized research for better analysis and customized stories for effective communication.

Research is not an end for air quality management; rather, it is a foundational tool that provides the necessary data and information to enable informed and effective decision-making. Research provides a scientific footing to all policy choices, identifies scientific skill-gaps for targeted capacity building, and gives scientific credibility to communication and public messaging. Research is essential for making smart, well-grounded decisions, as it gives stakeholders the confidence and evidence they need to justify and implement measures for air quality improvement.

**For better air quality, irrespective of the amount of research and communications, what we need is a systematic reduction in the emissions at all the sources.**

# References


1. Vollset, S.E.; Ababneh, H.S.; Murray, C.J.L.; GBD-Collaborators. Burden of disease scenarios for 204 countries and territories, 2022-2050: a forecasting analysis for the Global Burden of Disease Study 2021. *The Lancet* **2024**, *403*, 2204-2256, doi:https://doi.org/10.1016/S0140-6736(24)00685-8.
2. HEI-SoGA. *State of global air (SOGA). A special report on global exposure to air pollution and its health impacts*; Health Effects Institute, Boston, USA: 2024.
3. Guttikunda, S.; Jawahar, P. Can We Vacuum Our Air Pollution Problem Using Smog Towers? *Atmosphere* **2020**, *11*, 922, doi:https://doi.org/10.3390/atmos11090922.
4. Guttikunda, S.K.; Ka, N.; Tejaswi, V.; Goel, R. Fuel Station Survey (FuSS) to Profile In-Use Vehicle Characteristics for a City's Vehicle Exhaust Emissions Inventory. *Preprints* **2024**, doi:https://doi.org/10.20944/preprints202406.0534.v1.
5. Jin, C.; Wang, Y.; Li, T.; Yuan, Q. Global validation and hybrid calibration of CAMS and MERRA-2 PM2.5 reanalysis products based on OpenAQ platform. *Atmospheric Environment* **2022**, *274*, 118972, doi:https://doi.org/10.1016/j.atmosenv.2022.118972.
6. Weyant, C.; Athalye, V.; Ragavan, S.; Rajarathnam, U.; Lalchandani, D.; Maithel, S.; Baum, E.; Bond, T.C. Emissions from South Asian Brick Production. *Environmental Science & Technology* **2014**, *48*, 6477-6483, doi:https://doi.org/10.1021/es500186g.
7. Jaiprakash; Habib, G. On-road assessment of light duty vehicles in Delhi city: Emission factors of CO, CO2 and NOX. *Atmospheric Environment* **2018**, *174*, 132-139, doi:https://doi.org/10.1016/j.atmosenv.2017.11.039.
8. Wiedinmyer, C.; Dickinson, K.; Piedrahita, R.; Kanyomse, E.; Coffey, E.; Hannigan, M.; Alirigia, R.; Oduro, A. Rural–urban differences in cooking practices and exposures in Northern Ghana. *Environmental Research Letters* **2017**, *12*, 065009, doi:https://doi.org/10.1088/1748-9326/aa7036.
9. Shah, R.U.; Robinson, E.S.; Gu, P.; Robinson, A.L.; Apte, J.S.; Presto, A.A. High-spatial-resolution mapping and source apportionment of aerosol composition in Oakland, California, using mobile aerosol mass spectrometry. *Atmos. Chem. Phys.* **2018**, *18*, 16325-16344, doi:https://doi.org/10.5194/acp-18-16325-2018.
10. Apte, J.S.; Messier, K.P.; Gani, S.; Brauer, M.; Kirchstetter, T.W.; Lunden, M.M.; Marshall, J.D.; Portier, C.J.; Vermeulen, R.C.H.; Hamburg, S.P. High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Environ Sci Technol* **2017**, *51*, 6999-7008, doi:10.1021/acs.est.7b00891.
11. Martin, R.V.; Brauer, M.; van Donkelaar, A.; Shaddick, G.; Narain, U.; Dey, S. No one knows which city has the highest concentration of fine particulate matter. *Atmospheric Environment: X* **2019**, *3*, 100040, doi:https://doi.org/10.1016/j.aeaoa.2019.100040.
12. Dammalapati, S.; Guttikunda, S.K. Data from small monitoring networks is unreliable: Case of Indian cities. *SIM-air Working Paper Series #47-2024 and #48-2024, UrbanEmissions.Info, New Delhi, India* **2024**, doi:https://dx.doi.org/10.2139/ssrn.4956327.
13. Mathieu-Campbell, M.E.; Guo, C.; Grieshop, A.P.; Richmond-Bryant, J. Calibration of PurpleAir low-cost particulate matter sensors: model development for air quality under high relative humidity conditions. *Atmos. Meas. Tech.* **2024**, *17*, 6735-6749, doi:10.5194/amt-17-6735-2024.
14. Kushwaha, M.; Sreekanth, V.; Upadhya, A.R.; Agrawal, P.; Apte, J.S.; Marshall, J.D. Bias in PM2.5 measurements using collocated reference-grade and optical instruments. *Environmental Monitoring and Assessment* **2022**, *194*, 610, doi:10.1007/s10661-022-10293-4.
15. Holloway, T.; Miller, D.; Anenberg, S.; Diao, M.; Duncan, B.; Fiore, A.M.; Henze, D.K.; Hess, J.; Kinney, P.L.; Liu, Y.; et al. Satellite Monitoring for Air Quality and Health. *Annual Review of Biomedical Data Science* **2021**, *4*, 417-447, doi:https://doi.org/10.1146/annurev-biodatasci-110920-093120.
16. Ustin, S.L.; Middleton, E.M. Current and Near-Term Earth-Observing Environmental Satellites, Their Missions, Characteristics, Instruments, and Applications. *Sensors* **2024**, *24*, doi:https://doi.org/10.3390/s24113488.
17. Li, C.; van Donkelaar, A.; Hammer, M.S.; McDuffie, E.E.; Burnett, R.T.; Spadaro, J.V.; Chatterjee, D.; Cohen, A.J.; Apte, J.S.; Southerland, V.A.; et al. Reversal of trends in global fine particulate matter air pollution. *Nature Communications* **2023**, *14*, 5349, doi:https://doi.org/10.1038/s41467-023-41086-z.
18. van Donkelaar, A.; Hammer, M.S.; Bindle, L.; Brauer, M.; Brook, J.R.; Garay, M.J.; Hsu, N.C.; Kalashnikova, O.V.; Kahn, R.A.; Lee, C.; et al. Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. *Environmental Science & Technology* **2021**, *55*, 15287-15300, doi:https://doi.org/10.1021/acs.est.1c05309.
19. Guttikunda, S.K.; Dammalapati, S. Beginners Handbook on Assembling Air Pollution Models. *SIM-air Working Paper Series #52-2024, UrbanEmissions.Info, New Delhi, India* **2024**, doi:https://dx.doi.org/10.2139/ssrn.5000911.
20. Guttikunda, S.K.; Zlatev, V.B.; Dammalapati, S.K.; Sahoo, K.C. Mapping PM2.5 Sources and Emission Management Options for Bishkek, Kyrgyzstan. *Air* **2024**, *2*, 362-379, doi:https://doi.org/10.3390/air2040021.
21. Okure, D.; Guttikunda, S.; Sserunjogi, R.; Adong, P.; Dammalapati, S.K.; Lsoto, D.; Green, P.P.; Bainomugisha, E.; Xie, J. Integrated Air Quality Information for Kampala: Analysis of PM2.5, Emission Sources, Modelled Contributions, and Institutional Framework. *Environmental Science: Atmospheres* **2025**, doi:https://doi.org/10.1039/D4EA00081A.

22. Guttikunda, S.K.; Dammalapati, S.K.; Tefera, W.; Xie, J. Modelling particulate matter (PM2.5) source contributions for air pollution management in Addis Ababa, Ethiopia. *Heliyon* **2025**, *11*, e43112, doi:https://doi.org/10.1016/j.heliyon.2025.e43112.
23. Guttikunda, S.K.; Dammalapati, S.; Jakubowski, P. Multi-Pollutant Emissions Inventory and Pm2.5 Pollution Source Apportionment for Bandung, Indonesia. *SIM-air Working Paper Series #58-2025, UrbanEmissions.Info, New Delhi, India* **2025**, doi:https://dx.doi.org/10.2139/ssrn.5392112.
24. Anenberg, S.C.; Belova, A.; Brandt, J.; Fann, N.; Greco, S.; Guttikunda, S.; Heroux, M.E.; Hurley, F.; Krzyzanowski, M.; Medina, S.; et al. Survey of Ambient Air Pollution Health Risk Assessment Tools. *Risk Anal* **2016**, *36*, 1718-1736, doi:https://doi.org/10.1111/risa.12540.
25. Pozzer, A.; Anenberg, S.C.; Dey, S.; Haines, A.; Lelieveld, J.; Chowdhury, S. Mortality Attributable to Ambient Air Pollution: A Review of Global Estimates. *GeoHealth* **2023**, *7*, e2022GH000711, doi:https://doi.org/10.1029/2022GH000711.
26. Johnson, T.M.; Guttikunda, S.K.; Wells, G.; Bond, T.; Russell, A.; West, J.; Watson, J. *Tools for Improving Air Quality Management. A Review of Top-down Source Apportionment Techniques and Their Application in Developing Countries*; ESMAP Publication Series, The World Bank, Washington DC, USA: 2011.
27. Guttikunda, S.K. What is Air Pollution Source Apportionment: An illustrated Primer. *SIM-air Working Paper Series, UrbanEmissions.Info, New Delhi, India* **2024**, doi:https://dx.doi.org/10.2139/ssrn.4915647.
28. Guttikunda, S.K.; Dammalapati, S. Value of Statistical Life (VSL) to support cost-benefit analysis of India's air quality management. *SIM-air Working Paper Series #55-2024, UrbanEmissions.Info, New Delhi, India* **2024**, doi:https://dx.doi.org/10.2139/ssrn.5250231.
29. Guttikunda, S.K.; Dammalapati, S. A primer on ABC's of air quality. *SIM-air Working Paper Series, UrbanEmissions.Info, New Delhi, India* **2024**, doi:https://dx.doi.org/10.2139/ssrn.5004911.
30. Guttikunda, S.K. Why communicating air quality information in the simplest form gets more people to understand and get involved in the fight against air pollution. *EGUsphere* **2024**, *2024*, 1-11, doi:https://doi.org/10.5194/egusphere-2024-1712.

www.urbanemissions.info