AIR QUALITY IN ASIA

WHY IS IT IMPORTANT, AND WHAT CAN WE DO?

ADB

1. KEY POLLUTANTS AND POLLUTION SOURCES

Air pollution has been high on the scientific and political agenda for some time. Despite this, air pollution remains one of the major societal and environmental challenges.

THE MAIN AIR POLLUTANTS

Fine particulate matter (PM10 and PM2.5), also referred to as particulates or fine particles, are tiny particles of solid or liquid suspended in the air. Particulate matter with a diameter of less than 2.5 microns (PM2.5) is small enough to enter the respiratory system, and is linked to a range of adverse effects on respiratory and cardiovascular health. The main sources of PM2.5 are human activities such as the burning of fossil fuels in vehicles, power plants, agriculture, domestic combustion and industrial processes, as well as wind-blown dust from construction and agriculture. PM2.5 can also be formed as a secondary pollutants due to reactions between other chemicals in the atmosphere. Exposure to PM2.5 is linked to a wide range of respiratory and other health impacts – see Section 2.

Nitrogen oxides (NOx), and in particular **nitrogen dioxide (NO2)**, are produced from high temperature combustion of fuels including gasoline, diesel, fuel oil, coal, wood and natural gas. Nitrogen dioxide can sometimes be seen as a dome of brown haze above or downwind of polluted cities. The most prominent sources of oxides of nitrogen are internal combustion engines burning fossil fuels such as those found in vehicles and diesel generators, as well as all other kinds of combustion including power stations, home cooking and heating, and industrial processes. Exposure to nitrogen dioxide is linked to respiratory disease, and NOx also has adverse effects on agriculture and natural ecosystems both directly and due to its role in forming ozone at ground level.

Sulphur oxides (SOx) and in particular sulphur dioxide (SO2): Coal and liquid fuels often contain sulphur, and the combustion of these fuels generates sulphur dioxide. This is a major cause for concern in the use of coal and oil as power sources. Exposure to sulphur dioxide at high levels can affect respiratory health, and acid deposition derived from sulphur dioxide also has adverse effects on agriculture and natural ecosystems.

Ozone (O3) is generally not emitted directly to the atmosphere. Instead, it is formed in the atmosphere due to interactions between oxides of nitrogen, volatile organic compounds, and solar radiation. Because this process takes time, ozone levels are typically highest in the areas downwind of major cities and industrial areas. While ozone is beneficial at high altitudes in the atmosphere, at ground level it is linked to respiratory disease and symptoms, and can also affect plant health.

Carbon monoxide (CO) is a product of incomplete combustion as encountered in the operation of vehicles, heating, coal power generation, and biomass burning. Natural events such as volcanic eruptions, emission of natural gases, decay of dead vegetation and animals, and forest fires all contribute to atmospheric CO. Approximately 40% of global CO comes from these natural sources. Human activities such as fossil fuel consumption, garbage disposal, tobacco smoke, and charcoal fires account for the remaining 60% of global CO. Exposure to high levels of carbon monoxide can affect human health, although this is more commonly a problem resulting from poorly controlled indoor fuel burning.

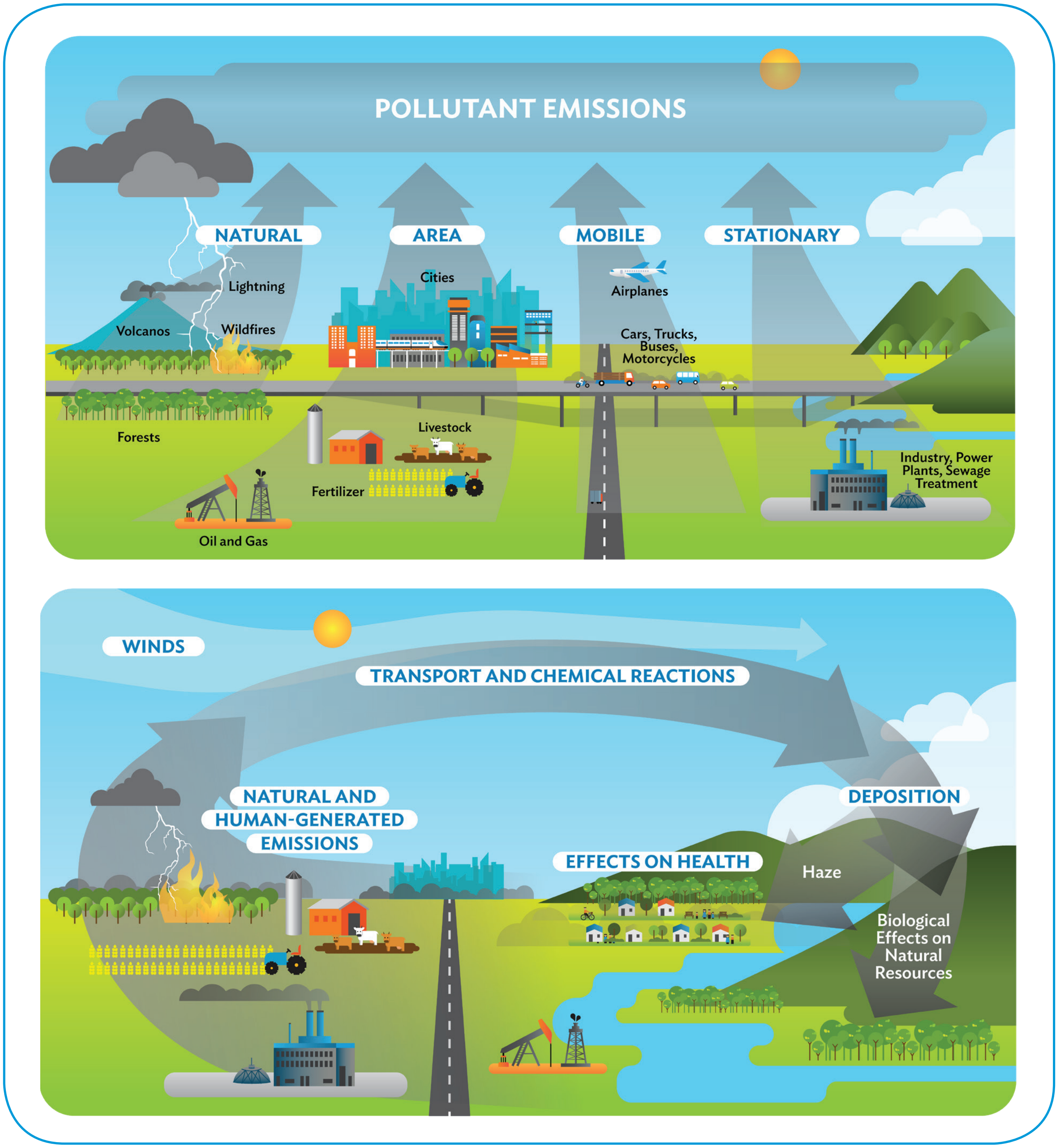
Volatile organic compounds (VOCs) are produced from human activity. Sources of VOC emissions include the incomplete combustion of fuel, evaporation of fuel and solvents, biomass burning, and some industrial processes. Plants have also the potential to emit a considerable amount of different types of VOCs. VOCs take part in photochemical reactions to produce secondary pollutants, such as low-level ozone, and can occasionally be directly toxic to people. The most common VOCs of human origin are alkanes, alkenes, esters, alcohols, and acids.

Ammonia is produced from natural and man-made sources, including agriculture and waste management. Ammonia is not normally directly harmful to people, but can have significant impacts on the natural environment, both directly and by contributing to acid and nitrogen deposition. Ammonia also contributes to the formation of secondary particulate matter in the atmosphere.

Urban and heavily industrialized areas with high population densities usually experience the highest levels of air pollutants, with the exception of ozone and ammonia, which are often higher in rural areas.

Understanding the formation of air pollution in Asia and in other regions relies on an accurate characterization of the direct emissions of air pollutants and their precursors at the local, regional and global scales. For example, although most of the air pollution experienced by individuals is from local or regional sources, under certain atmospheric conditions air pollution can travel long distances across national borders. For example, windblown dust from desert regions of Mongolia, Central Asia and China can carry particulate matter, fungal spores and bacteria which have been found to affect air quality in remote areas.

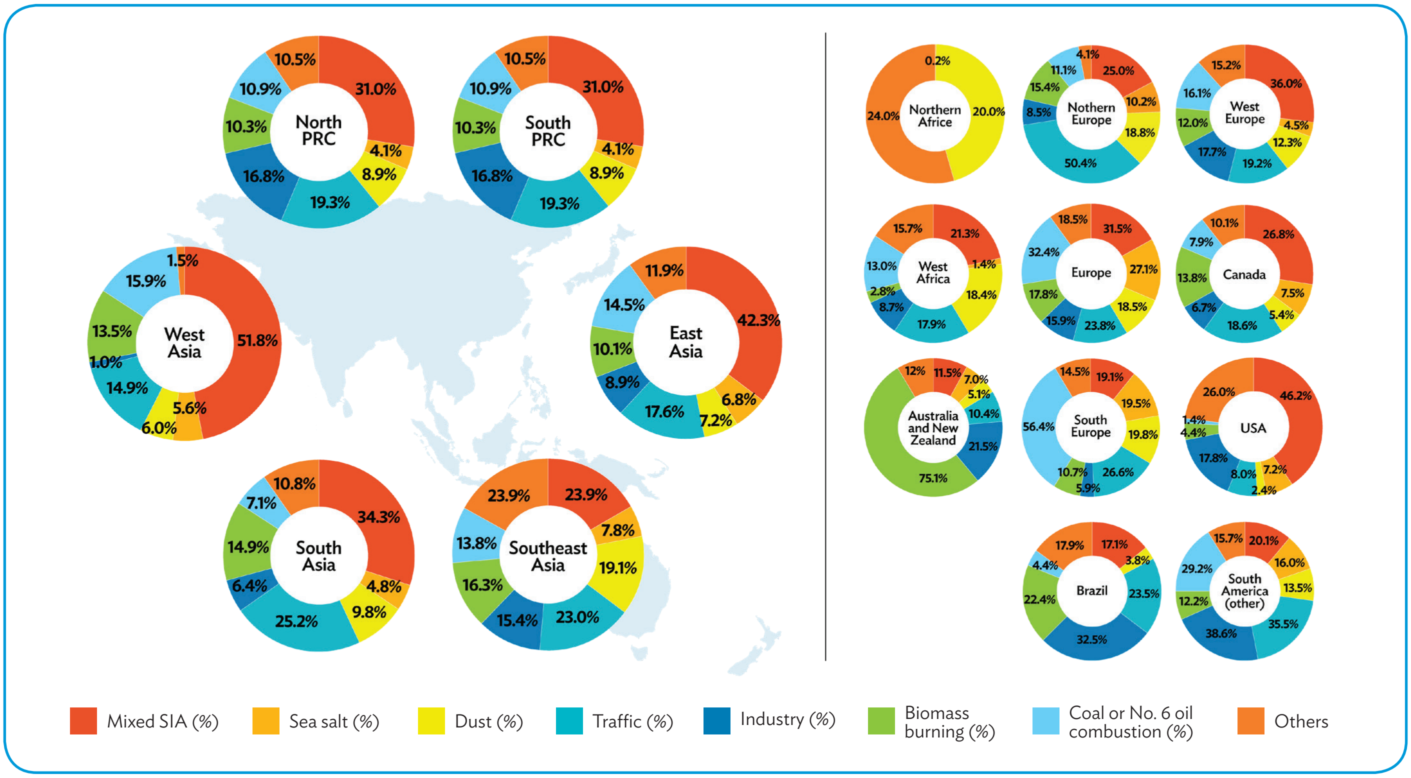
Figure 1: Sources, pathways and effects of air pollution



Source: https://www.nps.gov/subjects/air/sources.htm

A clear understanding of the source contribution to air pollutants helps to tackle adequately these sources and then to implement the most efficient measures. The variation in sources of PM2.5 in different regions in Asia is a good illustration of the diversity of sources of air pollution.

Figure 2: Source contributions to PM2.5 emissions

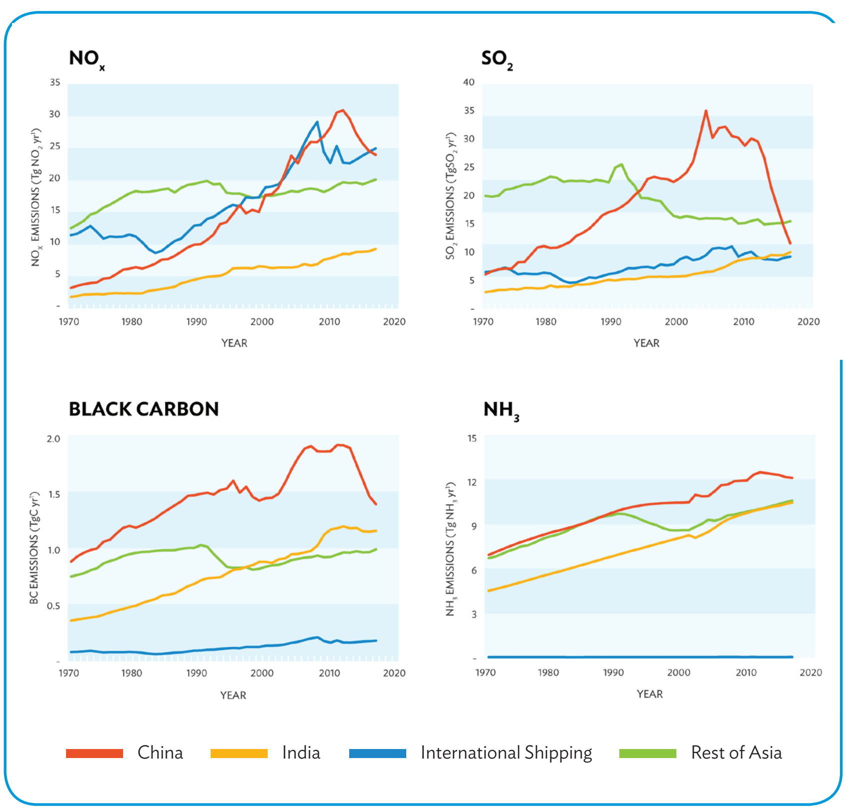


Source: Hopke et al. (2020).

Emissions of primary pollutants from human activity have increased in Asia over the past 50 years (e.g. McDuffie et al., 2020, Kurokawa and Ohara, 2020; Sadavarte et al., 2019), mainly driven by economic growth. Increases in emissions between 2004 and 2011 were largely driven by increasing domestic consumption, but export-related emission growth was also notable.

In the past 10 years, emissions of most pollutants in PRC started to decrease. The downward trend in NOx emissions from PRC since 2011 is mainly due to emission control measures in the power sector (Liu et al, 2017). A case study illustrating how PRC has decoupled air pollution from economic growth through appropriate investment and control is provided in Section 6.2. In contrast, in the rest of Asia, emissions continued to increase, although some studies indicate that the growth of emissions of air pollutants in more recent years is beginning to slow down (Meng et al., 2019).

Figure 3: Trends in emissions of key air pollutants from 1970 to 2017



Source: McDuffie et al., 2020

The following organizations are active in working to understand the effects of air pollution on health and the environment, and to improve air quality throughout Asia.

Figure 4: Examples of organizations active in improving air quality in Asia

Intergovernmental Agencies

- UNEP (Nairobi) The United Nations Environment Programme (UNEP)
- The Asia Pacific Clean Air Partnership (APCAP)
- The World Health Organization (WHO)
- The World Resources Institute (WRI)
- C40 Cities
- The International Centre for Integrated Mountain Development (ICIMOD)
- The Association of Southeast Asian Nations (ASEAN)
- South Asia Co-operative Environment Programme (SACEP)
- Malé Declaration on Control and Prevention of Air Pollution and its likely Transboundary Effects for South Asia

Donor Agencies

- The Asian Development Bank (ADB)
- World Bank Group
- The Clean Air Fund
- Gesellschaft für Internationale Zusammenarbeit (GIZ) (Germany)
- Swedish International Development Cooperation Agency
- Agence Française de Développement (AFD)

Research and Data Organizations

- Stockholm Environment Institute (SEI)
- The Asian Institute of Technology (AIT)
- OpenAQ

Non-Governmental organizations

- Clean Air Asia
- Pure Earth
- Environmental Defense Fund (EDF)
- Environment and Security Center of Mongolia (ESCM)
- Sustainable Development Policy Institute (SDPI)
- Global Alliance on Health and Pollution (GAHP)
- Climate and Clean Air Coalition

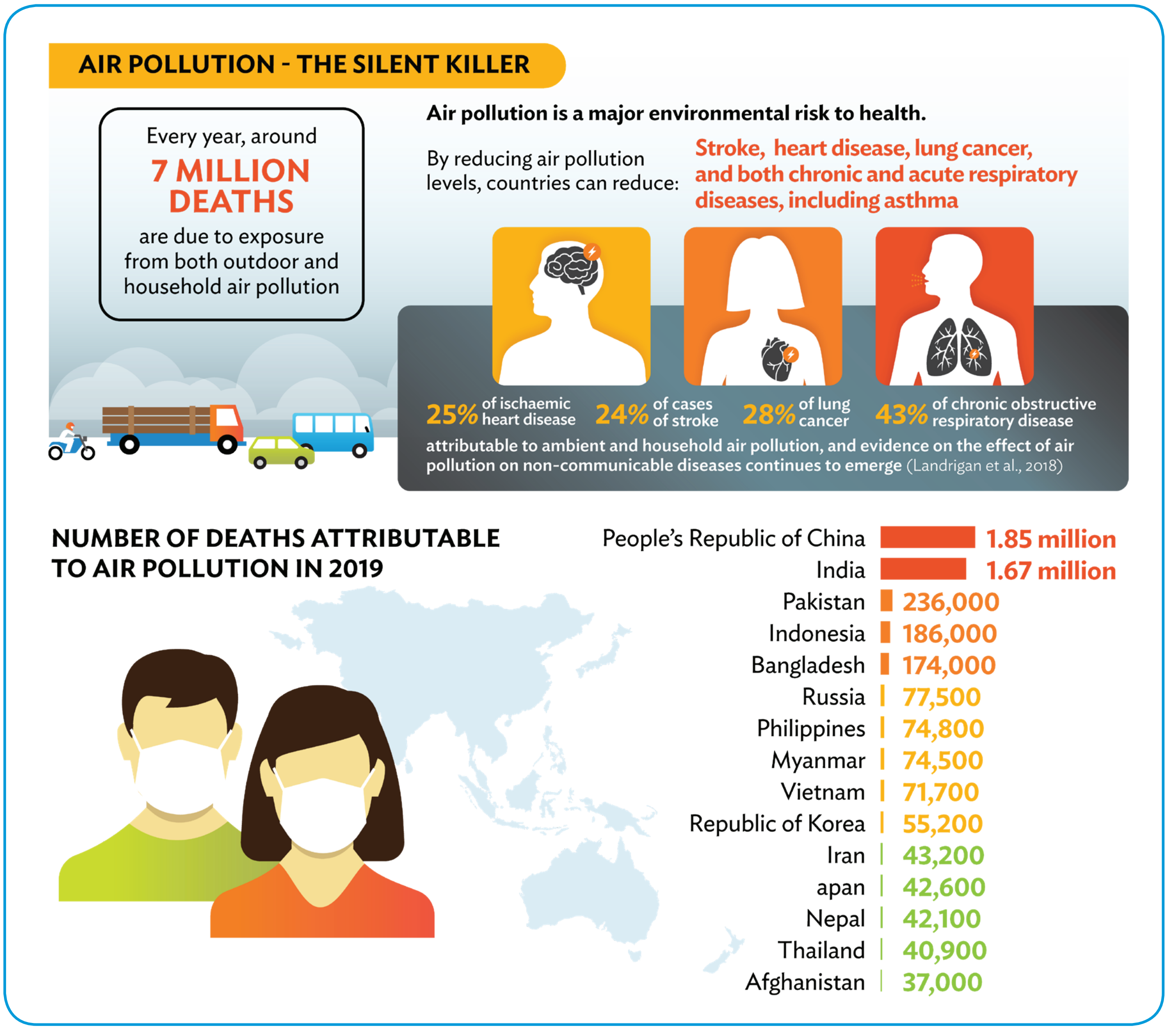
2. HEALTH AND ECONOMIC IMPACTS OF AIR

Air pollution causes and exacerbates a number of diseases, ranging from asthma to cancer, pulmonary illnesses and heart disease. Outdoor air pollution and particulate matter, one of its major components, have been classified as carcinogenic to humans by the International Agency for Research on Cancer.

The World Health Organization confirms that exposure to air pollution is a more important risk factor for major non-communicable diseases than previously thought. For example, air pollution is the largest environmental contributor to the burden of disease. In 2016, air pollution was the second largest of any risk factor causing non-communicable diseases globally, after tobacco smoking (Prüss-Ustün et al., 2019). In many countries, for example in southeast Asia, air pollution is the largest cause of non-communicable diseases, and evidence for the effect of air pollution on non-communicable diseases continues to emerge.

92% of Asia and the Pacific's population (~ 4 billion people) are exposed to levels of air pollution that pose a significant risk to their health. As a result, air pollution in Asia-Pacific region is estimated to be responsible for 4 million early deaths every year. In 2019, four Asian countries were in the top 10 of the highest population-weighted annual average PM2.5 exposures (India and Nepal were respectively the first and the second country) (State of Global Air 2020)

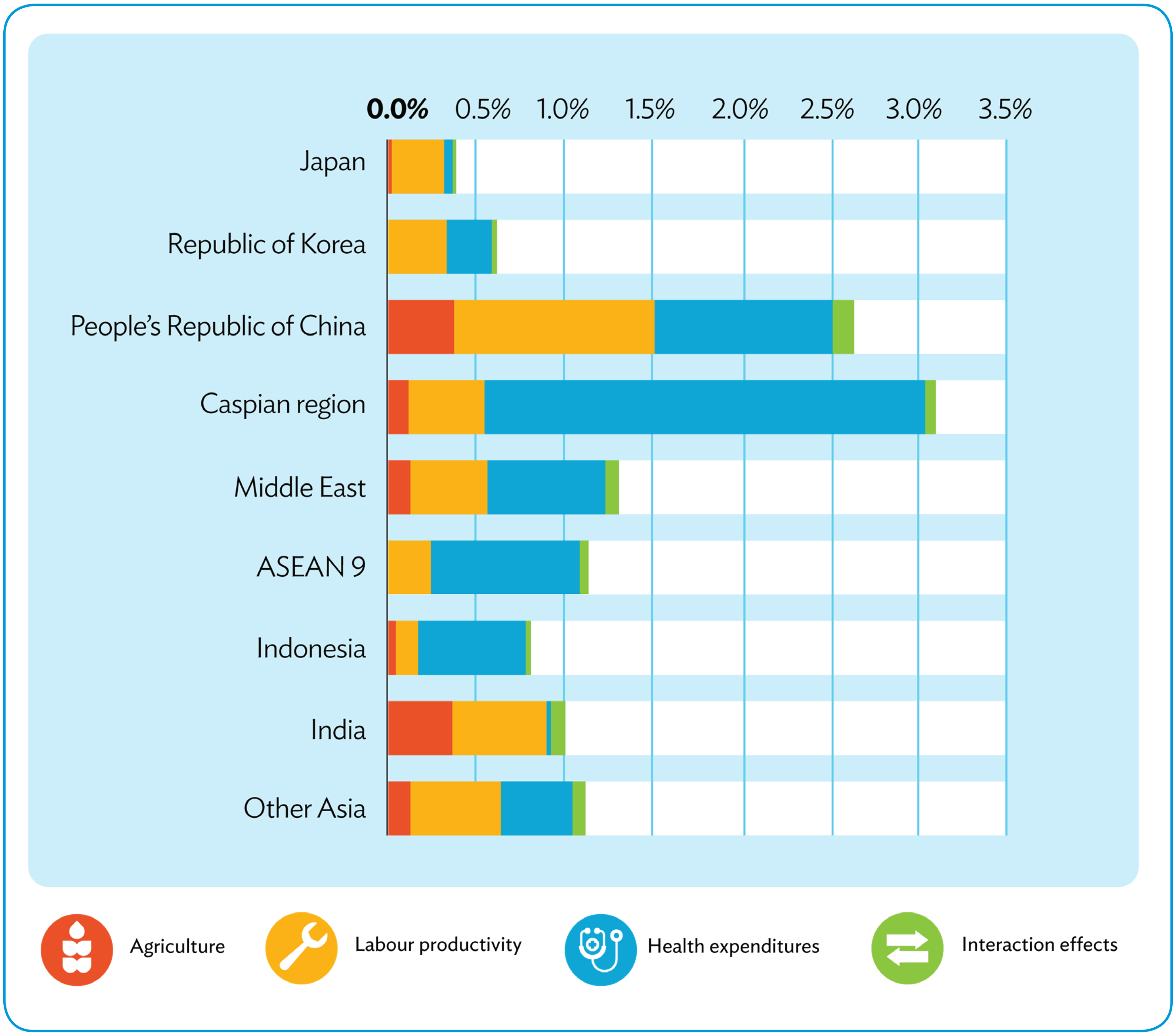
Figure 5: The global impact of air pollution on health (2019)



Source: Health Effects Institute. 2020. State of Global Air 2020; Global Burden of Disease Study 2019. IHME, 2020.

The effects of air pollution on Asian economies is substantial, with air pollution estimated by OECD to account for a reduction of 1% to 2.5% in GDP across different economies in Asia by 2060. These costs come mainly from reduced productivity, and increased healthcare costs. For context, the economic burden of smoking in PRC is estimated to be about 0.7% of GDP (Ekpu and Brown, 2015). Differences in projected GDP losses arise from factors such as the cost of healthcare, and the age profile of different populations.

Figure 6: Projected impact of air pollution on GDP in 2060



Source: OECD, 2016

3. AIR POLLUTION AND COVID-19

The severity of the Covid-19 pandemic has been increased by air pollution. At the same time, society responses to the pandemic have also had an effect on air pollution.

Current and past exposure to air pollution could plausibly affect individual responses to the Covid-19 virus, potentially making individuals more susceptible to the virus. It is difficult to be confident, but a preliminary estimate by Pozzer et al. (2020) suggests that particulate air pollution accounted for just over a quarter (27%) of Covid-19 mortality in East Asia with lower contributions of 15% in South Asia and 8% of Covid-19 mortality in West Asia. This means that the impacts of the Covid-19 pandemic would have been substantially lower if high air pollution was less widespread in Asia. This only adds to the health and economic burdens of air pollution shown in Figures 5 and 6, and further emphasises the importance of taking action to improve air quality.

At the same time, since the start of the global Covid-19 pandemic early in 2020, air pollution levels have dropped significantly in response to reductions in travel and economic activity during lockdown situations. This has resulted in some dramatic improvements in air quality. As economies restart, air pollution levels are returning towards pre-lockdown levels.

Figure 7: Haze shrouding New Delhi's India Gate before lockdown, and clear skies during lockdown

The Centre for Research and Energy and Clean Air (2020) analysed air pollution data to estimate how improve air quality has impacted on people suffering from pre-existing conditions, such as asthma, diabetes and heart disease. This study indicated that up to **11,000 early deaths have been avoided due to improved air quality** across Europe during the first 6 months of the pandemic.

Similarly, in PRC, the two months of pollution reduction during the initial Covid-19 lockdown is estimated to have **saved the lives of 4,100 children under 5 and 73,000 adults over 70 in China** (G-FEED Group, 2020). Sharma et al. (2020) estimated that the annual death toll in India could fall by **650,000** if the fall in air pollution levels driven by the country's lockdown were maintained (Sharma et al., 2020). These striking figures underline that major changes in activity such as those imposed during the Covid-19 epidemic can result in substantial improvements in air quality, and as a result, substantial improvements in health with associated economic and societal benefits.

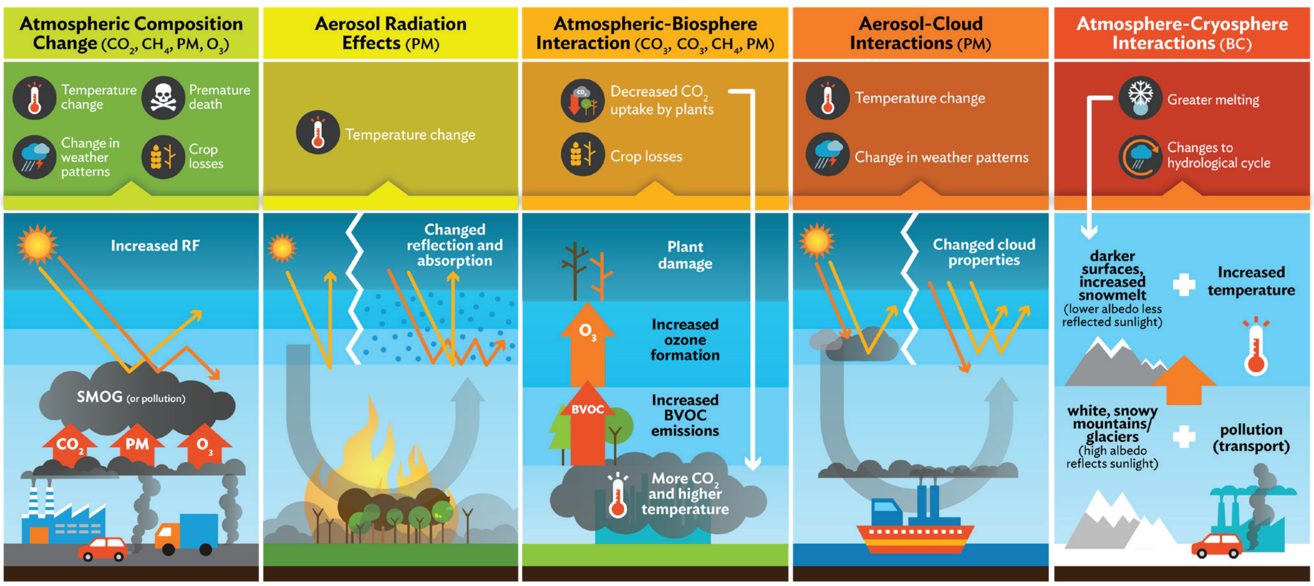
4. AIR QUALITY AND CLIMATE CHANGE – KEY LINKAGES

Climate change and air pollution are closely linked and it is often possible to address both simultaneously. The main sources of air pollutants and greenhouse gases (GHGs) are often the same: combustion processes (heating, electricity generation etc); transport; and agriculture. Additionally, some air pollutants also influence global and regional climates (Climate and Clean Air Coalition, 2019). Examples include:

- Deposition of air pollution can darken snow, resulting in increased heat absorption and shortening the snow season.
- Monsoon rains are a critical source of water for agriculture. Increased air pollution in the monsoon regions can result in changes to long-term rainfall patterns. There are still uncertainties in understanding the impacts of air pollution on the Asian monsoon due to the complex range of issues involved.
- Some air pollutants, such as ozone and black carbon act, as short-lived climate pollutants (SLCPs).

These interactions are illustrated in Figure 8.

Figure 8: Illustrations of interactions between air pollutants and climate change



Source: von Schneidemesser et al., 2015.

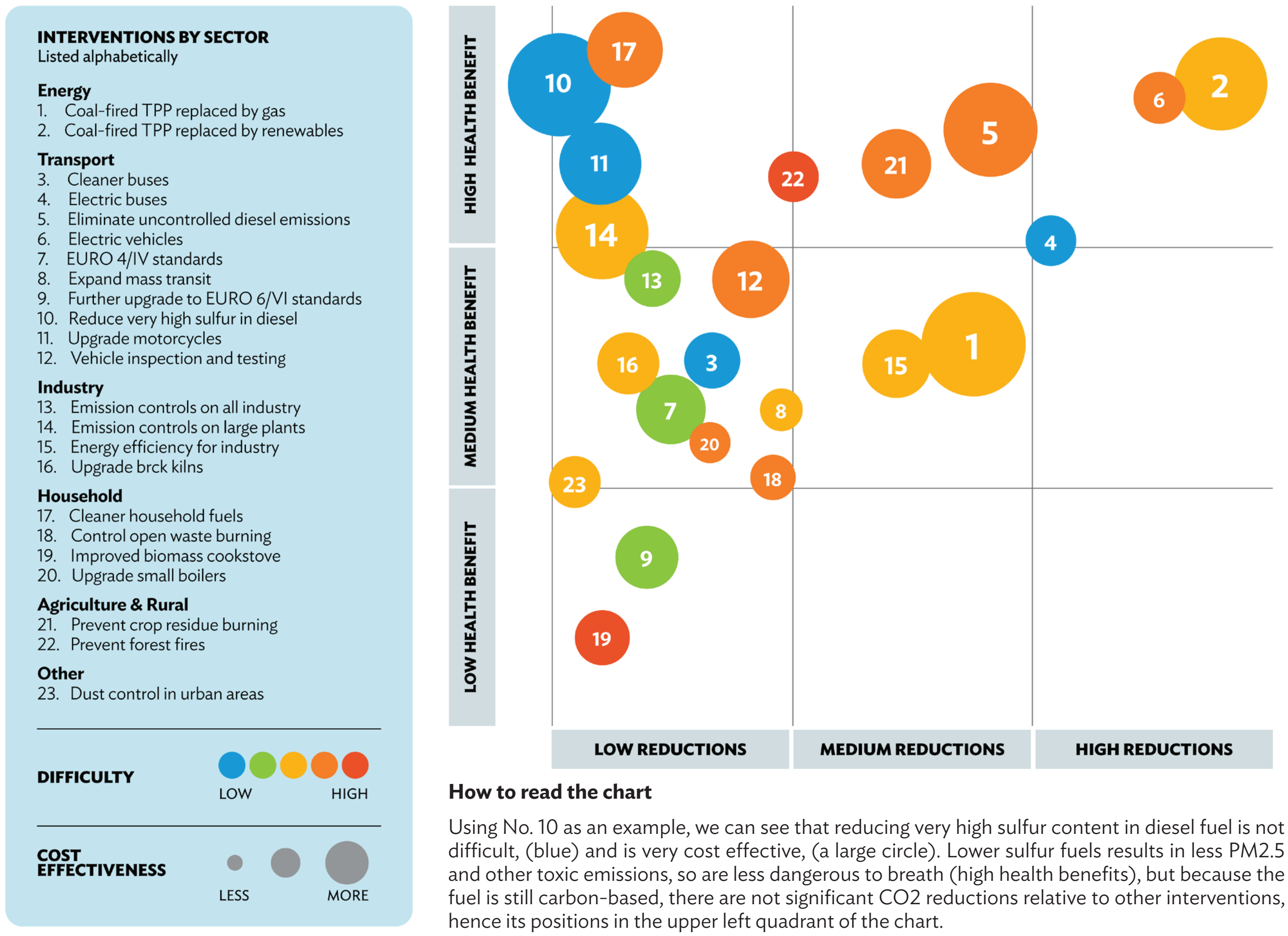
There is an increasing interest in simultaneously addressing air pollution and climate change through policies to promote measures offering multiple benefits, especially those that aim to reduce emissions of SLCPs. Policies that focus on reducing black carbon and ground-level ozone in the atmosphere contribute both to slowing global warming and to reducing air pollution. Such policies can complement other initiatives to reduce emissions of carbon dioxide and other greenhouse gases.

5. SOLUTIONS FOR IMPROVING AIR QUALITY AND EXPECTED HEALTH AND ECONOMIC BENEFITS

Research being carried out for ADB has highlighted a very wide range of measures for improving air quality and delivering associated health and economic benefits. These are set out in the Appendix, or by following this link .

The Global Alliance on Health and Pollution has produced a useful analysis of potential measures to deliver improvements in both air quality and greenhouse gas emissions (Figure 9). This shows that measures such as moving to electric vehicles and replacement of fossil fuels with renewables can be effective in improving both air quality and greenhouse gas emissions.

Figure 9: Interactions between air quality and climate improvement measures (GAHP, 2020)



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 results 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 CO2 reductions relative to other interventions, hence its positions in the upper left quadrant of the chart.

This chart is based on experience and professional judgment to provide an indication of the general magnitude of climate and health benefits and costs (GAHP, 2020).

- **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 tons of CO2 equivalent reduced: Low: estimated to be less than 0.1% of total CO2 releases for the urban area. Medium: up to about 2%. High: above 2%.
- **Cost.** This is considered as the direct cost that the implementing agency has to provide in the context of a major city. Low: estimated costs over five year less than $5 million. Medium: up to $100million. High: above $100 million.

More information on these measures and the information summarized in Figure 8 is available at: https://gahp.net/wp-content/uploads/2020/06/AirPollutionReport_6_22_Final.pdf

6. SUCCESS STORIES

6.1. City-scale initiatives to improve air quality

1 Dhaka (Bangladesh): Two-stroke engines ban (GAHP, 2020)

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 centre.

The government of Bangladesh promulgated an order banning all two-stroke engines from the roads in Dhaka in December 2002. It has been found that the fine PM and black carbon concentrations decreased from the previous years because of the banning of two-stroke engines in Dhaka

2 Low Emission Zones in Europe

Many cities in Europe (Lisbon, Madrid, Oslo, etc.) have used Low Emission Zones in their city center in order to reduce air pollutants concentrations such as PM10 and NOx related to traffic. Due to the encountered success, the city of London has decided to go further by implementing Ultra Low Emission Zone. It was launched in April 2019.

Results after the initial 6 months of operations are:

1. The average compliance rate was 77% in a 24-hour period
2. NO_x reduction of 36% in the central zone
3. NO_2 concentrations at roadside reduced by 29%
4. CO_2 emissions from road transport reduced 4%
5. None of the air quality monitoring stations located in the ULEZ have measured an increase in NO2 since ULEZ introduction.
6. Introduction of ULEZ contributed to a reduction in traffic flow of between 3 to 9% compared to the previous year

In October 2021, the ULEZ area will be extended to cover the whole area encompassed by the North and South Circular roads.

3 Kolkata (India): Renewable energy on transport (Electric buses & ferries, solar panel on bus depot)

The city has a significant air quality problem with $PM_{2.5}$ concentrations of 85.4 ug/m3 in 2018 which exceeds the WHO recommended limit of 10 ug/m3 eightfold. A long-term plan was adopted to invest in 5,000 electric buses and fully electrify the ferries on the Ganges River by 2030. By 2030, it is estimated that the electric bus fleet will reduce CO_2 by about 200,000 tons a year. The transport operator is planning to invest in solar roofing its bus depots together with solar battery storage which will further contribute towards decarbonizing the transport system

WHO, UN Environment and Climate & Clean Air Coalition: BreatheLife

4 Can Tho (Viet Nam): Clean air action plan

Ongoing efforts include restricting personal transport, improving the public transportation system, encouraging biofuel use, increasing urban green coverage, and continuous air quality monitoring of some air quality indicators with one station at a traffic gateway of the city. https://breathelife2030.org/breathelifecity/canthovietnam/

5 Bogor (Indonesia): Clean air action plan

The objective is to reduce SO_x, $PM_{2.5}$ and VOCs emissions:

- Transport: promotion of mass public transportation; strengthening the vehicle inspection and maintenance program; promotion of walking and cycling; reducing emissions from stationary sources:
- Industrial: Improving the system for emissions testing and tracking industry compliance, expanding the reach of solid waste collection to reduce the open burning of garbage, banning rice straw burning and promoting sustainable agricultural practices.

(https://breathelife2030.org/news/bogor-city-develops-clean-air-action-plan-intends-join-breathelife-network/)

6 Singapore: Vehicle Emission Standards

Since September 2017, all new petrol vehicles are required to meet Euro VI emission standards, and since January 2018, all new diesel vehicles must also meet Euro VI emission standards. The revised standards are expected to result in reductions of up to 55% for CO and 51% hydrocarbon emissions.[1]

7 Delhi (India): clean buses

Over 10,000 electric and CNG buses have been deployed since 2000 by private and public operators, resulting in up to 97% reduction in emissions compared to diesel buses (Kathuria, 2005)

8 Hong -Kong (PRC): Cleaner buses

In 2010, the franchised bus companies completed retrofitting their Euro II and III buses with Diesel Particulate Filters, where technically feasible, to reduce particulate emissions by over 80% and "low emission zones" were established in three busy corridors in central Hong Kong. The government subsidized the bus companies to retrofit some franchised buses with selective catalytic reduction devices to upgrade their performance to at least Euro IV level by the end of 2017. They also subsidized to procure six hybrid buses and 36 electric buses for trial runs.

9 Shenzhen (PRC): Electric buses

Shenzhen has 16,000 electric buses in total with 180 depots with their own charging facilities installed. Each bus cost more than USD $250,000 and has been subsidized up to 50% by both national and local government. The switch from diesel buses to electric is expected to achieve an estimated reduction in CO2 emissions of 48% and similar reductions in air pollutants.

10 Hanoi (Viet Nam): Motorcycle pollution

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. The objective is for 80% of those living in the city limits to have access to some form of public transportation within 500 meters of their home.[2]

11 Ulaanbaatar (Mongolia): Energy efficiency stoves / Air Quality Improvement Program / electricity tariff subsidy

3 projects to use cleaner domestic fuel:

The Mongolian Government introduced in Ulaanbaatar a program of subsidized, energy efficiency stoves, distributing more than 100,000 stoves between 2011 and 2013 (Clean Cooking Alliance, 2015). It achieved a 65% reduction in particulate emissions. Through widespread adoption, ambient concentrations could be reduced by 30%.

The Asian Development Bank (ADB) implemented the Ulaanbaatar Air Quality Improvement Program policy-based loan. Phase 1 has enabled the end of use of raw coal for heating and its replacement with less polluting alternatives. Phase 2 of the project will accelerate implementation of relevant policies and regulations. The aim is to reduce annual average ambient PM2.5 concentrations by 30% in 2021 compared to 2019.

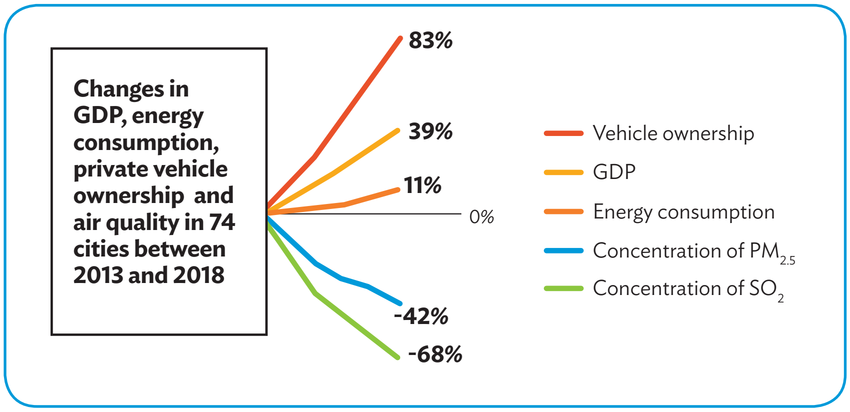
The Air Pollution Action Plan 2017–2025 includes significant financial support for households in ger districts to use to use electric heating stoves as well as additional support for the transition to clean coal technologies. The Air Pollution Action Plan estimates over USD 200 million in government support for the roll-out of 2.5 kW electric household stoves in 130,000 households.

6.2. Country scale initiatives to improve air quality

12 PRC (air quality management)

PRC saw significant breakthroughs with the Path to Clean Air policy 2013-2017".[3] This focused on: Science-based capacity building; control of key pollution sources; supporting measures; and inter-departmental coordination and cooperation. As a result, PRC has substantially reduced pollutant concentrations:

Figure 9: Economic development and improvement in air quality in the People's Republic of China (2013 – 2018) (MEE, 2019)



Source: Chinese Academy of Environmental Planning.

[1] https://www.nea.gov.sg/media/news/news/reducing-pollution-from-in-use-vehicles-to-achieve-better-air-quality
[2] https://vneconomictimes.com/article/society/motorbikes-not-cars-the-environmental-threat
[3] www.allaboutair.cn/uploads/soft/181114/Breakthroughs_ChinasPathtoCleanAir2013-2017.pdf

13 Bangladesh (Improved fertilizer application)

The Accelerating Agriculture Productivity Improvement project in Bangladesh[4] was funded by the United States Agency for International Development (USAID). The project involved 1.3 million farmers in 22 districts. The measures implemented included deep placement of urea to optimize nutrient uptake, alternate wetting and drying to reduce anaerobic decomposition in rice fields and soil management improvements for vegetables and high value crops. These measures were found to reduce unintended losses of nitrogen, with some farms showing a decrease in emissions of up to two-thirds.

14 Nepal: Clean Brick Initiative

The Initiative enables entrepreneurs and government policymakers to adopt cleaner brick-making technologies. The key measures are to improve local technical capacity in the design, manufacture, mechanization, efficient operation, and maintenance of energy-efficient brick kilns. Alongside this, the personal exposure of laborers to pollution is reduced by improving their working conditions. These measures can reduce pollutant emissions by more than 90%.[5] The initiative will share best practices from Nepal with other countries in the region and vice versa.

https://www.icimod.org/initiative/about-air-pollution-solutions-initiative

15 Malaysia : Financing options related to transport sector

Green technology financing scheme (GTFS 2.0) was introduced in Malaysia (effective 1st January 2019). It focuses on 3 categories of the transport sectors transport infrastructure; vehicles and green fuels production

Philippines and Thailand: biodiesel

16 Philippines

The Philippines enacted the Biofuels Act in 2006 following which the blending of coco biodiesel or coconut methyl ester in petroleum diesel started in 2007. During the first year, a 1% blend was used which was subsequently increased to 2% after a year. It has remained at this since then but the plan is to increase the blend to 5% by 2021.

17 Thailand

Thailand is a major international producer of biodiesel. Thailand introduced an option for B2 (2% blend) biodiesel in 2008 which was subsequently increased to 7% in 2014 and intends to further increase the blend to 10% with a long-term target of 30% blend by 2025.

4 USAID 2016
5 https://www.ccacoalition.org/en/initiatives/bricks

APPENDIX 1: MEASURES TO IMPROVE AIR QUALITY

Table A1: Measures to address domestic sources of air pollution

Measure	Pollutant(s) targeted	Description
Improvements in fuel quality	PM, SO_x	• Preparation and separation of raw coal (including washing) • Regulating type of coal used in households • Enclosure of coal distribution and storage centres • Establishing a clean coal supply chain • Improved standards for the use of biomass fuel
Switching to cleaner fuels	PM, NO_x, SO_x,	• Regulating or eliminating the use of solid fuels and banning construction of new coal-fired boilers • Introducing / extending the use of natural gas, LPG, renewable or electric stoves and heating sources, or less polluting solid fuels (e.g. wood pellets) • Expanding the coverage of central heating systems in homes and businesses or use of district heating systems
Improvements in energy efficiency	PM, NO_x, SO_x	• Replacing old and inefficient energy devices with new, more efficient boilers and stoves • Improvement of building fabric: Insulation of walls, ceilings and windows and draft reduction • Good housekeeping / servicing of existing boilers / stoves • Installation and use of climatic controls • Use of eco-labelled, efficient devices and appliances • Energy efficient lighting
Installation of end of pipe technologies	PM, NO_x	• Filters in household (kitchen e.g. rangehoods) • Catalytic insert for stoves (such inserts do not work on fireplaces because the flue gas temperature too low, or for mineral fuels because the catalyst clogs or is poisoned by sulphur and/or heavy metals). Use on stoves has mixed success but essentially needs to be built in to appliance, because the stack temperature is typically too low for the catalyst to operate effectively. • Cyclones / de-dusters / etc. for boilers
Promotion of clean operation and energy efficient behaviour	PM, NO_x, SO_x	• Communication and engagement, i.e. provision of information, training, personal advice, demonstrations, goal-setting • Provision of information tools, e.g. meters, temperature gauges, thermometers • Standby switches, turning off lights
Extraction/ Indoor air quality	PM, NO_x, SO_x	• Combustion gas extraction (stove chimney, hoods over cooking stoves) • Use or building controls to require minimum ventilation or extraction requirements • Minimum standards for construction of such chimneys (i) to protect user of appliance from combustion products, (ii) to protect chimney and building from fire, (iii) to mitigate impact on external environment

Table A2: Measures to address transportation sources of air pollution

Measure	Pollutant(s) targeted	Measure description
Emissions standards and inspections for road vehicles	PM, NO_x, (SO_2)	• Establishing testing and vehicle maintenance centres • Roadside emissions testing • Awareness campaigns • Improving fuel quality
Promote the use of low emission vehicles and reducing demand	PM, NO_x, (SO_2)	• Upgrading to newer, cleaner conventional fuelled vehicles, or switching to cleaner conventional fuels (e.g. from diesel to petrol) • Promotion of renewable fuels such as ethanol and biodiesel • Switching to mixed power trains (e.g. hybrids) • Switching to unconventional fuels (e.g. to electric, hydrogen or biomethane powered vehicles) • Retro-fitting existing vehicles (e.g. fly-wheels on buses) • Active travel (e.g. walking and cycling) • Optimisation of logistics / deliveries • Adoption of urban mobility plans to regulate and streamline commuting • Car-sharing or car clubs • Encouraging flexible working • Vehicle population control and changes to parking provision in city centre
Improved public transport and traffic changes	PM, NO_x, (SO_2)	• Greater provision and use of public transport (e.g. trolley-buses, buses, trains, metros, etc.) • Optimisation of urban planning and layout • Improvements to junctions and speed controls • Bypass construction • 'tidal lanes' and widening of roads • Intelligent traffic control systems and traffic management
Fugitive Dust control	PM	• Street sweeping • Paved roads • Dust sprays • Requirements for dust management plans • Control of construction activities and sites
Electric transport	PM, NO_x, (SO_2)	• Requires electrical charging infrastructure • Requires reliable electrical supply • May be offsets with emissions from electricity generation
Eliminate 2-stroke engines	PM, NO_x, (SO_2)	• Introducing technological solutions to minimize emissions • Implementation of stringent regulations • Provision of financial incentives to discourage usage
Integrate land-use and transport planning	PM, NO_x, (SO_2)	• Promotion of mix use development • Discourage sprawl • Encourage smart urban growth • Development of mass transit initiatives/BRT-bus rapid transit systems • Identification and development of feeder routes along the transport corridors. • TDM measures to be explored and implemented
Financing options	PM, NO_x, (SO_2)	• Provision of tax incentives for renewing public vehicles registration • Offering cash for older public vehicles to get them off the roads • Ensuring credit for purchasing new public vehicles • liberalizing the trade of new vehicles for public use • Optimize financing options especially micro-financing according to market dynamics • Explore funds like multilateral climate funds, bilateral funds, carbon markets

Measure	Pollutant(s) targeted	Measure description
Emissions testing	PM, NO_x, (SO_2)	• Establish roadside testing facility. • Install specialized equipment remotely measures tailpipe emissions from vehicles passing a given point. • Introduce awareness campaigns to encourage users to conduct testing (e.g. highlighting the potential safety improvements and cost savings)
Improve fuel quality	PM, NO_x, (SO_2)	• Upgradation to better quality fuels • Coupling clean fuels with clean engine technologies • Investments by fuel industry as well as auto industry
Alternative fuels	PM, NO_x, (SO_2) CO_2	• Explore and usage of alternate fuels-Ethanol, CNG, Propane, hydrogen, bid diesel, electricity etc • Regulatory and financial support for alternative fuels
Second-hand vehicles and engines	PM, NO_x, (SO_2)	• Monitor and record share of 2nd hand cars • Ensure meeting of "emission standards" and "safety standards" • In place regulations for managing vehicles import
Vehicle replacement	PM, NO_x, (SO_2)	• Replacement of high emitting vehicles through different schemes • Optimal balance between "financial benefits" and "environmental benefits" required
Low emission zones	PM, NO_x, (SO_2)	• Limiting vehicles entry to a zone • Improvement in vehicle emissions legislation • Usage of technology for enforcement
Central area congestion charging zones	PM, NO_x, (SO_2)	• Limiting vehicles entry to a smaller targeted zone • Usage of technology for enforcement • Alternative modes of transport may be needed • Explore co-benefits with improving journey times
Policies to promote biking and walking	PM, NO_x, (SO_2) CO_2	• Promotion of mix use development • Discourage sprawl • Encourage smart urban growth • Requires investment in safe cycling routes and infrastructure • Explore health and climate co-benefits
Landscape and planting	PM, NO_x, (SO_2) CO_2	• Requires sufficient space for urban planting • Careful planning required to avoid causing increased impacts • Explore co-benefits for climate and urban liveability
Transit oriented development	PM, NO_x, (SO_2) CO_2	• Promotion of mix use development • Discourage sprawl • Encourage smart urban growth • Development of mass transit initiatives/BRT-bus rapid transit systems • Identification and development of feeder routes along the transport corridors. • TDM measures to be explored and implemented
Park & Ride	PM, NO_x, (SO_2) CO_2	• Requires suitable, attractive public transport systems • Requires suitable secure parking areas • Strengthen parking controls in central areas
Parking controls	PM, NO_x, (SO_2)	• Encourages use of alternative modes of transport • Alternative modes of transport may be needed • Requires clear signage and enforcement • May be co-benefits for reduced congestion

Table A3: Measures to address waste sector sources of air pollution

Measure	Pollutant(s) targeted	Measure description
Solid waste management	NO_x, NO_2, PM, SO_2, CO, PAHs, VOCs, heavy metals, dioxins and furans CH_4	• Development of appropriate waste collection, recycling and disposal systems and infrastructure • Collection and treatment of wastewater • Capture / recovery of waste gases (e.g. from landfill or wastewater treatment plant), with flaring or utilisation (e.g. AD) • Reduction or recycling of waste • Diversion of organic waste (either domestic or industrial) from landfill to treatment using AD, composting or incineration

Table A4: Measures to address agriculture sector sources of air pollution

Measure	Pollutant(s) targeted	Measure description
Managing agricultural crop residues	PM, NO_x, SO_2, CH_4, VOC	• Ban outdoor agricultural waste and waste burning in urban and surrounding areas • Satellite remote-sensing technology could be used to identify key monitoring areas and monitor burning activities • Strategies to properly manage harvest residue, e.g. alternative uses such as use of hay silage for cattle or improving soil structure through incorporation of harvest residue or manure, etc.
Manure and fertilizer management	NH_3, PM	• Low-till farming, alternative cereal harvesting • Covering outdoor storage of manure, including AD • Free range poultry • Ensuring sufficient manure storage capacity • Use of low protein feeding strategies • Prohibit use of ammonium carbonate fertilisers • Replacement of urea-based fertiliser with ammonium nitrate based fertiliser • Replacement of inorganic with organic fertilisers • Use of fertiliser application methods to reduce ammonia emissions • Low-emission manure spreading techniques • Adaptation of animal housing • Use of low nitrogen feed

Table A5: Measures to address industry sector sources of air pollution

Measure	Pollutant(s) targeted	Measure description
Industrial process emissions standards and post-combustion controls	PM, NO_x, SO_x, VOC	• Flue gas Dust Removal (e.g. cyclones, bag filters) • Flue gas Desulfurization • Primary NOx control (low NOx burners or similar) • Flue gas Denitrification (e.g. catalytic reduction) (less common than primary NOx control) • VOC Management • Integrated treatment for Coal-Fired Boilers • Preventing leaks, and good practice on flaring • Closed storage and enclosed materials transport • Preparation and separation of raw coal (including washing) • Enclosure of coal distribution and storage centres • Establishing a clean-coal network • Energy efficiency measures • Fuel switching to cleaner fuels such as gas, LPG, electricity or renewables • Fuel sulphur limits • Reducing or eliminating existing, or banning construction of new, coal fired boilers • Minimum emission standards for new plant (maximum emission limit values)
Improve efficiency and introduce emission standards for brick kilns	PM, NO_x, SO_x, VOC	• Existing technologies are replaced with cleaner production techniques and technology (e.g. HHK) • Regulation, supervision and enforcement programme requiring upgrade/ improved performance of existing facilities to meet specified standards • Closure of existing polluting facilities, if operating outside permitted levels. • Reducing production from plants if operating outside permitted production or capacity thresholds • Minimum emission standards for new plant (maximum emission limit values)
Solvent use	VOCs	• Reduction in solvent content of paints; Increased use of water-based paints, inks and coatings • Covers, seals and vapour recovery in manufacture and application of coatings, inks, adhesives, surface cleaning, and in manufacture of pharmaceutical products, vegetable oil refining, dry cleaning • Absorption, filtration or incineration of exhaust gases • Good housekeeping, solvent management plans, leak detection and repair • Cleaner production

Table A6: Measures to address energy sector sources of air pollution

Measure	Pollutant(s) targeted	Measure description
Renewables and low-carbon power generation	PM, NO_x, SO_x	• Introduction of a FIT • Transition towards a low-carbon portfolio of technologies, including gas, nuclear, renewables (including onshore and offshore wind, solar and marine and biomass conversion) and carbon capture and storage (CCS)
Upgrading existing plant	PM, NO_x, SO_x	• Introduction of advanced design units • Upgrading existing operational units • Substantial retirement of smaller, less-efficient plants • Upgrade of electrostatic precipitators (ESPs) and the inclusion of bag filters • Upgrade of the flue gas desulphurisation units (FGD) • Introduction of NOx control systems
Demand-side energy efficiency improvements	PM, NO_x, SO_x	• Industry, commercial and large users energy audits, trainings, and certifications • Introduction of Standard Offers to large users implementing energy saving measures • Encourage residential users to use low energy appliances and devices
Active load management	PM, NO_x, SO_x	• Introduction of time-of-use pricing • Introduction of interruptible tariffs • Providing customers with smart electricity readers
Active network management	PM, NO_x, SO_x	• Support the development of network innovation projects enabling accelerated penetration of distributed renewable generation at distribution level

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