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LMIC Urban Air Pollution Solutions

TECHNICAL DOCUMENT

USAID FROM THE AMERICAN PEOPLE

COLUMBIA | MAILMAN SCHOOL OF PUBLIC HEALTH

Vital Strategies

"INVISIBILITY IS A STRANGE FEATURE OF THIS CRISIS. YOU SEE ONE PERSON RUN OVER IN THE STREET AND YOU'LL NEVER FORGET IT, BUT THOUSANDS DYING FROM THE EFFECTS OF DIRTY AIR WILL NEVER EVEN FAZE YOU."

Excerpt from Choked: Life and Breath in the Age of Air Pollution
(written by Beth Gardiner, 2019, University of Chicago Press).

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I.

Introduction

This technical document is intended to aggregate potential policy-relevant solutions to control air pollution and improve health in low- and middle-income countries (LMICs). The goal is to take an evidence-based approach to identify actions that may be applicable and encouraged to improve air quality management in cities and, through their influence, at the national level. Examples of activities that may build towards an air quality management program include air quality monitoring, determining the sources of emissions that contribute to local air pollution (source apportionment), and interventions that transition away from the most polluting fuels. The document characterizes these activities, including entry points and best practices, and describes case studies that illustrate current efforts to address the air quality challenges in LMICs. A brief review of the health impacts of improved air quality is included in Appendix A.

The document is focused on approaches to reduce air pollution that achieve positive health impacts, however, it does not include short term exposure-reduction measures that only reduce air pollution exposure but do not mitigate air pollution levels, such as the use of respiratory masks or indoor air filters. Air pollution mitigation measures can result in other health co-benefits that are not directly associated with reduced air pollution such as a reduction in injuries and noise or an increase in physical activity from clean public transport, cycling and walking (not described in detail here). Additional non-health co-benefits related to forests, climate, gender equity, and livelihoods are included in Appendix B.

Initial input for this document was obtained from the participants at the Air Pollution Solutions Workshop that took place at Columbia University in March 2019. The Workshop convened technical experts to aggregate a set of incremental, evidence-based solutions to air pollution that are appropriate to LMIC cities in sub-Saharan Africa and South Asia.

1.1 BACKGROUND ON AIR POLLUTION

Air pollution is a mixture of chemical components, including fine particulate matter that is less than 2.5 micron diameter (PM2.5), coarse particulate matter (PM2.5-10), ozone, sulfur dioxide (SOx), nitrogen oxides (NOx), and other chemicals. These chemicals are ubiquitous, are associated with a variety of deleterious health effects, and have been regulated over decades in the United States, Europe, and elsewhere. The World Health Organization sets air quality guidelines for these pollutants, along with less stringent interim target levels for locations where air pollution levels far exceed the guidelines.

Air pollution includes both household air pollution (HAP) that originates in the household (e.g., from cooking, heating, and lighting) and ambient air pollution (AAP) that is external to buildings. AAP can result from both man-made sources (e.g., electricity generation, vehicles, agricultural fires) and natural processes (e.g., natural forest fires, wind-blown dust). HAP can also be a substantial contributor to ambient air pollution in places where burning solid fuels or kerosene for household energy is widespread.

National governments have required nationwide air pollution monitoring, set national ambient air quality standards and emissions standards from sources such as vehicles and power plants, and set renewable energy standards and fuel taxes. These national actions have resulted in broad air quality improvements in the U.S., Europe, and other countries over decades. A more recent example is China's National Action Plan on Air Pollution Prevention and Control (2013-2017), which has resulted in a 40% decline in PM2.5 levels in some regions. Since urban air quality is influenced by local emissions as well as emissions from other cities and rural areas, national action to address air pollution is usually needed. In addition, many countries have signed on to regional agreements (e.g., the Convention on Long-Range Transboundary Air Pollution) to address air pollution from long-range pollution transport. Since air pollution can travel over long distances, national and regional action is needed to coordinate air quality management across administrative boundaries.

Cities, as places of commerce, media organizations and large and growing educated, middle class populations, can help to influence national clean air policies. Local actions might include improving solid waste management, controlling vehicle emissions, expanding public transportation, promoting energy efficient housing, and implementing zoning and land use policies. In addition, local policies may be directed at reducing emissions of air pollution in rural areas, such as disincentivizing peat, agricultural, and forest burning, as well as providing access to clean fuels to reduce solid fuel burning for household energy uses.

1.2 CONSIDERING SOLUTIONS TO AIR POLLUTION

Solutions to mitigate air pollution can be most effectively developed and implemented in the context of an overall air quality management (AQM) system. In LMIC settings without a prior history of air quality management activities, it is important to start by establishing an AQM system designed to assess the current levels, impacts, and sources of air pollution. Such a system should include at least the following three aspects. Each aspect makes a unique and complementary contribution to air quality management and needs to be tracked and measured for progress.

1) **Air quality monitoring** to measure and characterize current air pollution levels and source influences, and to track air quality improvements following interventions to reduce emissions and exposures. This provides key input to AQM planning.
2) **Health assessments** to quantify community health risks from air pollution or reduced cases of disease from air quality improvements. This can provide useful information and guidance to health care providers, communities, and government sectors.
3) **Emitting sectors** (emissions and source assessments) to identify potential interventions or other air quality solutions and to inform policy. These inventories and estimates should be quantitative. This can lead to advice to government, business, and society.

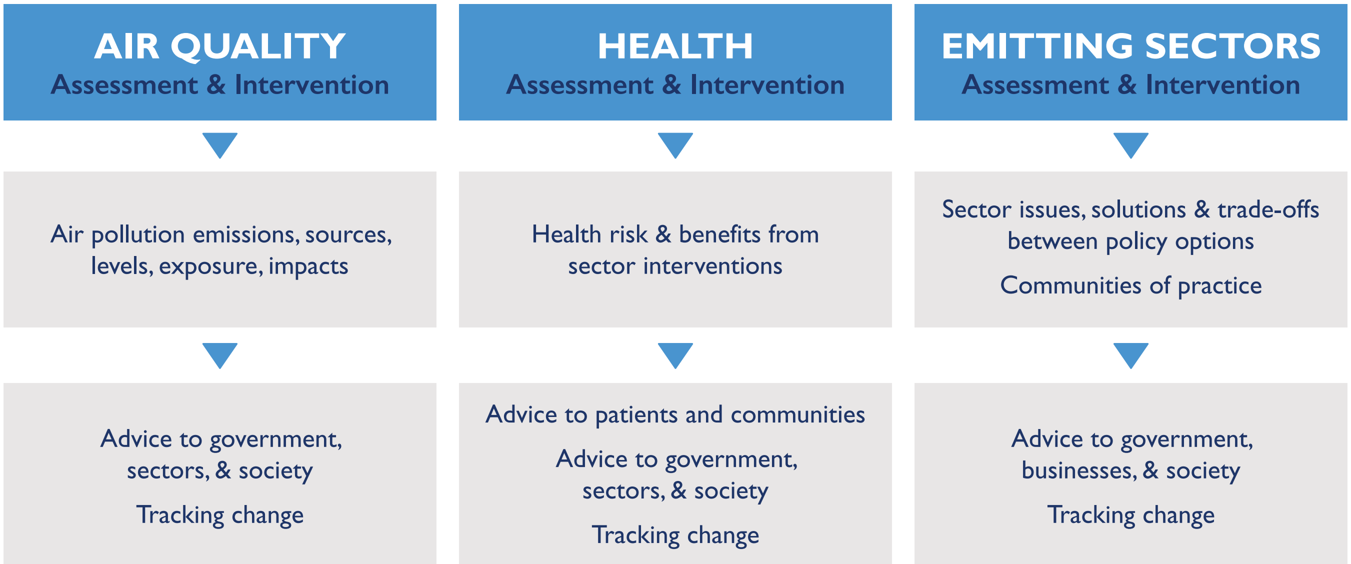

Figure 1. Air Quality Management Framework that serves as a model to link air pollution and health in LMICs (contributed by Dr. Carlos Dora).

Air pollution exposures lead to health risks which influence the sector interventions and inform solutions, policies, and communities of practice. Figure 1 illustrates a specific focus on the source of the health risk, tracking, monitoring and evaluation, and the estimates of human exposure risk. This framework can be used to help map AQM tasks to respective roles that can be played by environmental experts, by the health sector, and by the emitting sectors for their active and balanced engagement. Engaging national or municipal departments of environment, energy, transportation, and health, as well as local politicians, can help ensure broad understanding and support for undertaking action.

2.

Strengthening air quality programs

Creating a new air quality program requires numerous considerations about the existing programs and partners as well as how to reach key stakeholders for broader consultation.

2.1 INITIAL STEPS

1. Review existing planning documents for identified solutions:
Most national governments have National Action Plans and other types of national level planning documents that may offer insight into that government's priorities for action. Local governments, particularly local transportation or health departments, may have related documents. Where such documents do not yet exist, some initial planning, along the lines of the Megacity Framework (see Section 5.1, case study), may be useful by using existing data and implementing a few achievable measures. For most cities, imperfect data is still sufficient to begin a planning process, with a commitment to improve data over time.

2. Identify local partners:
In addition to local and national governments, there is a significant investment by many international groups in the air pollution and health space: United Nations Environment Program, Clean Cooking Alliance, World Health Organization, The World Bank, Climate and Clean Air Coalition, C40, Rockefeller Foundation, GEOHealth hubs, and Vital Strategies.

Clean air is a often a local problem and benefits from local solutions and local stakeholders. The models for making decisions can be established for city-level decision making. Important local partners could also include academic institutions which may have, or be well-positioned to acquire, technical skills needed to support government (e.g., monitoring, modeling).

3. Invest deeply, not broadly:
Initial investments might include mitigation support for priorities identified in existing planning documents. Early work might focus on one or two sectors, such as household heating and cooking (e.g., transition to clean household fuels) or locally based industrial sectors (e.g., improved brick kilns) or civic and urban issues (e.g., reduced open trash burning). Later investments might focus on improving air quality monitoring; data management and training; outreach and communications planning; secondary city monitoring. Future work might including industrial source emission standards; laboratory analytical capacity building and trainers; and enhanced vehicle standards. These are all areas where strategic investment can catalyze progress.

2.2 DEVELOPING A COMMUNICATION STRATEGY

For all air quality programs, the communication and outreach strategies are critical. Key stakeholders should be considered from the initial planning stages.

The impacted public can be one of the most powerful motivators of political will, yet many low-income country residents do not fully understand the linkages between air quality and health outcomes and or the sources that are the most important contributors to local air pollution. Investment efforts can focus on public information campaigns, education programs for public health and medical providers, and in many locations religious institutions and traditional leaders. Communication strategies often include analyses for: Who does the public listen to? Where do they get information they trust?

Raising awareness about elevated levels of air pollution is critical to building interest and concern in the public domain. Making air pollution more visible could play an important role in advocacy. Key examples of existing monitoring and reporting for ambient air quality and household air pollution are listed in Table 1 (e.g., www.airnow.gov and www.acqicn.org). Communicating about the health risks of air pollution can also be effective and can engage a broader audience including the health sector. Several countries have devised Air Quality Indices (Figure 2), which relate concentrations to a color scale with recommendations about which population sub-groups should take action to limit exposure. Additional communication tools are under development through the WHO BreatheLife Campaign (www.breathelife2030.org) and additional programs (see Table 2 for additional examples of health communications).

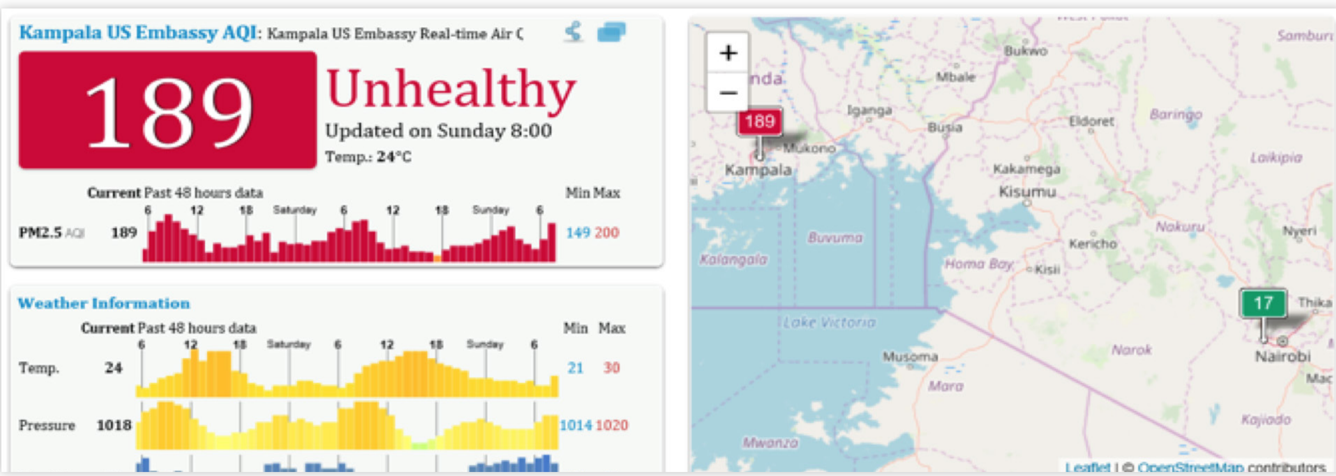

Figure 2. Air Quality Index data shown for U.S. Embassy in Kampala (https://openaq.org).

Beyond local communication, high profile global events (e.g., a special session at the United Nations General Assembly on air pollution) provide a special opportunity to link global engagement around air pollution with country engagement around key issues. With some advance planning, high burden countries in Africa and South Asia could play a major leadership and convening role. If multisectoral engagement is extrapolated across the continuum of the air quality issues, then long range transboundary issues for air also become important for global discussion.

Existing resources can be tailored to the local context for more effective communication with the public and decision-makers in specific locations. The Air Pollution Knowledge Assessment (ApnA) city program at urbanemissions.info currently includes cities in India, but is expanding to other regions, and is an example of how localized data can be presented for the unique context of individual cities (http://www.urbanemissions.info/india-apna). Since emission sources often produce both air pollution and greenhouse gases, leveraging public awareness of one can have benefits for mitigating both issues.

Table 1. Air quality and household air pollution data resources

ORGANIZATION	RESOURCE	DESCRIPTION
U.S. EPA	www.airnow.gov	Global real-time air quality measurements
OpenAQ	www.openaq.org	Global real-time air quality measurements (Figure 3)
World Health Organization	http://maps.who.int/airpollution	Global ambient air quality database
United Nations Global Pulse	www.hazegazer.org	Real-time forest and peatland fire haze across Indonesia
NASA	https://airquality.gsfc.nasa.gov	Air quality information from satellite remote sensing
U.S. EPA	https://www.epa.gov/air-trends	U.S. trends in emissions and air pollution levels (useful example for other countries)
WHO BreatheLife	www.breathelife2030.org	Air quality levels for cities worldwide

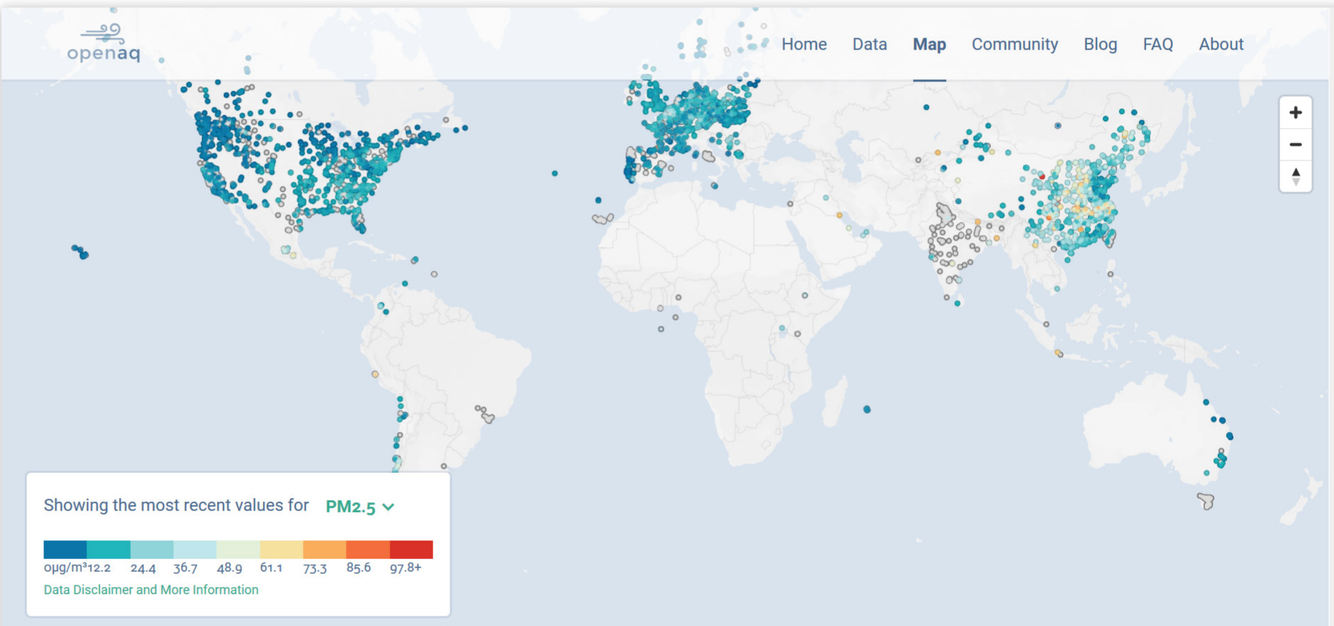

Figure 3. Real-time map of PM2.5 monitor locations and measurements from www.openaq.org.

Table 2. Air pollution health risks and impacts resources

ORGANIZATION	RESOURCE	DESCRIPTION
World Air Quality Project	https://aqicn.org/map/world https://waqi.info	Global real-time air quality index
U.S. EPA	https://www.airnow.gov/index.cfm?action=airnow.global_summary	Global real-time air quality index at U.S. embassies and consulates
Institute for Health Metrics and Evaluation	https://vizhub.healthdata.org/gbd-compare	Data visualizations report Global Burden of Disease estimates
Health Effects Institute	https://www.stateofglobalair.org	HEI/IHME data on air quality and health
U.S. EPA	https://www3.epa.gov/airnow/ozone-c.pdf	Health effects of PM2.5 and ozone
U.S. EPA	https://www.epa.gov/pmcourse	Health care professional training
Clean Cooking Alliance	https://www.cleancookingalliance.org	Provides links between household air pollution and health

The necessarily multisectoral approach includes a wide variety of stakeholders to support and influence air pollution initiatives through funding, advocacy, convening power, creative solutions, and more. Some of those stakeholder groups include:

- Academic institutions
- Health providers, extension workers, and their medical institutions
- Public health professionals (including Ministry of Health, health sector managers)
- Professionals in environment, health and city management (energy and transportation)
- Civil society organizations and affected communities
- Private sector including corporate social responsibility, public-private partnerships, and profit-driven private companies
- Governments including Ministry of Finance that can levy taxes as incentives
- Diaspora
- Communicators including the media
- Schools and children

The U.S. EPA developed a Public Participation Guide that is available in multiple languages at:
https://www.epa.gov/international-cooperation/public-participation-guide

3.

Actions to reduce leading sources of air pollution

This section summarizes pragmatic approaches to solve air pollution problems in LMIC environments, organized by source of pollution, including household cooking with cleaner fuel, reduced trash burning, cleaner industrial technologies, cleaner vehicles and fuels, reduced agricultural burning. The importance of addressing regional sources beyond urban settings is critical to improving air quality.

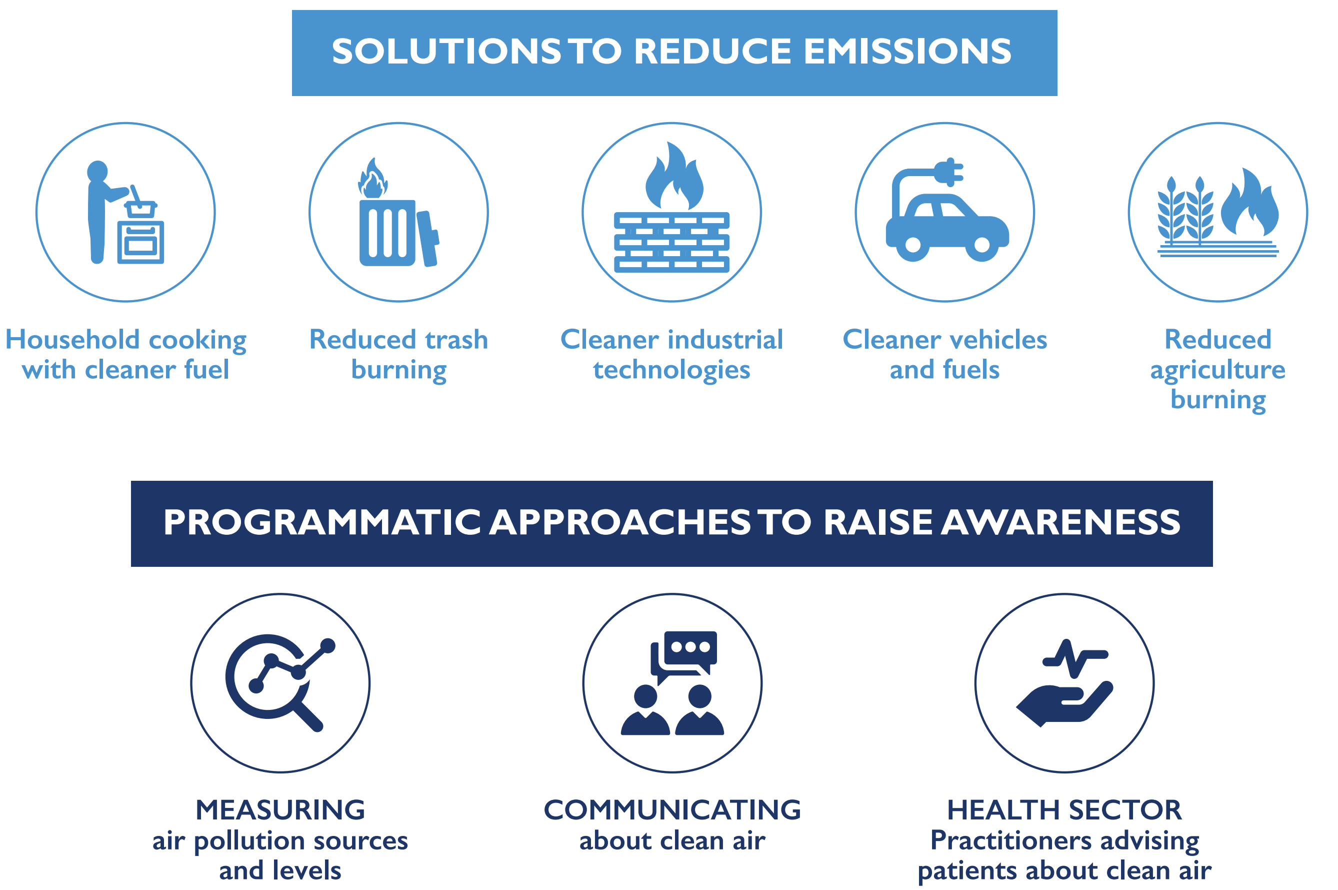

Figure 4. Solutions for reducing air pollution.

3.1 TRANSITIONING TO CLEANER HOUSEHOLD FUELS

Household air pollution (HAP) from the inefficient combustion of solid fuels for cooking or heating remains a major global health risk and is also a significant contributor to ambient air pollution. Exposure to HAP has been estimated to contribute to several million premature deaths each year in LMICs, and this does not include the additional health effects of ambient air pollution from household sources, which has been shown to reach 25% of AAP in India. While early efforts to reduce HAP targeted cleaner burning stoves, recent attention has emphasized the need to ensure the availability of clean fuels for maximum health benefit. The transition to clean household fuels, including liquefied petroleum gas (LPG), biogas, ethanol, pellets, and electricity for cooking has the potential to reduce exposures to HAP and improve maternal and child health (https://www.harpnet.org/wp-content/uploads/2017/10/f1-HAP-Briefer-DIGITAL.pdf)[1].

Early evidence has shown that when exposure to HAP is reduced, this can reduce adverse health outcomes. Reduction in severe pneumonia cases in children was shown in Guatemala and Mexico when HAP was reduced by using chimneys and enclosed combustion chambers, and the duration of upper and lower respiratory infections was lower in households with wood-burning chimney stoves compared to children in households with open woodfires. Randomized controlled trials (RCTs) in Nigeria found use of ethanol cookstoves, compared to firewood or kerosene stoves improves birth outcomes, including higher birth weight and lower perinatal mortality, lowers maternal blood pressure, and reduces the blood inflammatory biomarker (TNF-alpha) in pregnant women [2].

These findings illustrate the potential health benefits that are possible when HAP exposure can be effectively reduced. However, reducing the health impacts of household air pollution requires a dramatic reduction in population exposure to HAP, as was described in the *WHO Guidelines for Indoor Air Quality*, and cannot be easily achieved without switching away from biomass in its currently used forms (firewood, charcoal, crop residues, dung). The improved biomass cookstoves that have been designed to optimize efficiency, but not necessarily clean emission, have been promoted for decades, and while often effective in laboratory testing, do not in practice achieve the WHO Air Quality Guideline for exposure to particulate matter. Clean household air requires the transition away from burning biomass and replacement with clean household energy sources such as electricity, LPG, ethanol, or biogas. Providing household access to affordable and available clean fuels holds promise for hastening the transition of households to clean indoor air. Here we briefly summarize each of these fuel options.

Liquefied Petroleum Gas (LPG), Piped Natural Gas (PNG), and Biogas

LPG is a clean-burning, portable cooking fuel that is a by-product of oil and natural gas production and refining. LPG sources are extensive; a global LPG surplus exists and is projected to continue to 2050 [3]. PNG allows for a continuous supply of gas to be provided at the household level. In addition, renewable biogas can be produced from the fermentation of organic wastes and residues. Since LPG, PNG, and biogas combustion emits much less particulate matter than burning firewood, charcoal or kerosene, LPG, PNG, and biogas fuels lead to lower personal exposures to air pollution and are expected to reduce the associated health burden. Additionally, LPG, PNG, and biogas combustion emits much less black carbon than do solid fuels, one of the leading global warming agents.

When countries implement and enforce sustainable, proven models for gas sector growth and safety and invest in required infrastructure, with appropriate expert assistance, there is the potential to rapidly scale nationwide LPG availability, adoption and use. A holistic approach is essential: policies and programs should make save, reliable LPG stoves available to consumers along with the proper design of the enabling conditions for a sustainable, bankable LPG sector including a functional fuel supply chain, pricing and competition rules, and a safety ecosystem. Countries such as India, Indonesia, Malaysia, Vietnam, Senegal, Cote d'Ivoire, Brazil, Colombia, and others have achieved LPG use for cooking by 75% or more of their urban populations, and in some cases, 50% or more of their rural populations. LPG is already the main cooking fuel in many Latin-American countries and India and Indonesia are rapidly expanding LPG use. Microfinance solutions and household subsidies can address some of the up-front cost barriers to the transition to LPG.

Biogas can be considered a 'boutique' clean fuel. Biogas generation requires a minimum amount of animal waste and considerable household effort, as well as suitable temperature requirements to sustain gas production. Biogas programs have been successful in some rural and peri-urban areas, for example, where there is adequate animal waste readily available. Biogas has been a functional clean fuel option in Nepal for over a decade, but households generally need a back-up energy source during winter months. Thus ensuring the availability and use of clean supplemental energy sources, such as electricity or LPG, is necessary to achieve truly clean household energy.

Ethanol fuel

Ethanol is a renewable biofuel that can be used for cooking and that burns much cleaner than traditional biomass fuels with a cost that is similar to that of kerosene or charcoal, depending upon the specific geography. Cooking with ethanol has the potential to effectively reduce HAP exposures and improve health outcomes. A 2017 meta-analysis of clean cooking solutions showed an 83% emissions reduction for ethanol stoves [2]. When crops are used for biofuel stock, there can be competition for land previously used in food production.

The most significant challenge to widespread implementation of ethanol as a clean household fuel has been ensuring consistent supply, especially where it is also used in the transportation sector. Ethanol has a largely global supply chain. One issue that has been tackled by Koko Networks, which operates in East Africa and India, is the distribution of the ethanol in a refillable canister. Sustainable supplies of feedstock for ethanol production are available in the molasses waste stream and this waste is a much more sustainable source than corn or other food that is diverted to ethanol production.

Pellets

Biomass pellets and briquets can be a clean fuel for the future when manufactured with appropriate source materials and adopted by households. Findings of biomass assessment studies in Kenya and elsewhere show adequate source material to produce pellet-based fuel in volumes that can meet the needs of household cooking. Pellets are produced by the compression of biomass to produce a consistent and clean-burning material. Clean household air is only achieved when pellets are manufactured to a high standard, are burned in stoves intended to meet the Tier 4 performance targets for emissions, and are burned in appropriate stoves that are operated correctly including both stove maintenance and pellet storage.

Although pellet production from biomass could be carried out in most locations, the raw materials must be dry and available throughout the year and compressed using specialized equipment. The production of consistent high-quality pellets with a supply chain capable of delivering pellets throughout all seasons can be challenging. Inyenyeri, a hybrid private company in Rwanda, has developed both a pellet production process and a business model for pellet-based household fuel that is now serving over 15,000 households, however, scaling up pellet production on a sustainable commercial basis is itself a challenge and requires a high degree of quality assurance [4].

Electricity

About 1 billion people still live without access to electricity, representing 13% of the global population in 2018, improved from 17% in 2010, and 24% in 1990. The International Energy Agency (IEA) predicts that 8% of the global population will still lack access to electricity in 2030, far short of the SDG7 goal of universal access. Sub-Saharan Africa and South Asia continue to have the largest deficits in access to electricity, with 87% of the people without electricity residing in rural areas.

Solutions to the access gap have the potential for major co-benefits for air quality and health, especially with off-grid solar systems such as mini-grids and home solar solutions, which are having substantial success in sub-Saharan Africa where connecting rural areas to national grids is costly and technically challenging.


Photo: Abid Omar, Pakistan Air Quality Initiative

3.2 REDUCING COMMUNITY AIR POLLUTION THROUGH CLEANER BRICK KILNS

Brick manufacturing is a major source of ambient air pollution in many LMICs in South Asia where about 300,000 brick kilns contribute one of the major sources to air pollution in the region. Reducing emissions from brick kilns has the potential to significantly improve air quality. In Nepal, about 1000 brick kilns operate during early winter through late spring and contribute to 40% of elemental carbon in the region.

The 2015 Kathmandu earthquake damaged 110 of the 112 brick kilns in the Valley, and this damage to the brick kilns provided a unique opportunity to rebuild more energy efficient and less polluting brick kilns. A coalition of partners joined together to develop new brick production technologies that can reduce emissions, energy use, and improve brick quality. One outcome has been a set of guidelines to rebuild "zig-zag" fixed chimney brick kilns that are earthquake resistant, energy efficient, worker friendly, and with lower emission. Since 2015, under the leadership of ICIMOD, trainings and site visits have been organized for brick entrepreneurs in Nepal, Pakistan, India, and Bangladesh to facilitate conversion from fixed chimney bull's trench kiln (FCBTK) to zigzag kilns. A study performed in Nepal showed that converting from FCBTK to zigzag kilns can reduce PM2.5 emissions by ~20% and BC emissions by ~30%, based on emission factor estimates of per kilogram of fuel [5].

Policy changes have supported the effort to convert from FCBTK to zigzag kilns. In 2018, the Environmental Protection Agency (EPA) of Punjab Province (India) released a directive to convert all kilns to zigzag technology. In India, the Central Pollution Control Board has directed conversion of FCBTK into zig-zag in regions with high air pollution levels. In Nepal, based on measurement campaigns supported by CCAC, revisions have been made to emission standards for brick kilns. For the region, one of the significant steps has been the formation of the Federation of South Asia Brick Kiln Associations (FABKA) consisting of members from India, Pakistan, Bangladesh, and Nepal. FABKA aims to support cross boundary knowledge sharing and work on making kilns less polluting and more sustainable.

Conversion from FCBTK to zigzag kilns has led to a reduction in fuel consumption, increased production of grade A bricks, and a less capital-intensive kiln, making it economically viable for brick entrepreneurs. In the past, technical know-how was passed most commonly from father to son and many brick entrepreneurs lacked the necessary information for best practice or standards. Instruction manuals and trainings provided to construct and operate zigzag kilns has leveraged for easy adoption. This success story in the region highlights how collaboration among stakeholders is important towards developing an effective solution.

3.3 REDUCING COMMUNITY AIR POLLUTION THROUGH REDUCED TRASH BURNING

Burning trash, particularly in urban areas, leads to substantial emissions of particulate matter, volatile organic compounds (VOCs), and a wide range of toxic pollutants including cancer-causing dioxins. Reducing trash burning is estimated to reduce up to 40% of air pollution in LMIC urban areas. Open waste burning in LMIC cities is caused in part by the lack of systematic waste collection. Because trash disposal is a multi-faceted problem including large landfills, small informal dumpsites, and local incineration, it is difficult to regulate. Burning trash does reduce the waste volume and thus makes more space available at dumpsites, but burning also leads to high levels of air pollution including toxic and carcinogenic gases emitted from burning plastics.

To address the challenge of solid waste combustion, the Climate and Clean Air Coalition has created a Waste Initiative which supports the adoption of policies and measures that will help national and local governments reduce black carbon emissions from open waste burning, reduce associated pollution that threatens local communities, and work towards universal collection through cooperation and planning with sub-national governments. The Waste Initiative provides partners with tools and technical resources that will help them reduce the occurrence of open waste burning by:

- Supporting the creation of integrated solid waste management systems that improve waste collection and reduce the occurrence of trash in streets or informal dumpsites susceptible to open burning.
- Supporting improved landfill management, which can reduce the occurrence of spontaneous fires.
- Carrying out outreach efforts at the community level, to encourage waste reduction including reuse/recycling/composting and to educate the public on the hazards of open waste burning

The Ghana Sanitation Ministry banned open burning in the city of Accra in 2018. Numerous countries have instituted bans on plastic bags that lead to plastic waste.

3.4 MOVING AWAY FROM OPEN BURNING (AGRICULTURAL, FOREST, AND PEAT BURNING)

Open burning of forests and/or crop residue is an integral part of traditional agricultural operations in many LMICs. The emissions from agricultural fires make a significant contribution to regional air pollution. For example, the $6B palm oil industry in Indonesia is responsible for immense fires in the peat bogs that create a toxic haze over much of the Indonesia region, extending as far as Singapore. In 2015, peat and forest fires in Indonesia caused an estimated 100,000 premature deaths, 90% in Indonesia, but thousands more in Malaysia, Singapore, and other countries in the region. In Northern India, open burning of agricultural residue is a seasonal source of air pollution with impacts on air quality as well as public health that extends into parts of Pakistan and Bangladesh [6]. Regional cooperation and action can lead to signficiant improvements in air quality.

Reductions in open burning will be essential to achieving clean air in downwind cities. USAID works in Indonesia with the government and many international partners to support peat restoration and to combat peat and forest burning. The Center for International Forestry Research (CIFOR, www.cifor.org/library/7289) works with communities at the local level to understand the economic, social and political dynamics causing forest and land fires. CIFOR also carries out research on how to facilitate and mainstream land clearing and development that does not depend on using fire.

In Africa, improved forest management and maintenance practices that address rural livelihood and land use challenges are urgently needed. Charcoal remains an important cooking fuel in many parts of Africa, particularly in cities where its compact form facilitates storage and delivery as compared with wood. Since charcoal production, that is known to rapidly degrade forest resources, is tied to both cooking and livelihoods, the transition away from charcoal will need to ensure a transition for livelihoods. Charcoal production involves low-oxygen combustion of wood and is a major source of PM, including both black and organic carbon. Reducing dependence on charcoal as a cooking fuel will depend on availability of alternative household fuels as well as new jobs, including opportunities such as distributing and servicing cleaner fuel and technologies for households.

3.5 FOCUSING ON INNOVATIONS THAT REDUCE TRANSPORTATION SECTOR SOURCES

The transportation sector is a major and increasing source of air pollution in LMIC cities, including those in Africa, where older, poorly tuned vehicles using a range of fuels can lead to extremely high emissions and localized impacts [7]. The problem is exacerbated by increasing traffic congestion, weak regulations, and lack of enforcement. Important progress has been achieved in eliminating lead from gasoline in all African countries and reducing the sulfur content of diesel fuels, enabling the use of high efficiency exhaust particle traps in some countries. Additional entry points for mitigating emissions from motor vehicles include improving fuel standards (specifying the carbon and sulfur content and quality of commercial motor fuels), regulations to require catalytic emission controls on vehicles (which will work as planned only if fuel quality is controlled), and inspection and maintenance programs in which annual inspections and testing are required in order to keep a vehicle on the road. Some combination of one or more of these solutions will likely be the natural starting point for transportation system air pollution emission mitigation in LMIC cities.

Example of reducing sector sources: E-mobility

E-mobility innovation may provide a new direction in transportation, taking the lead from emerging developments in high income countries. Within the US, a new paradigm of "autonomous, shared, and electric" is emerging. In India, a related but slight variation has been proposed, namely "connected, shared and electric". The market indicators for growth and innovation are demonstrated by year on year growth of 30% (globally) and dozens of models of electric vehicles available on the market. Commitments by governments and car companies are driving policy and market developments. The Government of India has committed $1.4 Billion towards electrifying the transportation sector. Ford Motor Company has planned for $11 Billion for electric vehicle development with a promise of having 40 electric vehicles by 2022. How and when these innovations will become available at scale in LMIC cities is a major open question.

E-mobility innovations have the potential to impact both local air pollution and climate change mitigation. Renewable electrification of the transportation sector is considered an important component of different pathways to achieve deep decarbonization of the economy. Switching to the LMICs and taking India as an example, transportation accounts for a relatively small portion of fine particulate (PM2.5) emissions on a national level (at 2%); however, on a local level, transportation is roughly 20-30% of PM2.5 emissions.

In the India context, relevant trends include utility load growth (and revenue sources that can help combat utility financial problems) and renewables integration, as electric vehicles offer a source of batteries. The storage capacity from electric vehicle batteries is another important factor, and is projected to dwarf other storage. In India, a national mission on electric mobility has commenced. It addresses all segments of the e-mobility value chain: manufacturers, charging infrastructure companies, fleet operators, and service providers. The policies include public fleet procurement, EV readiness, financial incentives (and disincentives for polluting vehicles), bulk procurement for cost reductions, and an overarching goal of 30% EV penetration by 2030.

Key challenges include driving range anxiety, cost, and lack of consumer awareness; inadequate charging infrastructure; disagreement about the role of utilities in financing, owning and operating EV charging infrastructure, and insufficiently developed interoperability standards; and distribution network concerns from the impacts of charging. Progress is being made on all these fronts. Drive range has increased significantly and are reaching 400-500 km. Capital costs are declining and some projections estimate parity within a few years. Utilities can mitigate reliability concerns through smart charging techniques to limit the charging draw with transformer constraints. Utility investment in charging infrastructure (vs. private investment) can help ensure equity; the same regulatory tools (i.e., cost effectiveness analysis) and processes can be used for other utility investments apply well for e-mobility and are well suited to incorporate health benefits.

4.

Building towards an air quality management program

AQM systems are essential to achieving long-term, sustained improvements in air quality. An integrated AQM system can answer questions such as: what are the key air pollutants affecting air quality locally? how high are air pollution levels? what are the key sources of local air pollution? and how is the air pollution affecting local public health? This section describes approaches for characterizing air pollution levels, sources, and associated health impacts (see Figure 5).

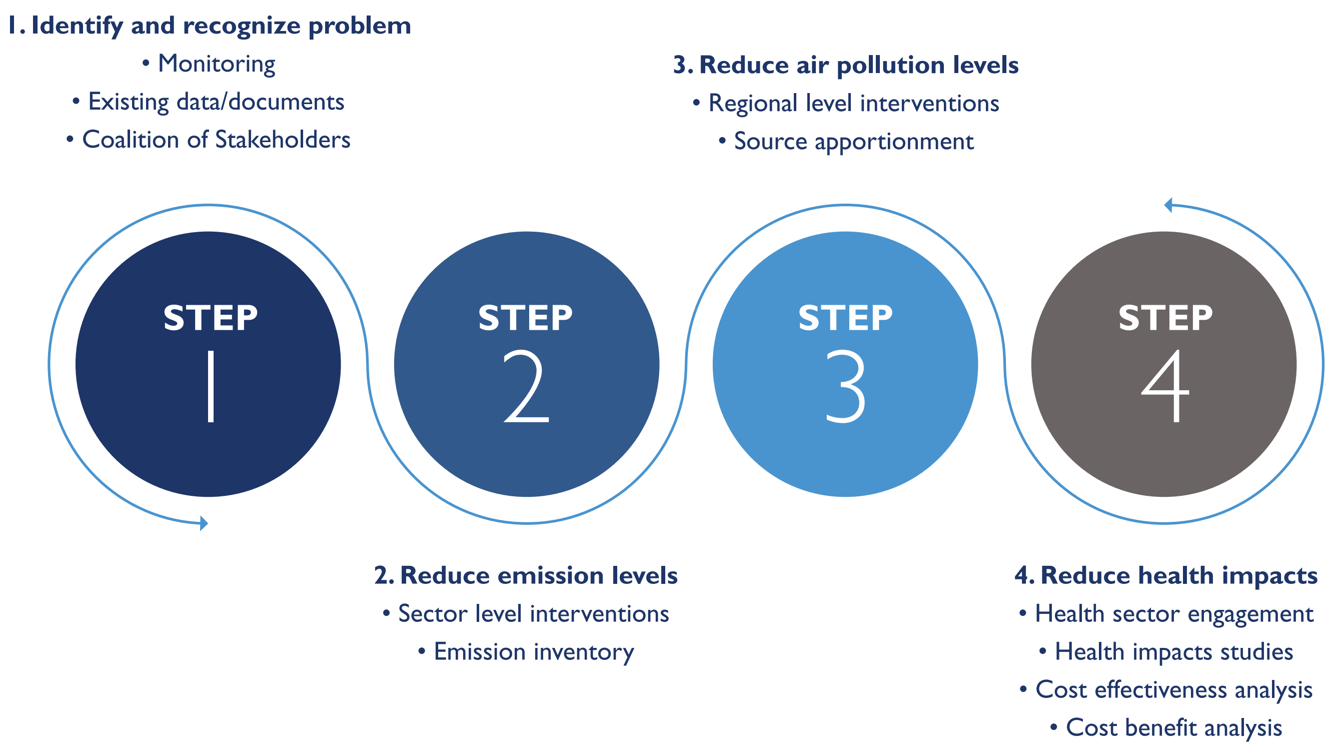

Figure 5. The stages of air quality management (adapted from United Nations Environment Program, *Air Pollution in Asia and the Pacific: Science Based Solutions,* Nov 2018).

4.1 MONITORING OF AIR POLLUTION LEVELS

Monitoring air pollution levels is a critical first step in understanding the relevance of air pollution in any location. Air quality monitoring makes it possible to address several key objectives: assessment of air quality and health risk, source attribution, understanding the contributions of constituent parts of air pollution, compliance and accountability, trend monitoring, and informing the public (see also, *Filling the Gaps* report). Monitoring can also be used for research and to evaluate atmospheric and exposure models. While actions to reduce air pollution levels could in theory be implemented without air pollution monitoring, the lack of data on air pollution levels would make it impossible to evaluate progress.

Ground-based air pollution monitoring networks operate in numerous countries. Such networks consist of one or more stations placed strategically in cities (e.g., Delhi, Addis Ababa, and others) and other locations. Stations may consist of a climate-controlled structure with several high quality instruments to measure pollutants such as PM2.5, PM10, SO_2, NO_2, CO, and possibly others. Many of these measurements are collected and displayed in real-time at www.openaq.org, providing open access to view observed air pollution levels. Due to the cost and technical requirements of this type of high quality air monitoring system, many LMICs are lacking any ground-based monitors. The absence of air pollution observations is a key challenge to addressing the air pollution problem because current air pollution levels in these locations remain less characterized than in locations with surface monitors. Increasingly sophisticated air pollution models based on satellite remote sensing, ground observations, and chemical transport models make it possible to estimate air pollution levels globally. While less precise than ground monitors, these estimates can be used to confidently identify urban areas with pollution levels well above health-based standards.

Several relevant air pollutants can be monitored, but, typically, PM2.5 measurements are a good way to begin an air monitoring program. A network of ground-based PM2.5 monitors that operate on a consistent schedule can be a useful starting point. Depending on the equipment and site selected, a network can provide granular, small area specificity with high time resolution. Additional information about spatial variability in air pollution levels can be developed by incorporating information from other types of monitors, such as satellite remote sensing, a temporary network of low-cost sensors, and/or mobile monitoring. These additional information sources can be more economical than high-quality ground-based monitors, but may be challenged by quality and calibration issues.

Decision-making steps for choosing the type of monitoring network:

- **Scope of the system** – The scope for air quality monitoring programs range from simple neighborhood data (e.g., alerting residents of high air pollution days) to advanced surface monitoring stations that measure both concentrations and particle composition for source identification (e.g., reporting temporal and spatial variability with high precision). Air quality monitoring strategy and sensor selection should be selected to be fit for purpose.
- **Real-time vs. filter-based PM sampling** – Low cost real-time sensors provide ongoing data, but lack accuracy and do not provide for speciation analyses; integrated filter sampling provides a more accurate measure of PM2.5 and can support the identification of particle composition, but only provides one value per sample which is typically taken once per day.
- **Chemical species** – Most air quality monitors report particulate matter, typically PM2.5; additional monitors are typically necessary to measure CO, SOx, NOx, and other chemical species. Monitoring the mass of PM2.5 is a critical first step, and other species can be added later.
- **Sensitivity of measurements** – Low cost sensors often measure air quality with crude accuracy and precision; the uncertainty in these measurements may be acceptable if the monitoring goal is to signal poor air quality without precise numerical values.
- **Quality assurance/quality control** –Data quality can be highly variable across monitors. Data quality objectives, standard operating procedures, training protocols, and data management and reporting plans are part of a monitoring plan. Monitors also need to be calibrated and maintained on an ongoing basis to correct for measurement artifacts and ensure data quality. Without QA/QC procedures, the quality of monitor data can be undermined which can damage public trust in the data.
- **Locations for monitors** – Monitoring locations are often public areas of interest to the local population such as road intersections, educational institutions, health facilities, related public spaces, and background locations to understand regional air pollution.
- **Data management system** – Monitoring data should be archived and tracked in a data management system, including redundant data recording and archiving of meta-data (e.g., location, timing, and quality checks needed to interpret the data). Data management systems can also automate public access to the data.
- **System maintenance** – Air quality monitors and data management systems need to be maintained on an ongoing basis to ensure proper functioning with no loss of fidelity in the measurements, and data consistency, and accuracy.
- **Cost of the system** – Air quality monitors range in price from $100 to $200,000 with additional expenses for calibration as well as maintenance and operations. The total system cost will also depend upon density of the monitors in the network. Guidance is available on how different types of sensors can be used for different purposes (EPA's air sensor toolbox https://www.epa.gov/air-sensor-toolbox, performance evaluation http://www.aqmd.gov/aq-spec, and *Filling the Gaps* report).

How do low cost PM monitors work?

Humidity and temperature affect the air quality monitors and need to be measured separately for the calibration process. Low cost air quality monitors are typically optical instruments that monitor the scattering of laser light due to particles in the air. These monitors require that assumptions be made about the sizes and shapes of the particles and the effects of humidity on particle growth. The light scattering is fairly simple, but the algorithms used to convert light scatter to particulate matter levels are more complex and are often proprietary. Furthermore, these monitors require correlations with reference methods to calibrate the reported values, and these calibrations must be repeated in the local area where the monitors are deployed.

4.2 UNDERSTANDING CONTRIBUTIONS OF AIR POLLUTION SOURCES

Once air quality monitoring is in place, the monitors can be used to determine which emission sources contribute most to local air pollution. These source contributions estimates are essential to prioritize mitigation strategies as major sources of air pollution (e.g., power generation, traffic, dust, forest fires, household combustion, agricultural burning) vary by location. Because this type of analysis can estimate or "apportion" the fractions of observed air pollution contributed by different source types, it is often referred to as "source apportionment."

There are two approaches for conducting source apportionment analyses: bottom-up, which relies on emissions inventories, and top-down, which analyzes source signatures in air monitoring data (see below). The bottom-up approach produces estimates of source contributions to pollution at any location, as it is conducted on a gridded scale, but estimates are obtained from imperfect knowledge of source emission strengths on the grid and simplified representations of atmospheric processes within chemical transport models or dispersion models. The top-down approach provides more accurate results for specific locations where air quality monitors are located. However, top down methods cannot distinguish emissions from different sources burning the same fuels, cannot locate sources in space, and are backwards looking. More details on source apportionment can be found elsewhere (https://esmap.org/sites/default/files/esmap-files/7607-Source%20Web%28Small%29.pdf). Since source apportionment is a highly technical process, a university or technical government agency can be a good partner for this work.

A source apportionment result can be illustrated in a histogram (see Figure 6).

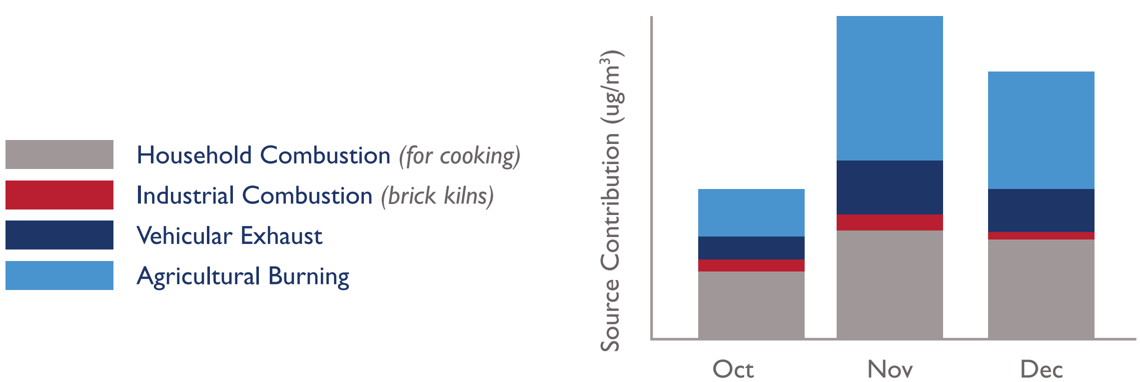

Figure 6. Example of results from a source apportionment study to show how different emissions contribute to the overall emissions inventory.

Bottom-up approach

The bottom-up approach requires computational modeling to simulate the effects on air pollution levels from local emissions from a variety of source sectors. The steps include developing an emissions inventory that reflects the emissions of all air pollutant emission species from all source sectors across a gridded geography across the entire region of interest and then simulating the effect of those emissions on air quality using a chemical transport model. Developing emissions inventories and simulating effects on air quality are resource-intensive processes that require highly specialized technical training. Emissions data may be obtained from information on industrial activity, traffic volumes, household surveys on source of cooking fuel, seasonal burning data, etc. Emission levels are estimated by a combination of combustion efficiency, activity factors, and emission factors. In a few cases, actual emissions may be monitored at the source, but this is rare in LMICs. If local data on emission factors and activity factors are not available to develop a locally-specific emission inventory, data from nearby locations can be used as proxies. Reduced-form tools that remove the need for chemical transport modeling are increasingly available.

Top-down approach

The top-down approach uses data from both an air pollution monitoring network and tracer species to map amounts of pollution by type and then later identify the emission sources. Different air pollution sources have different "fingerprints" for the specific pollutants they emit, such as trace metals, sulfates, nitrates, organics, etc. Monitoring to identify these sources of air pollutants typically requires that the specific chemical species of the pollutants be identified. For PM2.5, filters can be used as the data collection tool. The filters collect air pollution for 24 hours and are then analyzed for individual chemical species in the sample of particles (i.e., analysis tools include X-Ray Fluorescence). This chemical species data is typically generated by university or government laboratories, and requires advanced analytics. Results are then matched against known chemical profiles of emission sources to estimate the contributions of different sources to pollution levels in the location of each monitor. These results are averaged to estimate contributions of emission sources across a city. A variety of statistical methods have been developed to recognize source signatures from a set of air monitoring samples. See also https://source-apportionment.jrc.ec.europa.eu/Docu/european_guide_SA_SMs_2019.pdf

4.3 ESTIMATING PUBLIC HEALTH IMPACTS OF AIR POLLUTION

Quantifying the local public health burden from air pollution can help put air quality in context for decision-makers, public health practitioners, and the public. Pollutant concentrations on their own do not convey information about the health risks from air pollution that are experienced by the local population. With enough granularity, air pollution health impact assessment can provide estimates of disease burden and how it compares to other local risk factors. The contributions of specific emission source sectors to the local air pollution disease burden can identify which sectors have the most impact on health. Health impact assessment can also be used to estimate the reduced number of cases of death or disease from an action that improves air quality.

Typically, health impact assessments use the following approach:

Pollutant-attributable cases of health outcome = Pollutant concentration change * Concentration-response factor * Exposed population * Baseline disease incidence rates

- Pollutant-attributable cases of health outcome: the number of cases of mortality or disease (e.g., lower respiratory infection) in an exposed population that are attributable to the change in pollutant levels
- Pollutant concentration change: the difference between the starting pollutant concentration and the pollutant concentration occurring after an emission change (e.g., implementation of a policy to transition from burning biomass to burning ethanol).
- Concentration-response factor: the estimated percent change in the risk of a health outcome resulting from a unit change in pollutant concentration, typically from epidemiology studies.
- Exposed population: the number of people who are affected by the change in pollutant concentration.
- Baseline disease incidence rates: estimates of the number of cases of disease in a given population over a given period of time (e.g., the number of cases of lower respiratory infection annually per 100,000 people).

Several tools are now available to automate this health impact analysis. There are two overall categories of air pollution health impact assessment tools: full-scale tools that require air quality modeling data for the health impact assessment (e.g., BenMAP-CE, AirQ+) and reduced-form tools that connect emissions to health impacts, without needing chemical transport modeling (e.g., LEAP-IBC, TM5-FASST). Generally, reduced-form tools provide initial results when chemical transport modeling is not yet available or where many different policy scenarios are being compared. Full-scale models can be used to assess a smaller number of policy scenarios in more detail.

Tool for full-scale health impact assessment: BenMAP-CE

The environmental Benefits Mapping and Analysis Program – Community Edition tool (BenMAP-CE) is an open-source computer program that was developed by the U.S. Environmental Protection Agency and can be applied to any city or country, anywhere in the world. The program calculates the number of cases of disease associated with air pollution changes, using either modeled or monitored air pollution levels, population datasets, disease incidence rates, and epidemiologically-derived concentrations-response factors. BenMAP-CE can help answer questions such as "What is the burden to human health of total air pollution?" and "What are the benefits of policies reducing air pollution by a certain amount?" BenMAP-CE first determines the change in ambient air pollution levels using user-specified air quality data. These data must be input into BenMAP-CE as either modeling data or generated from air pollution monitoring data. Then, the program uses epidemiologically-derived health impact functions to translate the change in pollution concentrations to the number of pollutant-attributable cases of various health endpoints. BenMAP-CE training materials are available for many countries worldwide (see https://www.epa.gov/benmap).

Tool for reduced-form health impact assessment: LEAP-IBC

The Stockholm Environment Institute (SEI), in partnership with the U.S. Environmental Protection Agency and University of Colorado, has been developing extensions to the Long-range Energy Alternatives Planning system (LEAP) to allow it to be used for planning joint strategies to combat air pollution and climate change. LEAP is an integrated energy and climate mitigation planning tool that is widely used in LMICs as the basis for their energy and climate mitigation planning. It has been used by more than 40 countries to help develop their Nationally Determined Commitments, submitted to the Paris Climate Conference, and is now used in more than 190 countries globally. A new extension to LEAP, the Integrated Benefits Calculator (IBC) allows users to quickly assess the climate change, human health and ecosystem benefits of alternative emissions scenarios. The tool is made available at no charge to governments, NGOs, and academics in low and lower-middle income countries and is designed to be usable by planners, not just than expert modelers. It currently works at a national scale, and a version suitable for use at the city scale is under development.

Tool for estimating health impacts of household air pollution: HAPIT

The Household Air Pollution Interventions Tool (HAPIT) was developed by University of California-Berkeley and is made available on the Clean Cooking Alliance webpage (https://householdenergy.shinyapps.io/hapit3/). HAPIT can be used to estimate changes in health impacts from household air pollution as a result of interventions designed to lower exposure levels. Potential types of interventions that can be analyzed include cleaner burning stoves, cleaner fuels, providing chimneys or other ventilation changes, movement of the stove to a different location, or a combination of any of these. Users input pre- and post-intervention PM2.5 exposure levels, as well as specific population data for the population affected by the intervention. HAPIT then provides estimates of averted cases of disease and disability-adjusted life years resulting from the intervention. HAPIT can also be used to evaluate other interventions for household air pollution (e.g., lighting and spaceheating). While household air pollution contributes to ambient air pollution, HAPIT does not currently estimate changes in health impacts from changes in community or regional ambient air pollution levels.

Health impact assessment, as described above, is a straightforward approach to calculate "estimated" health impacts given observed concentrations of pollutants and general knowledge about the magnitude of health impacts that may result from those concentrations. However, these methods have limitations such as assumptions that the existing health effects can be predicted by data that was obtained in some other part of the world (e.g., USA or Europe). This assumption is limited in its validity due to global differences in the characteristics of: air pollution, health care systems, population activity patterns, housing structures, etc. For this reason, epidemiologic studies in the country of interest are valuable, with the goal of generating more locally-relevant exposure-response functions. By linking the air pollution data to local health records from hospitals or other sources, local researchers can use time series methods to analyze and report on the exposure-response functions.

4.4 WAYS FORWARD

The next steps for implementing air pollution solutions include raising awareness of air pollution and health as described earlier in Figure 4. Raising awareness includes making measurements of air pollutants and then communicating those levels of air pollution and their health impacts. The health sector can play a significant role in this communication. Other aspects of raising awareness include broadening and maintaining the evidence base, sharing knowledge, and considering incentives that align with improved practices.

4.4.1 Engaging the health sector

Historically, air quality management has been viewed as an environmental issue, often without consistent and direct engagement from health, energy, transportation, and other sectors that influence, or are influenced by, air quality. Engaging the health sector is a newer approach to addressing air quality. While the medical health sector has recognized the importance of air pollution as a health risk for some time, their direct involvement in air quality planning has been limited historically. In contrast, the public health sector has historically been more engaged, especially through research, to characterize levels of air pollution and their health effects via epidemiologic studies, as well as in developing air quality standards. Both sectors will need to play larger roles in promoting awareness of and building support for air quality improvement initiatives in LMICs.

Key strategies that may be relevant entry points for health sector engagement include:

1. Public health professionals can develop an investment case for actions to improve air quality by compiling data that links air pollution with health outcomes and delineates health care costs and economic implications. Governments often make decisions based on cost of action vs inaction, or by comparing costs of action vs. benefits of action. Estimates of the local health benefits from various actions that reduce air pollution (e.g., using BenMAP-CE, LEAP-IBC, HAPIT, or other health impact assessment tools) can provide valuable information to decision-makers. In addition, air pollution interventions are under discussion to be included in the Lives Saved Tool (LiST), which will enable the cost-benefit analysis for these interventions to be readily compared to other public health interventions. Hospital data records, surveys, and insurance data can be used to generate health outcome data for use in epidemiologic studies to quantify health impacts of air pollution, but these records may not be readily available. Measuring outcomes at the health center level allows health providers to monitor patients, potentially identify risks specific to communities, and educate patients on these risks.

2. Health care professionals play a role in messaging and advocacy. Frontline care providers are a powerful entry point with respect to empowering patients with knowledge of air pollution risk factors and also influencing the health sector by joining other providers to emphasize the importance of air pollution as a risk to patients and public health. To ensure health care providers are equipped with accurate information and knowledge on key risks and interventions, appropriate information must be available for continuing medical education and related programs. Information can also be disseminated through professional medical associations and convenings. For example, Doctors for Clean Air Program in India is allowing doctors and physicians to engage in the discourse on air pollution and raising awareness about the impact of air pollution on respiratory and cardiovascular health. The Pan Africa Thoracic Society in South Africa trains physicians to better recognize the health effects of air pollution and advises patients about reducing their risk. In this context, national and local health agencies can also play an important role by designing awareness programs tied to broader public health surveillance initiatives.

3. Hospitals and health facilities advocate for best practices. Health facilities can select clean energy sources and clean waste disposal options. The medical sector consumes large fractions of total national energy and if that investment were in clean energy, both the reduced air pollution and the demonstration to the public would be significant. Additionally, health facilities at every level (community to tertiary care hospitals) generate waste – the transition from local incinerators to environmentally friendly waste disposal practices would both reduce air pollution and provide a model of best practices for the community. The Ministry of Health can integrate environmental health mandates to ensure health programming includes environmental perspectives. The organization Healthcare Without Harm has challenged health care systems to opt for environmentally friendly alternatives as health care should not contribute to environmental pollution or disease.

4. Ministries of health engaging in inter-ministerial convergence may improve planning and policy implementation by integrating across health, environment, energy, and transportation ministries. While environment ministries may be viewed as the natural government structure for air pollution management, ministries of health can model planning processes, implement policies and programs, host data, and drive structural changes that eventually link relevant ministries such as environment, energy, transportation and finance to facilitate cross-sectoral collaboration and response to air pollution. Ideally, ministries of finance, which have convening power, would lead programs and policies surrounding air pollution. Air pollution requires multiple relevant sectors and stakeholders to facilitate interministerial convergence in data sharing, planning and response to air pollution. The health sector has an opportunity to exert influence over emitting sectors by highlighting the public health consequences of action vs. non-action.

4.4.2 Broadening and maintaining the evidence base

The knowledge gap on air pollution, health effects, control measures, and regulatory/policy frameworks in LMICs limits progress in air quality. Investments in research across this full spectrum are essential for generating the localized data and knowledge for taking action. A first critical step is to establish routine, ongoing air monitoring networks in LMIC cities. Further research can be divided into two overarching categories:

Air quality research to better understand air pollution, its sources, and its health effects

Air pollution data will generate new information about health effects as well as the influence of specific emission sources. These results can help focus efforts on key emission sectors and developing control measures aimed at reducing emissions. Air quality modeling can support scenario analyses that enable balancing a complex set of options to reach the optimal cost and benefit outcomes (and simulate air quality and health improvements under different policy scenarios). The availability of air quality data will also enable and leverage epidemiologic studies aimed at quantifying the health effects of air pollution in the cities and countries in which air quality management programs are under development.

Implementation research to better understand effectiveness of air quality programs and policies

Implementation research allows existing mitigation strategies to be examined in new contexts and countries to create evidence-based implementable solutions. The roles for policy, city leadership, health practitioners, local civil society, and others that can be examined through an implementation research agenda. Since the major emission sources differ in LMICs as compared with the U.S. and Europe, research is needed to understand which control measures may be appropriate in LMICs, as well as how different sectors and stakeholders can most effectively work together to implement those control measures.

Implementation research is important for setting emission standards and national ambient air quality standards, as well as developing effective systems for monitoring and enforcing air quality policies. Implementation research is also needed to understand the effectiveness of different emission interventions. For example, for household air pollution, implementation research has been critical to improve our understanding of which clean fuels and improved stove designs are appropriate in different contexts, which factors lead to household adoption and exclusive use of those cleaner technologies, and how clean household energy improves emissions, air quality, and health outcomes. Similar implementation research is important for reducing trash burning, agricultural burning, and transportation emissions.

4.4.3 Sharing information about air pollution levels and associated health impacts

1. Information for the public

Setting up ground monitors in locations that do not have existing monitors can substantially improve the availability of information. Making these observations public by providing data to websites such as OpenAQ helps to bring public attention to the issue. Currently, much of the world is lacking air quality monitoring, making it difficult to provide high-quality information about pollution levels in Africa, Latin America, and throughout much of Asia. Other types of information have been used to fill in the gaps – including satellite remote sensing of aerosol optical depth and chemical transport models. However, these methods have challenges and limitations, and past experience indicates that ground monitor observations are more highly trusted by local officials compared with estimated concentrations.

In addition, it is important to invest in training for local analysts to operate and maintain air quality monitors, develop emissions inventories, assess impacts of emission sources on air quality, and estimate health impacts of air pollution changes. Capacity building ensures that these key elements of air quality management systems are sustained over time. Air quality and health impact assessment tools that are easy to use and understand by local analysts and officials are also needed.

2. National and intergovernmental efforts to share information

Countries and cities that have long histories of managing air quality can provide a rich resource for cities and countries just getting started with air quality management. Several efforts are already underway to share information for different world regions and contexts.

The U.S. EPA engages with countries to set up air quality monitor networks and report the measurements through its AirNOW public information system, trains users around the world to run the air pollution health impact assessment tool BenMAP-CE, and maintains an Air Quality Training Institute on a wide variety of air quality management topics (https://www.apti-learn.net/LMS/EPAHomePage.aspx). The World Bank has also developed training courses through its Open Learning Campus, including an Introduction to Air Quality Management course.

Climate science provides some examples for how national entities share information about air. The Climate and Clean Air Coalition's Supporting National Action Planning Initiative engages directly with countries around the world to develop national action plans to mitigate short-lived climate pollutants. Through this process, they are providing expert assistance to develop emission inventories, estimate air quality and public health impacts of policies, and navigate the national regulatory and political landscape to incorporate short-lived climate pollutants into policy-making.

3. Knowledge sharing between cities

Several efforts to share knowledge between cities worldwide are underway, including by C40 Cities Climate, the Climate and Clean Air Coalition/World Health Organization Urban Health Initiative, Clean Air Asia, and the Global Urban Air Pollution Observatory (Table 3).

Table 3. Existing efforts to share knowledge on air quality management among cities worldwide (see Appendix C for more detail).

PROJECT/ORGANIZATION	DESCRIPTION OF KNOWLEDGE SHARING ACTIVITIES
C40 Cities Climate	C40 convenes networks that provide a range of services in support of cities' climate change, air quality, and public health efforts; C40 also coordinates technical assistance, research, and communications support to cities.
Climate and Clean Air Coalition/ World Health Organization	Urban Health Initiative aims to generate replicable tools and guidance materials for cities worldwide to realize climate, air quality, and health co-benefits.
Clean Air Asia	Cities Clean Air Partnership provides cities with incentives, direct support, and technical assistance to promote continuous incremental movement toward achieving clean air targets.
Global Urban Air Pollution Observatory	The Observatory aims to facilitate collection and sharing of data on urban air pollution and associated health impacts, develop cooperation and exchanges between member cities, provide curated information about technological innovations and regulatory developments in cities, and promote local initiatives that have proved successful at lowering pollutant concentrations
World Bank	Pollution Monitoring and Environmental Health aims to develop robust air quality management plans which will provide the basis for implementing projects to reduce air pollution and simultaneously short-term climate pollutants and greenhouse gases.

4. South-South Learning

South-South Cooperation is an exchange of information, resources, and technology between LMICs in the Global South. Several examples of South-South Cooperation demonstrate how countries in the Global South can cooperate to address air pollution given similarities in emission sources, public health challenges, and other energy, environmental quality, and governance issues. For example, the Climate and Clean Air Coalition and Clean Cookstove Alliance have facilitated knowledge exchange in a South-South Cooperation Workshop in Kenya in July 2018. There is cooperation between: (i) India and Ghana on LPG distribution for household energy needs; (ii) China and Myanmar in 2014 demonstrating bilateral support for clean cooking. Through these partnerships, countries can share valuable insights with each other to help advance air pollution mitigation efforts across the Global South. Such exchanges can focus on a narrow aspect of the problem (e.g., clean cookstoves, emission control technologies) or can be designed to address the issue more broadly, considering sustainable development and public health goals.

4.4.4 Paying for air pollution mitigation

Taxes, Fines and Subsidies. One aspect of paying for eco-services is to assess a small environmental- or eco-tax on fossil fuels. Before a revenue generation scheme can be introduced, the public needs to trust the government that the revenue generated will be used appropriately and in a way that benefits the public broadly. Fuel taxation is particularly challenging because there are few fuel suppliers and the costs typically are passed on to the consumer. The "emitting sector" also needs to be included in the taxation framework. Fuel taxes can have the added benefit that clean fuels can become more cost competitive (e.g., in Kenya, ethanol became cost competitive and LPG more cost-competitive when higher emitting fuels such as charcoal, firewood, and kerosene were taxed). One complexity with adding taxes and fines is the requirement for enforcement. Other complications arise when fuels are used for multiple purposes; for example, when diesel is taxed to encourage fuel switching to cleaner fuels, it may increase the price of public transport systems that also rely on diesel. In some cases, existing subsidies may be redirected towards the populations who need it most (such as in India, with efforts to redirect the clean fuel subsidies).

Public Private Partnerships (PPPs). PPPs can be effective for promoting clean air solutions. Creating a local biogas plant through a PPP may create jobs and clean household fuel and may facilitate reductions in burning wood or dung that are highly polluting fuels.

5.

Case Studies

Several LMIC case studies of air pollution mitigation are described below that illustrate working to solve air quality challenges in local areas.

5.1 GHANA: BUILDING AIR QUALITY MANAGEMENT PROGRAMS IN ACCRA

What is the problem? Many of the most rapidly growing urban areas in LMICs have limited data, resources and capacity, but significant health impacts from air pollution. Enhancing air quality management planning in urban areas and using available data can help accelerate local action and improve public health.

What actions are being taken? In 2015, the U.S. EPA began supporting air quality management planning in Accra, Ghana in strong partnership with EPA Ghana through the Megacity Partnership. That partnership led to the 2018 launch of an integrated air quality management plan (AQMP) for Accra, focused on reducing PM2.5 and ozone, along with the precursors that form those two pollutants. Beginning in August 2018, the partnership initiated a follow-on air sensor pilot designed to deploy and operate a low-cost particulate matter air sensor network in and around Accra to complement the Ghana EPA's existing network of air quality monitors. Preliminary findings from this pilot should be available by early 2020.

What are the results of the actions? The most visible accomplishment was launch of the 2018 AQMP, but the Partnership has a robust capacity building component. Notably, the planning and the associated capacity building set the stage for Ghana EPA to receive follow-on support from the World Bank's Pollution Management and Environment Health (PMEH) program. In December 2018, the World Bank issued a request for proposals to conduct additional monitoring data development, laboratory analysis and AQM training and support with a goal of revising the AQMP in 2021 based on improved data [8].

The Megacity Partnerships have illuminated several key themes that might inform others as they engage in work to support evidence-based solutions to air pollution challenges in LMICs.

1. Strengthening long term capacity. Any organizations working with LMIC governments should keep central the capacity building necessary for air quality management to continue beyond the lifespan of any given project. The projects must be guided by local decision-making, buy-in, and resource commitments, and should invest in local staff, build lasting support networks and enable communities of practices by and for LMIC practitioners.

2. Lowering emissions and improving public health. The Partnership establishes a framework for immediate action that can achieve near-term emission reductions and reduce human exposures. The experience of the Partnership suggests that where air pollution levels are high, initial measures to improve air quality likely can be identified and justified even when air quality and source attribution information is initially lacking. The experience in Accra also shows that such early success builds a foundation for additional donor support.

3. Equipment, data and guidance relevant to LMIC conditions. Developed country solutions can inform, but may not be implementable, in countries that are fundamentally different, both environmentally and politically. Existing open source software tools for archiving, interpreting and communicating about air pollution data and supply chain issues can be informative.

4. Communications. Building capacity to communicate about air pollution is as important as the technology and staffing investments. The goal is to develop publicly available and understandable air quality information. The public is a key partner in air quality solutions, but needs quality and timely information to be an effective advocate.

5.2 INDONESIA: DEVELOPING A ROADMAP FOR ADDRESSING AIR POLLUTION

What is the problem? Indonesia is challenged by high air pollution levels from (i) landscape fires, particularly on peatland, that are used to clear land for agricultural production; and, (ii) the growing contributions of urban air pollution. Jakarta, with 8 existing coal-fired power plants, vehicular emissions, industrial sources and domestic sources, has average levels of pollution at least 3-fold higher than WHO Air Quality Guideline.

Nationally, BKMG (National Meteorological Agency) has monitoring systems dispersed throughout the country. These typically monitor PM10 levels, rather than the more important PM2.5, and numerous monitoring stations are not active. Lacking sufficient spatial and temporal data, the specific type and source of pollutants that are most responsible for elevated particle levels are not well understood.

Indonesia has a national action plan on climate change which includes quantifiable emission reduction targets of 29% by 2030 and 41% with international assistance. However, the national baseline is unclear, the plan does not acknowledge the presence of high-risk areas, and concrete strategies for emission reduction are missing.

What actions are being taken? Some progress is being made towards developing a roadmap for reducing air pollution in Indonesia, though the country needs to move from planning into actions that result in substantial air quality improvements. Jakarta is one of the 94 world megacities that is participating in the C40 initiative. In addition, Jakarta recently established a partnership with UNICEF. In July 2018, Vital Strategies partnered with Indonesia's Ministry of National Development Planning, the Provincial Government of Jakarta, and UNICEF Indonesia to host "The Air We Breathe," a symposium in Jakarta that called on experts to discuss air pollution and children's health and the evidence-based policies needed to create cleaner air. Vital Strategies and UNICEF Indonesia also released an evidence brief (https://www.vitalstrategies.org/publications/air-pollution-a-threat-to-childrens-health-in-indonesia/) aimed at informing governments and other stakeholders on the health risks of air pollution experienced by children. Clean Air Asia has outlined a set of interdependent steps to inform action.

There are active efforts underway to ensure complementarity in workstreams. Key priorities have been widely agreed and include efforts to:

- Quantify air quality, as well as the leading sources of pollution, through increased air quality measurement and modeling
- Measure, regulate, and track progress on air quality in a transparent way
- Increase public awareness about air quality and its impacts
- Reduce emissions from leading sources by supporting strategies to reduce emissions from coal-fired power plants through existing technologies; reviewing and strengthening vehicle emission standards; fostering the introduction of innovations to reduce vehicular emissions (retrofitting older vehicles, considering taxes, subsidies, trade-ins); and introducing clean burning motorcycles.
- Support policy-relevant impact assessments including impact modeling of interventions, developing the economic case for addressing air pollution, and assessing/costing long term solutions including renewable energy sources.

5.3 NEPAL: PROGRESS ON AIR POLLUTION IN KATHMANDU

What is the problem? Air pollution in the Kathmandu Valley is high – about 5 times higher than the WHO Air Quality Guideline – and transport is the main source of air pollution in the Valley. The growing pollution has attracted significant media attention, and advocacy groups have also raised their voices against the pollution. The government has responded with a few measures, but these are often scattered and insufficient. The multi-sectoral nature of the air pollution problem there requires coordination across sectors, and yet no central agency is responsible for air quality management.

What actions are being taken? The Mayors of the 18 municipalities in Kathmandu Valley have a created a Forum to further coordinate and share experiences among the city governments. As city governments are responsible for overall urban development and management of basic urban services such as waste management, they can play an important role in providing solutions to urban pollution. The recently elected Kathmandu city officials – local elections were held in 2017 after 20 years – can take on this responsibility if their capacity is enhanced and they are provided with the full support and cooperation of other agencies [9].

There are many entry points to reducing air pollution in Kathmandu. In the case of urban mobility, cities can adopt the Avoid-Shift-Improve strategy to reduce air pollution by reducing travel, shifting to environment friendly modes of transport, and improving the energy efficiency of vehicles. Cities can promote compact settlements with streets that promote walking, cycling and public transport to reduce the use of polluting vehicles and shift to environmentally friendly modes of transport. In this context, the Global Street Design Guide, prepared by National Association of City Transportation Officials (NACTO) in the US and Global Designing Cities Initiatives based on experiences from 72 cities in 42 countries, can be a useful resource for city governments and is already used in Mumbai and Addis Ababa.

In the long-term, managing air pollution in an integrated manner is essential. Actions such as designing compact cities with streets that prioritize walking, cycling and public transport, promoting electric vehicles, particularly for public transport, and managing waste effectively are key solutions to air pollution.

5.4 EAST AFRICA: ASSESSING AIR POLLUTION EXPOSURES AND HEALTH RISKS

What is the problem? Eastern Africa is one of the fastest growing regions in the world, demographically and economically. Since the 1960's, the population of Ethiopia quadrupled to over 100 million, and the population of Kenya and Uganda increased five-fold. Population pressure in these countries results in environmental degradation, poverty and conflict. Seeking alternative livelihoods, people migrate to urban centers. These emerging cities face tremendous resilience and sustainability challenges.

What actions are being taken? The Eastern Africa GeoHealth Hub has conducted situational analysis and needs assessment (SANA) in these four countries and has selected ten schools in each major city for monitoring PM2.5 and children's health over one year per city in a rotating schedule. Beta Attenuation Monitors (BAM) have been installed at strategic locations to continuously monitor PM2.5 in each city.

The GEOHealth Hub intends to partner with relevant government institutions to establish air quality monitoring programs in the respective countries and continue to study the long-term effects of air pollution. In Ethiopia, Addis Ababa City Administration and Oromia Regional State are likely candidates to host the program in partnership with the Federal Environment, Forest and Climate Change Commission which is responsible for the implementation of the government's Climate Resilient Green Economy Strategy. Many international partners are interested in working with the Addis Ababa City government in efforts to control air pollution. The U.S. EPA is adding Addis Ababa to the Megacities Partnership Program. In addition, NASA's forthcoming MAIA satellite will monitor PM2.5 and its component species from space at a 2x2 km spatial resolution over entire cities and will use Addis Ababa as one of its core air pollution sites. The SPARTAN PM network will also place a monitor to identify leading sources of pollution and allow better benchmarking of the NASA satellite data. With such growing interest in the air pollution-health-development nexus, practical solutions to combat air pollution may be available soon.

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A.

Appendix

HEALTH IMPACTS OF AIR POLLUTION

Air pollution is associated with a range of health outcomes, including cardiovascular disease, respiratory disease, lung cancer, diabetes, low birth weight, neurodegenerative disease, and premature mortality. Most of the health damage from air pollution is thought to result from long-term exposure to PM2.5 and and short-term exposure to PM2.5 as well as gases such as ozone, SO_2, and/or NO_2. Among the ubiquitous air pollutants, PM2.5 is the pollutant most associated with disease and mortality burdens on a global basis. PM2.5 refers to any airborne particle smaller than 2.5 micrometers in aerodynamic diameter, regardless of its composition. Some components of PM2.5 (i.e., generated by particular fuels or sources) might be more or less toxic than others. Regardless of the source, inhalation of PM2.5, ozone and other air pollutants can lead to both immediate and long-term impacts on human health. There are extensive studies of health outcomes associated with air pollution, including epidemiological and toxicological studies underlying these associations. Comprehensive systematic reviews have been carried out by the U.S. Environmental Protection Agency and the World Health Organization, among others [10].

According to the Institute for Health Metrics and Evaluation Global Burden of Disease (GBD) 2017 Study, ambient and household air pollution was responsible for approximately 4.9 million premature deaths worldwide, making it the 5th leading risk factor affecting mortality globally. Ambient PM2.5 was associated with 2.9 million deaths globally. Use of solid fuels (both biomass-burning stoves and open fires) in households is estimated to contribute to 1.3 million annual premature deaths globally (3% of total global deaths) and more than 50% of premature deaths from pneumonia among children under 5 years of age. It should be noted that these numbers do not reflect the full public health burden from air pollution, as they consider only a few air pollutant categories (ambient PM2.5, household air pollution, and ozone) and six health outcomes (stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, lower respiratory infections, and diabetes). The GBD currently excludes other air pollution-related risk-outcome pairs for which the literature supports associations such as the effects of traffic-related NO_2 on pediatric asthma incidence.

Most of the worldwide air pollution-related premature deaths (approximately 75%) occur in LMICs, and the vast majority of air pollution-related deaths among children under 5 years old occur in LMICs. LMICs tend to have much higher levels of ambient PM2.5 and HAP as compared with higher sociodemographic index countries. The opposite trend is observed for the air pollutant ozone.

Due to their physiology and the degree of exposures, children are uniquely vulnerable to air pollution. Children breathe twice as quickly as adults and take in more air relative to their body weight. Global estimates suggest that nearly 1 in 10 under-5 deaths are linked to air pollution in children. Pregnant women are also at risk as the fetus is highly susceptible to air pollution toxins due to high level of cell proliferation and organ development.

Prenatal and childhood health effects of air pollution have the potential for impacts on health and productivity across the life course. UNICEF reports that over 300 million children are exposed to health-damaging levels of outdoor air pollution, and daily HAP exposure further contributes to their exposures.

In sub-Saharan Africa, AAP is estimated to reduce the average life expectancy of children by 4–5 years, which accounts for 18% of all losses in life expectancy from AAP. Ambient PM2.5 levels across the continent of Africa correlate a 10 ug/m3 increase in PM2.5 with a 9% rise in infant mortality in West Africa. Perhaps the most significant takeaway from this study was that modest reductions in PM2.5 exposures are predicted to have health benefits to infants that are larger than most other health interventions. HAP is estimated to contribute more than 50% of premature deaths from pneumonia among children under 5 years of age. Examples of health impacts from HAP include a higher risk of all-cause mortality in children by 27% and a 73% increased risk of acute lower respiratory infections (ALRI) in children, the leading cause of child death globally. HAP also contributes to lower birth weight, increased risk of newborn mortality, stillbirth, severe and moderate childhood stunting, and impaired child cognitive development [11].

While biological mechanisms of action vary depending on the pollutant, many of the adverse health impacts of air pollution are thought to be related to oxidative stress and inflammation that occurs in the lung and may have systemic effects in other parts of the body when transported via the bloodstream. When pollution is inhaled, the site of greatest initial impact is usually deep the lungs, where sensitive cells can be damaged. This damage can lead to the recruitment of inflammatory cells that are designed to fight infections and repair damage. This ensuing oxidative stress and inflammation can lead to further damage in the lung, and potentially elsewhere in the body. With repeated exposure, this pattern of ongoing oxidative stress and inflammation can lead to chronic lung and heart disease, much like the effects of cigarette smoke.

As this section makes clear, air pollution is responsible for a significant burden of disease and death around the world. By reducing human exposure to air pollution, both ambient and household, we have a significant opportunity to improve health outcomes.

B.

Appendix

CO-BENEFITS FROM AIR POLLUTION MITIGATION ACTIONS

Transitioning to clean energy will not only reduce air pollution and improve public health, but will also yield co-benefits for the environment, forests, climate, gender equity, and livelihoods that lead to self-reliance. For example, when households transition away from burning biomass, forest degradation is concomitantly reduced, and women and girls no longer spend time collecting biomass. These co-benefits can play a key role in decision making and policy development and lead to a multi-sectoral interest in reducing air pollution [12].

Reducing the use of wood as a fuel can both reduce air pollution and reduce **forest degradation**. Similarly, reducing burning that leads to forest degradation can also reduce air pollution. Forest and peat fires are a serious and persistent problem, particularly in Asia and the Pacific. Today up to 7% of the world's population uses slash and burn agriculture. This agriculture clearing and preparation method is a major contributor to increased air pollution and a major cause of forest fires. Fire smoke emissions are an important contributor to global mortality, associated with an estimated 339,000 premature deaths annually, mostly in Sub-Saharan Africa and Southeast Asia. Smoke from these landscape fires contains PM2.5 and a variety of other chemical components that are associated with respiratory health effects. In addition to the health-damaging air pollution, the use of fire as a land-clearing approach is a major threat to biodiversity in many regions, and wildfire is one of the major sources of landscape-based CO2 emissions. Some approaches for reducing smoke from landscape fires include promoting no-burn methods in the agricultural sector as a whole, which may decrease forest fires by up to 90 per cent in some countries. In addition, where land-clearance activities cause the majority of fires, creating a market for useful agricultural-residue products may provide greater incentives for no-burn clearing methods.

Air quality is also closely related to **climate change**. As many emission sources release both air pollutants and greenhouse pollutants, air pollution mitigation approaches will often have ancillary benefits for climate change. In particular, any approach that reduces the combustion of fossil fuels, including those approaches aimed at increasing energy efficiency, promoting electrification of households by generation from renewable sources, and increasing access to public transportation to reduce fossil fuel use in households and vehicles, will likely yield co-benefits from reduced emissions of pollutants relevant for both health and climate. In contrast, air pollution control measures that remove air pollutants from effluent streams, but do not reduce fuel combustion (e.g., adding catalytic converters and diesel particulate filters for vehicles or scrubbers for power plants), may only reduce air pollution and not reduce greenhouse gases.

Climate change can increase air pollution by increasing reaction rates that affect the production efficiency of ozone and secondary organic particles in the atmosphere. Climate change can also increase air pollution by increasing "natural" emissions of landscape fire smoke and wind-blown dust. Air pollutants, some considered “short-lived climate pollutants” (e.g., black carbon and methane) can also affect the climate. Air pollution and greenhouse gases are both emitted simultaneously when fuel is burned; therefore, reducing fossil fuel combustion can yield simultaneous benefits for mitigating climate change and air quality, while also improving public health. In contrast, air pollution mitigation actions that reduce air pollutants from effluent streams (e.g., catalytic converters and diesel particulate filters on vehicles and scrubbers on electricity generating units) will not achieve climate and air quality co-benefits as greenhouse gases are still emitted. While these “end-of-pipe” control measures are likely cheaper and easier to implement, the societal benefits from reducing fossil fuel combustion can be far greater.

Increasing access to clean energy also improves **gender equity** as clean energy access can reduce the time required to collect firewood for cooking, a task primarily carried out by women and girls. As women and girls perform most of the world’s unpaid care work, they bear the impact of collecting firewood which increases time poverty and may also increase their vulnerability to gender-based violence. Furthermore, as girls transition away from fuelwood collecting, they can pursue other opportunities such as education, earning income, or rest. Unpaid work can impact girls’ education as they are the first to be pulled from school when household tasks need to be completed. It is globally recognized that time poverty is a key driver of gender inequality. Transitioning households away from solid fuel combustion can therefore yield multiple societal benefits – reduced household and ambient air pollution, improved health status, and more opportunities for women and girls within their households and communities.

Reduced forest degradation, climate change mitigation, and gender equity are just three of the many co-benefits that can be achieved by taking action to address air pollution. To realize these co-benefits, it is important to take an integrated and comprehensive approach to planning air pollution mitigation that considers contributions from multiple emission sectors, as well as the many different health, social, and economic impacts that different approaches can have. A narrow assessment of approaches that only includes technological approaches to reducing air pollution, or that considers impacts only to air quality, may miss opportunities to improve health and well-being for communities beyond the health benefits from reduce air pollution exposure.

C.

Appendix

ADDITIONAL DESCRIPTIONS OF EXISTING EFFORTS TO SHARE KNOWLEDGE AMONG CITIES

C40 Cities Climate. C40 connects about 100 of the world's greatest cities, representing 700+ million people and one quarter of the global economy. C40 has historically focused on driving urban actions that reduce greenhouse gas emissions and climate risks, and is increasingly incorporating air quality into their activities. C40 convenes networks that provide a range of services in support of cities' climate change and public health efforts. Through these networks, city practitioners from around the world advise and learn from one another about the successes and challenges of implementing climate and air quality action. C40 also coordinates technical assistance, collaborative research, and communications support to cities. By incorporating a more direct focus on air quality in addition to their traditional greenhouse gas mission, cities will be able to improve their understanding of mitigating measures that achieve co-benefits for climate, air quality, and health. For example, one activity underway is to incorporate PM2.5 and associated health impacts into C40's Pathways climate action planning tool. This additional functionality will allow cities to estimate air quality and health co-benefits of various approaches to reducing greenhouse gases. Since these air quality and health co-benefits would be local and immediate, as opposed to the long-term and global benefits of greenhouse gas mitigation, they could provide strong added motivation for cities to take action.

The Climate and Clean Air Coalition/World Health Organization Urban Health Initiative. The Urban Health Initiative started in 2016 and focuses on engaging the health sector to realize climate and health benefits. Partners include the Climate and Clean Air Coalition, the World Health Organization, UN HABITAT, UN-Environment Programme, Vital Strategies, Local Governments for Sustainability (ICLEI), and Internatioanl Centre for Integrated Mountain Development (ICIMOD). The Urban Health Initiative began with two pilot projects in Accra and Kathmandu, with the goal of proving the concept and generating replicable tools and guidance material for other cities. The steps involved are to assess and map current policies, build competencies among health policymakers to assess health impacts and communicate them, develop tools for assessing health and economic benefits, assess and test alternative scenarios on policy options, integrate health into urban policies, intensify demands for change through communications, and incentivize urban leaders to act by tracking air quality and climate indicators. As part of this initiative, the CCAC and WHO launched their BreatheLife communications campaign, which shares information about actions cities globally are taking to address air pollution. Activities are currently ongoing.

Clean Air Asia. Clean Air Asia's Cities Clean Air Partnership (CCAP) established a platform for cities to cooperate and jointly address air quality challenges. The goal is to provide cities with incentives, direct support, and technical assistance to promote continuous incremental movement toward achieving clean air targets.

Specific activities include the City-to-City Cooperation (C3) program, which partners volunteer cities together to allow exchange of information on effective practices and solutions to address specific air quality management challenges faced by cities, the City Certification Program, which will allow cities to communicate air quality management achievements through a "seal of approval", and a Knowledge Platform, an online resource for sharing best practices.

Global Urban Air Pollution Observatory. The recently launched Global Urban Air Pollution Observatory (GUAPO) is a collaborative platform for multilateral cooperation between cities globally. Specifically, GUAPO's objectives are to facilitate collection and sharing of data on urban air pollution and associated health impacts, develop cooperation and exchanges between member cities, provide curated information about technological innovations and regulatory developments in cities, and promote local initiatives that have proved successful at lowering pollutant concentrations. The global exchange platform and other activities, including thematic working groups and data repositories, are still under development. Member cities to date are Paris, the Hague, Abidjan, Besancon, London, Madrid, New York, Tokyo, and Seoul.

World Bank. World Bank's Pollution Management and Environmental Health (PMEH) activity was launched to provide increased support on pollution management, and focuses on air quality management, water pollution, and toxic sites management. PMEH goal for air quality is to develop robust air quality management plans which will provide the basis for implementing projects to reduce air pollution and simultaneously short-term climate pollutants and greenhouse gases. PMEH is conducting air quality-focused projects in Hanoi, Lagos, Cairo, Johannesburg, Beijing, and China nationally. An overarching goal of the program is to generate and share knowledge on pollution and its health impacts, and to promote awareness of environmental health issues among policymakers, business partners, city leaders, and the general public.

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