The Case for Closing Global Air Quality Data Gaps with Local Actors

A Golden Opportunity for the Philanthropic Community

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Acknowledgements

We would like to gratefully acknowledge the financial support of Open Philanthropy. Data contributions from the Clean Air Fund, OpenAQ, and the Atmospheric Composition Analysis Group at the Washington University in St. Louis were especially helpful in our analysis.

This report has greatly benefited from feedback from Aarsh Batra, Aidan Farrow, Collins Gameli, Tom Grylls, Sarath Guttikunda, Chris Hagerbaumer, Randall Martin, Pallavi Pant, Arindam Roy, R. Subramanian, and the many local actors who we spoke with about their work and the potential of where they see it could go with a better supported global air quality data infrastructure ecosystem.

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AT A GLANCE

This report is a strategic playbook for entities working on global to local public health and environmental issues highlighting low-hanging opportunities to make progress on air pollution in key regions around the world, specifically in the form of closing country-sized data gaps.

Fine particulate air pollution ($PM_{2.5}$) is the greatest external threat to public health with the average person on the planet losing more than 2 years of life expectancy according to the Air Quality Life Index, with the loss even higher at 3.1 years outside of OECD countries.

Why is reliable air quality monitoring so important for addressing air pollution? The history of progress on air pollution in countries including Japan, the United States, England, and China, reveals that improvements in air quality were preceded by the public demanding improvements and causing air quality to become a political priority. The foundation for these demands was data that illustrated the depth of the problem and then, later, data to assess progress. Thus, our theory of change is that closing air quality data gaps can allow people to lead healthier and longer lives.

The report outlines:

- Why closing air quality data gaps is a key catalytic step for reducing the most human health-harming outdoor air pollutant, $PM_{2.5}$. (Section 1);
- The countries with the largest opportunities for a small, well-supported effort to effect positive national-level changes by closing data gaps, (Section 2);
- The local actors who are well-poised to close these gaps (Section 3); and
- Four guiding tenets for philanthropies on how to inject more resources into the space in a maximally effective way (Section 4).

Section 1 spells out the theory of change for how closing $PM_{2.5}$ data gaps can create the foundation for—and in some cases directly spur—reductions in $PM_{2.5}$ levels by sharing examples in countries across the world.

In Section 2, we identify 46 countries where there are especially high opportunities for relatively small investments to support local actors in building the necessary data infrastructure to advance policy that reduces $PM_{2.5}$ pollution. 838 million citizens in these 46 high opportunity countries breathe air with $PM_{2.5}$ levels that are 4 times higher than the World Health Organization (WHO) guideline. Sixty-one percent of high opportunity countries are located in Africa, 22 percent in Asia, 15 percent in Latin America, and 2 percent in Europe. Meanwhile, across all of these countries, there are a total of only 30 government-run $PM_{2.5}$ monitors. In comparison, the country of Finland, one of the few countries that already meets the WHO guideline for $PM_{2.5}$, has more monitors for its population whose size is 1/152ndth of those 46 countries. Seventy-four percent of these high opportunity countries receive less than 100,000 USD annually from international donors to address outdoor air pollution (100,000 USD is a rough threshold for the amount needed to sustainably run a single government-grade $PM_{2.5}$ monitor each year). In fact, the combined total outdoor air pollution funds from international donors known to be received annually by these 34 countries is less than 73,000 USD.

Section 3 analyzes a landscape of 75 local actors working on closing $PM_{2.5}$ data gaps within their country and shares the results of 26 in-depth interviews to identify challenges and opportunities, and spotlights several local efforts globally. The most frequently cited amount of funding that local actors would find meaningful to their work was 50,000-100,000 USD per year. As a point of comparison, the entire African continent currently receives less than 300,000 USD in philanthropic funding annually for addressing outdoor air pollution.

Section 4 puts these geographical and local actor analyses together from a funder's perspective. It finds that a 4 to 8 million USD annual injection of funding could make substantial progress in closing country-level $PM_{2.5}$ data gaps across the world. It also finds that if even one effort in one small country were to catalyze clean air action that modestly lowered their national annual $PM_{2.5}$ levels, the avoided health damages in that one country alone would offset the cost of that annual global injection of funding. Section 4 also provides four guiding tenets for entities interested in funding in this space.

SECTION 1

Motivation

$PM_{2.5}$ takes away more years from average human life expectancy than HIV/AIDS, malaria, and tuberculosis—combined.[1,2]

$PM_{2.5}$ pollution is a major global health threat, yet has been severely under-funded and consequently under-monitored—especially in the most polluted and data-poor regions.

Thirty-nine percent of countries worldwide, predominantly those located in the Global South, lack basic air pollution data infrastructure such as pollution monitoring and open air quality platforms.[3] Without basic data on the quality of air, it is difficult to advance research on the impacts of air pollution, galvanize citizens to call for clean air actions, and build policies to confront the largest environmental threat to human health: $PM_{2.5}$. Given the neglected nature of the issue and the necessity and relative low-cost of generating and sharing $PM_{2.5}$ data compared to its impact, there is a golden philanthropic opportunity to directly support local actors to generate this information in '$PM_{2.5}$ data gap' countries.

1 Institute for Health Metrics and Evaluation 2019 Global Burden of Disease result tool, Date accessed: 23 Oct 2023

2 Air Quality Life Index Annual Update, 2023

3 OpenAQ. 2022. "Open Air Quality Data: The global landscape"

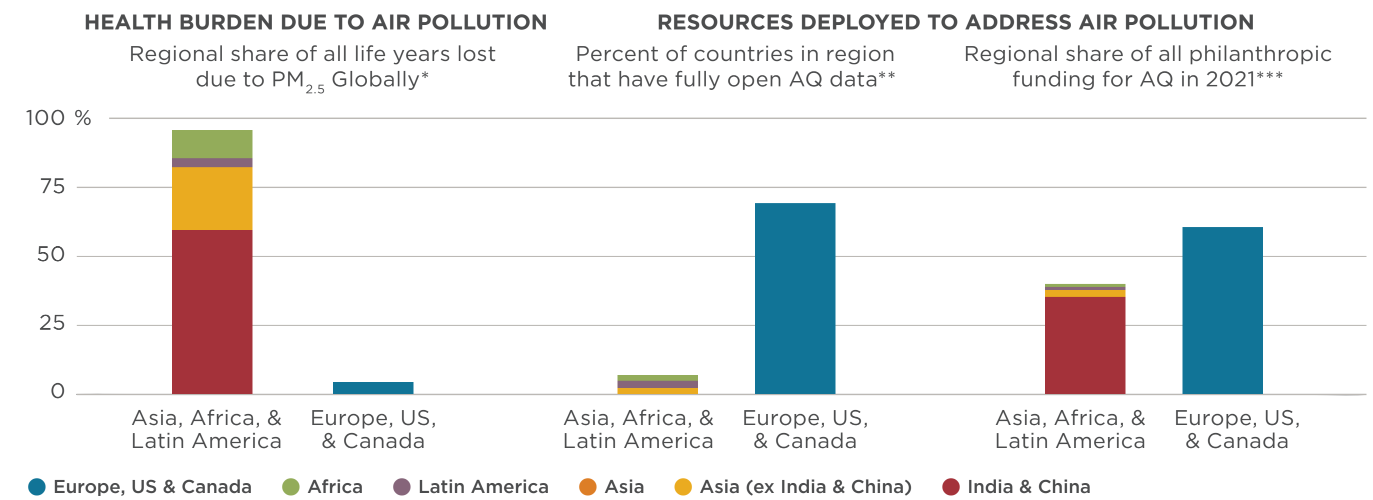
Despite the health burden of $PM_{2.5}$, there is a mismatch between it and the resources deployed to address the issue (Figure 1.1). For example, 96 percent of total life years lost due to $PM_{2.5}$ occur in Asia, Africa, and Latin America.[2] However, just 3.7, 6.8 and 19 percent of governments in Africa, Asia, and Latin America, respectively, provide fully open air quality data.[3]

It is well-established that the sustained presence of air quality data infrastructure is a foundational ingredient for policy action, including the creation or revision of national-level ambient air quality standards.[4] This finding is intuitive; it is difficult to prioritize policy on an issue that is not tracked and difficult to set a guidepost for change when there is no datapoint to aim to lower. In Europe, the US, and Canada, 69.2 percent of governments produce open data and 76.4 percent have a $PM_{2.5}$ air quality standard. Contrast this with Africa, for example, where 6.8 percent of governments produce open data and only 4.9 percent of countries have a $PM_{2.5}$ air quality standard.[2]

4 Vahlsing and Kirk (2012)

FIGURE 1.1

Resources to Address $PM_{2.5}$ Pollution Are Not Adequate to Address the Scale Of The Health Burden, Nor Applied in a Geographically Strategic Manner



Sources: *Air Quality Life Index Annual Report 2023, **OpenAQ 2022, "Open Air Quality Data: The global landscape"; ***Clean Air Fund, 2022, "The State of Global Air Quality Funding"

Lack of this infrastructure also impedes efforts to accurately estimate exposure to $PM_{2.5}$ pollution from satellite-derived data and to conduct large cohort epidemiological studies in many of the world's most polluted places, negatively affecting both international and national-level science and policy efforts.[5] Despite Asia bearing the greatest brunt of health burden due to $PM_{2.5}$, there have only been eight large cohort $PM_{2.5}$ and mortality epidemiology studies conducted on the continent outside of China. There have been zero such studies in Latin America and Africa. Meanwhile, Europe, the US, and Canada, regions with the least $PM_{2.5}$ health burden and yet where a key ingredient for such studies—data—is more available, have had sixty such studies.[6]

5 Chi Li et al. (2023); Raheja (2023); Bittner, et al. (2022); Apte et al. (2021); Donkelaar et al. (2021); Hammer et al. (2020); Martin et al. (2019); Pinder et al. (2019)

6 This analysis captures all epidemiological research studies (>1000 people), that are long term (>1 year) with unique cohorts and measure the impact of ambient $PM_{2.5}$, PM_{10}, TSP, Ultra Fine Particulate Matter on Mortality (cause-specific, all cause, premature)/Life Expectancy published between 1993 and early 2023. The underlying dataset can be accessed here: https://docs.google.com/spreadsheets/d/1AljEJhNPLWX_8xRbT_HJuERBpbQt_QGixgJ9jEzFyQw/edit#gid=1301709334 and analysis at: https://github.com/aqli-epic/epi.meta.analysis

Lastly, country-wide $PM_{2.5}$ data gaps keep a region off the "data flywheel," whereby once a location gets a base-level amount of data, that location is "on the map" and attracts follow-on resources and additional activities. (For instance, refer to the example from Ghana mentioned later on in this section.)

Against this backdrop, outdoor air pollution is a severely underfunded issue, receiving less than 64 million USD worldwide from philanthropic foundations in 2021.[7] This amount is comparable to what Americans are estimated to lose each year in spare change.[8] Meanwhile, Europe, the United States, and Canada received 34 million USD in philanthropic foundation funding devoted to addressing air pollution in 2021, while the entire continent of Africa received less than 300,000 USD in philanthropic funds for air pollution reduction that same year[7] (i.e. roughly the current price of a single-family home in the United States[9]).

7 Clean Air Fund. 2022. "The State of Global Air Quality Funding"

8 CBS News. 2016 "Americans throw away $62 million in coins each year."

9 U.S. Census Bureau and U.S. Department of Housing and Urban Development. 2023. "Median Sales Price of Houses Sold for the United States [MSPUS]."

Even a single $PM_{2.5}$ monitor in a country can spur national-level impacts.

In 2008 in Beijing, the U.S. Embassy began automatically tweeting hourly $PM_{2.5}$ levels from a device deployed on the embassy's roof.[10,11] Access to this data led the public to pay closer attention to the air they breathed during especially bad "airpocalyses" in Beijing in 2010 and 2011. Eventually, third-party software developers began to scrape the data. With the information posted on social media and developers converting the dry, technical information to user-friendly apps, for the first time, real-time, understandable air pollution information made its way into the hands of millions of Beijingers. Small technical differences between the data produced by the U.S. Embassy and the official Chinese sources spurred a more detailed interest from the public in what exactly $PM_{2.5}$ was and how it was being measured.

The public outcry to reduce air pollution became so loud that the Chinese government laid out a National Air Quality Action Plan in 2013 and soon after declared a "War on Pollution" in 2014, devoting hundreds of billions of dollars towards its air quality management infrastructure, policies, and enforcement.[2] While that first U.S. monitor did not play the only role in driving China to action, it was a major catalyzer.[10,11,12,13]

From 2013 to 2021, China has significantly reduced its annual average $PM_{2.5}$ by 42 percent.[2] This is the largest decline in $PM_{2.5}$ levels over a comparable time period any country has experienced since measurements have been available. In just four years after the programme's launch and a 29 percent reduction in $PM_{2.5}$ annual average levels, Eastern and Central China alone benefited by an estimated 73 billion USD in avoided deaths.[14] The rough cost of a well-deployed single monitoring system similar to the one that played such an outsized, accelerating role in China's progress today: 100,000 USD.

The impact of a single, well-sustained $PM_{2.5}$ data point in China's clean air trajectory is remarkable in its magnitude—but it is not a unique outcome. In fact, as the US Embassy $PM_{2.5}$ monitoring program in Beijing was replicated at other US embassies across the world by the US Department of State, a startling impact was observed: In non-OECD countries where $PM_{2.5}$ monitors were deployed and where data access was previously limited, annual $PM_{2.5}$ levels at the deployment locations were observed to be lower by more than 10 µg/m³ over a six year period relative to what they would have been had the monitors not been put in place (Figure 1.2).[13] This decline, if sustained, could translate into a year of added life expectancy for those who breathe that cleaner air.[2] Examples from elsewhere and in different cultural, governmental and resource regimes abound. In Pakistan, a single $PM_{2.5}$ monitoring effort led by a citizen scientist using lower cost sensors helped move the Pakistan government to declare air pollution a national emergency in 2017.[15] Following that action, the government formed a Smog Commission to investigate sources and solve air pollution problems in the country. Prior to this action, the government, which did not publicly monitor air pollution, had not adequately responded to citizen demands to address—or even acknowledge—air pollution as an issue.[15] In Ghana, a single low-cost monitor deployed by a professor in Accra in 2015 led to more resources, including 10 regulatory grade monitors deployed across the country.[16] It is remarkable that such low initial investments of a single monitor have resulted in national-level impacts in resource availability and policy.

These three examples from China, Pakistan, and Ghana illustrate that both government-grade or lower cost sensing monitoring in areas with a lack of $PM_{2.5}$ data can spur national-level action and encourage the investment of follow-on resources. In the cases of both Pakistan and Ghana, individual $PM_{2.5}$ monitoring efforts with outsized impact were led by local actors who were—and are—embedded in their communities' political and social contexts. It is worth noting that the $PM_{2.5}$ monitoring example in China led by the US Embassy, not a local actor, has had a difficult time replicating the same impact for other pollutants in China.

10 "Opinion: How the US Embassy Tweeted to Clear Beijing's Air", Wired Magazine, 2015

11 "Rooftop sensors on US embassies are warning the world about 'crazy bad' air pollution", Science Magazine, 2018

12 "Years of Breathing Dangerously: A Beijing Air Pollution Timeline", the beijinger, 2015

13 Jha and La Nauze (2022)

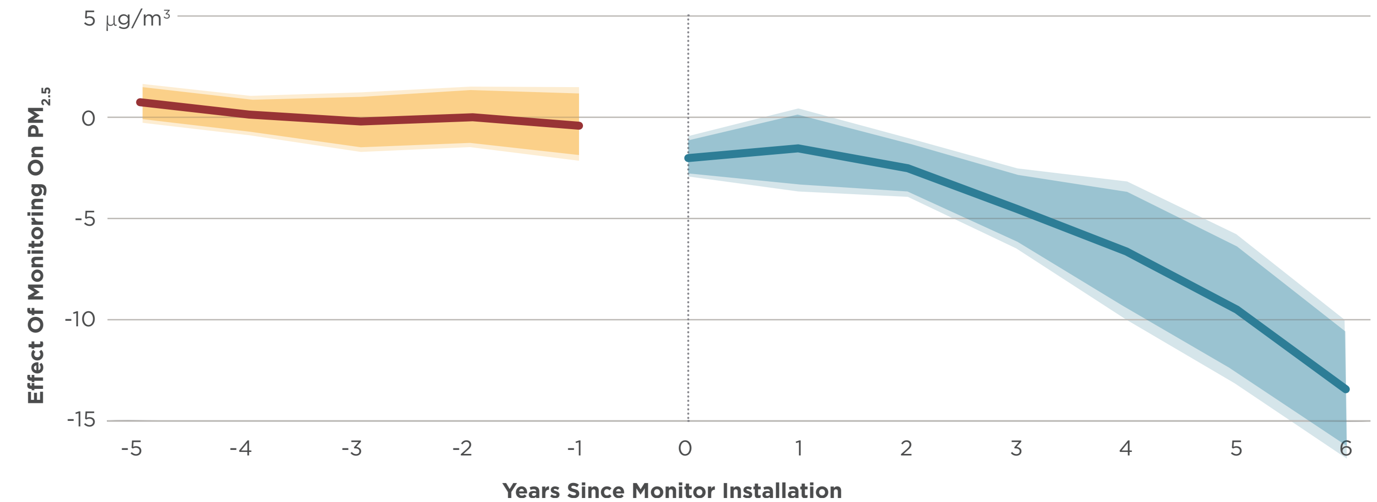
14 Zhang et al. (2021)

15 Discover, How One Person in Pakistan Made a Difference for Air Quality, 2020

16 Scientific American, People Who Are Changing the Environment One Community at a Time, 2023

FIGURE 1.2

The Effect a Single $PM_{2.5}$ Monitor, Established by the US Department of State at Embassies in Non-OECD Countries, Has Had on Lowering Outdoor $PM_{2.5}$ Levels Relative to What They Would Have Been if the Monitors Were Not Present, As Estimated from Satellite-Derived $PM_{2.5}$ Data



Source: Figure modified from Jha and La Nauze (2022).[13] Dark and light gray shaded areas correspond to 90% and 95% confidence intervals.

When launching a similar monitoring project for ozone in 2021, the US Embassy in China received fierce backlash from the local community.[17] While the US State Department has successfully deployed $PM_{2.5}$ monitoring efforts across the world, making their data fully open—and with documented outsized national-scale impacts,[10,13] local actors seeking to collaborate with them for activities such as co-location of their sensors for calibration are not easily able to do so, most often due to security protocol barriers.[18] As detailed in Sections 2, 3, and 4 of this report, for these reasons and several others, it is our belief that supporting local actors to design and implement air quality monitoring projects will maximize the potential to catalyze national-level clean air action with $PM_{2.5}$ monitoring.

Data begets data, and where there are $PM_{2.5}$ data gaps, there are golden opportunities to kick-start data flywheels.

Currently, twenty-five countries[19]—seventeen in Africa—do not have a single government $PM_{2.5}$ monitor,[3] have not enacted national ambient air quality standards for $PM_{2.5}$, and receive trackable international donor support below 100,000 USD annually[20] (the minimum needed to sustainably operate a government-standard $PM_{2.5}$ monitor annually). In fact, the combined international donor funding for these twenty-three countries is less than 100,000 USD annually. Yet, the 172 million citizens of these countries experience annual $PM_{2.5}$ levels that are 3.5 times the WHO Organization guideline, as determined by satellite-derived estimates.

The rest of this report describes these golden opportunities to close country-sized $PM_{2.5}$ data gaps to accelerate clean air action, the local actors who can lead this process, and guidance on best funding practices to maximize impact.

17 "Why US Embassy's air quality monitoring meets backlash in China this time" Global Time, 2021

18 Personal communication with authors from conservations with both local actors interviewed for this report and others in the air quality community.

19 Angola, Belarus, Bhutan, Bolivia, Botswana, Burundi, Central African Republic, Djibouti, Equatorial Guinea, Eritrea, Gambia, Haiti, Honduras, Lesotho, Liberia, Mauritius, Morocco, Namibia, Nicaragua, Papua New Guinea, Sierra Leone, Swaziland, Timor-Leste, Zambia, Zimbabwe

20 Calculated from trackable country-level international donor data from the State of Global Air Quality Funding 2023 report by the Clean Air Fund. See State of Global Air Quality Funding 2023 Methodology for more information.

SECTION 2

Opportunity Score

Estimating Country-Level $PM_{2.5}$ Data Gap-Closing Opportunities

To identify locations with the highest possibilities for supporting a single or small, sustained (multi-year) $PM_{2.5}$ monitoring effort that could help catalyze national-level impact, we have developed a metric called the Opportunity Score.

The Opportunity Score weighs three overall factors:

1. The **importance** of $PM_{2.5}$ pollution as an issue compared to other countries (e.g. severity of annual average $PM_{2.5}$ levels as determined by satellite-derived estimates, size of population) and within the country itself (e.g. how high the issue ranks as a risk factor for mortality compared to other national issues).
2. The **neglectedness** of $PM_{2.5}$ pollution relative to other countries in terms of resources invested by its government (e.g. lack of existence of government air quality monitoring or policy structures) or international donor funding.
3. The **tractability** of contributing to tangible solutions in the country relative to others (e.g. opportunity to invest in basic data infrastructure due to a lack of current government investment and the existence of local groups with expertise and interest in monitoring $PM_{2.5}$).

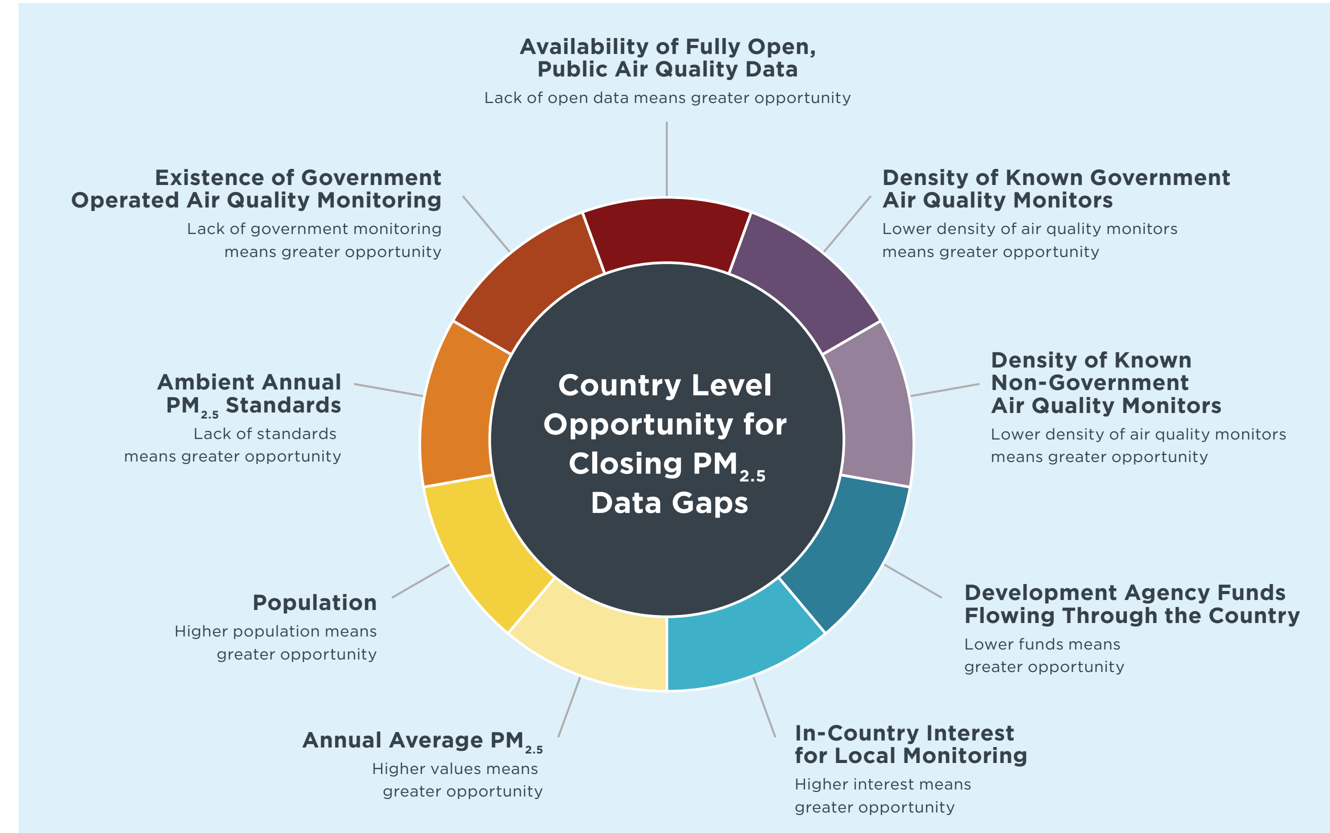
Figure 2.1 depicts the broad breakdown of each of these factors in our country-level calculation of the Opportunity Score.

Using this framework, countries have a higher Opportunity Score when they have a combination of:

- high $PM_{2.5}$ levels,
- large populations,
- little air quality management or policy infrastructure,
- low amounts of resources flowing into the country targeted at air pollution, and
- high interest from local groups well-poised to conduct long-term air quality monitoring

FIGURE 2.1

Factors Determining Opportunity Scores Assigned to Countries



The country level annual average $PM_{2.5}$ values we use are from satellite-derived estimates produced by Washington University in St. Louis and are not from ground monitoring, since it is not available in many locations. While the majority of the underlying data for calculating the Opportunity Score is already publicly available, one significant data source was not: information on existing local actors who would be well-poised to measure and openly share $PM_{2.5}$ pollution data for sustained periods. Without this information, the tractability of closing $PM_{2.5}$ data gaps is unknown. To understand the local actor landscape better and incorporate it into the Opportunity Score, we created a public registry of $PM_{2.5}$ data gap closing entities and individuals[21] and have sought to populate that registry with every relevant local effort we could find and that was willing to be part of the registry. Section 3 provides a deeper analysis of the local actor landscape.

To emphasize: The Opportunity Score calculates where there is the highest likelihood that a *small* level of support to local actors in a given country could result in national-level impacts. While the calculation prefers places with large populations and high pollution levels, if all else is equal, it also prioritizes places with a lack of air quality infrastructure such as little monitoring, open data, ambient air quality standards, and international development funding. As seen in the next subsection, this methodology leads to prioritizing places that have not traditionally been high on the international air pollution community's priority list for funding, and means, in some cases, places with lower air pollution levels but less air quality infrastructure in the form of government air quality monitoring, ambient air quality standards, and

21 The public registry form is available here: https://docs.google.com/forms/d/e/1FAIpQLSe5vVSEM78q3YOgvAaI6c9GWBoSyJKDoADXOl-wcerwxE_kgg/viewform. The registrants who allowed themselves to be listed publicly here: https://docs.google.com/spreadsheets/d/1qL_WLU_Q6N3AOxomkNqZEhvHyqazNul7WQeiwU9EcwA/edit?usp=sharing.

international donor funds, are prioritized over those with higher air pollution levels and more air quality infrastructure.

Appendix A describes the methodology, data sources, and the 12 sub-metrics within the Opportunity Score in more detail.

OPPORTUNITY SCORE RESULTS

We have calculated an Opportunity Score for 147 countries, with scores ranging from the least opportunity— 2.0 for Switzerland— to highest opportunity—13.2 for the Democratic Republic of the Congo. Based on the distribution of Opportunity Scores, we have separated countries into four bands: High, Medium-High, Medium, and Low. Figure 2.2 highlights countries with High and Medium-High Opportunity Scores.[22]

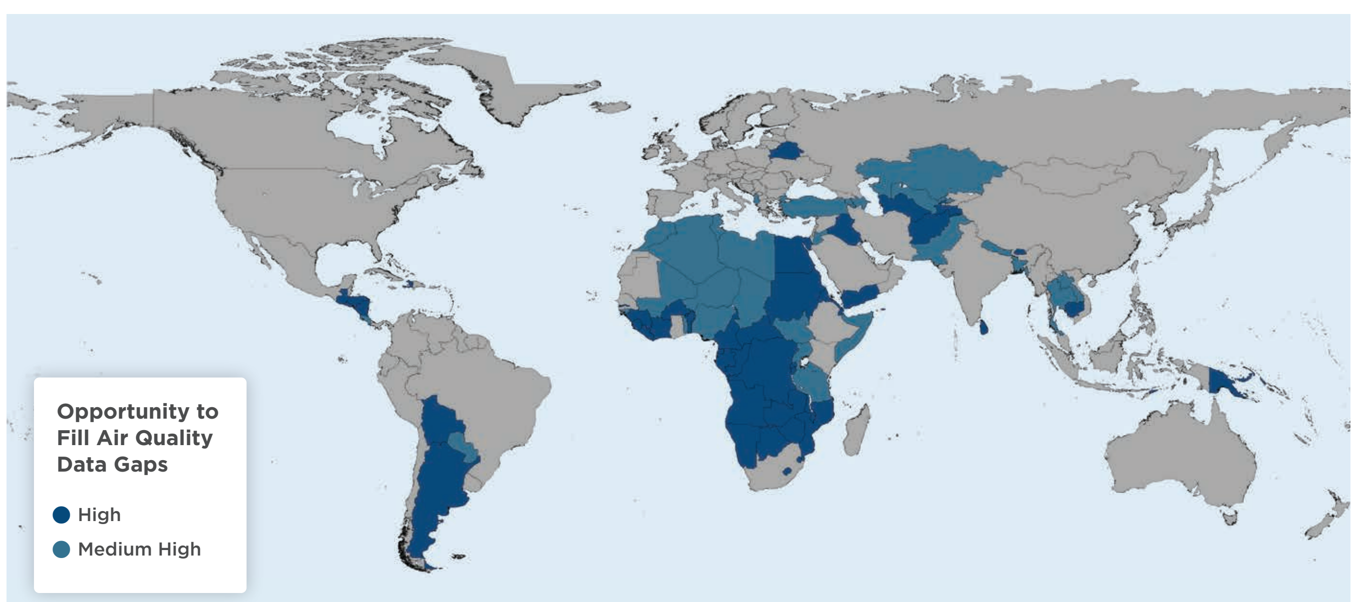
Table 2.1 shows the regions where each of the 46 High Opportunity Score countries are located and their characteristics aggregated by region. Sixty-one percent of High Opportunity Score countries are located in Africa, 22 percent in Asia, 15 percent in Latin America, and 2 percent in Europe. The 838 million people in these High Opportunity Score countries experience average annual $PM_{2.5}$ levels of 20 $\mu g/m^3$, four times the WHO guideline. None of these countries have existing fully open air quality data produced by their governments, and only a small minority—11 percent— have national ambient air quality standards. Thirty-four countries— 74 percent—with High Opportunity Scores receive less than 100,000 USD from international donors to address outdoor air pollution, less than the annual amount needed to sustainably run a single government-grade $PM_{2.5}$ monitor. In fact, the combined total in trackable international donor organization funds received annually by these 34 countries for outdoor air pollution is less than 73,000 USD.[20]

The highest scoring country is the Democratic Republic of the Congo with a score of 13.2, a population of 105 million and an annual average $PM_{2.5}$ level of 35 $\mu g/m^3$, seven times the WHO guideline. Cameroon comes close behind with an Opportunity Score of 13.0, a population of 29 million and annual average $PM_{2.5}$ levels of 31 $\mu g/m^3$, more than six

22 See Table B1 in the Appendix for a list of all countries in High and Medium-High Opportunity Score bands and relevant metrics.

FIGURE 2.2

Countries in the 'High' and 'Medium High' Opportunity Band, Representing Locations Where There Are the Greatest Opportunities to Fill $PM_{2.5}$ Data Gaps



Source: EPIC Analysis

TABLE 2.1

Regional Locations and Characteristics of High Opportunity Score Countries

Region	Africa	Asia	Europe	Latin America
Number of 'High Opportunity Score' countries	28	10	1	7
Number of 'High Opportunity Score' countries without national ambient air quality standards*	27	8	1	5
Number of 'High Opportunity Score' countries without fully open government data[1]	28	10	1	7
Number of 'High Opportunity Score' countries receiving less than 100,000 USD annually in international donor funding for outdoor air pollution[20]	19	7	1	7
Total Population in 'High Opportunity Score' countries (in millions)	548.6	171.5	9.4	108.1
2021 Annual Average $PM_{2.5}$ level across 'High Opportunity Score' countries (in $\mu g/m^3$)[3]	21	19	13	18

Source: EPIC Analysis

times the WHO guideline. Neither country has national ambient air quality standards, nor $PM_{2.5}$ data produced by its government; however, this report identifies local actors active in both countries who could potentially sustainably operate, share, and activate their communities with $PM_{2.5}$ monitoring (see Section 3).

In contrast, countries with well-publicized $PM_{2.5}$ pollution challenges like China and India score much lower (6.6 and 7.6, respectively) and do not make it into High or Medium-High Opportunity Score categories. This makes sense, though it should be noted that while India and China—or other countries—may not rank high in this Opportunity Score, it does not mean that air pollution isn't a significant challenge that needs to be addressed in those locations. The Opportunity Score attempts to describe the marginal value of investing to close basic $PM_{2.5}$ air quality data gaps to catalyze national-level clean air action. Given the stage of sophistication—and even existence—of Indian and Chinese air quality management and each country's resource landscape, a single, relatively small air quality monitoring effort would not be expected to have a national-level impact in either location. Just in terms of air quality monitoring infrastructure alone, there are 492 government air quality monitoring stations online in India[23] and 1865 in China[24], compared to a total 30 government air quality monitors in the 46 High Opportunity Score countries representing 838 million people. The total number of government air quality monitors in these 46 High Opportunity Score countries is fewer than the number of government air quality monitors deployed and openly sharing data in Finland for its 5.5 million people breathing air that already meets the WHO guideline for $PM_{2.5}$.

See Appendix Table B1 for the full list of 75 High and Medium-High countries.

23 Station number retrieved 6 Nov 2023 as the combined "Live" and "Delayed" monitor count at the Central Pollution Control Board, (https://airquality.cpcb.gov.in/ccr/#/caaqm-dashboard-all/caaqm-landing) reporting continuous station status. Note: This monitoring number differs from what was used as input to the Opportunity Score in Section 4, which relied on the number of monitors that are currently accessible via OpenAQ (419).

24 China's government station number derives from the number of stations that are available at OpenAQ.org. The exact number may be higher.

Image credit: Rose Alani

SECTION 3

The Global Landscape of Local Actors in $PM_{2.5}$ Data Gap Regions

Local actors who can close $PM_{2.5}$ data gaps can come from many walks of life and can include members of community organizations, government agencies, non-profit groups, medical fields, media entities, the private sector, and research and academic institutions.

Local actors play **the key role** in driving long-term clean air action given the complex social and political dynamics at national- or subnational-levels that must be navigated and the often local nature of both sources and impacts of air pollution. For these reasons, the local actor landscape is a key component of how we have calculated the opportunity for national level impact via closing $PM_{2.5}$ data gaps in a given country in Section 2. Additionally, understanding the local actor landscape is necessary to develop best practices for providing resources, like finding a meaningful level of funding to local actors, identifying current barriers, and understanding opportunities local actors identify for their work.

We could not find an existing resource that describes the current landscape of local actors well-poised to close $PM_{2.5}$ data gaps across the world; therefore, we created an open, public registry,[25] inviting local actors in self-identified $PM_{2.5}$ data gap locations to register, as well as reaching out to known local actors doing such work already in our networks.

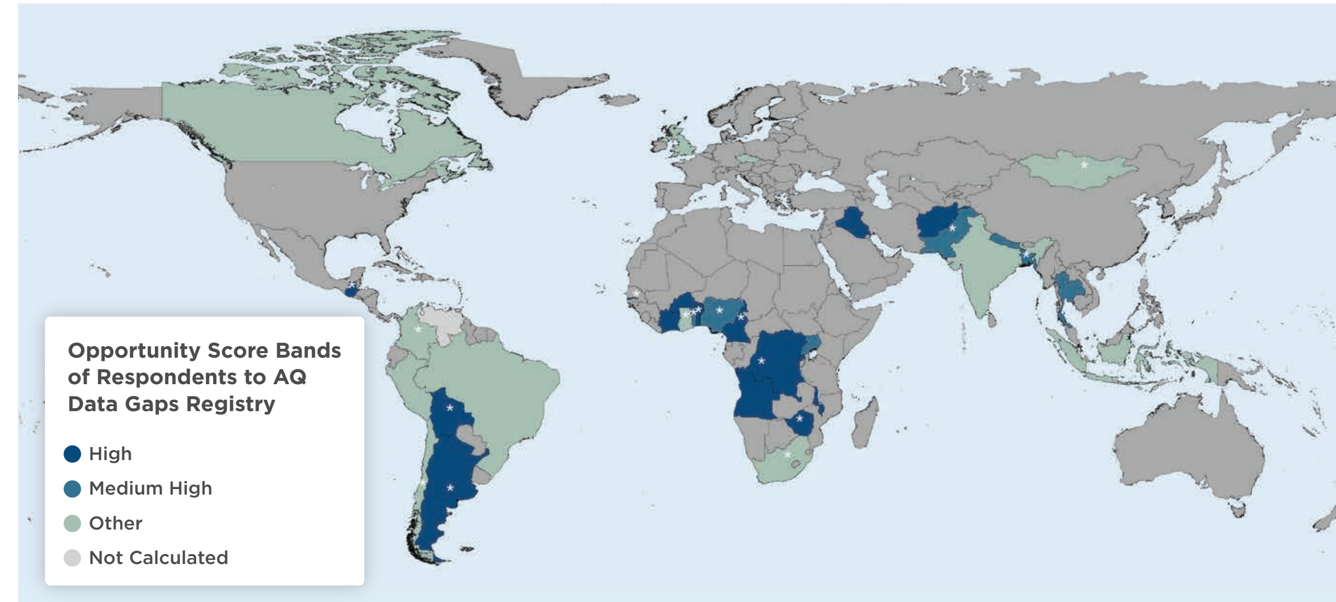
3.1 Aggregate Findings About the Global Landscape of Local Actors

The registry has received 78 responses from 36 countries to date. Registrants have come from a variety of fields, including the research community, technology sector, health care community, and non-profit space. Thirty-seven registrants came from those working in countries with High or Medium-High Opportunity Scores. Most respondents were already monitoring or had recently monitored $PM_{2.5}$ levels in their community but often had limited ability to share the data openly or to monitor in a long-term manner.

25 EPIC's Form for the Public Registry of $PM_{2.5}$ Data Gap Closing Entities/Individuals is accessible at https://docs.google.com/forms/d/e/1FAIpQLSe5vVSEM78q3YOgvAaI6c9GWBoSyJKDoADXOl-wcerwxE_kgg/viewform and will remain open indefinitely to continue to capture and highlight self-identified local actors working to close $PM_{2.5}$ data gaps across the world.

FIGURE 3.1

Locations of Local Actor Respondents to the Public Registry of $PM_{2.5}$ Data Gap Closing Entities/Individuals; White Asterisks Indicate Country Locations of Local Actors with Whom We Had Extensive Interviews



Source: EPIC Analysis

The full list of registrants who agreed to make their information public, including their names, geographic location of their work, affiliation, and contact information is available at: https://docs.google.com/spreadsheets/d/1qL_WLU_Q6N3AOxomkNqZEhvHyqazNul7WQeiwU9EcwA/edit?usp=sharing.

To gain a more in-depth understanding of their current work, the challenges they currently experience or foresee experiencing, and the opportunities they see in data-gap closing activities, we interviewed 26 local actors who responded to the registry.[26] Sixteen of these interviewed local actors came from countries with High or Medium-High Opportunity scores.

26 The questions for the in depth analysis can be found: https://forms.office.com/r/3FuK6Syx9Z

The rest of this section details our findings from these 26 in-depth interviews, describing challenges, resource needs, and suite of activities of local actors.

Local actors face major resource constraints, obstacles connecting with local and global communities, and infrastructure challenges.

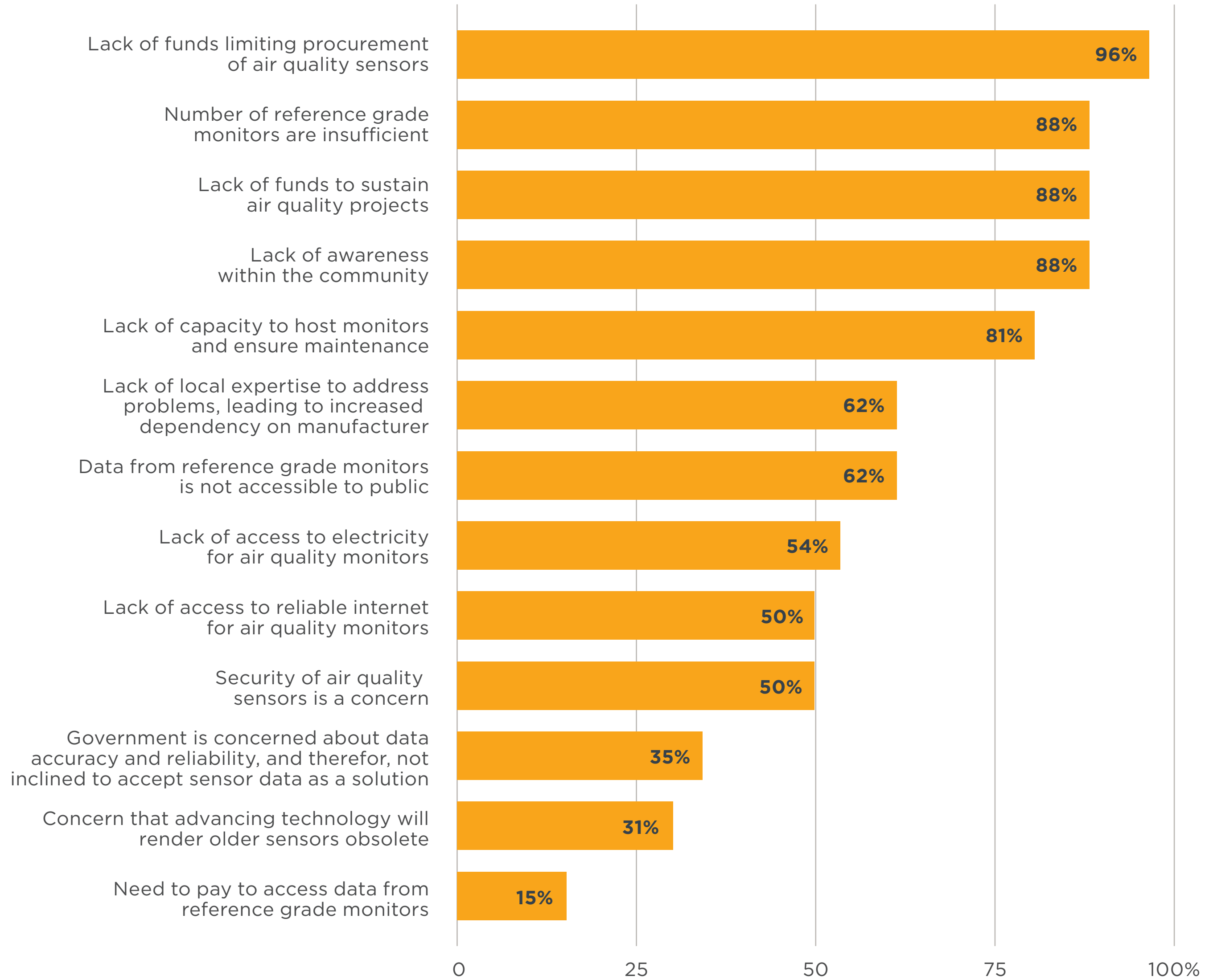
From information supplied in the initial registry to the in-depth conversations, local actors expressed five main challenges for sustainably monitoring air pollution. Figure 3.2 shares the detailed categories of the challenges.

Five main challenges faced by local actors in monitoring air pollution:

Data Resources: There is an insufficient number of high quality (or "reference grade") monitors, typically deployed by governments, that are often needed for justification, calibration and/or comparison for wider monitoring

FIGURE 3.2

Detailed Challenges Local Actors Shared They Faced Working on Air Pollution Monitoring During in Depth Interview



Source: EPIC Analysis

networks. Where monitors do exist, the data are not always shared openly or require payment for access, as several local actors noted. Where data is shared openly, co-location is not always allowed.

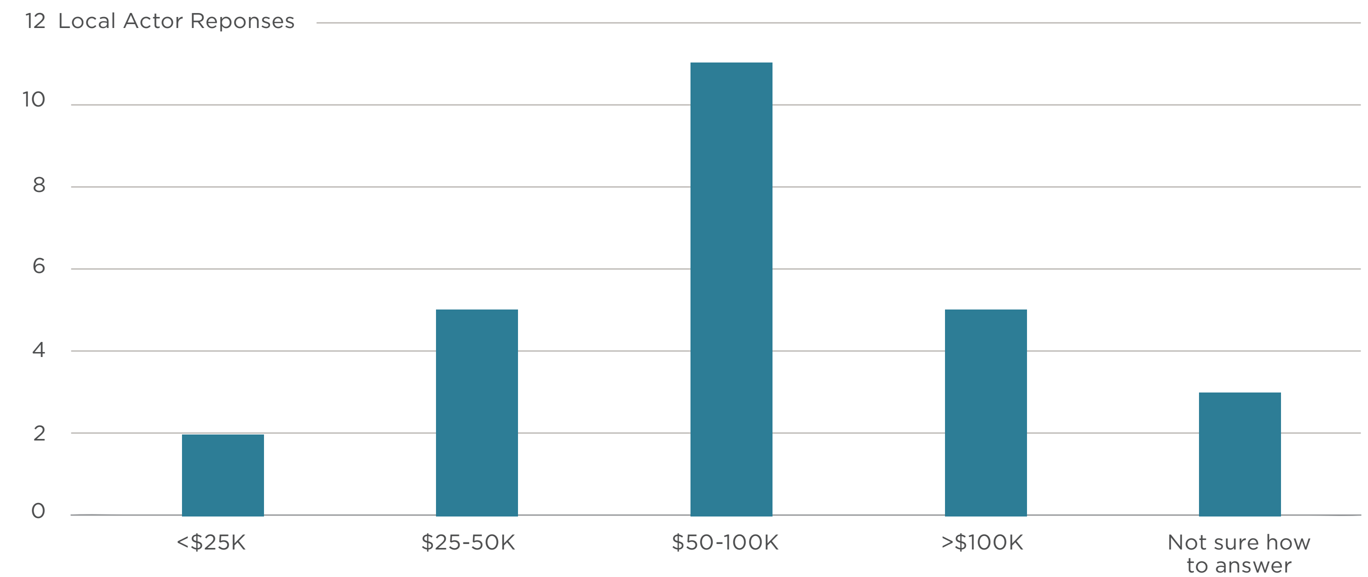
"Air quality data is not free even though the law says it should be free. It's extremely expensive, and we have to manually request it."

Financial Resources: There is a lack of adequate and multiple year funding from local, national, or global sources for local actor air quality monitoring. The funding that does exist often must flow through foreign collaborators with strict stipulations on how that funding can be spent—often only on instrumentation, not ongoing instrument consumables, staffing, or professional development. This translates to local actors being unable to build air quality monitoring programs specifically designed to move policy in their country, and they cannot adequately access funds to sustainably operate air quality monitoring or engage their communities on the issue.

"Funders get disinterested after a year or two."

FIGURE 3.3

Responses Received by Local Actors to the Question, "How Much Annual Funding Would You Need in Order to "Charge Up" Your Work in Monitoring $PM_{2.5}$?"



Source: EPIC Analysis

Local Technical Resources: There is an absence of local or sometimes regional technical expertise to compare experiences, troubleshoot and provide mentorship. This hampers sustainable air quality monitoring. Several local actors noted that a lack of technical resources also creates a dependency on foreign collaborators and consulting companies, which ultimately reduces local actors' ability to shape an air quality project toward local policy impact—and reduces the total amount of funding that goes directly to the local actor.

"[Our current blocks] include a lack of local technical expertise to fix any issues in the monitors. Imported monitors usually require consultation with the parent company."

Community Awareness: It is difficult for local actors to engage either their local or the international air quality community about their work. There is an identified need to have support for better vehicles of communication on air pollution issues locally. There is also a desire to have a better way to "on ramp" their work to the global air quality community, who some believed they could leverage for better political and social impact in their own country.

"I want to develop a training program for media professionals, to enable them to amplify our efforts and connect with a broader community."

Infrastructure: Local actors cite issues with long-term hosting and upkeep of air quality networks due to a lack of the necessary infrastructure, such as uninterrupted power supply, stable internet connection, and a secure location to house their equipment.

"The security of solar-compatible devices is a major concern due to the heightened risk of solar panel theft."

What is a meaningful level of annual funding for local actors?

Determining a meaningful level of annual funding needed to support local actors in $PM_{2.5}$ monitoring is a key metric to understanding how to support global air pollution issues. During our extensive conversations, local actors were asked how much they would need in order to "charge up" their work in monitoring $PM_{2.5}$, so that they could do it sustainably. The most frequent response—received by 42 percent of respondents—was an amount between 50,000 and 100,000 USD annually.

SPOTLIGHT

Local Actors

This section highlights eight local actors working across Africa, Latin America and Asia. The full registry of self-identified local actors are available at epic.uchicago.edu/trends/air-quality-monitoring/.

AFRICA

Robert Mbiake in Cameroon

Robert Mbiake at the University of Douala has begun setting up an extensive $PM_{2.5}$ network, the first of its kind in Cameroon, across the country's two largest cities, Douala and Yaoundé. Prof. Mbiake seeks to develop a program that uses the data from the network to convey air pollution information to journalists, students, and municipalities.

"Without the ability to monitor air quality in real-time, the task of managing and mitigating air pollution levels becomes significantly challenging, if not impossible. A real-time air quality network serves as a critical tool in our efforts to address and combat air pollution. And while we have made a start, we have a long way to go."—Robert Mbiake

Country Profile: Opportunity Score 13.0 (High)**:** Annual average $PM_{2.5}$ levels are more than 6 times the WHO Guideline. There is no public $PM_{2.5}$ data produced by the government, nor is there a national ambient air quality standard for $PM_{2.5}$.

Permian Health Lung Institute in The Gambia

Gambian natives and medical professional Awa Sabally-Touray and Sunkaru Touray, a pulmonologist, recently founded the Gambia-based Permian Health Clean Air Initiative. The institute has rapidly set up a network of low-cost $PM_{2.5}$ sensors and hosted a national air quality conference, both the first of their kind in The Gambia. The Institute plans to establish a government-grade monitor in collaboration with the Government of The Gambia, as well as conduct several communications and capacity building activities.

"While I was visiting The Gambia, I observed that many women had chest x-rays that looked similar to those of coal miners in the US, even though most Gambian women do not smoke or work in coal mines. Recognizing the connection between air quality and lung health, I decided to look for information on air quality in Gambia. However, I found that there was none available. This experience inspired me to establish an air quality network in The Gambia."—Sunkaru Touray, Pulmonologist and Critical Care Physician

Country Profile: Opportunity Score 10.4 (High)**:** Annual average $PM_{2.5}$ levels are more than 1.4 times the WHO guideline. There is no public $PM_{2.5}$ data produced by the government, nor is there a national ambient air quality standard for $PM_{2.5}$.

Rose Alani in Nigeria

Rose Alani, an Environmental Chemist established the Air Quality Monitoring Research Group at the University of Lagos. The research group is a partner in a multi-African institution air quality monitoring, modeling, and advocacy project that will deploy a total of 65 sensors across Lagos, Accra, Yaoundé and in Burundi, with one government-grade reference monitor in Lagos. Part of the motivation of this work is to stimulate the transition from the use of fossil fuel-powered generators to renewable sources of energy such as solar.

"In Nigeria, the use of generators is prevalent in both housing units and industries. Transitioning away from these fossil fuel-powered machines has the potential to bring about significant change. By reducing their use, emissions can be cut, and air pollution alleviated by up to 50%, resulting in a notable improvement in the region's environmental quality. A continuous air quality monitoring network would serve as a valuable tool to verify the implementation of such policies and to determine their effectiveness."—Dr. Rose Alani

Country Profile: Opportunity Score 9.0 (Medium-High)**:** Annual average $PM_{2.5}$ levels are more than 4.5 times the WHO guideline. There is no public $PM_{2.5}$ data produced by the government, nor is there a national ambient air quality standard for $PM_{2.5}$.

LATIN AMERICA

Rodrigo Gibilisco in Argentina

Rodrigo Gibilisco, founder of Breathe2Change, is leading a project for school children that has deployed twenty-five $PM_{2.5}$ sensors at astronomical observatories across northern Argentina. The next steps of the project include installing a reference-grade monitor in a government facility, and capacity and dialogue-building activities, such as facilitating stakeholder meetings and hosting workshops.

"I grew up surrounded by sugarcane fields in Tucuman province. It was normal for me to witness crop burning and the black rain that followed, until I began traveling. When I experienced the world outside my province, I realized, 'This isn't normal.' I was deeply concerned about how this was impacting the health of people in my province, as well as the environment. Further not having access to air quality data meant that people cannot make informed decisions. This realization became the driving force behind Breathe2Change."—Rodrigo Gibilisco

Country Profile: Opportunity Score 10.2 (High)**:** Annual average $PM_{2.5}$ levels are more than 2 times the WHO Guideline. There is no public $PM_{2.5}$ data produced by the government, but there is a national ambient air quality standard for $PM_{2.5}$.

Christian Saravia in Guatemala

Christian Saravia founded Ambente in 2019 to close air quality data gaps in Guatemala. Today, Ambente's work has resulted into a network of 10 real-time low-cost sensors across Guatemala City. To address the lack of air quality policies and guidelines by the Government of Guatemala, Christian would like to develop a real-time air quality information platform and convene stakeholders and conduct air quality capacity building workshops.

"During my Postgraduate Studies of Environmental Management in Germany in 2016, my primary focus was on air quality management. However, when I tried to access data related to air quality, I quickly realized how scarce it was with an insufficient number of reference-grade monitors and the lack of publicly available data. This realization led me to create Ambente and establish an air quality network."—Christian Saravia

Country Profile: Opportunity Score 9.8 (High)**:** Annual average $PM_{2.5}$ levels are more than 5.5 times the WHO guideline.There is no public $PM_{2.5}$ data produced by the government, nor is there a national ambient air quality standard for $PM_{2.5}$.

Fernando Velarde Apaza in Bolivia

Fernando Velarde Apaza is a researcher at the Laboratory for Atmospheric Physics at Mayor de San Andrés University and is in charge of the CHC-GAW station. He has helped strategically deploy a series of low-cost air quality sensors, including two measuring $PM_{2.5}$, across La Paz. The goal of the project is to provide scientists, policymakers, and the public with more comprehensive information of air quality and how they are transported across the region. The next stage of the project involves deploying a reference-grade monitor to help calibrate monitors for new locations and to build the team's technical capacity.

"A combination of satellite data, low-cost sensor data, reference-grade data, and advanced modeling techniques must be used to better understand what is polluting our air. Further, we need communication of this information, we need action plans and active participation from everyone. This integrated approach is crucial for addressing the complex issue of air pollution and working towards cleaner air."—Fernando Velarde Apaza

Country Profile: Opportunity Score 11.8 (High)**:** Annual average $PM_{2.5}$ levels are more than 5 times the WHO Guideline. There is no public $PM_{2.5}$ data produced by the government, nor is there a national ambient air quality standard for $PM_{2.5}$.

ASIA

Peshawar Clean Air Alliance (PCAA) in Pakistan

PCAA is a civil society alliance that began with a small group of concerned individuals and one crowd-sourced air quality monitor in 2020. PCAA has over 150 members, and through several partnerships has deployed a network of twenty-three $PM_{2.5}$ monitors across all major cities in the province of Khyber Pakhtunkhwa. Its next steps are policy-focused and include using data it produces to help guide governmental budget priorities, regulations and policies from green transport to improved waste management.

"Most of us are either residents of Peshawar or are frequent visitors. We observed significant systemic gaps in air quality monitoring, related policies and even communication. More importantly, no one was actively addressing a critical issue that impacts both human health and the environment. It was this realization that motivated us to work on improving Peshawar's air quality by generating solid evidence to advocate for effective policies."—Taimur Khan

Country Profile: Opportunity Score 8.2 (Medium-High)**:** Annual average $PM_{2.5}$ levels are more than 8.5 times the WHO guideline. There is no public $PM_{2.5}$ data produced by the government, but there is a national ambient air quality standard for $PM_{2.5}$.

Naimul Kazi in Bangladesh

Naimul Kazi is a researcher at the University of Dhaka who has previously deployed indoor and outdoor $PM_{2.5}$ sensing networks at Rohingya refugee camps. He now aims to establish a continuous air quality monitoring network in schools and hospitals across Dhaka city. The data from this network can be used for the development and implementation of currently lacking air quality policies and guidelines.

"Establishing and maintaining a real-time air quality network is vital in the management of air pollution but it's also cost-intensive. A consistent flow of financial support for air quality monitoring is therefore essential to provide the necessary scientific evidence needed to develop effective policies."—Naimul Kazi

Country Profile: Opportunity Score 8.4 (Medium-High)**:** Annual average $PM_{2.5}$ levels are more than 14.5 times the WHO guideline. There is no public $PM_{2.5}$ data produced by the government, but there is a national ambient air quality standard for $PM_{2.5}$.

SPOTLIGHT

Focus on Global Air Quality Data Infrastructure

Closing air quality data gaps to advance clean air often requires local investment and specific policy, political, cultural, and scientific knowledge in a community. By its very nature, solutions from one locality to the next are not identical, making them difficult to scale. However, one way in which solutions to addressing local air pollution are scalable is by improving global public air quality data infrastructure. This ‘infrastructure’ refers to publicly-available tools and capacity-improving resources that reduce inefficient duplication of effort or remove other barriers for local actors to take clean air action via data. An added benefit of such infrastructure is that it can also act as a convening force across geographies to build communities of practice through shared, transparent standards, tools, and practices. Some examples of global air quality data infrastructure and opportunities for its expansion:

Image credit: AirQo

Data Generation and Sharing

Many options on the market for lower cost air quality monitoring devices do not operate in a fully transparent manner, may require deep technical expertise to operate correctly, or do not make it easy or even possible for the device owner to share or fully own the data they produce. Informal do-it-yourself efforts relying on open-source kits are commendable but also face inherent issues with scale. This state of the field has created a barrier to entry for local actors and has also posed issues for experts in establishing standards amongst themselves. A company out of Thailand, **AirGradient** (airgradient.com), has adopted a unique approach of making their hardware and software fully open-source. In such a transparent framework, there exists a possibility to more readily establish community norms for deployment protocols and standards, data management, and data-sharing. Meanwhile, **AirQo** (airqo.net), a non-profit in Uganda, addresses the barrier-to-entry gap in a different way, providing affordable air quality deployment and data management-as-a-service customized to the African context, thereby not only meeting local actor needs but also convening regional and continent-level communities.

Data access

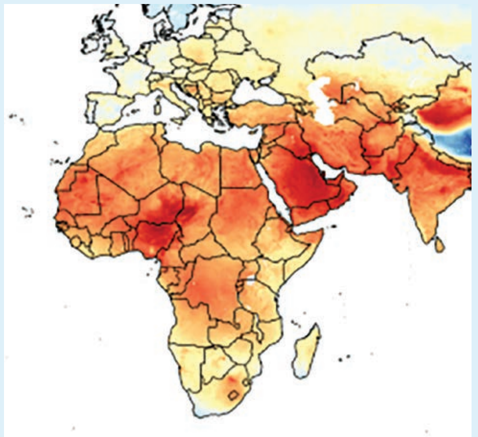


Image credit: ACAG

The open-source open air quality data platform operated by the US-based non-profit **OpenAQ** (openaq.org) enables programmatic access to real-time and historical air quality data from governments and others across the world. This alleviates policy actors, researchers, journalists, and others from having to build and maintain these same data pipelines to access global datasets. Since the data is in the same format, it also allows open-source tooling that can be shared and adapted to local context. Another global data access ‘good’ is satellite-derived air quality information from such efforts as the **Atmospheric Composition Analysis Group** at the Washington University in St. Louis (sites.wustl.edu/acag/datasets/surface-pm2-5/), which produces monthly and annual $PM_{2.5}$ datasets used across the world by policy actors and researchers. There still remain ‘last mile’ gaps in connecting ground-measured or satellite-derived technically fully open global data to non-technical users, especially in their local context.

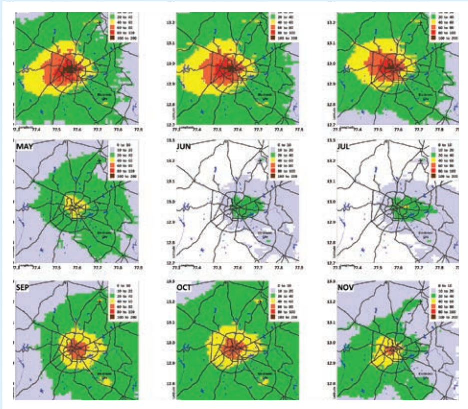


Image credit: Urban Emissions

Data usage

Once data is produced, another global issue across local actors is finding easily accessible ways to use it for modeling emission sources, estimating health impacts, or raising awareness. One rich repository of modeling tools and resources from source apportionment to air quality management and applications in cities across Asia, Africa, and Eastern Europe is **Urban Emissions** (urbanemissions.info), an entity based in India. For estimating health and economic estimates, the **US EPA’s BenMap** (epa.gov/benmap) is an open-source tool that allows a user to regionally-customizable input data. Both resources—and many others like them—require investment to scale to new audiences in new geographies through avenues such as toolkits and workshops.

Image credit: Rodrigo Gibilisco

SECTION 4

Funder's Perspective

Value and Guidance for Supporting the $PM_{2.5}$ Data Gap Landscape

Value of supporting the $PM_{2.5}$ Data Gap Landscape

Efforts addressing one of civilization's largest public health threats, $PM_{2.5}$,[1,2,27] is deeply underfunded.[28,29] Outdoor air pollution as a whole receives less than 1 percent of international donor funding.[29]

Figure 2.2 and Appendix B of this report outline the 75 highest opportunity places where supporting a small or single sustained $PM_{2.5}$ monitoring effort would have the highest prospect of national level impact.[30] Section 3 describes the local actor landscape and reports that annual support on the order of 50,000 to 100,000 USD would be meaningful toward $PM_{2.5}$ gap-closing efforts by local actors.

Putting these data together from a funder's perspective, a back-of-the-envelope calculation shows that an investment of approximately 6 million USD per year could sustainably support a local actor in every one of the 75 High and Medium High Opportunity Score countries in monitoring and producing open $PM_{2.5}$ data. Such an effort would provide locally-generated $PM_{2.5}$ data to the 2 billion people living in these 75 countries, currently cumulatively losing 4.5 billion years to $PM_{2.5}$ pollution.[2] As documented in Section 2, access to sustainably produced data is a necessary basic piece of infrastructure on which a suite of national-level civil society, research, and policy actions can be built. As also highlighted in Section 2, these efforts would feed into international research and policy activities that currently do not adequately include data from "$PM_{2.5}$ data gap" regions–a significant oversight in international pollution efforts.

The avoided health costs due to even one moderately successful $PM_{2.5}$ data-generating effort in a small country could easily justify the cost of a 6 million USD per year program to close global $PM_{2.5}$ data gaps. For example, a World Bank report estimates that Guatemala's 17 million citizens breathe air that causes 1.4 billion USD in annual health damages due to $PM_{2.5}$.[31] If a supported effort ultimately leads to a tiny decrease in $PM_{2.5}$ levels—as small as reducing the damage $PM_{2.5}$ causes by just 0.4 percent—it would provide enough social return on investment to cover the costs of a 6 million USD annual global data gap closing program.

27 World Health Organization, Key Facts, December 2022

28 "Spotlight on Air Pollution in Africa", Mead et al. (2023)

29 "The State of Global Air Quality Funding," Clean Air Fund, 2023

30 See Appendix B, which lists each of the 75 High and Medium-High Opportunity Score countries by score.

Recommended Funder Tenets for Most Effectively Closing $PM_{2.5}$ Data Gaps

Injecting more financial resources into supporting the closure of country-level $PM_{2.5}$ data gaps is necessary but insufficient for achieving the maximal impact. The manner in which air quality data infrastructure is funded dictates how effective the sector's landscape can be. This section lists four tenets for funders to follow to achieve maximum impact with their resources.

TENET 1
Support local ownership and globally-shared infrastructure

Local actors will inherently have a longer-term commitment to $PM_{2.5}$ monitoring projects; a keener understanding of geographical, political, and social contexts for moving national-level policy forward; offer networking for building long-term capacity; and engage more effectively with their community than non-local actors. Supporting programs that directly fund local actors (as opposed to out-of-country institutions with local actors as sub-grantees or volunteers) fosters better design and implementation of $PM_{2.5}$ monitoring programs, efficiently advancing national-level policy actions. South-south partnerships should also be supported and prioritized since countries in the Global South may be more ready to adopt from each other, given similarities in resources, capacities, and other social and geopolitical contexts.

Meanwhile, supporting global infrastructure that makes it easier, more reliable, or faster for local actors to generate, share, and use air quality data can help scale local—and international— efforts everywhere. Examples of such infrastructure can range from open-source hardware or software for monitoring and quality control to open data-sharing platforms where contributors retain their ownership and common tooling can be built for capacity-improving and global networking opportunities (See Spotlight: Focus on Global Air Quality Data Infrastructure for detailed examples).

31 "World Bank. 2020. The Global Health Cost of Ambient $PM_{2.5}$ Air Pollution.

TENET 2
Fund more than monitors

In addition to the physical equipment necessary for local actors to measure $PM_{2.5}$, there are several other critical aspects of a sustained $PM_{2.5}$ monitoring program that must be supported, including:

- Adequate staffing, instrument consumables, and ongoing reliable power and security needs to ensure continued air quality monitoring operations and maintenance;
- Technical infrastructure to ensure the quality of data and to make data fully open and able to be disseminated freely in near real-time; and
- Communication support to make data relevant to the public and engage relevant policy stakeholders.

TENET 3
Fund humbly and with a long-term view

Provide multi-year funding where possible. At minimum, help strategize the sustained operation of monitoring with local actors and transparently convey the likely duration of funding that can be provided.

Significantly reducing $PM_{2.5}$ pollution demands years of collaborative efforts across many types of local entities. For instance, China is the fastest example we know of a country reducing their $PM_{2.5}$ levels, bringing their levels down by 40 percent over seven years. This happened after the country had enough political will to declare a War on Pollution in 2014 and invested 270 billion USD into the effort at a national level.[32] Rather than setting goals for absolute changes in $PM_{2.5}$ levels when supporting $PM_{2.5}$ data gap closing projects, it is more realistic to focus on intermediate goals, such as data utilization in national

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and international policy, an increase in other in-country air pollution projects, donor funding influx, or enhanced media coverage.

TENET 4

Fund flexibly

Offer unrestricted grants and allow varied approaches across countries. Local actors, often operating with smaller budgets with limited administrative capacity, may find strict funder requirements burdensome to the point of negatively impacting their ability to carry out a project.[33] Many data-gap closing projects are the first of their kind—by the very nature of the project—and flexible funding can help more nimbly navigate the "expected unexpected" issues that arise in such projects.

Allow for flexible project activities and monitoring approaches to meet multiple local policy and capacity contexts. For example, a highly respected research group deploying an expensive, government-grade $PM_{2.5}$ monitor may be what is required to push policy to the next level in one country, while a citizen science effort utilizing lower cost sensors could drive progress in another.

33 Recently, a US based non-profit made headlines for turning down funding due to cumbersome funder requirements: https://www.greeleytribune.com/2023/10/24/epa-colorado-air-pollution-monitoring-grants-complications/

Conclusion

This report emphasizes a crucial, overlooked opportunity to reduce the largest environmental threat to global health: closing country-wide $PM_{2.5}$ data gaps with focused financial support to local actors. Our analysis identifies high opportunity countries across the world, predominantly in Africa, Asia, and Latin America, where a single, sustained $PM_{2.5}$ monitoring effort could have a national-level impact. The majority of the highest opportunity countries do not currently receive even 100,000 USD annually in international donor funds for outdoor air quality efforts, roughly the minimum amount needed to run a single government-grade monitor.

Through extended interviews with local actors, we also identified a specific funding sweet spot—ranging from 50,000 to 100,000 USD annually—that would allow local actors to establish, expand, and better connect to their communities $PM_{2.5}$ monitoring efforts.

Putting our analyses of the data gaps and the needs of local actors together, we find that a 4 to 8 million USD annual injection of funding could make substantial progress in closing country-level $PM_{2.5}$ data gaps across the world. We also find that if even one effort in one small country were to catalyze clean air action that modestly lowered their national annual $PM_{2.5}$ levels, the avoided health damages in that one country alone would offset the cost of that annual global injection of funding.

There are few philanthropic opportunities in which 50,000 to 100,000 USD could have a national-level impact on a major public health issue. Given the relatively small scale of resources needed by local actors to close $PM_{2.5}$ data gaps across the world, this analysis reveals that funders from major international donor entities to small family foundations with a variety of geographic priorities can make a powerful impact on this global $PM_{2.5}$ landscape.

APPENDIX A
ABOUT THE OPPORTUNITY SCORE

How should this score be used—and not used?

The Opportunity Score is designed to estimate the countries with the highest likelihood where a single or small, sustained effort to openly produce $PM_{2.5}$ data by a local actor could result in national-level clean air policy impact. Typically, the countries with the highest Opportunity Scores are those with a combination of: (a) annual average $PM_{2.5}$ pollution levels above the World Health Organization Annual Guideline for $PM_{2.5}$, (b) little or no government- or non-government-generated data, (c) little or no donor agency and/or philanthropic foundation funding for outdoor air quality, and (d) little or no evidence for existing national ambient air quality standards.

The Opportunity Score is a tool designed to describe where major $PM_{2.5}$ data infrastructure gaps exist, and where it would be most valuable to fill these gaps. It can be used for strategic decision-making by philanthropies, governments, development agencies, and other actors seeking to tangibly impact global air quality data infrastructure.

The Opportunity Score **is not** designed to dictate attention or funding strategy for **all** types of outdoor air quality activities. For example, India or China have lower "Opportunity Scores" because adding another monitoring effort to the countries' numerous other monitoring networks and other activities is not likely to have a national level impact. Clearly, there remains a lot of other impactful clean air work left to be done in both countries, as well as several other lower Opportunity Score countries in this analysis.

Methodology

The Opportunity Score incorporates multiple factors to determine the largest $PM_{2.5}$ data-gap closing country-level opportunities, in terms of potential for a single well-supported $PM_{2.5}$ monitoring effort to have a national-level impact.

The current iteration of the Opportunity Score uses 12 country-level indicators. Table A1 lists each metric in more detail.

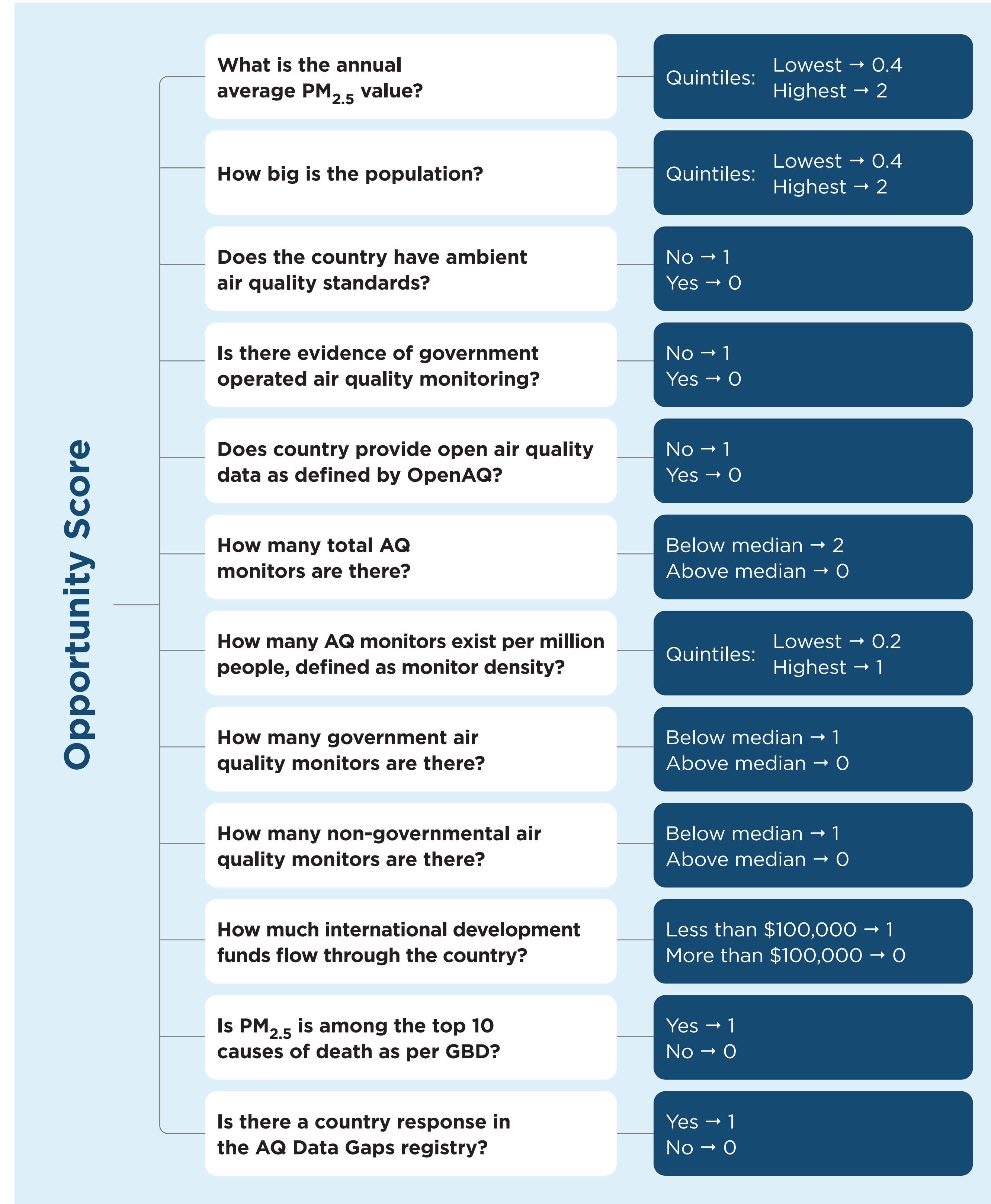
For this analysis, we have removed countries with annual average $PM_{2.5}$ levels at or below the WHO Guideline of 5 µg/m³. We have also removed countries with very small populations (< 800,000). As noted in Table A1, we have doubled the weight of three key indicators: population, $PM_{2.5}$ annual average concentration, and total number of monitors. High income countries, as classified by the World Bank, receive a value of zero for the international development funding indicator. We have also removed six high income countries, as identified by the World Bank from the High and Medium-High bands. Finally, we have also removed conflict zones and countries sanctioned by the United States from the dataset, as these locations may present logistical difficulties for funders to engage.

In the future, we would like to expand the types of input indicators, perhaps including other factors such as energy or electricity consumption at the country level or philanthropic foundation funds flowing through the country, pending global data availability.

The Opportunity Score is the sum total of the twelve indicators that can range between 1 and 15. In the current iteration, the Opportunity Scores of countries range from 2 to 13 and are divided into four bands indicating the priority level as follows-

- High: Opportunity Score >= 9.8
- Medium-high: 9.8 > Opportunity Score >= 8.2
- Medium: 8.2 > Opportunity Score >= 5
- Low: Opportunity Score < 5

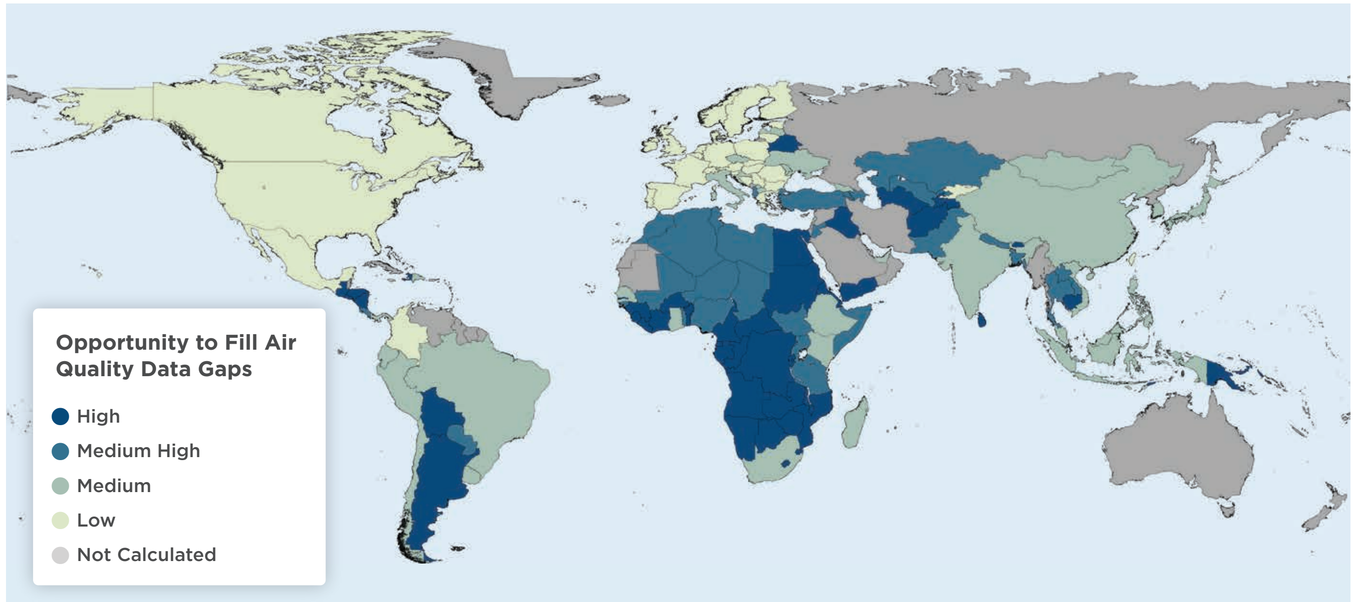
FIGURE A.1
Diagram of Opportunity Score Methodology and Indicators



Source: EPIC Analysis

FIGURE A.2

Opportunity Scores Across the World



Source: EPIC Analysis

TABLE A.1

Description of Country-Level Indicators Used for the Opportunity Score

Indicator	Description	Weighting	Data Source
1. Satellite-derived Annual Average $PM_{2.5}$	Higher value indicates bigger opportunity	Quintile distribution ranging from 0.4 to 2, with 0.4 being the lowest pollution quintile and 2 being the highest pollution quintile	Atmospheric Composition Analysis Group, University Washington in St. Louis/Air Quality Life Index
2. Population	Higher value indicates bigger opportunity	Quintiles distribution ranging from 0.4 to 2, with 0.4 being the lowest population quintile and 2 being the highest population quintile	LandScan
3. Ambient air quality standards	Measure of existence of legal framework for national-level ambient air quality standards; absence indicates bigger opportunity	Binary distribution with a value 1 if there is no standard and is zero otherwise	Air Quality Life Index compilation of several sources
4. Government operated/ sponsored air quality monitoring	Measure of existence of legal framework for air quality; absence indicates bigger opportunity	Binary distribution with a value 1 if there is no evidence of government operated/sponsored AQ monitoring and is zero otherwise	OpenAQ report: Open Air Quality Data: The Global Landscape 2022
5. Presence of fully-open data generated by the government	Measure of government backed air quality infrastructure in a country; absence indicates bigger opportunity	Binary distribution with a value 1 if a country meets all four criteria of open data as defined by OpenAQ and is zero otherwise	OpenAQ: Note this source can provide a proxy but not an exact or official count of monitors available in a country.
6. Total number of air quality monitors	More monitors mean more data is available for measurements and calibration; lower value indicates bigger opportunity	Binary distribution with a value 2 if the number of government monitors are below median and is zero otherwise.	Sum of Indicators 8 and 9.
7. Density of air quality monitors	Measure of proliferation of AQ monitors. Defined as the number of monitors per million people; lower value indicates bigger opportunity	Quintiles of the ratio ranging from 0.2 to 1, with 0.2 being the highest monitor density quintile and 1 being the lowest monitor density quintile	Calculated as the ratio of indicators 2 and 6
8. Number of government monitors	Measure of legal framework for air quality; lower value indicates bigger opportunity	Binary distribution with a value 1 if the number of government monitors is below median and is zero otherwise	OpenAQ: Note this source can provide a proxy but not an exact or official count of monitors available in a country
9. Number of non-government monitors	Measure of public awareness for air quality; lower value indicates bigger opportunity	Binary distribution with a value 1 if the number of non-government monitors is below median and is zero otherwise	OpenAQ: Note this source can provide a proxy but not an exact or official count of monitors available in a country
10. Amount of international development funding for outdoor air quality	Available international development funds for air quality infrastructure development; lower value indicates bigger opportunity	Binary distribution with a value 1 if the amount of international development funding in a country is less $100,000 and is zero otherwise	Clean Air Fund report: The State of Global Air Quality Funding 2023, specifically Outdoor Air Quality Funding
11. Ranking of cause/risk of death	Measure of the top ten risks/causes of death as depicted by loss in life expectancy; if $PM_{2.5}$ is in the top 10 risks/causes of death, it indicates a bigger opportunity	Binary distribution with a value 1 if $PM_{2.5}$ is among the top 10 risks/causes of death for a country and is zero otherwise	AQLI for $PM_{2.5}$ and Global Burden of Disease tool by IHME for all other risks/causes
12. Countries with responses to the AQ Data Gaps registry (as of 9 November 2023)	Measure of tractability in case an opportunity to create impact becomes available; having a response from a country indicates greater opportunity	Binary distribution with a value 1 if there is a registry response from the country and is zero otherwise	AQ Data Gaps Registry for Locally-led PM2.5 Data Collection

What are some limitations of the Opportunity Score?

- For Indicators 8 and 9, the total number of government and non-government monitors, these values were obtained from OpenAQ. They should be viewed as the lower bound for these values, since all monitors may not report to OpenAQ. The use of data from OpenAQ was the most optimal choice, given the absence of a universally recognized data source for global government or non-government monitors.
- The underlying data for Indicator 10 uses available country-level outdoor air pollution international donor data (See Footnote 20). If data were not available for a country, we have assumed there is zero international donor data. Additionally, some large regional international donor funding covering several countries was unable to be deconvolved and assigned to individual country-level funding amounts.
- Inclusion of a metric is not a reliable indication of the underlying *quality or implementation* of that metric. For example, just because a country has ambient air quality standards does not mean there is effective enforcement of those standards.
- Indicator 12 relies on a public registry we have created of self-identified local actors who have indicated that they are currently working on—or are well poised to work—on $PM_{2.5}$ data gaps within their countries. This registry will not have captured all local actors in this space. One's own knowledge of other local actors should be weighted with the Opportunity Scores presented here.

We suggest using the Opportunity Score as a guiding tool that takes these limitations into account.

Contributing to the Opportunity Score

We are constantly updating the Opportunity Score, both in terms of its construction and underlying available data. If you would like to point to new data sources, call out errors, or give feedback, please visit the GitHub Repository housing this project: https://github.com/Air-Quality-Data-Gaps/opportunity -score.

APPENDIX B

HIGH AND MEDIUM-HIGH OPPORTUNITY SCORE COUNTRIES

Important Note: The Opportunity Score calculates where there is the highest likelihood that a small level of support (50,000-100,000 USD in annual funding) to local actors in a given country could result in national-level impacts. While the calculation prefers places with large populations and high pollution levels, if all else is equal, it also prioritizes places with a lack of air quality infrastructure such as little monitoring, open data, ambient air quality standards, and international development funding. This methodology leads to prioritizing places that have not traditionally been high on the international air pollution community's priority list for funding. For example, this means that a place with high air pollution levels and relatively high levels of air quality infrastructure like Bangladesh (74 µg/m³ annual $PM_{2.5}$, >1 billion USD in international development funding, evidence of government operated air quality monitoring and a $PM_{2.5}$ ambient standard) ranks lower than a country with lower air pollution levels but less infrastructure, like the Democratic Republic of the Congo (35 µg/m³, 3.7 million USD in international development funding, no evidence of government-operated air quality monitoring or an ambient air quality standard).

For the full set of indicator data underlying the Opportunity Score and scores from all countries analyzed, please see our GitHub repository: https://github.com/Air-Quality-Data-Gaps/opportunity -score

TABLE B.1

High and Medium-High Opportunity Score Countries and Relevant Metrics, Ordered from Highest Score to Low

	Population (in millions)	$PM_{2.5}$ (in µg/m³)	International development Funding for outdoor air pollution in USD million[34]	Number of government air quality monitors[35]	Density of total number of monitors	Does the country have open data?[36]	Evidence of government sponsored/operated air quality monitoring[37]	Does the country have ambient air quality standard?	Opportunity Score
Democratic Republic of the Congo	104.99	34.64	3.687839	1	0.05	N	N	N	13.2
Cameroon	28.57	30.98	0.598264	NA	0.35	N	N	N	13
Honduras	9.31	25.14	NA	NA	0.54	N	N	N	12.6
Equatorial Guinea	0.84	29.06	NA	NA	NA	N	N	N	12.4
Bhutan	0.86	30.59	NA	NA	NA	N	N	N	12.4
Lesotho	2.18	23.11	NA	NA	NA	N	N	N	12.4
Burundi	12.24	31.91	NA	NA	0.16	N	N	N	12.4
Zambia	19.09	18.5	0.005352	NA	0.16	N	N	N	12.4
Angola	33.43	16.89	NA	NA	0.09	N	N	N	12.4
Central African Republic	5.4	25.57	0.003748	NA	0.37	N	N	N	12.2
Republic of the Congo	5.46	32.41	0.177365	NA	NA	N	N	N	11.8
Bolivia	11.76	25.19	NA	NA	1.28	N	Y	N	11.8
Malawi	19.97	16.16	0.523787	NA	NA	N	N	N	11.8
Iraq	39.65	24.62	1.029644	3	0.18	N	Y	N	11.8
Rwanda	12.93	32.36	0.171360	2	0.46	N	Y	N	11.6
Zimbabwe	14.8	14.36	NA	NA	0.07	N	N	N	11.6
Côte d'Ivoire	28	10.76	NA	1	0.18	N	N	N	11.6
Afghanistan	37.46	16.9	NA	2	0.08	N	N	Y	11.4
Gabon	2.28	23.57	NA	1	6.15	N	N	N	11.2
Djibouti	0.92	17.44	NA	NA	NA	N	N	N	11
Nicaragua	6.22	13.56	0.024935	NA	NA	N	N	N	11
Belarus	9.44	12.75	NA	NA	NA	N	Y	N	11
Haiti	11.01	10.09	NA	NA	NA	N	N	N	11
Benin	13.28	17.42	11.24738	NA	0.08	N	N	N	11
Cambodia	17.3	19.84	77.694996	NA	NA	N	Y	N	10.8
Yemen	30.31	14.75	11.978233	NA	NA	N	N	N	10.8
Swaziland	1.12	15.9	NA	NA	NA	N	N	N	10.6
Eritrea	6.09	12.95	0.003548	NA	NA	N	N	N	10.6
Sierra Leone	6.74	11.63	NA	NA	NA	N	N	N	10.6
Gambia	2.21	7.06	NA	NA	1.36	N	N	N	10.4
Tajikistan	8.98	16.69	NA	3	0.33	N	Y	N	10.4
Botswana	2.35	12.85	NA	NA	NA	N	N	N	10.2
El Salvador	6.49	25.84	0.011573	NA	0.31	N	Y	Y	10.2

34 Calculated from trackable country-level international donor data from the State of Global Air Quality Funding 2023 report by the Clean Air Fund. See State of Global Air Quality Funding 2023 Methodology for more information.

35 Provided by OpenAQ

36 OpenAQ. 2022. "Open Air Quality Data: The global landscape"

37 OpenAQ. 2022. "Open Air Quality Data: The global landscape"

	Population (in millions)	$PM_{2.5}$ (in µg/m³)	International development Funding for outdoor air pollution in USD million[34]	Number of government air quality monitors[35]	Density of total number of monitors	Does the country have open data?[36]	Evidence of government sponsored/operated air quality monitoring[37]	Does the country have ambient air quality standard?	Opportunity Score
Guinea	12.8	11.2	NA	1	0.08	N	N	N	10.2
Burkina Faso	21.36	8.52	13.798376	NA	0.05	N	N	N	10.2
Argentina	45.89	11.15	NA	7	0.33	N	Y	Y	10.2
Bahrain*	1.37	17.92	NA	NA	NA	N	Y	N	10
Qatar*	2.45	30.05	NA	1	2.45	N	Y	N	10
Liberia	5.11	10.48	NA	NA	0.39	N	N	N	10
Turkmenistan	5.55	10.37	NA	2	0.54	N	N	N	10
Saudi Arabia*	33.43	25.03	NA	4	0.24	N	Y	Y	10
Sudan	46.71	11.37	11.994919	3	0.06	N	N	N	10
Timor-Leste	1.39	10.53	NA	NA	2.15	N	N	N	9.8
Namibia	2.67	11.97	NA	NA	0.75	N	N	N	9.8
Kuwait*	3.01	17.16	NA	1	3.65	N	Y	N	9.8
Papua New Guinea	7.19	12.86	NA	NA	0.14	N	N	N	9.8
Guatemala	17.4	29.05	0.022909	2	2.18	N	Y	N	9.8
Sri Lanka	22.83	18.79	NA	1	0.79	N	Y	Y	9.8
Mozambique	30.8	12.41	9.308776	NA	0.23	N	N	N	9.8
Egypt	106.25	18.24	0	1	0.03	N	Y	Y	9.8
Armenia	3.02	19.51	0.1632291	1	2.32	N	Y	N	9.6
Albania	3.08	13.53	NA	NA	NA	N	Y	Y	9.6
Singapore*	5.84	13.01	NA	NA	NA	N	Y	Y	9.6
Laos	7.59	27.16	0.034281	7	4.61	N	N	N	9.6
Togo	8.28	15.4	0.139637	NA	1.33	N	N	N	9.6
South Sudan	11.01	16.04	0.956087	NA	0.09	N	N	N	9.6
Somalia	12.04	9.16	0.797821	NA	NA	N	N	N	9.6
Uzbekistan	30.99	20.04	208.96131	1	0.29	N	Y	N	9.6
Kazakhstan	19.24	13.28	NA	2	1.04	N	Y	N	9.4
Tanzania	61.74	16.38	0.478855	NA	0.21	N	N	N	9.4
Turkey	81.85	21.78	NA	346	4.33	N	Y	N	9.4
Azerbaijan	10.21	12.4	NA	1	0.2	N	Y	N	9.2
Jordan	10.91	18.6	2.833282	5	0.64	N	Y	N	9.2
Chad	17.45	11.14	0.598264	1	0.11	N	N	N	9.2
Mali	20.12	6.79	11.250753	1	0.05	N	N	N	9.2
Niger	23.6	8.87	0.398843	NA	0.17	N	N	N	9.2
Nepal	30.46	51.71	5.628082	3	2.99	N	Y	N	9.2
Morocco	35.8	8.83	NA	NA	0.06	N	Y	N	9.2
Uganda	44.57	26.69	14.549741	1	1.1	N	Y	N	9.2
Costa Rica	5.12	12.51	NA	1	0.59	N	Y	N	9
Paraguay	7.26	13.69	NA	NA	NA	N	Y	Y	9
Nigeria	218.6	23	3.707943	3	0.27	N	Y	N	9
Mauritius	1.34	6.07	NA	NA	NA	N	Y	N	8.8
Guinea-Bissau	1.9	8.57	0.678864	NA	NA	N	N	N	8.8
Thailand	69.32	23.19	0.090934	258	5.16	N	Y	Y	8.8
Tunisia	11.72	8.62	0.259846	NA	NA	N	Y	N	8.6
Libya	7	6.78	0.557172	NA	0.14	N	N	N	8.4
Bangladesh	164.8	73.96	1052.4682	4	0.29	N	Y	Y	8.4
Oman*	3.6	12.12	NA	NA	NA	N	Y	N	8.2
Algeria	43.48	6.15	0.317866	1	0.02	N	Y	N	8.2
Pakistan	238.04	44.73	19.145064	5	0.13	N	Y	Y	8.2

*These six countries are considered "high income economies" by the World Bank. Their high Opportunity Scores may signal a lack of public knowledge of their government's current level of investment and policy-setting in addressing air quality rather than a lack of investment.

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Christa Hasenkopf is the Director of Clean Air Programs at EPIC. Her career focuses on efforts that open up information, resources, and networks so that more people in more places can help make the air they breathe healthier. Previously, she co-founded and was the CEO of OpenAQ, an environmental tech non-profit, which fosters a global community around the world's largest open database of air quality information. She has also served as the Chief Air Pollution Advisor to the Office of Medical Services at the US Department of State and in multiple positions at the US Agency for International Development. Hasenkopf received a PhD in Atmospheric & Oceanic Sciences from the University of Colorado and a BS in Astronomy & Astrophysics from The Pennsylvania State University.

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