Air Pollution Interventions

SEEKING THE INTERSECTION BETWEEN CLIMATE & HEALTH

GAHP
GLOBAL ALLIANCE ON HEALTH AND POLLUTION

AIR QUALITY ASIA
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BOSTON COLLEGE
SCHILLER INSTITUTE FOR INTEGRATED SCIENCE AND SOCIETY
Global Public Health and the Common Good

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The Global Alliance on Health and Pollution (GAHP) is a collaborative body made up of more than 60 members and dozens of observers that advocates for resources and solutions to pollution problems. GAHP's overall goal is to reduce death and illness caused by all forms of toxic pollution, including air, water, soil and chemical wastes, especially in low and middle-income countries.

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Summary for Policymakers

CONTEXT

Urban air pollution is a significant health concern in most low- and middle-income countries (LMIC) and often getting worse. Especially in high density cities, bad air contributes to significant levels of premature death and disease. Many millions of people die prematurely every year, although the lack of detailed monitoring presents challenges in determining worldwide totals. The most recent figures, which vary depending on the analytical approach used, indicate that between 3.0 million (HEI SOGA 2019) and 4.2 million (WHO 2018) premature deaths are caused every year by ambient (outdoor) air pollution.

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When household (indoor) air pollution (HAP) primarily produced by solid fuel-burning stoves is included, the number of pollution-related deaths rises by about another 2.9 to 4.3 million per year, depending on estimates (Lancet Commission 2017). Household air pollution in particular disproportionately affects women and children. Air pollution is a key driver in infectious disease and has been recognized as a significant contributing factor in the severity of the COVID-19 pandemic.

Climate change accelerated by human activity is firmly recognized as a major global problem and characterized by many as an emergency. Air pollution and climate change are closely linked: both are largely driven by the burning of fossil fuel and biomass for energy production and transportation. Yet coordinated planning between air pollution and climate, often undertaken at the national level, can meet with implementation difficulties. Key stakeholders, especially at sectoral or local levels, can have differing objectives and responsibilities, and determining effective priorities is often complex.

AIMS AND APPROACH

This report looks at actual air pollution interventions in developing countries in order to identify the most successful, practical actions to achieve co-benefits of pollution reduction and climate change mitigation. Not all interventions to reduce air pollution impact climate change significantly, and vice versa. A goal of this report is to identify those actions and interventions that can both improve health by reducing air pollution and impact climate change.

The report is intended to help governments and policymakers understand the impact of more than 20 identified practical interventions for addressing air pollution and to determine which of those interventions may be most feasible and effective for their particular communities. It is especially written for national, state/provincial, and city governments that have not yet managed to constrain air pollution and are exploring ways forward.

Several cities with decades of experience in tackling air pollution were selected for review, including Beijing, Bangkok, Delhi, Mexico City, and Santiago, Chile. Other cities with relevant activities were also examined.

Specific outcomes of interventions have lacked systematic analysis for effectiveness, and very little analytical data is available. The approach for this report thus relied on experienced consultants to document the interventions and outcomes and on a panel of knowledgeable experts to review and assess the findings. This is not, therefore, a scientific study. Rather the authors sought to learn from the experience of those who have been actively involved in implementing interventions to combat air pollution. In this boots-on-the-ground approach, the authors asked those deeply involved with air pollution projects around the world what had worked and what had not.

The subsequent findings are summarized and shown in the graphic, “Estimated Relative Benefits of Interventions,” which is included for convenience at the end of the summary and in the body of the report.

It should also be noted that actions to limit particulate pollution can be consistent with the United Nation's Sustainable Development Goals (especially health SDG 3.9, but also 7 and 13) and international agreements to achieve Net-Zero Carbon by 2050 (Rafaj 2018).

SCOPE

For simplicity, health impacts considered are deliberately restricted to those caused by airborne particulate matter which are 2.5 microns in size and smaller. Known as PM2.5, these particles account for over 85 percent of air pollution mortality (Institute for Health Metrics and Evaluation.) Thirty times smaller than the width of a human hair, PM2.5 is particularly deadly because the particles can carry other pollutants and once inhaled, they easily penetrate deep into the lungs and enter the bloodstream to cause damage to cardiovascular and respiratory systems. Secondary particulate pollution arising from chemical reactions in the atmosphere are also important, but beyond the scope of this report. Atmospheric chemistry is complex and there are even more important air pollutants, including ozone, nitrogen oxides (NOx), and aerosols, but these are also not included here.

Also for simplicity, carbon dioxide (CO_2) release is the main consideration for climate change, along with black carbon (BC), tiny particles of soot which can affect global warming. The latter are a major component of short-lived climate pollutants (SLCPs).

INTERVENTIONS

The first step to address air pollution is to identify the main sources of emissions. An appropriate emissions inventory of point and non-point sources and a monitoring and source apportionment system are basic requirements. Air quality information is used to determine sources of air pollutants, identify hot spots of exposure, and subsequently to see if programs are moving in the right direction. Adequately financed and stable local agencies and academic institutes are necessary to run and evaluate these programs. Reasonable targets and a timeline for interventions ought to be shared publicly. Good public communications and increasing awareness have been shown to improve outcomes.

Practical interventions examined include controlling or closing coal-fired power plants, improving fuel quality, reducing crop burning, improving vehicle standards, and other actions which can reduce the levels of particulates (improving health) or reduce CO_2 and black carbon (benefiting climate). A full list of the most significant interventions is provided in Table 1 in the report. These interventions vary in practical effectiveness. Some produce more benefits for air quality than climate and vice versa, while a number provide significant benefits for both. Interventions also vary according to cost effectiveness, both for governments and consumers. Some are more politically viable than others and, most importantly, different interventions are more appropriate at different stages of economic and institutional development.

Insights from reviews covering more than 30 countries and cities suggest that there has been a generally consistent sequence of interventions over decades in most places, starting with basic point source control and subsequently moving to address issues on a sectoral basis. Some forward-looking urban areas, such as Mexico City and Beijing, have begun to develop and implement comprehensive urban Air Quality Action Plans.

Actual targets selected for intervention at any time reflected local priorities, capabilities, and resources available. These choices represent, in broad terms, the perceived relative value/benefit of the different options available to policy makers. It may be effective for city programs to start with urgent, high health-benefit particulate reduction actions, such as closing old power plants, which often have the best political and public buy-in.

RELEVANCE

In practical terms, national governments usually control vehicle and fuel standards, transboundary issues, and energy policy. City administrations can address traffic issues, planning and urban development, as well as construction impacts and waste burning. Overall, national governments usually have a larger potential to impact air pollution than cities. Transboundary issues across both state and national boundaries can also be substantial, and formal "airshed" agreements can facilitate broad progress, as has occurred in southern California and Europe.

Interventions most relevant to cities and economies with limited resources include emissions controls on power stations and large industries, lower sulfur fuels for transport, and tackling old, highly polluting diesel heavy vehicles. Addressing the problems of household air pollution should focus on cleaner fuels and upgrading living conditions. Any city with ambition can begin to "leapfrog" and introduce low cost measures, such as walking and cycling zones, more green areas, and improved access to public transport.
In middle-income cities and those that have already made progress tackling basic problems, well-designed broad programs of interventions should be developed and supported with strong monitoring and public engagement. Programs typically include dealing with small scale industry and home heating, vehicular standards, road dust, and upgraded public transit.

Cities with greater resources or ambition can look at expanded renewable energy sources, planning and transportation, electric vehicles, circular economy, building efficiencies and heat pumps, green spaces and walkable urban cores, zero waste, and other emerging sustainable development options.

Informed governments can avoid simply following patterns of the past and seek innovative and cleaner outcomes. Successes in this approach abound—examples include the development of electric tuk-tuks in Bangkok, non-motorized transport (NMT) in Nairobi [Raje 2018], and heavy vehicle access controls in Delhi. Approaches such as these should be encouraged, although replication and scaling up often requires leadership, strategic financing, and focused efforts.

CONCLUSIONS

The single most effective action to achieve co-benefits is to phase out the use of coal and other fossil fuels, such as lignite and tar products, for power production. Some countries have made major progress toward replacing fossil fuel with renewable sources, but it is projected that by 2050 about 20% of global electricity production will still be based on coal (US Energy Information Administration 2019). Continuing efforts will be required to accelerate reductions in emissions from coal power generation, including promoting awareness of the socio-economic benefits of such changes.

Other effective interventions include mass transit systems, reducing agricultural and forest burning, moving to electric vehicles (especially buses), and urban redesign to promote non-motorized mobility. Upgrading fuel quality (such as that required to meet EURO standards) can reduce emissions of particulate matter, nitrogen dioxide, and other pollutants detrimental to health but has limited impact on climate change. Improved solid fuel cookstoves can provide some relief from smoke in the immediate vicinity, but moving to cleaner fuels is usually needed to achieve healthy household air quality.

Air pollution control and climate change adaptation in large urban areas should plan for future decades, addressing not just current problems but also future challenges. Integrated and holistic approaches to transportation, infrastructure and urban planning, as well as industry and construction provide co-benefits in terms of individual and public health, better mobility, and a more attractive environment. A major challenge is to convince sectoral agencies, planners and budget authorities at all levels—national, sub-national and metropolitan—to adopt air quality as a priority.

The long game, which should be kept in view at any level of intervention, is to move to a more efficient, electricity-based economy, powered by carbon-free sources. The general direction should include scaling up of renewables, vastly increased use of non-motorized transport or electric vehicles (or other new technologies), and forward-looking urban design and transportation systems which reduce the need for individual vehicles.

Finally, many opportunities exist to tackle both the health consequences of air pollution and climate change. Donors and development agencies can support government actions, assisting local agencies and individuals who are developing practical and holistic programs to reduce the impacts of air pollution. Local capacity development should be a priority with donors, along with assistance in launching scalable interventions.

ESTIMATED RELATIVE BENEFITS OF INTERVENTIONS

BASED ON CASE STUDIES AND EXPERT JUDGMENT

INTERVENTIONS BY SECTOR
Listed alphabetically

Energy
1. Coal-fired TPP replaced by gas
2. Coal-fired TPP replaced by renewables

Transport
3. Cleaner buses
4. Electric buses
5. Eliminate uncontrolled diesel emissions
6. Electric vehicles
7. EURO 4/IV standards
8. Expand mass transit
9. Further upgrade to EURO 6/VI standards
10. Reduce very high sulfur in diesel
11. Upgrade motorcycles
12. Vehicle inspection and testing

Industry
13. Emission controls on all industry
14. Emission controls on large plants
15. Energy efficiency for industry
16. Upgrade brick kilns

Household
17. Cleaner household fuels
18. Control open waste burning
19. Improved biomass cookstoves
20. Upgrade small boilers

Agriculture & Rural
21. Prevent crop residue burning
22. Prevent forest fires

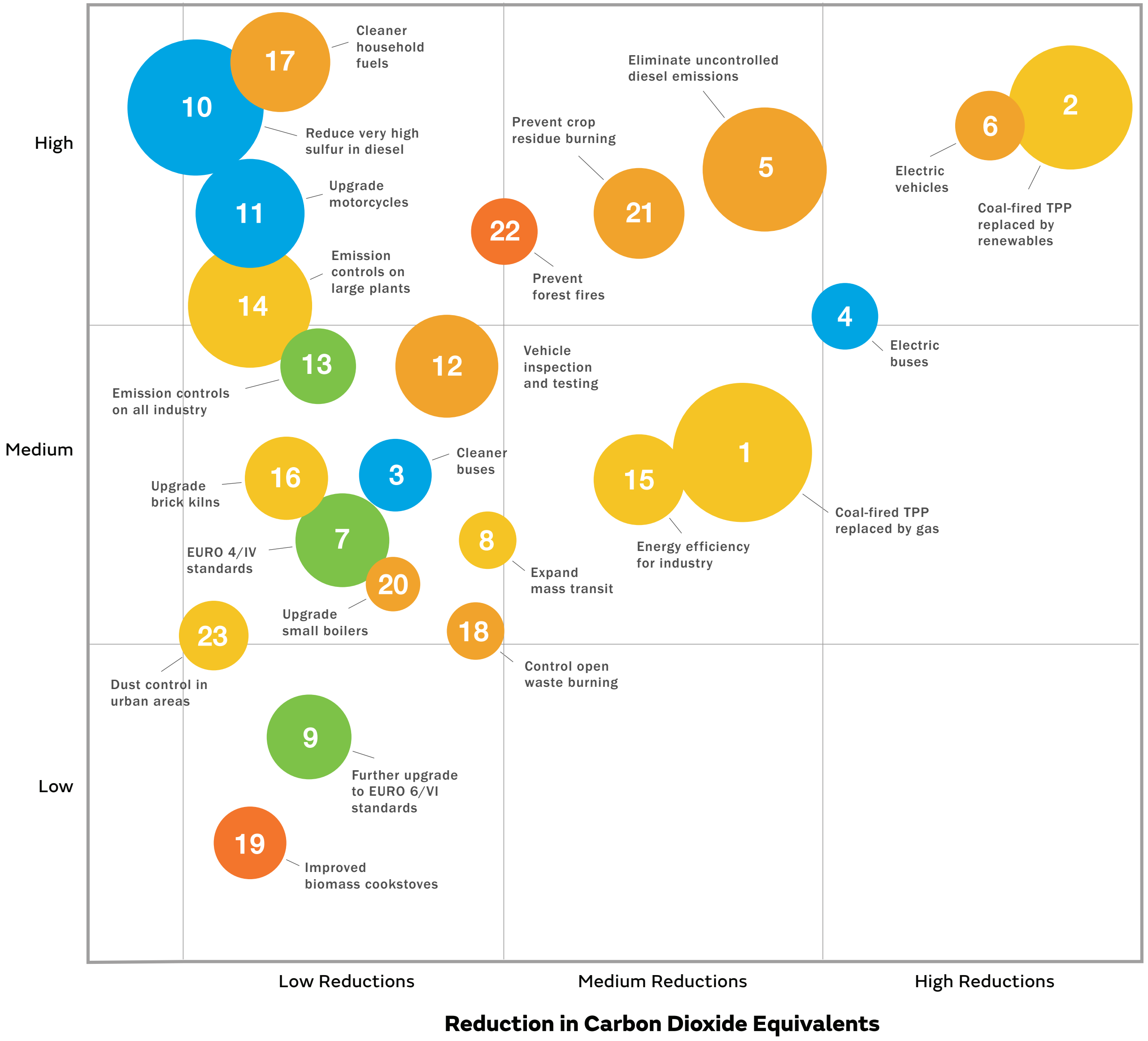
Other
23. Dust control in urban areas

DIFFICULTY
LOW — HIGH

COST EFFECTIVENESS
LESS — MORE

How to Read the Chart
Using No. 10 as an example, we can see that reducing very high sulfur content in diesel fuel is not difficult, (blue) and is very cost effective, (a large circle). Lower sulfur fuels result in less PM2.5 and other toxic emissions, so are less dangerous to breath (high health benefits), but because the fuel is still carbon-based, there are not significant CO_2 reductions relative to other interventions, hence its position in the upper left quadrant of the chart.

Health Benefits
Reduction in PM2.5



NOTES TO FIGURE

This figure was developed in order to provide a concise overview of the relative effectiveness of all the interventions assessed. It was prepared by the study team and reviewed and revised in discussions with the review group.

The data necessary to quantify the benefits is not available; and therefore, the team used experience and professional judgment to estimate both health benefits and climate change benefits in terms of their relative size and general magnitude. Health benefits were treated as estimated reductions in ambient PM2.5 as a result of the intervention, assuming that implementation was broadly successful. Climate benefits were estimated as reductions in the tons of CO_2. The figure refers to interventions designed to reduce air pollution and, therefore, does not include actions designed specifically intended to reduce other greenhouse gas emissions, such as methane or HFCs.

General guidance in initially classifying the benefits was given to reviewers in the following terms.

Health benefits. PM2.5 levels are used as proxy. **Low:** estimated reduction in average ambient PM2.5 concentrations of less than about 1%. **Medium:** reduction about 1 to 5%. **High:** above 5 %.

Climate benefits. Metric is tonnes of CO_2 equivalent reduced: **Low:** estimated to be less than 0.1% of total CO_2 releases for the urban area. **Medium:** up to about 2%. **High:** above 2%.

Cost. This is considered as the direct cost to government coffers—the funding that the implementing agency has to provide. Clearly, there will often be considerable direct costs to industry or to individuals in actually putting the intervention into practice. These costs are considered in the context of a major city. **Low:** estimated costs over five year less than $5M. **Medium:** up to $100M. **High:** above $100M.

Feasibility. This is a judgment on how straightforward the interventions would be to implement, especially in cases where the government directs an action that imposes costs on others. Issues could include possible public outcry against increased costs; resistance from companies; objections from utilities who would have to implement; and/or possible interagency complexities.

Estimates were made separately for each intervention and plotted accordingly. Revisions and adjustments were made to reflect consensus views, particularly on the relative positioning of some interventions. With more data and analytical effort it would be possible to refine some of these estimates; readers are encouraged to make these calculations and to share the results publicly.

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Introduction and Context

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

SCOPE

Increasing levels of air pollution, especially fine particulates (measured as PM2.5), are now recognized as among the most significant causes of premature death worldwide, as well as causing disability and reduced life expectancy (Health Effects Institute 2019, Landrigan et al 2017). Climate change, driven by burning fossil fuels, is a major threat to human health and economic development. It is essential to examine the extent to which both issues can be tackled together. Which programs are most effective in generating co-benefits across health and climate?

Aside from cost, there are a number of frequent obstacles to progress, including political resistance, the challenges of infrastructure upgrading, and the need to understand cultural constraints. This report examines the demonstrated effectiveness of air pollution control interventions undertaken in a representative sample of large developing countries and cities. Investigators considered the health benefits and economic savings generated by reducing air pollution and curbing carbon emissions. For clarity, the scope of this report was deliberately restricted to PM2.5 as the main cause of health impacts in air pollution and CO_2 and black carbon as the largest long-term drivers of climate change. Atmospheric chemistry is complex. There are other important air pollutants, including ozone, NOx and aerosols, but these are beyond the scope of this report. Secondary particulates from agricultural ammonia emissions reacting with urban traffic emissions is emerging as an important aspect but beyond what can be addressed here.

This report has identified and reviewed the major interventions that were carried out in selected cities over the past two decades. Extensive information on the range of actual interventions was collected from Beijing, Mexico City, Delhi, Bangkok, Santiago, Bogota, and Sao Paulo, and details of specific measures were taken from more than 25 other cities and countries. Specific outcomes of interventions have lacked systematic analysis for effectiveness, and very little analytical data is available. However, the information on implemented actions shows what have been the priority measures adopted and indicates the outcomes of these interventions—as far as they can be measured or estimated. The broad effectiveness of the interventions is summarized in Section 5 and presented in the Annex.

The approach for this report thus relied on experienced consultants to document the interventions and outcomes and on a panel of knowledgeable experts to review and assess the findings. This is not, therefore, a scientific study. Rather the authors sought to learn from the experience of those who have been actively involved in implementing interventions to combat air pollution. In this boots-on-the-ground approach, the authors asked those deeply involved with air pollution projects around the world what had worked and what had not.

Transboundary air pollution requires that coordination and control mechanisms be established between rural and city authorities or across national boundaries. This could include establishing a formal airshed management structure, such as exists in California. At times, transboundary movement of particulates can be the largest single source of pollutants, as is the case for Delhi (Amman 2017).

Pollution and Greenhouse Gas (GHG) generation are often tied to the stage of economic and social development. Population and economic growth in cities and countries are both an important challenge and an opportunity to make significant improvement. Comprehensive planning is needed, exploring a range of options, followed by undertaking effective interventions to control pollutants. These programs need to be underpinned with continuing monitoring programs that adequately and reliably collect data on the most important air pollutants.

AIR POLLUTION AND ITS IMPACTS

Air pollution is one of the greatest causes of premature death globally. Estimates of the scale of the impact are based on worldwide health data collected under the Global Burden of Disease (GBD) process, led by the Institute for Health Metrics and Evaluation (IHME) and the WHO. The most recent figures, which vary with specifics of the analytical approach used, indicate that between 3.0 million (HEI SOGA 2019) and 4.2 million (WHO 2018) premature deaths are caused every year by ambient (outdoor) air pollution. This range arises from the difficulties of estimating pollution levels for every country in the world and the challenges of extrapolating medical evidence to the global population (Ostro 2018). A major challenge is the lack of ground-level monitoring data in many parts of the world. Atmospheric models and satellite observations are used to estimate pollution levels in these areas but need to be further refined to improve accuracy and confidence (Alvarado 2019). In addition to the damage caused by ambient pollution, indoor or household air pollution (HAP) affects about 3 billion people who cook and heat their homes with biomass and coal, with another 2.9 to 4.3 million premature deaths per year, depending on the estimates (Lancet Commission 2017). Women and children are disproportionately affected. These estimates continue to be refined as better data on pollution is obtained and more detailed health analysis is carried out (Burnett 2018, Lelieveld 2020).

Irrespective of the variability in the estimates, the overall impacts of air pollution are huge and largely preventable. The latest State of Global Air study (SOGA 2019) by the Health Effects Institute (HEI) and the Institute of Health Metrics and Evaluation (IHME) estimates that air pollution of all types caused 4.9 million premature deaths in 2017—about ten percent of all deaths (HEI 2019).

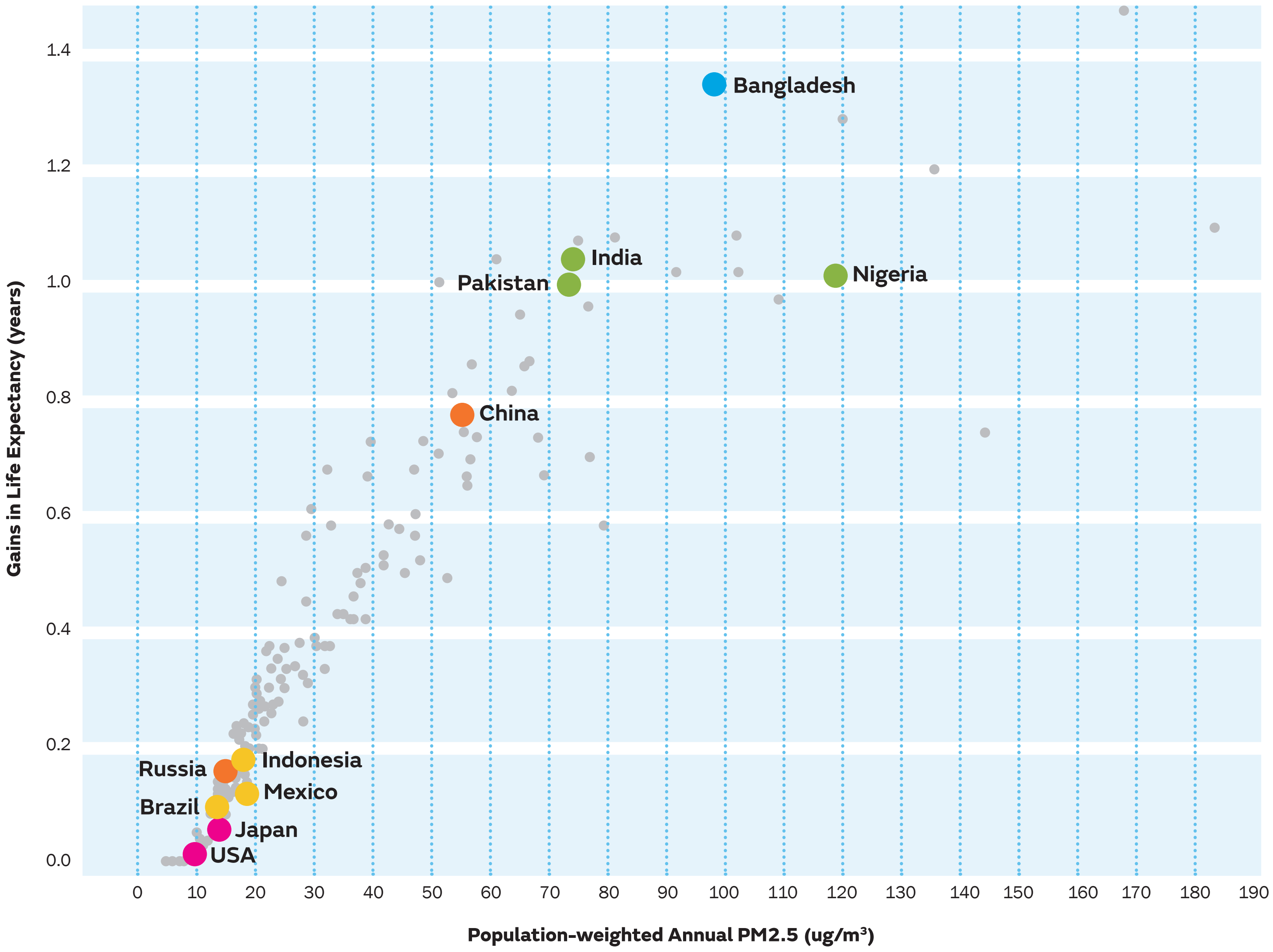
AIR POLLUTION IS ONE OF THE GREATEST CAUSES OF PREMATURE DEATH GLOBALLY

The majority of health impacts are in urban areas. Pollution data is increasingly available for cities but the health impacts are not as well defined at the city level. Most of the health impact is associated with the cardiovascular impact of PM2.5. Small particles less than 2.5 microns are not caught by the cilia of the lungs and airways,

PM2.5 CONCENTRATIONS AND GLOBAL LIFE EXPECTANCY

Hypothetical increases in life expectancy among the 11 most populous countries if PM2.5 concentrations were limited to the WHO Air Quality Guideline, showing that those with the highest exposures and often lowest sociodemographic (SDI) levels have the most to gain (based on 2016 data).

- High SDI
- High-Middle SDI
- Middle SDI
- Low-Middle SDI
- Low SDI



* Ambient PM2.5 Reduces Global and Regional Life Expectancy—Environmental Science & Technology Letters (ACS Publications). https://pubs.acs.org/doi/10.1021/acs.estlett.8b00360 (January 3, 2019).

and penetrate through the walls of the lung's air sacs into the bloodstream where they are carried throughout the body to increase the risk of heart disease, strokes, and other life-shortening diseases. Air pollution reduced life expectancy worldwide on average by 1 year and 8 months in 2017 (HEI/SOGA 2019). Specific estimates for selected cities in India and China range from 1.3 years to up to 4 years (ALQI 2019).

REDUCING AIR POLLUTION LEVELS TO WHO RECOMMENDED FIGURES COULD SAVE MILLIONS OF LIVES

The focus in city efforts is on ambient (outdoor) air pollution. Household Air Pollution (HAP) is a serious problem in many low-income rural and peri-urban areas and is gradually reduced as economic conditions improve in those areas and access to cleaner fuels is achieved. On the other hand, with strong economic growth and a lack of adequate pollution controls, ambient air pollution in many cities is increasing over time.

Countries and cities that have come to grips with particulate emissions, including most US and European cities, are now are facing a growing burden of disease from ozone. This report does not have the scope to examine ozone challenges or interventions. Ozone is dependent on sunlight and precursor chemicals (such as carbon monoxide (CO), nitrogen oxides (NOx), methane (CH_4), and non-methane volatile organic compounds (NMVOC)), and therefore the relevant interventions are often different from those focused on PM2.5.

Reducing air pollution levels to WHO recommended figures could save millions of lives and would have very large economic benefits (World Bank and IHME 2016, UNEP/CCAC 2019). The figure from HEI shows the gains in life expectancy possible if WHO guidelines were reached (HEI 2019). The scale of the finance required and the disruption associated with a rapid transformation mean that a quick switch is rarely possible. Change is typically achieved over a period of some years, even if the relevant policy or investment decision can be made quickly and some initial steps implemented.

CLIMATE LINKAGES

Climate change and air pollution are closely linked and both can be addressed simultaneously. The main sources of air pollutants and greenhouse gases (GHGs) are the same: combustion processes (heating, electricity generation etc); transport; and agriculture. Methane emissions from agriculture are now recognized as also being a contributor to secondary particulate generation.

When coal, oil, and other fossil fuels are burned they produce CO_2, which is the primary driver of climate change, and other pollutant gases and particulates. Complete combustion of fuels should produce mainly CO_2 and water but combustion is rarely complete. Incomplete combustion gives rise to a host of other pollutants, including primary particles of black carbon and organic carbon, as well as CO, CH_4 and NMVOCs. In particular, lower-temperature combustion of coal, wood, oil and gasoline produce large numbers of primary particles and gaseous pollutants.

Clearly, CO_2 from burning fossil fuels has generated most of the global warming seen to date, but other emissions also warm the climate. Methane is the second most important greenhouse gas, released from coal, oil and gas extraction, incomplete combustion and other sources. Another strong climate forcing agent is black carbon or 'soot'—particles from incomplete combustion that are black in color. Black carbon is released from incomplete combustion in a wide variety of sources, including diesel emissions, open and domestic biomass burning, and industry. Black carbon contributes to direct warming of the atmosphere by absorbing incoming solar radiation (UNEP/WMO, 2011). Although these particles do not persist long in the atmosphere before dropping out, regular and persistent emissions of black carbon have a large effect on climate forcing. At high latitudes, black carbon can also fall onto glaciers and ice caps, absorbing heat and hastening their melting as well as reducing the 'albedo' (the amount of light that is reflected) thus further warming the ground.

Black carbon is never emitted on its own. The net effect of all emissions on climate forcing need to be considered, as it is emitted with other gases and particles, some of which lead to warming and others to cooling of the atmosphere. Combustion of fossil fuels with a high sulfur content leads to sulfate particles in the atmosphere, which reflect the sunlight back into space and cool the atmosphere. Low temperature combustion can lead to considerable emissions of organic carbon particles which form a large proportion of the white smoke from vegetation fires with lower temperature combustion—as opposed to the black carbon smoke from diesel trucks and buses. These organic carbon emissions can lead to cooling of the atmosphere as they reflect sunlight back into space.

In areas where coal is heavily used, including for household cooking and heating, such as in China, large emissions of sulfur have resulted in damage to health (because sulfate particles are a component of PM2.5) and agriculture (direct effects of SO_2 and indirect effects of sulfate particles acidifying soils). At the same time such emissions have reduced the warming experienced regionally and globally and masked the warming impact of the CO_2 and other components. The government in China implemented a

MONITORING IS AN ESSENTIAL STEP IN TACKLING PARTICULATE POLLUTION IN ANY CITY

comprehensive flue-gas desulfurization policy which resulted in reduction in SO_2 emissions and related harm, but the warming that had been suppressed by cooling aerosols was unleashed, while the emissions of CO_2 from burning coal continue. The balance of the warming from different combustion sources and the impact of different mitigation measures on the climate will therefore be dependent on the ratio of the emissions of warming and cooling substances. This has made the assessment of climate impacts for different air pollution interventions complex, but much has been done to identify the measures that will lead to rapid reductions in warming drivers, as well as improvements in human health from reduced levels of air pollution (Shindell 2012).

An IPCC Working Group (IPCC 2013) indicated that to achieve the 1.5^{o} C target of the UNFCCC Paris Agreement, black carbon emissions from specific sources would need to be reduced by about 50%. According to the UNEP/WMO assessment (UNEP/WMO 2011) and associated paper in Science (Shindell et al., 2012), the most climate benefits would be achieved by reducing emissions from black carbon-rich sources, such as diesel emissions and cooking with solid fuels. That work indicated that fully implementing 16 “readily available measures” focusing on reducing emissions from both black carbon-rich and methane sources has the potential to halve the rate of warming in the next few decades, as well as save millions of lives globally. These measures have been included in those considered here.

An important factor is that the lifetime of black carbon in the atmosphere is only a few days, compared to CO_2 which will persist in the atmosphere for hundreds or thousands of years. Therefore, eliminating black carbon can reduce warming in the near term. Also, the measures that reduce black carbon will also reduce other pollutants which result in PM2.5 with significant health benefits. It is worth clarifying that CO_2 in itself is not harmful to human health, at atmospheric concentrations. It is particulates, especially the smaller ones, that are harmful.

UNDERSTANDING SOURCES OF AIR POLLUTION

Monitoring is an essential step in tackling particulate pollution in any city. Understanding the source of pollutants is also critical to designing interventions. In a large urban area there are many sources of particulates, inside and outside the city boundaries, with the final composition at any time determined by the quantities and location of each sources, the topography and meteorology of the city and season and time of day. Accurate monitoring data and analysis are key to effective planning.

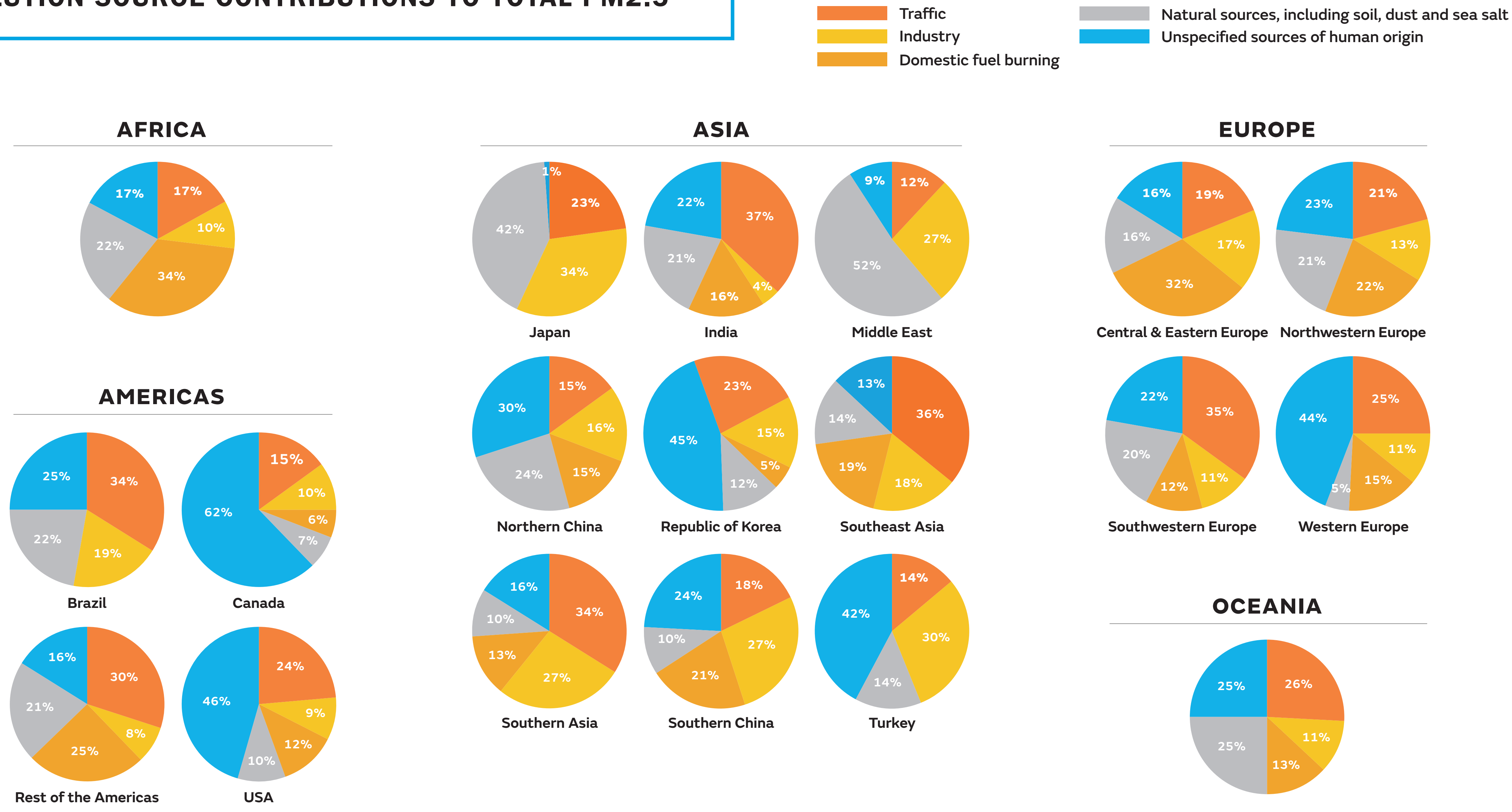
Source apportionment studies provide estimates of the contribution of each major source. They may be based on measurement and mapping of individual sources (an Emissions Inventory) or by examining the characteristics of the air mixture and determining the contribution of different types of source. Atmospheric chemistry models are important in linking emissions data to measured concentrations. These studies provide a good understanding of the relevance of the major sources but always have some level of uncertainty, which should not stop needed action being launched.

In important airsheds, often involving major cities, there are always a number of major sources—typically some combination of traffic, power generation, industry, construction, and domestic fuels, together with open burning, natural sources (soil, dust, sea salt) and others. City studies show that interventions to address particulate air pollution can be grouped broadly corresponding to the major areas identified in most source apportionment studies. These typically include energy production, industry, transportation, domestic cooking and heating, construction and roads, and agriculture.

The figure on the following page, drawing on a WHO database, summarizes information from source apportionment studies worldwide. The most significant implication is to note the variety of sources in different regions (Karagulian et al. 2015).

It can be noted from these data that each region shows the impacts of multiple sources and, therefore, intervention design needs a multi-pronged or integrated approach. In the Middle East, natural dust is the biggest problem. In Asia, Latin America, and the Caribbean, transport is a significant contributor. In North America, where average particulate levels are low, the dominance of the catchall term “unspecified sources of human origin” highlights the complexity of identifying and further reducing ambient levels.

POLLUTION SOURCE CONTRIBUTIONS TO TOTAL PM2.5



Source: Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level
https://source-apportionment.jrc.ec.europa.eu/Docu/Karagulian_et_al_2015.pdf

2

Experiences of Developing Cities

CITIES AND INTERVENTIONS IDENTIFIED

As part of this study, different sets of proposals or approaches actually applied or proposed in the cities examined were identified. Nearly 100 different proposals were listed, many of which are similar or overlapping. These are listed in Annex 1.

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

The interventions vary in terms of their health impact, climate impact, the extent of the area addressed, their political viability, cost of implementation, and the agencies responsible for implementation. Based on information from the city studies, consideration of the extensive literature, and inputs from members of the review panel, a shorter list of 22 interventions was defined, covering those effective actions that have demonstrated real success in different contexts. Some of these are city level while others require a more regional or airshed approach.

These 22 interventions can be grouped to reflect the main types of source which generate the air pollution: energy and industry, transport, households and agriculture. Examples of these approaches had been identified and reviewed as part of the city studies and associated research. Details of the interventions and summaries of different examples are included in Annex 2.

The selected interventions reflect the actual experiences of recent decades of a number of LMIC cities that have been making efforts to control and reduce air emissions, as identified in studies under this project. About 30 cities and regions provided different examples. Reports detailing multi-phased programs were reviewed from cities in Asia and Latin America, covering Beijing, Bangkok, Delhi, Hong Kong, Mexico City, Santiago, Sao Paulo and Bogota. These all started from heavily polluted conditions several decades ago and several are now close to achieving relevant standards under most conditions and are now moving into integrated pollution control mechanisms found in European and US cities.

Information from some cities in Africa has been incorporated in order to provide broader geographical coverage, but relevant data on trends and interventions are limited. Modeling studies and global reports provide some estimates for air quality in some African cities and monitoring data collection is improving (Pope 2018), but evidence of successful interventions is scarce.

EFFECTIVENESS OF INTERVENTIONS

Based on the city reviews, 22 widely used interventions were selected by the project team to allow a simple comparative estimate of the practical effectiveness of different measures. Post-implementation analysis of the health or climate benefits of specific interventions is unfortunately rarely available.

Assessment of each intervention by the project team (subsequently discussed and refined with the review panel) was developed using professional judgment and broad data drawn from studies. The focus was on the two main criteria used in this report: health benefits and climate benefits. In addition, estimates were made of costs to the government and the feasibility of implementing the interventions. The assessments represent a consensus view from the team and are necessarily qualitative and judgmental. The data necessary to quantify the benefits is not available and, therefore, the team used experience and professional judgment to estimate both health benefits and climate change benefits in terms of their relative size and general magnitude. Health benefits were treated as estimated reductions in ambient PM2.5 as a result of the intervention, assuming that implementation was broadly successful. Climate benefits were estimated as reductions in the tons of CO_2. The figure refers to interventions designed to reduce air pollution and, therefore, does not include actions designed specifically intended to reduce other greenhouse gas emissions, such as methane or HFCs.

VIRTUALLY ALL OF THE AIR POLLUTION INTERVENTIONS PROVIDE SOME LEVEL OF CLIMATE BENEFITS

The results in the table are based on the circumstances of the cities examined and so the overall context is that of lower- and middle-income cities. Application to other locations would require adjustment for the specific local circumstances. Nevertheless, this approach can provide a clear framework for carrying out a comparison of options in any location.

The assessment of the interventions shows that there are some actions that are genuinely “win-win” because they can achieve both high health and high climate benefits. Virtually all of the air pollution interventions provide some level of climate benefits, although the extent varies. It may be necessary and effective for city programs to start with urgent, high health benefit pollution reduction actions, since these often have the best political and public buy-in. Success in these initial interventions will establish confidence and provide a platform for further interventions that do provide real co-benefits.

The interventions presented here show some overlaps (for example, with fuel quality and vehicle emissions standards). In reality, such overlaps are inevitable in the design of comprehensive programs addressing sectors such as power production or traffic control.

ASSESSMENT OF INTERVENTIONS IMPACTING CITIES

	HEALTH BENEFIT	CLIMATE BENEFIT	COST TO GOVT.	GENERAL FEASIBILITY
Coal-fired Power Plants and Large Industry				
Coal-fired Power Plants Replaced by Gas	Medium	Medium	Medium/High	Medium
Coal-fired Plants Replaced by Renewables	High	High	Medium	High
Mandating Clean Fuel/Efficiency/Emissions Standards—Large Plants	Medium/High	Low	Medium	Medium
Vehicles Control, Fuel Types and Standards				
Reducing High Sulfur in Diesel Fuel	High	Low	Low	High
Control of Emissions from Highly Polluting Diesel Vehicles	High	Medium/High	Medium	Low
Moving Towards High Emissions Standards: Euro 3, Then Euro 3 to 4, etc.	Medium/Low	Low	Medium	Medium
Vehicle Inspection and Testing	Medium	Med/Low	Medium	High
Upgrading 2- and 3-Wheel Motorcycles	High	Low	Medium	Medium
Electric Vehicles	High	High	Medium	Low
Public Transport				
Low-emissions Buses	Medium/Low	Low	High	High
Electric Buses	Medium	Medium	High/Medium	High
Expanding Rapid Mass Transit	Medium/Low	Low/Medium	High	Medium

ASSESSMENT OF INTERVENTIONS IMPACTING CITIES

	HEALTH BENEFIT	CLIMATE BENEFIT	COST TO GOVT.	GENERAL FEASIBILITY
Industry Sector Upgrade				
Upgrading Brick Kilns	Medium	Low	Moderate	High
Tighter Emissions Controls on All Industry	High	Low	Moderate	High
Energy Efficiency Standards for Industry	Medium	Medium	Low	Medium
Domestic Cooking and Heating				
Cleaner Biomass Cookstoves	Low	None	Low	Low
Better Domestic Fuel and Heating	High	Low	Medium	Medium
Upgrade/Replace Building Boilers or District	Medium	Low	High	High
Agriculture				
Addressing Seasonal Crop Burning	Medium/High	Medium/High	Low/Medium	Medium
Preventing Forest Fires and Land Clearance	Medium/High	Medium/High	Medium	Low
Other Interventions				
Dust Control in Urban Areas	Low/Medium	None	Medium	High
Control Open Burning and Waste Burning	Medium	Low	Medium	Medium

General guidance in initially classifying the benefits was given to reviewers in the following terms.

Health benefits. PM2.5 levels are used as proxy. **Low:** estimated reduction in average ambient and household PM2.5 concentrations of less than about 1%. **Medium:** reduction about 1 to 5%. **High:** above 5 %.

Climate benefits. Metric is tonnes of CO_2 equivalent reduced: **Low:** estimated to be less than 0.1% of total CO_2 releases for the urban area. **Medium:** up to about 2%. **High:** above 2%.

Cost. This is the direct cost to government—the funding that the implementing agency has to provide. Clearly, there will often be considerable direct costs to industry or to individuals in actually putting the intervention into practice. These costs are considered in the context of a major city. **Low:** estimated costs over five year less than $5M. **Medium:** up to $100M. **High:** above $100M.

Feasibility. This is a judgment on how straightforward the interventions would be to implement, especially in cases where the government directs an action which imposes costs on others. Issues could include possible public outcry against increased costs, resistance from companies, objections from utilities who would have to implement, and/or possible interagency complexities.

Estimates were made separately for each intervention. On completion of the initial table, revisions and adjustments were made to reflect consensus views, particularly on the relative positioning of some interventions. With more data and analytical efforts it would be possible to refine some of these estimates.

ROGUES LIST—INEFFECTIVE INTERVENTIONS

A number of interventions that are claimed to enhance air quality were also reviewed, and included here as examples considered ineffective investments to reduce air pollution.

Smog Towers. Installations placed in urban centers that filter local air.

Odd/even car days. Programs that restrict vehicles often result in more vehicles being purchased, often those with poorer emission standards.

Flyovers. Valuable for improving traffic flow but not significant in reducing urban air pollution.

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

3

Constraints & Challenges

NATIONAL, SUB-NATIONAL, OR CITY RESPONSIBILITY

Many of the basic and essential actions to initially address air quality in cities are under the control of national governments, such as power plant development, road fuels quality, and vehicle technology requirements. Therefore, the national authorities may have to be the ones to take the initial actions.

In many cases, the air quality problems are spread across a city or cities and the surrounding area and, therefore, an "airshed" approach, such as that used in California, is essential. Obvious candidates would be the plains of Northern India, including Delhi, and the Beijing-Tianjin-Hebei (BTH) region in North-East China, where much of the pollution crosses local administrative boundaries.

Concerted action involving national, sub-national (state/provincial), and city agencies is usually required to ensure that regulatory requirements are actually enforced. Environmental enforcement has been a challenge for all governments over the decades since regulations were first introduced.

Typically, the studies have shown that after initial successes have been achieved in tackling the basic problems by regulation, then the emphasis moves to urban layout, transportation, and infrastructure requirements, which are typically under the control of the cities themselves (Arup 2015). The impacts of other pollutants such as NOx and ozone also become more important and need to be addressed specifically. Ozone may be more regional in nature and harder for cities to control.

Leading cities across the world are continuing to drive down pollution levels and are taking the lead in implementing measures to reduce their carbon footprint and to create more liveable cities (C40 CITIES. 2019)

ORGANIZATIONAL/ FINANCIAL REQUIREMENTS

Successful interventions cannot be achieved by policy or regulation alone. There is always a need for information collection and dissemination and for institutions capable of applying and updating the relevant requirements. All of these efforts require the availability of adequate human and financial resources and, therefore, an appropriate and regular budget allocation. These in turn rely on solid public and political backing for the program of action.

Many interventions will require significant capital investment. Where the intervention can be implemented as part of infrastructure or equipment upgrading and replacement, then the marginal costs may be small. Renewable power is increasingly competitive with fossil fuels, for example, and new vehicles are cleaner than those that they replace (IEA 2019). Generally, annualized costing, which incorporates operation and maintenance, provides a better basis for cost comparison. Governments will have to finance those assets which are publicly owned but should also estimate and take into account the private sector and household costs that are associated with new initiatives.

MULTIPLE MODALITIES

A common thread through many of the interventions is three-fold linkage of possible approaches to many air pollution problems. This involves: **cleaner fuel**, **better technology**, and **more efficient operation**. The choice and quality of fuel that is burned is obviously a fundamental determinant. Technology covers the combustion mechanisms and physical controls/treatment used to reduce the impacts of burning the fuel, as well as modal shifts and non-motorized approaches. Operation is a broad term to cover the behavior of the operators and any regulatory or administrative measures used to ensure that the appropriate fuel is used and that the technology is working correctly. Some combination of these factors is often used to address a major source of pollution, such as power generation or road transportation.

PROGRESSION OVER TIME

Case studies indicate that interventions are generally phased in over time, with those that can bring the most significant impacts and which are most straightforward to implement usually being undertaken first.

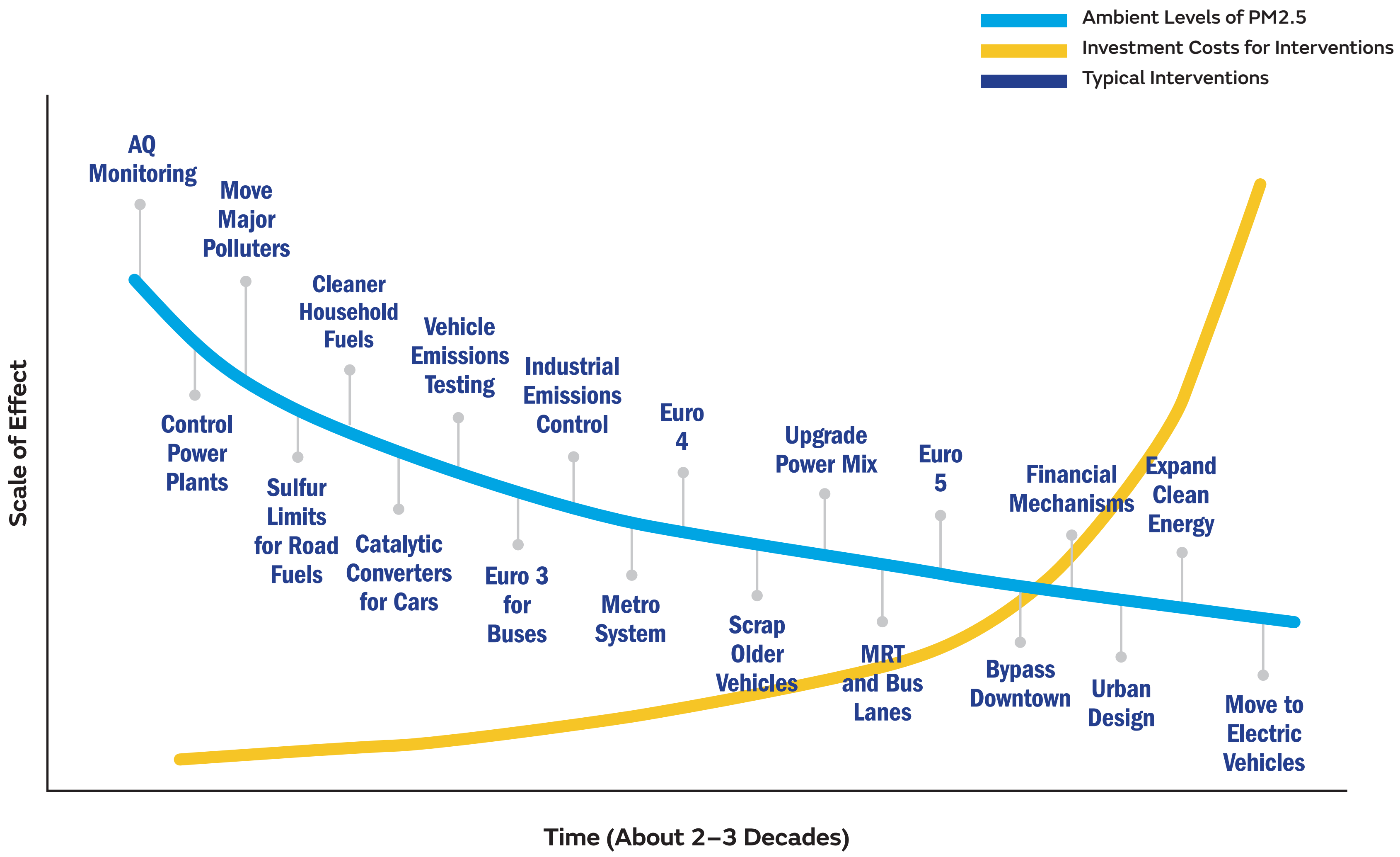
City programs may start with urgent, high health benefit pollution reduction actions, since these often have the best political and public buy-in. There is typical broad sequence in which interventions are adopted, which is, of course, adjusted for specific local characteristics and on resources available. Examples of the sequence of such interventions, over two decades, are provided in the Annex for Mexico City and Santiago. Other cities show similar broad patterns.

Significant interventions in the major sectors, such as transport and energy, show a pattern of evolving from relatively basic and simple efforts to increasingly complex and overlapping actions, such as different technical standards for separate classes of vehicles. The case studies also show that major interventions overlap in time. This is almost inevitable in large cities facing problems from multiple sources where it is notoriously difficult to separate out different measures and would take several years to be able to evaluate fully.

The figure on the following page is a generalization, based on the case studies, which shows a typical sequence of interventions—over a period of decades—together with illustrative growth in population/consumption and in expenditure on air pollution control. Experience also shows that continued effort and improvement are required just to maintain benefits achieved in the context of growing cities,

It can also be observed that this sequence of interventions, based on city studies and generalized here for a typical city, can be interpreted as options for cities at different levels of organization and finance. The chart depicts subsequent levels of interventions, progressing from early or initial efforts on the left to more advanced interventions on the right. Levels of PM2.5 fall over time, as investment costs rise.

TYPICAL SEQUENCING OF INTERVENTIONS BASED ON CITY REVIEWS



DEFINING THE BENEFITS AND COSTS

The broad benefits of reducing air pollution in a metropolitan area or region are clear in terms of both health and climate change. A review by the U.S. Environmental Protection Agency of the first 20 years of the U.S. Clean Air Act (from 1970 to 1990) concluded that average benefits exceeded average costs by a factor of about 42 (US EPA Oct 1997). An updated report in 2011, estimating results for 1990-2020, arrived at a central estimate of more than 30. Estimates for pollution control programs in California over four decades yielded a benefit ratio of 4.

An estimate of the co-benefits of reducing CO_2 emissions from big polluters concluded that the local air pollution benefits per ton of CO_2 avoided by substituting low-carbon energy would exceed the costs of abatement for most large CO_2 emitting countries (Hamilton 2017).

Estimating the specific local benefits and the attributable costs for an individual intervention is more complex and needs to be carried out at a high level of detail for which the data may not be available. However, some estimates are available and the World Bank has carried out relevant economic analyses in Colombia, Pakistan, and Lao Republic. As an example, the benefit ratios of low-sulfur diesel and of diesel particulate control in Dakar (Senegal) were estimated to be between 1.5 and 2.5 for different scenarios (Senegal CEA WB 2008).

It is frequently more straightforward to analyze interventions in terms of cost-effectiveness in reducing air pollution or of achieving specific targets, for example, in London (Greater London Authority 2017).

TIMESCALE FOR CHANGE

Achieving impacts from new policies and regulations will always take time. Establishing an effective administration is a gradual process. Therefore, changes in the regulatory regime must supported with budget and political backing, sustained over periods of years.

> A REVIEW BY US EPA OF THE FIRST TWENTY YEARS OF THE US CLEAN AIR ACT CONCLUDED THAT AVERAGE BENEFITS EXCEEDED AVERAGE COSTS BY A FACTOR OF ABOUT 42

A fundamental factor in any timescale for change is the rate of growth and of replacement of key infrastructure, such as power stations and vehicles. A move to a greater portion of renewable power in an energy system will depend on the rate at which old dirty plants are replaced by renewables, which may often take years. Cleaning up vehicle fleets, whether buses, lorries or private vehicles, usually is

IT IS CRITICAL FOR DEVELOPING COUNTRIES TO ESTABLISH CLEAR AND BELIEVABLE TIMESCALES FOR INTRODUCING STRICTER EMISSIONS STANDARDS FOR VEHICLES AND INDUSTRIES

achieved by a mixture of tighter standards for new vehicles, inspections to control the existing fleet, and incentives or restrictions in order to eliminate old and polluting vehicles. Often, the average age of the fleet is a good indicator of the quality of the vehicles.

In this context, it is critical for developing countries to establish clear and believable timescales for introducing stricter emissions standards for vehicles and industries. This will help prepare the industries for the changes and will allow them to bring in upgrades to changes to their products and operations in a timely way.

POLITICAL ECONOMY

Many countries and cities have studied and learned about what has worked in more developed countries. They have adapted and adopted commonly used institutional structures and regulatory systems, including core legislation to address pollution and environmental objectives, including climate change. These approaches have been shown to be effective in many countries. However, the actual results have often been slow and disappointing, with little measurable change. Wide variations can be seen in outcomes in superficially similar cities.

These variations are related to how political and social factors affect the operation of the regulatory and economic systems—the informal "rules of the game," which exist alongside the formal structures. It is beyond the scope of this report to examine the political economy of pollution control in different cities, but the importance of these factors must be taken into account in planning interventions. Basic aspects that can be analyzed for the real effectiveness of institutions and regulation include actual budget allocations, which reflect political priorities; reporting lines within agencies, reflecting where key decisions are made; and actual staffing levels compared with nominal numbers. Other important factors include the extent of participation and influence of affected parties and the demonstrated operational capability and autonomy, as presented in an analysis of the environmental sector in Sindh Province, Pakistan (Sanchez-Triana 2015).

4

Going Forward: Addressing both Health and Climate Change

Based on the results of the city studies, review of the extensive current literature, and inputs from a high-level review panel, the most effective interventions for national governments and for cities at varying levels of development are summarized in the following table. The state of economic development and the institutional capacity of a city are major controllers to both the state of air pollution and the options for taking effective action.

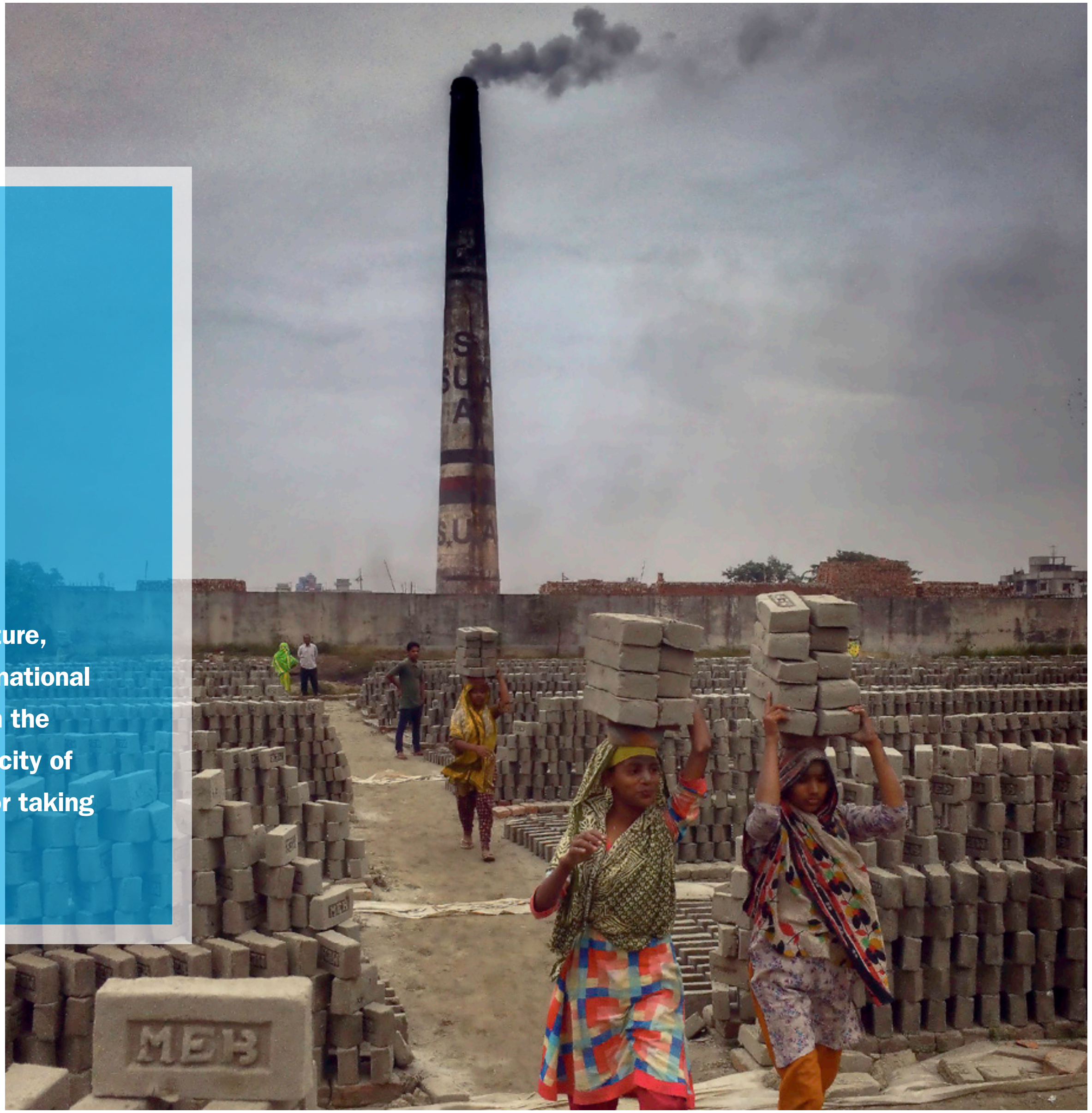


Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

RANGE OF POSSIBLE ACTIONS FOR DIFFERENT CITY CONTEXTS

Limited Ambition and/or Resources
Moderate Progress
High Income and/or Ambition
Aims for 2050*
2050: zero net carbon 2030: healthy air

Sector	AIR POLLUTION ACTIONS (Limited Ambition and/or Resources)	CLIMATE EFFECTS	AIR POLLUTION ACTIONS (Moderate Progress)	CLIMATE EFFECTS	AIR POLLUTION ACTIONS (High Income and/or Ambition)	CLIMATE EFFECTS	EXAMPLES OF COMMITMENTS AND PROGRESS (Aims for 2050*)
Energy	Control power plant emissions	Low	Upgrade power production	Med	Replace fossil fuel with renewables	High	Sweden, Costa Rica, Uruguay, and others
	Control diesel generator sets	Low					
Transport	Reduce sulfur in diesel	Low	Implement vehicle emissions standards	Low	Replace bus, delivery and motorcycle fleets with electric vehicles	High	Zero-emissions bus fleets (Auckland, Los Angeles)
	Control diesel emissions	Med	Require low-emissions buses	Med	Adopt EV for personal transport	High	Ultra-low emissions city center (London, Seoul, Milan)
	Replace two-stroke motorcycles	Low	Introduce rapid mass transit	Med	Expand opportunities for non-motorized transportation	Med	Carbon-neutral city (Copenhagen)
Industry	Impose emissions control	Low	Stringent emissions controls on industry	Low	Adopt more efficient energy sources	Med	

RANGE OF POSSIBLE ACTIONS FOR DIFFERENT CITY CONTEXTS

Limited Ambition and/or Resources
Moderate Progress
High Income and/or Ambition
Aims for 2050*
2050: zero net carbon 2030: healthy air

Sector	AIR POLLUTION ACTIONS	CLIMATE EFFECTS	AIR POLLUTION ACTIONS	CLIMATE EFFECTS	AIR POLLUTION ACTIONS	CLIMATE EFFECTS	EXAMPLES OF COMMITMENTS AND PROGRESS
Household	Upgrade brick kiln technology	Med	Require energy efficient process for industry	Med	Zero waste and circular economy processes	Med	
	Support uptake of cleaner domestic fuels	Limited*	Upgrade or replace building or district heating boilers	Low	Low energy buildings, with efficient cooling and heat pumps	Med	
	Control open waste burning	Low	Improved solid waste collection	Low	Reduction and recycling	Low	
Agricultural and Rural	Control and eliminate burning of crop residues	Med	Prevent use of forest burning for land clearance	Med	Sustainable land use management	Med	
Other	Control dust in urban areas	None	Restrictions on dust from construction and roads	Low	More compact and walkable urban cores	Low	Traffic-free city blocks (Barcelona)

*Although some low-income country air pollution interventions have limited to no benefit to climate, depending on fuel source, they have extremely significant health impacts, making them appropriate considerations for policymakers.

NOTE: Examples taken from C40 cities literature and world energy data

POLICIES AND INSTITUTIONS

Interventions intended to bring about air quality improvements will often require significant changes in sectors such as energy and transport. Successful intervention in key areas of the economy requires public and political support, expressed in the adoption of relevant policies and the necessary institutional structures. Analysis and discussion will be required of proposed interventions, include trade-offs which often occur. This analysis could include addressing efficiency in the design of regulations, the effectiveness of enforcement of regulations and the institutional capacity of the agencies to monitor and respond to changes resulting from the interventions.

It is also important to have a clear framework for identifying and dealing with the economic and social consequences of sectoral changes and any potential adverse environmental outcomes (Sanchez-Triana 2013). Specific policy options can then be assessed for dealing with the potential consequences. Cities which have developed successful multi-year Air Quality Programs, such as Beijing and Santiago, have built these programs on clear policies and institutions which have developed, over the years, the necessary skills and capabilities.

TRANSITION TO COMPLEX INTERVENTIONS

Initial efforts to control air pollution with traditional pollution management approaches have generally been successful when effectively implemented. However, in the context of rapid growth in population, industrial expansion, rising energy consumption, and many more vehicles in many cities, a broader integrated pollution prevention approach is required. In rapidly growing cities, traditional pollution control measures, such as end-of-pipe equipment, have limited additional capacity to bring pollution levels down even lower and to achieve desired air quality targets.

Present interventions in middle- and upper-income cities are showing diminishing returns: more of the same efforts will not produce significant further improvements. There is a need to move to regional or airshed scale and to adopt approaches, such as:

- prevention of pollution rather than end-of-pipe controls;
- energy efficiency in construction, manufacturing, transport etc.;
- increasing clean energy share;
- improved urban transport planning and management, including modal shifts;
- private transport constrained in some areas;
- more attention to urban design and layout.

THE MOST IMPORTANT STEP FOR RELEVANT AGENCIES IS TO RAISE THEIR LEVEL OF AMBITION IN ACHIEVING AIR QUALITY AND CLIMATE OBJECTIVES

The current air quality challenges in many cities now require the implementation of comprehensive measures integrated with national and local development aims. These policies must focus on energy structure optimization, energy efficiency, fossil fuel consumption reduction, electrification of transport, advanced mass transport options, and industrial structure upgrading. These policies have multiple benefits and converge with policies for climate and national economic development.

Highly developed metropolitan areas, such as the those in the C40 Cities Climate Leadership Group, are carrying out many model actions to implement these approaches. It may be difficult for others to follow these initiatives in the short term but the direction has been set.

ESSENTIAL OBJECTIVES: HEALTHY AIR QUALITY BY 2030; CLIMATE NEUTRAL BY 2050

The most important step for relevant agencies is to raise their level of ambition in achieving air quality and climate objectives. There are current international goals for better air quality (as part of the SDG process) and for halting climate change (through UNFCCC). Countries and cities should establish their own local and shorter term targets which are consistent with these and which provide a clear and agreed framework for action at the local level.

5

Implications

Overall aim must be an economy where development is uncoupled from resource use and energy provision is decarbonized. Short-term actions can then be selected and implemented within that framework.

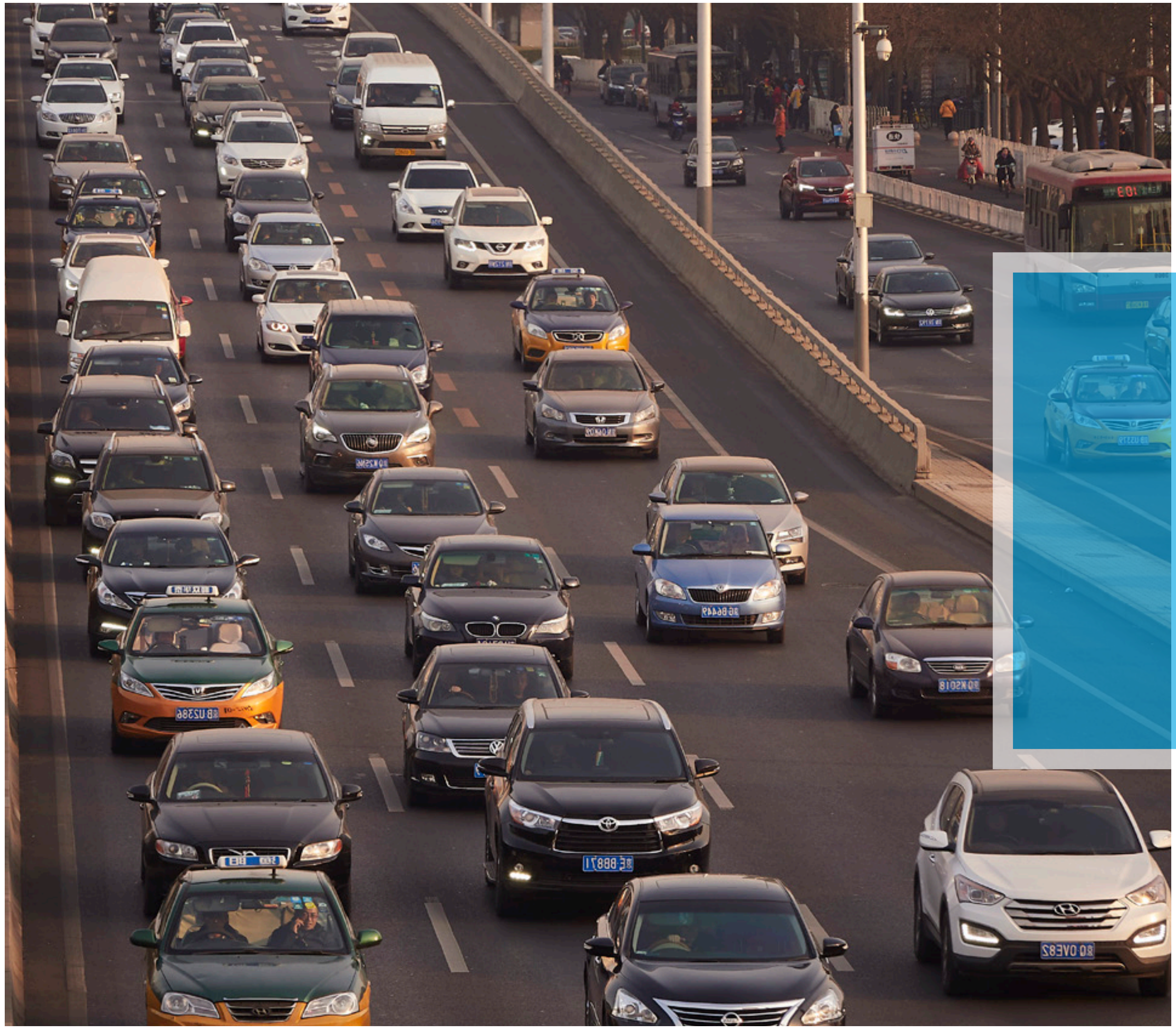


Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

The major damage to health and the largest driver of increased climate effects is the combustion of fossil fuels to provide energy for households and industry and to support the expansion of affordable transport for billions. The only sustainable solution lies in finding alternatives to the growing use of fossil fuel.

The plausible approaches lie in non-fossil energy production at a scale which can continue to support human development, together with planning and transportation systems which reduce the distances that people and goods need to travel, provide clean and efficient options for personal mobility, and which provide efficient and affordable options for mass transport.

GROWTH, DEVELOPMENT AND CLEANER ECONOMIES

Pollution control is not a one-off or static challenge. Urbanization and economic growth are increasing energy use, infrastructure construction, consumption, and vehicle use, all of which can increase pollutant emissions and impacts, as well as GHG releases. Cities have found it necessary to "run in order to stand still" just to ensure that average pollution levels do not increase with growth. In places, climate change is also impacting the problem. For example, summertime smog levels in Los Angeles have increased slightly in recent years. The increase in smog has been attributed in part to hotter temperatures and consequent ozone build-up, leading to a headline in the *Los Angeles Times*: "The war on Southern California smog is slipping. Fixing it is a $14-billion problem" (1 July 2019).

Air pollution and climate planning in large urban areas needs to look decades into the future and to address not just the problems of today but also the growing challenges that are rapidly coming. This air quality planning and management needs to be completely integrated with urban and energy planning.

BROAD IMPLICATIONS FOR POLICYMAKERS AND FOR DONORS

Policymakers:

- There are effective interventions available that are politically, financially, and socially acceptable at different stages of development. These air quality actions, summarized in this report, can provide net health and economic benefits and also result in upgraded and climate-resilient infrastructure and equipment. In an urbanizing world, national governments and cities need to set plausible targets in an airshed context and to implement coordinated and effective actions to move towards global aims.

- Identifying and tackling the sources are critical to any air pollution program. Basic requires include an appropriate emissions inventory and a monitoring

AIR POLLUTION AND CLIMATE PLANNING IN LARGE URBAN AREAS NEEDS TO LOOK DECADES INTO THE FUTURE AND TO ADDRESS NOT JUST THE PROBLEMS OF TODAY BUT ALSO THE GROWING CHALLENGES THAT ARE RAPIDLY COMING.

and source apportionment system. Adequately financed and stable local agencies and academic institutes are necessary to run and evaluate these programs.

- Effective planning, on-going communication with the public and private sectors, and adequate, stable resources are essential for success. Specific and representative results, achievable targets, and a timeline for interventions should be made publicly available, together with clear explanations of what these mean. Good public communications programs are essential.

Donors:

Donors can provide regional and local governments with access to a wide range of support and advice. They should continue to provide a comprehensive range of support, with coordination of efforts, and can assist governments to identify and access relevant funding, targeted at longer term, sustainable urban development.

- Institutions, in the broad sense, are important, and donors should encourage clear public priorities, open decision processes, and adequate technical capability and resources. Donors should particularly aim to identify and encourage local initiatives.
- Donors can make available appropriate and affordable tools and techniques for measurement and monitoring air quality and should support training and provide on-going collaboration for successful operation. Donors should also facilitate the sharing of success stories and support cities in generating public support for necessary action.

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Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

List of Potential Interventions

There are, of course, many other interventions which have been implemented, perhaps on a smaller scale, or which have the potential to be effective. An initial list of possible interventions was prepared by the study team. An analysis of the “Top 25 Clean Air Measures” for Asia sets out a range of current and prospective emissions controls that are considered to be the most effective (UNEP 2018). This listing included several of the interventions identified in the city studies. A full listing of these 25 options is provided in the table.

The report, “Low Cost Solutions for Africa” (Haq and Schwela 2010) provides a summary of low-cost tools, and policy instruments. These include necessary analytical tools as well as policies which have the potential to reduce air pollution. These policies would need to be developed further for application in specific city settings.

A study of ozone and black carbon contributions to global warming identified 14 measures that potentially could reduce the rate of temperature increase and also avoid pollution related deaths (Shindell et al. 2012). Some of these would have limited health benefits.

There are approaches which are applied in more developed cities which have stronger institutions and more capacity to implement management options. The C40 Cities, a network of some of the world's largest cities who are committed to addressing climate change, have presented examples of modern and innovative options which have been implemented, as models for other cities to build upon.

A summary report on the European Environment Agency has listed 13 measures which have been self-reported by EU countries as the ones that they have implemented to reduce emissions. These are also summarized here.

SUGGESTED INTERVENTIONS BY SECTOR

POWER GENERATION	TRANSPORT	HOUSEHOLD	INDUSTRY	AGRICULTURE	OTHER SOURCES
Initial GAHP List					
Coal Thermal Power Plants	Fuel	Clean cooking	Emissions standard	Crop residues	Construction
End of pipe	Vehicle tech	Coal conversion	EoP upgrade	Forest fires	Dust control
Diesel gensets	Emissions standard	Energy efficiency	Gas flaring	Livestock	Shipping
Other	Inspections	MSW upgrade	Diesel backup	N fertilizer	Waste burning
	Public Transport	Other	Coke ovens	Rice paddies	
	Eliminate high emitters		Other		
	Electric vehicles		Brick kilns		
	Traffic controls				
	Urban layout				
	Other				
GHG Control					
			Solvent use	Livestock	WWTP
			Gas flaring	Rice paddies	Mine CH4
			HFC		Landfill gas

This wide range of options is available for implementation in different circumstances and some are included in the assessment in the text above. Some of these are broad approaches under which a range of different specific interventions can be applied. In practice, there are a limited number of broad approaches which have been shown to be effective in LMIC cities.

SUGGESTED INTERVENTIONS BY SECTOR

	POWER GENERATION	TRANSPORT	HOUSEHOLD	INDUSTRY	AGRICULTURE	OTHER SOURCES
UNEP Solutions						
	Post-combustion controls	Emission standards for road vehicles	Clean cooking	Industrial process emissions	Nitrogen fertilizer application	Road dust
	Renewables for power generation	Vehicle inspection and maintenance	Residential waste burning	Solvent use and refineries	Manage agricultural crop residues	International shipping
		Electric cars	Energy efficiency standards for households	Brick kilns	Manage livestock manure	Wastewater treatment
		Improved public transport	Solid waste management	Energy efficiency for industry	Prevention of forest and peat fires	Coal mining
					Rice paddies	Oil and gas production
						HFC refrigerant replacement
Shindell						
		Diesel filters as step to Euro 6/VI	Waste separation and treatment	Replace traditional brick kilns	Livestock manure control	Mine ventilation air
		Ban high-emitting vehicles	Clean-burning biomass stoves	Replace traditional coke ovens	Intermittent aeration of rice paddies	Fugitive emissions from oil and gas
			Modern fuels to replace biomass stoves		Ban open burning of agricultural waste	Reduce pipeline transmission loses
						Upgrade wastewater treatment

This wide range of options is available for implementation in different circumstances and some are included in the assessment in the text above. Some of these are broad approaches under which a range of different specific interventions can be applied. In practice, there are a limited number of broad approaches which have been shown to be effective in LMIC cities.

SUGGESTED INTERVENTIONS BY SECTOR

POWER GENERATION	TRANSPORT	HOUSEHOLD	INDUSTRY	AGRICULTURE	OTHER SOURCES
SEI-HAQ					
	Traffic management		Ban obsolete technologies		Ban waste burning
	Regulate public buses		Limit sulfur in coal		Use cement plants to burn hazardous waste
	Segregated lanes		Use FGD		Collect used tires for controlled industrial fuel use
	Non-motorized transport		Low NOx operation		
	Ban or phase out obsolete vehicles		Increased energy efficiency		
	Constraints on vehicle use				
	Road pricing				
	Low sulfur fuel				
USAID/COLUMBIA					
	Fuel and vehicle standards and I&M	LPG, PNG (piped), and biogas	Convert brick kiln technology	Move away from agricultural, forest, and peat burning	Reduce open burning of trash (CCAC Waste Initiative)
	Electric mobility	Ethanol			
		Pellets			
		Electric mini-grids			

This wide range of options is available for implementation in different circumstances and some are included in the assessment in the text above. Some of these are broad approaches under which a range of different specific interventions can be applied. In practice, there are a limited number of broad approaches which have been shown to be effective in LMIC cities.

SEQUENCE OF INTERVENTIONS IN MEXICO

1989 The day without a car (Hoy no Circula) program launched

1989 Inspection and Maintenance (I&M) program for passenger cars is implemented

Integral Program Against Atmospheric Pollution in the MCMA (PICCA) | 1990-1994

1990 Closure and decentralization of Mexico's heavy industry (including cement plants)

1990 Lead-free gasoline introduced

1991 Closure and decentralization of Azcapotzalco oil refinery

1991 Introduction of 2-way catalytic converters for new passenger cars

1991 Reduction of sulfur in diesel from 2000 to 1000 ppm

1992 Substitution of fuel oil for natural gas in thermoelectric plants

1992 Reduction of reactive HC in gasoline

1993 Introduction of 3-way catalytic converters for new passenger cars

1994 Introduction of regulations for industrial emissions

Program to Improve Air Quality in the MCMA (PROAIRE I) | 1995-2000

1995 Vapor recovery systems for PEMEX's gas stations

1997 Distribution of improved reformulated gasoline

1998 Program for substituting passenger buses and cargo trucks with natural gas

1998 Leaded fuel banned

1999 Upgraded catalytic converters

1999 Vehicles with modern catalytic converters exempted from use restrictions

2000 Expansion of the Metro network (Line B)

PROAIRE II | 2001-2010

2002 Renovation of the public transport vehicle fleet (taxis and minibuses)

2004 Stricter emissions standards for light (passenger) cars based on US and Euro standards

2005 Mexico's first BRT implemented

2008 The Day without a Car program extended to Saturdays

2009 Norm with a timeline for Ultra Clean Diesel (to 15 ppm) is established

2010 Norm to regulate low sulfur levels (30 ppm) in gasoline established

PROAIRE III | 2011-2020

2012 Urban highway (North-South) completed

2014 Renovation of the Day without a Car program for Saturdays

2015 Renovation of the Day without a Car program based on emissions

2018 Emissions standards for diesel engines used in heavy-duty trucks and buses published

2019 Heavy-duty trucks and buses to use ultra clean diesel (sulfur content below 15ppm)

SEQUENCES OF INTERVENTIONS IDENTIFIED IN CASE STUDY CITIES

SEQUENCE OF INTERVENTIONS IN SANTIAGO

1990 Control of agricultural burning and scrappage of most polluting bus fleet

1991 Requirement of use of catalytic converters

1992 Setting emissions standards for industry

1993 Prohibition of open fires/chimneys; Sulfur reduction in diesel (5000-3000 ppm)

PPDA is launched

1997 Reduction of sulfur in diesel (from 3,000 to 1,500 ppm)

2000 Further reduction of sulfur in diesel (from 1,500 to 1.000 ppm)

2001 Elimination of lead in gasoline; reduction of sulfur in diesel (1,000 to 300 ppm)

2002 Removal of the 500 most polluting buses

2005 Removal of another 2,200 polluting buses; reduction of sulfur in diesel to 55 ppm

2007 Transantiago BRT system: remove 5,000 old buses; integrated with subway system

2008 Increased technical requirements for vehicle inspection

2009 Delivery of LNG to power plants and industries in the metropolitan region

2010 Setting of industrial emission targets for NOx and SO_2

2012 Air quality standards for PM2.5 established; Euro 5/V for public vehicles introduced

2013 Sulfur in diesel to 15 ppm, and Euro V for light diesel vehicles

2014 Euro 6 applied to light gasoline vehicles; introduction of carbon tax

2015 Public bike system implemented (about 255 kilometers of bike lanes currently)

Santiago Respira decontamination plan approved

2017 Update of the PPDA

2018 Introduction of EURO 4/IV emissions standards; introduction of first 100 e-buses

2019 Additional 100 e-buses introduced

2019 BRT upgraded to Metropolitan Mobility Network (Red Metropolitana de Mobilidad)

Examination of Main Interventions

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

A. Coal-fired Power Plants and Large Industry

INTERVENTION 1

Coal-fired Power Plants Replaced by Cleaner Power

SUMMARY

Polluting coal-fired power plants in urban centres are closed down and their energy output is replaced with cleaner fuel (typically gas) or renewable energy sources. This change is typically done toward the end of the life of the coal fired station when expansion of the energy supply is already in planning.

Health benefits: High or medium, depending on controls and performance of the replacement plant.

Carbon benefits: High, if replacement is renewable energy. Moderate if gas fired (about half the carbon emissions of coal).

Costs: Can be low for the utility if implemented as part of planned expansion and additional transmission costs are nominal. Increasingly, renewables, especially solar and wind, are cost competitive with coal and numbers of new coal plants are declining rapidly.

Feasibility: Negotiating changes in power planning may be difficult. If not scheduled, then potential rise in energy prices, which would be consumer borne

Key players: Usually national governments, with utilities, as part of national power planning.

EXAMPLES

REDUCING EMISSIONS FROM INDUSTRIAL SOURCES AND POWER PLANTS, HONG KONG. To reduce the emissions from the power sector, the government has prohibited the installation of new coal-fired power plant since 1997, encouraging the use of natural gas for electricity generation. Emission caps were tightened for the power sector from 2015 onward, requiring the power sector to maximize the use of existing gas-fired generation units and prioritize coal-fired generation units retrofitted with emission abatement facilities.

The first local commercial scale wind power station was commissioned in February 2006 and a photovoltaic solar system between 2010 and 2013.

INDUSTRY AND POWER PLANTS, DELHI. The National Thermal Power Corporation (NTPC) is retrofitting old electricity generating plants in Delhi from 2018 onwards to meet the revised stringent standards by 2022. The government is also considering the closing down of old polluting plants.

INTERVENTION 2

Coal-fired Power Plants and Large Industry Moved Outside City

SUMMARY

The studies identified cases where polluting coal-fired power plants in urban centers are closed down, and newer coal plants opened in rural areas, where emissions are either better controlled, or not in pathway to high density urban areas.

Health benefits: Medium, as PM2.5 is reduced in city and emission is now in less populated areas. However, a significant rural population may now be exposed, especially if controls in rural areas are not as stringent.

Carbon benefits: No change. Zero benefits.

Costs: Moving industry, in particular can have high costs, in terms of disruption and building new facilities. Typically governments have paid towards these costs.

Feasibility: Opposition by industry to disruption and costs; workers may not wish to move. Local issues—NIMBY.

Key players: Usually led by national governments but needs active cooperation of power sector and/or industry groups.

EXAMPLE

INDIA. In Delhi, about 8% of the ambient particulate pollution was due to power plants near the city. The Badarpur coal-fired power plant in Delhi, with an installed capacity of 700MW, contributed only 8% of Delhi's electric power but produced 80% of the city's particulate matter from the energy sector and an estimated 11% of the ultrafine particulate matter (PM2.5). The plant was reportedly closed permanently in late 2018. The shortfall is to be made up by imported power from larger and more efficient plants outside the city.

INTERVENTION 3

Mandating Clean Fuel, Efficiency & Emissions Standards—Large Industry

SUMMARY

For those industrial plants that have not been closed or moved, requirements to reduce emissions from large industry are established and enforced. This is the normal (but often difficult) process of reducing overall emissions from the major industrial plants.

Health benefits: Low/medium, depending on the extent to which highly polluting plants have already been closed or controlled.

Carbon benefits: Low. Efficiency and cleaner fuels will have some benefits but are unlikely to reduce carbon emissions considerably.

Costs: In principle there are very limited costs to government, apart from writing regulations. However, development and enforcement of regulations will usually require some level of additional government resources

Political Feasibility: Possible corporate pushback.

Key Players: Usually national governments, setting the requirements for industry. Larger cities will have their own requlatory and enforcement departments.

EXAMPLES

INDUSTRIAL POLLUTION MONITORING, DELHI. The Central Pollution Control Board issued directives in 2014 for highly polluting industries to install online monitoring systems, but installation has been slow. Continuous ambient air quality monitoring stations have been installed at critical locations in the city, and real-time data are available on a website (Aijaz 2018).

COAL COMBUSTION, BEIJING. A number of emissions control policies were implemented in stages since 1998 focusing on coal-fired power plants, coal-fired boilers, and residential coal use. To control pollution from coal combustion, the early measures encouraged substitution of high sulfur coal with of low sulfur coal and retrofits of coal boilers with desulfurization control. Later measures encouraged conversion from coal to natural gas, electricity, and other clean and high quality energy alternatives.

INDUSTRIAL POLLUTION PREVENTION AND CONTROL, BEIJING. Incentives or subsidies were granted for high polluting enterprises that chose to close their production or to implement extensive exhaust gas treatment in their production processes. For those who chose to remain in production, differentiated fees were charged.

ENERGY EFFICIENCY IN INDUSTRIES, INDIA. Policies include a market-based energy efficiency trading mechanism in eight energy-intensive industrial sectors accounting for one-third of total energy consumption in the country. The mandated decrease in the specific energy consumption has led to a decline of 4 to 5% in their specific energy consumption in 2015 as compared to that in 2012.

B. Vehicle Control, Fuel Types and Standards

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

Road vehicles—ranging from small motorbikes to massive trucks—are one of the major sources of air pollution in most cities. A range of different and often overlapping measures are put in place to control the emissions. These measures include controls of fuel quality, requirements for vehicle and control technology, and efforts to monitor and enforce such requirements. The interventions listed here reflect the main issues addressed in different cities.

Very broadly, as urban areas have grown, the first problems have been with predominantly diesel-engine vehicles (trucks, buses, and vans) that use old technology and operating on cheap dirty diesel. Crucial initial interventions have therefore been to require lower-sulfur diesel and to promote cleaner diesel technology. After these steps, broader vehicle emissions requirements are introduced in a phased way, over periods of years.

INTERVENTION 1

Reducing Sulfur in Diesel Fuel

SUMMARY

Sulfur occurs naturally in petroleum deposits. Refined fuels, such as diesel and gasoline, contain a level of sulfur, which depends on the original crude quality and on the processing methods. Sulfur is both a source of black carbon particles in itself and a corrosive material that can damage and eventually destroy the function of emissions controls. Poor quality fuel can contain 3,000-5,000 ppm of sulfur, while further processing can reduce this to 15 ppm, at some cost.

Health benefits: High, when very poor sulfur fuels are replaced. Low sulfur fuel directly reduces particulate emissions and is required for the operation of vehicle catalysts and other technologies. Overall, low sulfur fuel has a high levels of health benefits.

Carbon benefits: Overall, reducing sulfur in fuels may have negligible climate impact. While the elimination of black carbon emissions results in a small reduction in climate forcing, sulfur is also associated with white carbon particles, which are climate cooling.

Cost to Governments: Generally low, except in those countries where the government has a large stake in the petroleum sector. The main costs of sulfur reduction lie in new petroleum refining requirements and expanded distribution systems. Retrofitting refineries is costly. The incremental investment required for new plants is small. Costs are passed to the consumer.

Political Feasibility: Generally good. The main constraint to implementation has been the transition costs to refiners and the extent to which these are passed on to consumers. Timing for changeover can mitigate that impact—natural fluctuations in fuel prices can be more substantive than costs for low-sulfur fuel.

Ownership: National governments.

EXAMPLES

SANTIAGO. Chile introduced regulations for low-sulfur transportation diesel fuel in 2004, setting a standard 50 ppm for the metropolitan Santiago area and a higher one for the rest of the country. By 2013, the standard for the country was reduced to 15 ppm and similar standards were proposed for off-road uses, such as agriculture and mining.

CHINA began to regulate sulfur in gasoline in 1999, with a limit of 800 ppm which was reduced in stages to a mandatory standard of 50 on 2011. Diesel had a non-mandatory standard of 500 ppm in 2003, coming down to 50 ppm in 2014. At present, the standard for both China 5 (gasoline) and China V (diesel) is 10 ppm.

AFRICA. Fuel (diesel and gasoline) available in many African countries still has relatively high levels of sulfur. Following allegations that “African Quality” fuel is not fully refined, in order to reduce costs to the refiners [Public Eye 2016], many African countries committed to upgrade standards for both imported and locally refined fuels. Where cleaner fuels are not yet available, practical upgrading of vehicle emissions standards is delayed.

INTERVENTION 2

Reducing Emissions from Diesel Vehicles

SUMMARY

In the context of controlling particulates from vehicles, the major issue is diesel engines, and in particular older diesels, of which there are millions still in use in developing countries. The challenge in countries where older, dirty, diesel vehicles (often heavy-duty vehicles) predominate is to ensure that new vehicles meet higher standards and to retire and replace older polluting models. However, with diesel buses, trucks and minivans playing an important role in public transport and in commerce, change has to be managed carefully. In general, diesel and gasoline engines can produce similar levels of carbon emissions, although EURO V and EURO VI compliant diesels should produce less CO gas.

Uncontrolled diesel emissions from road and non-road engines can be one of the major sources of particulates, especially in rapidly growing cities. Reducing vehicle fleet levels from the equivalent of Euro I to Euro IV would achieve a reduction of about 80% in fleet emissions. Moving further to Euro V would reduce the remaining emissions by a further 80%. Progressive application of increasingly stringent standards will result in the overall fleet becoming cleaner and emissions dramatically reduced. The greatest benefits are in dealing with the heavy polluters: the marginal benefits of increasing standards reduce at each stage but are critical in achieving overall cleaner ambient air.

Air Quality and Health benefits: Medium to High. In urban areas where diesel is the main fuel and transport is the biggest polluter, achieving Euro IV could reduce particulate levels in the air by 20% or more.

Carbon benefits: Medium to High. Moving to Euro IV could reduce the CO emitted by diesels by half, which would bring down the carbon footprint of the city by a few percent. At the same time, diesel combustion is a major source of black carbon and so Euro IV standards would also deliver significant Short Lived Climate Pollutant (SCLP) benefits. For this reason, reducing diesel emissions has been identified as an important example of co-benefits.

Costs: High. To upgrade the diesel vehicles in a city to moderate pollution standards would be a very large and costly task, which can only be carried out over a period of years. Staging of implementation can reduce the impacts: requiring new vehicles to meet higher standards can mean that costs are absorbed in new and more efficient vehicles. The age and average life of the fleet—especially HDVs—largely control the natural replacement rate. Requiring earlier upgrading or replacement just to meet emissions requirements would impose larger costs on individual vehicle owners. In many places, governments have provided some form of incentive to speed up replacement.

Political Feasibility: Governments have to balance the public demand for cleaner air with the costs imposed on vehicle owners. This balance varies across cities and cultures and can be affected by severe pollution incidents. The case studies demonstrate that one consequence often is a slow and sequenced introduction of emissions standards, aimed at tackling one part of the problem at a time. Related practical approaches include beginning with government controlled (or influenced) fleets, such as buses and taxis, where the costs of vehicle upgrading can be subsidized to some extent.

INTERVENTION 2

Reducing Emissions from Diesel Vehicles

EXAMPLES

BANGKOK. As a major metropolitan area, Bangkok's emissions are dominated by mobile emissions sources and diesel vehicles have been the major contributor of PM2.5 in Bangkok since they do not have diesel particulate filters.

EMISSIONS STANDARDS FOR DIESEL ENGINES, MEXICO. By the end of 2018, Mexico affirmed its decision to ban high-sulfur diesel throughout the country and switch to consumption of ultra-low sulfur diesel (ULSD) exclusively. Proposed revisions to NOM 044 emission standards will require manufacturers/importers of new heavy-duty vehicles to move directly to either EPA 2010 or Euro VI standards, skipping over any interim steps. Currently, most of the heavy-duty vehicles (HDV) in Mexico meet EPA04 standard (which began implementation in the US in 2004), which reflects that the fleet has been lagging clean technologies for about 15 years. EPA 2010 and Euro VI are functionally equivalent standards, which take advantage of commercially available and cost-effective technologies capable of reducing emissions of PM up to 98%, and NOx by 89-96% below EPA 2004 levels. The implementation of NOM044 will be coordinated with ensuring the nationwide availability of ultralow-sulfur diesel (ULSD) with fewer than 15 parts per million (ppm) sulfur.

ELIMINATING HIGH EMITTERS, DELHI. Old vehicles were a major source of pollution in Delhi. De-registration of 10- to 15-year old diesel vehicles, requiring them to be taken off the road, has been conducted in a phased manner. Consequently, by 2018, most older diesel vehicles were removed from Delhi roads.

INTERVENTION 3

Stricter Emissions Standards: Euro 3, then Euro 3 to 4, etc.

SUMMARY

Once basic fuel quality has been addressed and action taken on the worst diesel vehicles, the usual next step is to establish vehicle emissions standards. These standards effectively require improvement in vehicle and pollution control technology and along with upgrading the quality of fuel to allow the control technology to function effectively. There are several different sets of standards addressing fuel quality (USA, China, India among others), but the Euro standards are often used as a basic reference. Euro standards are aimed at reducing emissions and require cleaner fuels as a key input. They also set increasingly strict limits on the emissions of nitrogen oxides, total hydrocarbon, non-methane hydrocarbons, carbon monoxide, and particulate matter. At any time a country may have different Euro-equivalent standards in force for diesel and gasoline vehicles and for different classes of vehicles (light-duty, heavy-duty, private, etc.).

Control of fuel quality is a major issue in many countries, given the cost difference between high quality fuel and many sub-standard substitutes or additives. So-called "fuel mafias" operate in some places, selling contaminated fuels, which can wreck emissions systems and thus prevent air quality improvements from being achieved.

Health benefits: High. Moving the whole vehicle fleet from Euro 1 to Euro 6 would result in an overall reduction of more than 95% in particulate emissions. In dense cities where road vehicles can represent 30-50% of the emissions sources, this would achieve large air quality and health benefits. In reality, it typically takes years or decades to make this change via successive upgrading of requirements, and so it takes time for benefits to be seen.

Carbon benefits: Medium. The reduction in carbon emissions (measured as CO) from Euro 1 to Euro 6 would be about 80% and there would also be significant reductions in black carbon as particulates are reduced. The contribution of transport to urban carbon emissions is about 23% (World Bank estimate) and, therefore, achieving full Euro 6 levels would have a considerable climate benefit.

Costs: Moderate. Upgrading vehicles to meet higher standards imposes costs on the owners. These typically include upgrading vehicles earlier than might otherwise happen. This can be a particular issue for heavy-duty vehicles, which are often old, costly, and a backbone of commercial transport.

Feasibility: Moderate, lengthy. Upgrading vehicle fleets—private and public, light and heavy—is a gradual process. The major standards systems (Euro and US EPA) address several categories of vehicles so that requirements can be introduced to match requirements and feasibility. The practical challenge is the pace of upgrading. Most

INTERVENTION 3

Stricter Emissions Standards: Euro 3, then Euro 3 to 4, etc.

systems, when introduced, apply to new vehicles only. In some cases, a period of time is established for older vehicles to be retrofitted or replaced.

Key players: National governments. All road users are potentially impacted by increased standards, and so introduction is gradual.

EXAMPLES

HONG KONG. From 1999 onward, the government has implemented measures to cut vehicular emissions, including an incentive program to replace diesel taxis and light buses with liquefied petroleum gas vehicles, the adoption of tighter fuel and vehicle emission standards whenever practicable, an incentive program to retrofit old diesel vehicles with particulate reduction devices, grants to help vehicle owners to replace their old vehicles with ones that comply with the prevailing emission standard for newly registered vehicles, stepping up the control on smoky vehicles, reduction of first registration tax for environment-friendly vehicles, etc. The number of smoky vehicles has been reduced substantially as a result of measures taken to reduce vehicular emissions in recent years. Ultra Low Sulfur Diesel (ULSD) which is the Euro IV requirement for motor vehicle diesel became the only motor diesel fuel to be available from July 2000. The sulfur content in unleaded gasoline was reduced from 0.015% to 0.005% in January 2005. Hong Kong was the first place in Asia to introduce ULSD on a full scale for its vehicle fleet. The diesel and gasoline specifications have been Euro V level since 2010.

BEIJING started with tightening of emission and fuel quality standards as part of an integrated “Vehicle-Fuel-Road” framework. Subsequently, the focus of vehicle pollution control gradually changed from gasoline vehicles emissions to heavy-duty diesel vehicle emissions. The Central Government has introduced a stepped set of standards which broadly follow Euro approaches, but which are designed for Chinese conditions.

EMISSIONS STANDARDS FOR DIESEL ENGINES, MEXICO. In 2018, Mexico banned high-sulfur diesel throughout the country and switched to consumption of ULSD. Manufacturers/ importers of new heavy-duty vehicles will have to move directly to EPA 2010 or Euro VI standards, skipping over any interim steps. Currently, most heavy-duty vehicles (HDV) in Mexico are required to meet the EPA04 standard, which was implemented in the United States 2004 and lags clean technology development and more recent emission requirements.

In 2014, the International Council on Clean Transportation (ICCT) carried out a cost benefit analysis of the proposed changes and concluded that updating NOM 044 is a highly cost-effective means of reducing the environmental impacts of diesel heavy-duty vehicles. While not quantified by ICCT, the regulation will likely result in real improvements in the efficiency of new engines sold in Mexico and the resulting fuel savings to end-users.

INTERVENTION 3

Stricter Emissions Standards: Euro 3, then Euro 3 to 4, etc.

DELHI: A range of actions has been initiated, including national vehicle emission limit Euro 3/III (and Euro IV in Delhi and other major cities) and leapfrogging from BS-IV to BS-VI emission norms by 2020 (BS-VI is equivalent to Euro VI). Fuel sulfur content limit nationally has been set at 350 ppm and 50 ppm in major cities. Public transport buses in Delhi are shifting from diesel to compressed natural gas (CNG).

The Supreme Court in 2001 passed an order for the compulsory conversion of all public transport vehicles (buses, taxis, auto rickshaws) plying in Delhi from diesel to CNG, which has lower emissions than gasoline or diesel. BS-VI grade fuel was introduced from April 2018, and efforts are being made to provide the fuel across NCR by April 2020. Cleaner fuels are also being introduced for buses.

CLEANER FUELS, BANGKOK. To reduce emissions from vehicles, new fuel quality standards were introduced, higher vehicle emissions standards were imposed, a mandatory vehicle inspection and maintenance program was implemented, and roadside pollution inspections began. The improvement in fuel standards commenced in the 1990s and began with moving Thailand off lead-based fuels and on to the Euro 3/III and then the Euro 4/IV emissions standards. (Mitchell et al 2014). The sulfur in diesel has fallen from 10,000 ppm in 1992 to less than 50 ppm in 2012 and will be 10 ppm by 2024.

VEHICLE FUEL STANDARDS, HONG KONG. The sulfur content in unleaded petrol was reduced in January 2005, in line with the European Union. Since April 2002, ULSD has been the statutory minimum requirement for motor vehicle diesel, three years ahead of the European Union. The statutory motor vehicle diesel and unleaded petrol specifications have been tightened to Euro V level since 2010. The major difference between Euro IV and Euro V motor vehicle fuels (both diesel and gasoline) is the tightening of the cap on sulfur content.

INTERVENTION 4

Vehicle Inspection and Maintenance

SUMMARY

Full success of regulations on cleaner fuels and less polluting vehicles is dependant on compliance. It is normal for governments to have some mechanism to ensure that emissions controls devices and systems are operating correctly. These approaches normally include testing as a requirement for vehicle registration and sometimes allow for roadside inspection or testing.

Health benefits: Low. An effective inspection and maintenance system will help to maintain the emissions reductions achievable under fuel and vehicle technology. In particular, I&M tends to ensure that the oldest and most polluting vehicles are replaced early. The scale of these increases is very dependent on the local circumstance, but is likely to be modest.

Carbon benefits: Low. As with air quality, the inspection and maintenance program will have modest benefits in terms of carbon reductions.

Costs: Low. The costs of public vehicle testing stations (or the installation of equipment in private workshops) are relatively low and should be covered by testing and/or registration fees.

Political Feasibility: This option is normally not a political issue, except where it is seen as part of regulatory upgrading which may generate some opposition.

EXAMPLES

BANGKOK. Vehicle inspection and maintenance. To renew a vehicle's registration and tax identification, the vehicle must pass periodic inspections. The authorities have the power to stop any vehicle suspected of being non-compliant and administer a roadside pollution inspection.

HONG KONG. Controlling smoky vehicles. Smoky vehicles spotted by accredited spotters have to undergo a dynamometer smoke test. Failure to pass the test will result in the vehicle licence being cancelled. The police also carry out roadside smoke-testing operations using a portable meter. Fixed penalty tickets are issued to the owners of vehicles failing the smoke test.

MEXICO. Vehicle Inspection and Maintenance Program. The Program was introduced in 1990 and mandates a test every 6 months for all gasoline motor vehicles as one of the strategies to decrease emissions. In 2014, the six states of the greater Mexico City megalopolis agreed to harmonize all I&M programs. Fraud has been a persistent problem in Mexico as in I&M systems worldwide, and enforcement remains a challenge. However, a government review of the program concluded that, despite problems, it had contributed to significant reductions in emissions.

INTERVENTION 5

Upgrading Two- and Three-wheel Motorcycles

SUMMARY

Motorized bicycles and tricycles have long been used for personal transport and for moving goods. With increasing economic growth, great numbers of such motorbikes have also led to congestion, pollution, and accidents in many urban areas. In 2004, it was reported that more than 75% of the vehicles in many Asian cities were motorcycles, providing mobility, although with social and environmental costs. Two-stroke engines have no separate lubrication systems and use oil mixed into their fuel to lubricate the engine. Many cities have taken measures to eliminate two-stroke vehicles in favor of four-stroke.

Air Quality and Health benefits: Can be high. Motorcycles provide the main source of mobility for millions of people, especially in Asia and Africa, but they are also often a major pollution source. Switching from two-stroke to four-stroke engines results in about a 70-80% reduction in vehicle particulate emissions. It is reported that in Dhaka that there was a 40% decrease in overall particulate levels when two strokes were banned.

Carbon benefits: Low. The carbon emissions of individual motorbike are modest in relation to overall emissions inventories. Moving to four-stroke engines would have limited carbon benefits.

Costs: Medium. Motorcycles (two- and three-wheeled) are prevalent in many cities and suburban areas because they are cheap and easy to maintain. The costs of upgrading to four-stroke engines are significant in relation to the costs of basic two-stroke models.

Political Feasibility: In developing countries, motorcycles are an important asset for the poorer segment of the population and for informal and small-scale business. Changes have been imposed in cities where the expected benefits are clear (Bangkok, Delhi), but wider upgrading is difficult.

EXAMPLES

TWO-STROKE ENGINES, BANGKOK. Emissions standards imposed in Thailand in 1997 were challenging for the manufacturers of two-stroke engines. When Thailand adopted the next level of Euro emissions regulations in 2001 motorcycle manufacturers switched to produce only four-stroke motorcycles. The number of motorcycles on the streets of Bangkok was about 4.4 million in 2012, and the near universal adoption of four-stroke engines had a significant beneficial impact on the air quality, especially at street level.

DHAKA BANGLADESH. In 2002, two-stroke “baby taxi” three-wheelers were banned from the streets of Dhaka, and it was reported that this resulted in a 40% reduction in particulates in the city center.

DELHI. Many of the three-wheelers in Delhi converted to CNG fuel following a 2001 Supreme Court order.

HANOI. Hanoi is one of the most polluted cities in the region and has about 5 million motorbikes. The Hanoi People's Council voted in 2018 to ban motorcycles in the inner city by 2030, citing pollution and road accidents. The city plans to spend the next 12 years investing in improved public transportation around the city and then gradually introducing no-go areas for motorcycles that will cover the entire inner city by 2030.

CHINA. In some Chinese cities, motorcycles have been banned altogether from the city center, so less powerful but cleaner electric bicycles are more common. The increasing numbers of electric bicycles are beneficial from a pollution point of view (apart from battery disposal concerns) but may increase accidents and congestion.

Other Transport Interventions Identified

THE DAY WITHOUT A CAR PROGRAM (HOY NO CIRCULA), MEXICO. When *Hoy No Circula* was implemented in 1989, the objective was to restrict on weekdays 20% of private vehicles, which, in turn, was expected to reduce emissions by about 12%. Initially the program seemed to be a success, but a number of studies later found that restrictions on car use failed to curb air pollution. Unfortunately there is no evidence that the projected benefits are actually realized. Likewise, there is no evidence that the restrictions induced substitution to any form of public transportation.

ODD-EVEN DAYS, DELHI. The Delhi government implemented an odd-even number plate scheme for private vehicles in 2016 in two phases for 15 days each in January and April. The aim was to reduce the number of on-road private cars using gasoline and diesel fuels and reduce vehicle emissions in key periods. The program reduced the number of cars on the road on given days, but did not appear to significantly reduce PM2.5 levels.

Thailand's experiences also underline some general lessons for developing countries contemplating emissions controls on diesel vehicles. Strengthening emission standards only will have limited effects without complementary improvements to fuel quality and inspection and maintenance programs to remove "super-emitters" from vehicle fleets. One of the more significant issues involved delays in improvements to fuel quality needed to effectively implement more stringent emission standards. It was only after these delays that Thailand gradually synchronized emission and fuel quality standards. Other challenges involved the implementation of inspection and maintenance programs for in-use vehicles.

Many years of experience with inspection and maintenance programs in Thailand have demonstrated that this is difficult to effectively implement. Policymakers will need to be proactive in thinking and acting, particularly in phasing in fuel quality standards as they are likely to encounter delays as oil refineries make necessary investments. Proactive planning is essential and requires engaging all relevant stakeholders in collaborative decision making processes.

C. Public Transport

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

Public mass transport can, in principle, move people in and out of cities and around with much lower emissions than an equivalent number of private vehicles. The challenge for city managers is to provide public transport systems which are efficient and affordable and which can attract people who otherwise would use private vehicles.

INTERVENTION 1

Cleaner Buses

SUMMARY

The bus—often simple and inexpensive—is the most common form of public transport in many countries. Barriers to entry are very low and, therefore, buses range greatly in quality. Upgrading buses and their operation is an essential part of increasing clean and functioning cities. Buses, especially in developing countries, are often individually owned, but in larger centers they are usually in fleets, either privately or publicly owned. Ownership is an important factor in being able to bring improvements in fleet performance.

CACC and partners including C40 are implementing a "Soot-Free Urban Bus Fleet" program to support cities to switch to soot free engines. The project is actively targeting 20 cities in 20 countries. Eleven of these cities are in CCAC member states. A "Megacities" Program was launched 2017 by major manufacturers with C40, CCAC, and ICCT to trial "low emissions technology" buses in 20 megacities.

Air Quality and Health benefits: Medium to high. Particulate and black carbon emissions can be reduced significantly by moving a bus fleet to "soot-free." The overall impact on a city's pollution will depend on the contribution of the buses to the particulate levels and on the time it takes to reduce the fleet emissions levels.

Carbon benefits: Medium. High levels of black carbon. The carbon benefits of moving from "average" buses to soot-free can be significant. Switching to electric buses eliminates both CO_2 and black carbon emissions.

Costs: High. Cleaner buses are more expensive than typical buses in many countries. The cost gap depends fundamentally on which emissions standard applies to the current bus fleet. Where the standard is equivalent of Euro III or IV or similar, the additional cost can be up to 50% greater. Where the standard is nearing Euro VI, then the costs of ultra-clean diesel and other clean vehicles, including electric, are all similar.

Political Feasibility: Cleaner buses are generally very positive on all aspects, apart from cost. If practical financing can be determined, then cleaner buses will be widely accepted.

Ownership: Cities and regional agencies.

INTERVENTION 1

Cleaner Buses

EXAMPLES

DELHI. During the debate about cleaner buses following the 1998 Supreme Court order to move to CNG, there were disagreements about this technology-driven approach, as diesel technology and standards were improving at the time. By the end of 2002 it was claimed that all buses were running on CNG in Delhi and by 2005, there were more then 10,000 CNG buses, of which 7,000 were run by private operators. In 2018, the Delhi government provided 2,000 new CNG busses and committed to a number of electric buses to run as shuttles to the Delhi Metro system. At the time, concerns were expressed about the high costs of electric buses compared to the new CNG buses and about the need for new bus depots for the electric buses.

HONG KONG. In 2010, the franchised bus companies completed retrofitting their Euro II and III buses with DPF, where technically feasible, aiming to reduce particulate emissions from diesel vehicles by over 80% and "low emission zones" were established in three busy corridors in central Hong Kong. Subsequently, the government subsidized the bus companies to retrofit some 1,030 Euro II and Euro III franchised buses with selective catalytic reduction devices to upgrade their performance to Euro IV or above level by the end of 2017. The government subsidized the franchised bus companies to procure six hybrid buses and 36 electric buses for trial runs to assess their operational efficiency and performance under the local conditions.

SHENZHEN, CHINA, has switched to an electric bus fleet and now has 16,000 electric buses in total, reducing not only pollution but also noise. In this fast-growing megacity of 12 million, the switch from diesel buses to electric is expected to achieve an estimated reduction in CO_2 emissions of 48% and reductions in pollutants, including particulate matter. This upgrade has been expensive (each bus cost more than £200,000) and has been subsidized up to 50% by both national and local government. Establishing the all-electric fleet has also required a network of charging stations, including 180 depots with their own charging facilities installed.

"CLEAN BUSES IN LATIN AMERICAN CITIES." This review by World Bank and others examined drivers and barriers for cleaner technologies in public transport in five LAC cities. The potential emissions reductions available depend on the specific technology (Euro VI, CNG, battery-electric, hybrid, etc) but all the approaches are significantly costly compared to the current fleets. The clean bus has a higher up-front cost but is competitive in terms of total costs of ownership. Currently, there are a number of low-emissions buses in operation in the five cities, but in reality these represent only about 1% of the city bus fleets. Despite the apparent advantages, operators are reluctant to adopt unfamiliar technologies, citing cost, performance, maintenance, and other issues. It is hoped that recent decreases in costs and growing share of renewables in the power grids will help to expand the clean component of the fleets.

INTERVENTION 2

Rapid Mass Transit

SUMMARY

Rapid Mass Transit systems operate as high capacity vehicles moving along dedicated ways. They include buses on separate road lanes, tramways, subways, and aerial mono- or dual-rails. To the degree that they substitute for passenger cars, they can greatly reduce the air emissions emitted in a city. Rapid Mass Transit requires expensive infrastructure and (usually) specialized rolling stock, and, therefore, is a costly approach but normally justified by reductions in travel times and improved air quality. Successful RMT systems need to continue to upgrade in order to avoid becoming overcrowded and slowed.

Air Quality and Health benefits: Low to medium. An RMT system can produce major pollution and health benefits if it takes (and keeps) private vehicles off the roads.

A practical challenge is that the systems need to keep up successfully with growing demand so that riders do not revert back to private vehicles.

Carbon benefits: Medium or low. The carbon benefits can be significant, reflecting the number of private vehicle trips eliminated.

Costs: RMT systems are very expensive, although they return positive net benefits in terms of travel times and health benefits. Large infrastructure projects such as some RMT systems are prone to delay and cost overruns.

Political Feasibility: RMT systems are fundamentally popular with citizens for the convenience that they can provide. The political risks lie in sourcing adequate finance and in avoiding major disruption during construction.

EXAMPLES

MEXICO. Bus Rapid Transit System (BRT). The BRT system was adopted in 2005, where prime road space was allocated to low-emission, high-capacity buses. The BRT system initially replaced conventional transport modes along 20 km of the main avenue and had a cost of USD $80 million (Schipper et al., 2009). Following the introduction of the Metrobus, the city's old buses and micro-buses operating on the same route were reallocated or scrapped. The replacement of these old units resulted in an important upgrade in local air quality. A study concluded that the implementation of the Metrobus network resulted in reductions in commuters' exposure to CO, benzene and PM2.5 ranging between 20% and 70%. One downside is that the demand for Metrobus services has continued to grow rapidly, requiring the introduction of more

INTERVENTION 2

Rapid Mass Transit

buses per lane and increasing travel time, which may reduce some of the benefits of the investment.

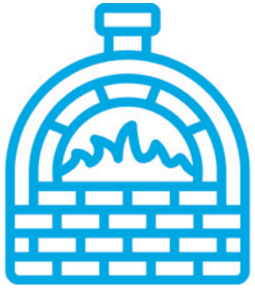
BANGKOK. Advanced public transport systems. Advanced public transport options implemented included the Mass Transit System (Skytrain) in 1999, the subway system in 2004 and Bus Rapid Transit in 2010. (Mitchell et al., 2014). However, despite these public transport options, vehicle numbers have been increasing due to population growth and by 2017 totaled nearly 9.5 million vehicles. Bangkok has plans to continue to expand the public transport system during the 2020s.

TRANSANTIAGO PUBLIC TRANSIT SYSTEM, SANTIAGO. The Transantiago public transport system comprises a bus rapid transit (BRT) network, feeder bus lines, expansion of and linkages to the metro system, and commuter rail system. It has been in service since 2017 and involved an investment of around US$6 billion over 10 years. The system has faced financial, institutional, legal, technical, and operational problems since its inception. Nevertheless, a study that focused on the impact on particulate matter air pollution levels in the city from 2007–2010 concluded that Transantiago directly contributed to a reduction of the daily average PM10 concentration levels in at least 3.9 µg/m3.

D. Industry Sector Upgrade

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

There are some industries that are widespread in or near cities and are highly polluting. Where these are small scale and not organized, regulation and control are very difficult. A sector approach that brings advice and incentives may be more effective. The brickmaking sector is highly important in many areas and can be highly polluting because of dirty fuels and inefficient furnaces. The large numbers of brick kilns in clusters near many Asian cities make a significant contribution to pollution in some urban areas.



INTERVENTION 1

Upgrading Brick Kilns

SUMMARY

Brickmaking is often an opportunistic and artisanal small-scale industry which springs up where suitable clay deposits have been identified and there is growing demand for bricks. This is often on the outskirts of an expanding city, thus reducing transportation costs. The industry is energy intensive and often uses cheap poor quality fuel (firewood, old tires etc.). The scale of individual furnaces is small and the efficiency is low, and, therefore, there are often dozens of furnaces in a district, all emitting large quantities of smoke. Improved technologies, which are more efficient and less polluting, are available, but uptake is often slow due to conservatism and lack of finance.

Air Quality and Health benefits: Medium. Depends on the location, number and density of individual kilns. In several cities (Delhi, Kathmandu) there are large clusters close to the city, which impact local air quality.

Carbon benefits: Moderate. Reduced emissions of black carbon and improved energy efficiency have climate benefits.

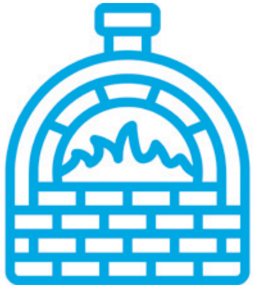
Costs: Moderate. Rebuilding kilns is a large investment for a small owner, but improved brick quality and reduced fuel use often provide a payback period for the investment of 1-3 years. In large clusters there is a reluctance for any one owner to take the upgrading risks and some form of government incentive or specific effort may be required to achieve changes.

Feasibility: Upgrading is technically straightforward, but owners/operators are usually reluctant to make changes, which can be expensive.

Key Players: City, business leaders, brickmakers associations

EXAMPLES

REDUCED EMISSIONS FROM BRICK KILNS IN NEPAL. After the destruction of more than 100 kilns in the Kathmandu Valley in the 2015 earthquake, nine kilns were rebuilt according to the new designs and other kilns adopted the brick stacking and firing pattern. Emissions measured from the new design of kilns showed a 60% decrease in particulate matter emissions and coal consumption was halved. The proportion of 'A' grade bricks increased to 90%, and worker exposure



INTERVENTION 1

Upgrading Brick Kilns

to high air pollution loads was decreased. The kilns are more structurally sound, earthquake resistant and energy efficient. The operating costs are much less and the baking process also tends to be much faster, reducing the number of days per cycle of brick production. With increased energy efficiency, more bricks are produced with lower carbon dioxide emissions with benefits for climate (CCAC, 2015).

BENEFITS OF REDUCING EMISSIONS IN CIUDAD JUÁREZ, MEXICO. An analysis (Blackman 2006) showed that the net benefits of controlling pollution from a collection of informal brick kilns are substantial—in the tens of millions of dollars—and exceed those for the two adjacent formal industrial facilities by a significant margin. However, the allocation of pollution control resources across formal and informal polluters does not reflect these benefits and maximum pollution reduction is not achieved.

FUGITIVE EMISSIONS FROM BRICK KILNS IN CHINA. Nearly half of all the world's bricks are produced in China, using a range of different kiln types. A study of a sample of the different types discovered that the fugitive emissions from the kilns (general leaks from the structure, doors, vents etc) were much higher than those measured at the stacks (Chen 2017). This indicates that the overall emissions of gases and particulates are more than double previous estimates and that the necessity and benefits of controlling brick kilns are also high.

E. Domestic Cooking and Heating

Photo: Larry C. Price/Pulitzer Center on Crisis Reporting

INTERVENTION 1

Cleaner Biomass or Coal Cookstoves

SUMMARY

The health impacts from cooking over biomass fires are now recognized as a major component of the global air pollution burden. The scale of the impacts, particularly on women and young children, has only recently been fully recognized. There are many versions of "improved stoves," which can burn the same fuels much more efficiently, in some cases reducing the amount of smoke released and also requiring less fuel. Improved stoves require careful field testing and measurement to ensure effectiveness. Despite the efforts of NGOs and governments, the uptake of such methods has been very slow. This generally has been ascribed to cost, tradition, and suspicion of new technology.

It is an issue in many peri-urban areas where services have not yet been developed and in cities where outdoor, open-fire cooking is common on public streets.

Air Quality and Health benefits: Low. Cleaner or improved stoves have been shown to reduce smoke from cooking fires by half to two-thirds. While children and women in close proximity to the stoves benefit from reduced emissions, their exposure to particulate matter typically remains well above recommended levels. Upgrading cooking does not reduce the exposures from other fires in a compound, such as ones used for warmth.

Carbon benefits: Nominal. There are not many carbon benefits from improved cleaner cookstoves because the fuel is wood or other biomass, and, therefore, reductions in volumes used have limited overall carbon savings.

Costs: Low. The costs of upgraded stoves are small but significant to impoverished communities. Even where stoves are donated to the families, they are often used only intermittently—often alongside the old stoves. The improved stoves are not valued by the users.

Feasibility: The problems of smoky stoves were long ignored in the communities, seen either as a fact of life or a woman's problem (and implicitly not worth the cost.) Several NGOs have been implementing programs in different cities and countries but with generally limited effectiveness. More recently, some governments have been much more supportive, but changing community attitudes is difficult.

INTERVENTION 2

Better Domestic Fuel and Heating

SUMMARY

A transition to clean energy is required beyond improved stoves. The most desirable approach is to move households up the “fuel ladder,” gaining access to cleaner, and more efficient fuels to use for cooking, heating, and lighting. Depending on the local situation, the first steps typically include gas (LPG or CGN) or liquid fuels such as bioethanol. Solar lighting is becoming more common but cannot meet other household needs. This is perceived as a rural problem, but many peri-urban or poor urban areas still use charcoal or wood for heating. Street vendors are often charcoal users.

Air Quality and Health benefits: The air pollution and health benefits from switching from solid fuels to a clean-burning fuel can be very high for the people directly (and indirectly) affected. Clean fuels have the greatest potential to bring health benefits to low-income households, as well as to promote climate co-benefits.

Carbon benefits: Nominal. Reductions in black carbon bring some benefit, but moving from burning biomass to fossil fuels in principle results in an increase in the release of carbon. The net benefit may be, therefore, only slightly beneficial.

Costs: High. Switching to a cleaner fossil fuel can be costly. The initial infrastructure (storage, pipework, burners) can impose an upfront cost, which is prohibitive for poor families, even if the running costs are manageable. Some form of subsidy to help low-income families could be justified.

Feasibility: Poor families typically do not have significant political influence and, therefore, there may be little support for the government subsidies or fuel price rises required to achieve phasing out of firewood.

Key Players: Governments, local communities, fuel suppliers

EXAMPLES

Despite decades of efforts by governments, NGOs, and academics to get households to switch to cleaner stoves and give up their traditional stoves, progress has been slow. Efforts currently focus on “cleaner cooking and heating” based on providing an alternative fuel, often bottled gas or biogas.

INTERVENTION 2

Better Domestic Fuel and Heating

LPG SUBSIDY SWITCH, INDIA. The costs of changing to LPG systems have been too high for many poor families in India. The government introduced a campaign to persuade wealthy households to forego their entitlement to some fuels subsidize and to transfer these to a program to subsidise LPG for poorer families. The program is progressing towards its initial goal of reaching 50 million households, which has been expanded to 80 million. Between 2016 and 2018 a reported nearly 40 million households took advantage of the new program. While this outreach has been very successful, many families are reported to be reducing LPG use because of cost and the government is examining how to address this.

LPG PROGRAMS. An increasing number of countries are moving to implement national LPG programs, including Cameroon and Brazil (Global LPG Partnership).

ENERGY TRANSITION, CHINA. China is ahead of most low- and middle-income countries in its energy transition: hundreds of millions of rural homes started using clean fuels such as electricity and gas in recent decades. However, recent research in China (Carter 2020) highlights the fact that even those households that have switched to cleaner fuels continue also to use their traditional coal and wood-burning stoves for cooking and space heating. Similar patterns have been seen in other countries.

J. Carl Ganter, Circle of Blue

F. Agriculture

INTERVENTION 1

Addressing Seasonal Crop Burning

SUMMARY

An increasing number of cities are finding themselves impacted by thick clouds of smoke blowing in from nearby agricultural areas during periods when farmers are burning stubble to prepare the land for another crop. The scale and intensity of the fires can cause air quality levels in the affected cities to become very poor for weeks at a time. There are usually alternative ways to manage the crop residues and to prepare the land for planting, but farmers, especially small farmers, are very reluctant to change traditional methods.

Air Quality and Health benefits: Medium to high. The benefits from preventing the smoke from seasonal burning would be high, if the burning could prevented. The health benefits of removing intermittent pollution are not well understood.

Carbon benefits: Medium to high. Stubble fires release large amounts of black carbon, as well as CO_2.

Costs: Medium. Alternative methods of stubble management can be used, which are as effective or more so, once implemented. The costs of transition to new methods can be significant and the government would normally contribute.

Political Feasibility: Long-term efforts are required to achieve large scale changes in farming practices, but newer and better methods can be instituted.

Key players: National government needs to take the lead since agricultural areas are often outside city boundaries and other local governments often show little interest in taking action.

EXAMPLES

AGRICULTURE AND BURNING, DELHI. The burning of paddy straw after harvest by farmers of Haryana, Punjab, and Uttar Pradesh during October and November, and wheat straw in April and May to clear the

INTERVENTION 1

Addressing Seasonal Crop Burning

fields is a source of air pollution in Delhi. A study by NASA scientists based on analysis of satellite data over a 15-year period (2002-2016) established a link between the burning of straw in Haryana and Punjab and an increase in PM2.5 concentrations in Delhi. Large-scale open burning of post-harvest crop residue and wood in nearby rural regions contributes to severe haze pollution in Delhi during winter and autumn with estimates of 42% ± 17%. In contrast, in summer about 83% of black carbon in Delhi's air is from fossil fuel sources

Government initiatives include awareness and capacity building, technological interventions, and creation of sustainable entrepreneurship models. The government is also offering subsidies of up to 50% for farmers to buy straw management machines. There are also financial incentives for farmers to retain paddy residue in fields as mulch for wheat crops. Recent reports indicate that straw burning is continuing as many farmers consider burning as a convenient and cheap option and the subsidized straw management machines are considered to be expensive to operate. In addition, there may be only a short window of time (about 3-4 weeks) between the harvest of a crop and the planting of the next crop, and this makes collection and transport of the straw offsite challenging.

POLAND AND UKRAINE. Poland had traditionally used stubble burning in some of its extensive wheat areas but has phased out the practice. Ukraine with similar agricultural conditions lags in upgrading burning.

CAIRO. Stubble burning has been identified as the cause of seasonal smoke clouds that impact seriously city air quality.

INTERVENTION 2

Forest Fires and Land Clearance

SUMMARY

In contrast to seasonal burning of farmland, many cities and regions are impacted by frequent dry-season fires in forests and undeveloped land. Some of the forest fires are natural, started by lighting or other accidental causes. However, many of the fires are started deliberately, either by farmers using slash-and-burn approaches in order to open new land or by corporations to clear forest land for expanding plantations. Legislation usually exists to prevent or constrain this practice, but it has proven very difficult to enforce in most places.

Air Quality and Health benefits: Would be medium to high if burning could be stopped completely.

Carbon benefits: Could be medium to high because of the amounts of black carbon released.

Costs: In theory, the costs of not burning are very low. However, the foregone costs to the perpetrators are high and, therefore, they resist efforts to control the burning.

Feasibility: Very difficult. Violence is often used against those trying to prevent the burning.

Key players: Private interests are reported to be the main drivers of the fires in many cases.

EXAMPLES

AMAZON. The fires in the past year have impacted air quality in many cities in Brazil and neighboring countries. Despite major efforts, control of the fires has been poor.

THAILAND AND SOUTHEAST ASIA. Every year, small- and large-scale burning in the region results in widespread haze and serious health impacts. Thailand, Indonesia, and other countries have programs to react to the fires but prevention has been weak.

INTERVENTION 3

Dust Control in Urban Areas

SUMMARY

Dust is often a major contributor to overall particulate levels in urban areas. Some of the dust is generated within the city, principally by roads and by construction work. It is often difficult to determine the extent to which the dust is made up of PM10 (typically mineral material) or PM2.5 (often combustion products), which have different overall health impacts. It can also be difficult to determine the original source of the dust, especially in dry parts of a country where wind-borne dust can travel long distances. There is limited data on effective interventions to reduce the health impacts of dust.

Air Quality and Health benefits: Low to medium, depending on the type of dust and the success in reducing levels

Carbon benefits: None

Costs: Low to moderate, depending on the scale and type of intervention.

Feasibility: Usually straightforward once effective interventions have been identified

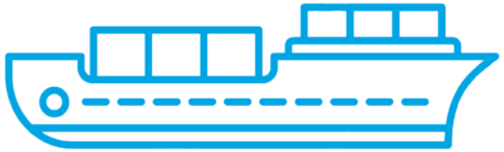
Key players: Wide range of parties have to be involved.

EXAMPLES

FUGITIVE DUST, BEIJING. To control fugitive dust, dust control technologies, processes, and management rules were promoted to reduce dust from construction sites, roads, and cleared land. In recent years, emissions of VOCs from establishments such as restaurants and vehicle repair facilities have also been included in air pollution control measures.

CONSTRUCTION AND ROAD DUST, DELHI. As economic activities in the region outside Delhi are expanding, demand for housing and infrastructure has grown. These construction activities generate considerable dust emissions, adversely affecting air quality particularly during the autumn and winter months when the climatic conditions lead to the trapping of these particles in the air. Many construction companies fail to comply with dust-control measures set by government. Road dust is one of the major sources of air pollution in Delhi. Despite a number of measures to address this issue, little progress has been made.

URBAN FORESTS TO IMPROVE AIR QUALITY, SANTIAGO. An analysis carried out in 2007 examined PM10 removal by Santiago's urban forests. Results indicate that managing municipal urban forests (trees, shrubs, and grass whose management is under the jurisdiction of Santiago's 36 municipalities) was a cost-effective policy for abating particulate matter. A comparison of the cost effectiveness of managing municipal urban forests and street trees to other control policies (e.g. alternative fuels) to abate PM10 in SMA was carried out. This concluded that municipal urban forest management efficiency was similar to these other air quality improvement measures, based on effectiveness and management costs. While the original analysis and cost should be updated, it suggested that the proposed increase of forests, vegetation, and green areas up to 100 hectares in the SMA under the Santiago Respira Program, could be considered a cost-effective measure to address air pollution.



INTERVENTION 4

Emissions Reductions from Ships

SUMMARY

For cities with large ports, ships usually produce a substantial proportion of PM2.5 emissions. The control of these emissions is mandated in many developed countries and port cities in developing countries can easily implement the required regulations.

Health benefits: Medium, as PM2.5 is reduced in cities with large ports

Carbon benefits: No change.

Costs: The costs are modest and paid by the shipping companies. They may be passed on to shipping consumers. The costs to governments is small.

Feasibility: Opposition by the shipping industry to costs

Key players: Usually led by national governments but needs active cooperation of the shipping sector.

EXAMPLES

HONG KONG has introduced requirements for ships in port.

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INTERVENTION 5

Ban Domestic and Commercial Waste Burning

SUMMARY

The traditional practice in developing countries with poor solid waste collection services is to burn domestic and commercial waste. As cities grow, this practice leads to poor air quality. The improvement in domestic and commercial waste collection combined with regulations to ban the burning of domestic waste greatly improves air quality.

Health benefits: Medium, as PM2.5 is reduced in cities.

Carbon benefits: No change.

Costs: The costs are moderate and paid by municipal authorities and collected from users. The cost to national governments is small.

Feasibility: Citizens accustomed to opening waste burning may oppose change.

Key players: National governments lead the change but must have active cooperation of city authorities.

EXAMPLES

Many cities have banned open burning of waste, but implementation is very varied.

US GLOBAL ALLIANCE ON HEALTH AND POLLUTION
c/o Pure Earth
475 Riverside Drive, Suite 860
New York, NY 10115
www.gahp.net

SWITZERLAND GLOBAL ALLIANCE ON HEALTH AND POLLUTION
c/o SPTS Sarl
Chemin de la Chesnaie 8
1219 Châtelaine
Geneva, Switzerland

For more information, visit **www.gahp.net**. Contact Rachael Kupka at rachael@gahp.net

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