Summary

AIR POLLUTION IN ASIA AND THE PACIFIC: SCIENCE-BASED SOLUTIONS

UN environment
United Nations Environment Programme

Asia Pacific Clean Air Partnership

Climate & Clean Air Coalition
to reduce short-lived climate pollutants

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ASIA PACIFIC CLEAN AIR PARTNERSHIP

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

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FOREWORD

It is an unfortunate fact that breathing clean air, the most basic human need, has become a luxury in many parts of the world. And while we have beaten many of the big killers of the past, air pollution is now ranked as one of the most serious health threats on the planet, with around a third of global air pollution deaths occurring in Asia and the Pacific. The good news, however, is that the region is also home to numerous and tested solutions that can help beat pollution, save lives and protect our planet.

Air Pollution in Asia and the Pacific: Science-based Solutions identifies 25 clean air measures that can positively impact human health, crop yields, climate change and socio-economic development, as well as contribute to achieving the Sustainable Development Goals. Implementing these measures could help 1 billion people breathe cleaner air by 2030 and reduce global warming by a third of a degree Celsius by 2050.

The top 25 measures not only represent wins for cities and countries looking to improve air quality, but also provide next-generation business opportunities and boost economic growth. India's east-coast state of Maharashtra and its capital city of Mumbai, for example, are embracing electric mobility, aiming to increase the number of electric vehicles in the state to 500,000, creating thousands of jobs and positioning the state as a globally competitive manufacturing destination for electric vehicles and their components.

We have seen how cooperation can lead to positive impacts. In China, the city of Shenzhen, with support from the national government and local transport agencies, is the first to adopt a fully electric solution for its public network of more than 16,000 buses. In Nepal, brick kilns destroyed during the 2015 earthquake have been rebuilt to be safer, less polluting and more efficient through collaboration between kiln owners and technical experts. In Toyama, Japan, integrating transport planning and waste management while promoting renewable energy and energy saving has made the air cleaner and the city more climate resilient.

This report underlines the importance of strong engagement with governments, the private sector and civil society – and the importance of simple and clear communication with citizens to be able to fully-implement recommended solutions.

I hope the report will inspire strong action from the Asia and Pacific region in our efforts to beat air pollution.

ERIK SOLHEIM
Head, UN Environment

MESSAGE FROM CO-CHAIRS

***Air Pollution in Asia and the Pacific: Science-based Solutions* aims to support efforts to reduce air pollution in Asia and the Pacific by proposing cost-effective options suited to the countries of the region.**

Air quality in Asia and the Pacific – what is its status?

The impact of air pollution on human health constitutes a serious public health crisis across Asia and the Pacific. About 4 billion people, around 92 per cent of the region's population, are exposed to levels of air pollution that pose a significant risk to their health: exposure to pollution levels in excess of the World Health Organization (WHO) Guideline for public health protection is associated with elevated risks of premature death and a wide range of illnesses. Reducing this health burden requires further action in Asia and the Pacific to reduce emissions that lead to the formation of fine particulate matter ($PM_{2.5}$) and ground-level ozone, which undermine people's health and well-being as well as food production and the environment.

Fortunately, governments in Asia and the Pacific have already adopted and implemented policies to reduce pollution levels. Without these, population-weighted exposure to harmful $PM_{2.5}$ would be expected to grow by more than 50 per cent by 2030, based on the region's projected economic growth of 80 per cent over the same period. These policies deliver significant benefits for air quality and health, a considerable achievement. However, they are not enough. Further action is necessary if the people of Asia and the Pacific are to enjoy air quality that conforms to the WHO Guideline.

Air quality in Asia and the Pacific – what can be done?

Air Pollution in Asia and the Pacific: Science-based Solutions uses the highest quality data available and state-of-the-art modelling to identify the most effective 25 measures to reduce air pollution. The analysis, which takes the region's considerable diversity into account, groups the selected measures into three categories that are fully described within the report:

i. conventional emission controls focusing on emissions that lead to the formation of fine particulate matter;

ii. further (next-stage) air-quality measures for reducing emissions that lead to the formation of $PM_{2.5}$ and are not yet major components of clean air policies in many parts of the region; and

iii. measures contributing to development priority goals with benefits for air quality.

If the 25 identified measures are effectively implemented, 1 billion people in Asia could enjoy air quality that conforms to the WHO Guideline by 2030, compared to only about 360 million in 2015. The reductions in outdoor air pollution could reduce premature mortality by a third, and about 2 million premature deaths from indoor air pollution could be avoided each year.

These 25 measures would also provide benefits for food and water security, environmental protection and the mitigation of climate change.

MESSAGE FROM CO-CHAIRS

Air Quality in Asia and the Pacific – how to achieve benefits?

Regional and national differences in priorities for action and ease of implementation require a flexible approach to tackling air pollution, so this report provides a range of options for countries to consider in the context of their national circumstances.

The region already has considerable experience with the implementation of measures to reduce pollutant emissions, but there is a need to strengthen compliance with existing policies and improve their alignment in order to enhance both their implementation and their effectiveness.

Improving compliance will require significantly greater institutional and human resource capacity to manage pollution-related issues in a wide range of agencies. This report discusses how better alignment of policies will require carefully designed inter-agency coordination mechanisms.

The focus of most air pollution prevention policies is on cities. However, as this report identifies, regions around cities contribute significantly to poor air quality within cities due to the atmospheric transport of air pollutants. To manage urban air quality effectively, regional, national, urban and rural authorities with responsibility for activities resulting in emissions need to collaborate more closely. As $PM_{2.5}$ and ground-level ozone are regional air pollutants, joint regional efforts and institutional mechanisms are also required to address them.

Many challenges arise from the findings of *Air Pollution in Asia and the Pacific: Science-based Solutions*. For example, the successful implementation of some smaller-scale measures may require forms of governance that facilitate coordination within and across stakeholder organizations at various levels of decision making. Collaborative regional and international initiatives also have an important role to play, as they can help provide the financial, technological and capacity-building support needed to carry through many of the proposed measures.

Despite these challenges, the benefits of implementing these 25 cost-effective measures to reduce air pollution outweigh the expense many times over, and we hope that this report will contribute to effective action.

The Co-Chairs of *Air Pollution in Asia and the Pacific: Science-based Solutions*

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KEY MESSAGES

THE NEED

Only the few ...

Less than 8 per cent of the population of Asia and the Pacific enjoyed healthy air – within the World Health Organization (WHO) Guideline – in 2015. That means that around 4 billion people, the other 92 per cent of the population, spread unevenly across the region and with the highest numbers living in South and East Asia, are exposed to levels of air pollution that pose significant risks to their health. Improving the lives of such a vast number of people requires action to reduce the emissions that result in the formation of fine particulate matter ($PM_{2.5}$) and ground-level ozone, both of which damage human health and well-being, as well as food production and the environment.

It may not get worse, but will it get better?

If current policies aimed at limiting emissions are effectively introduced and enforced, air quality will be no worse in 2030 than it was in 2015, despite population growth, rapid urbanization and an ever-increasing demand for goods and services. But nor will it be any better. This suggests that current policies are mitigating air pollution in valuable but limited ways. The 80 per cent economic growth forecast by 2030 compared with 2015 could be achieved with no further increase in air pollution while lifting tens of millions of people out of poverty. However, this still leaves more than 4 billion exposed to health-damaging levels of air pollution. Further action is needed to move towards the WHO Guideline and protect public health.

THE SOLUTIONS

The widespread effective implementation of only 25 measures will dramatically improve the situation

State-of-the-art modelling has been conducted on several hundred potential ways to reduce air pollution. The most effective 25 measures were selected as the best proven options, benefiting human health and the environment with regard to food security, air, water and soil quality, biodiversity and climate, whilst helping achieve the Sustainable Development Goals (SDGs).

THE BENEFITS

Improving health

By implementing the top 25 clean air measures, 22 per cent of the region's population, around 1 billion people, could enjoy air quality within the WHO Guideline by 2030, compared to less than 8 per cent in 2015. The number of people exposed to pollution above the highest WHO Interim Target could fall by 80 per cent to 430 million. Furthermore, premature mortality from outdoor air pollution could decline by about a third, and an additional 2 million premature deaths a year from indoor air pollution could be avoided.

Improving food security and protecting the environment

Ground-level ozone is the most important air pollutant responsible for reducing crop yields, and thus affects food supply. Implementing the top 25 clean air measures could reduce estimated ozone-induced crop losses considerably – by 45 per cent for maize, rice, soy and wheat combined. And, as ground-level ozone affects productive grasslands and forests in similar ways, adoption of the package of measures would also benefit the health of natural ecosystems. The measures will also reduce nitrogen and sulphur deposition to ecosystems and have benefits for water and soil quality, as well as biodiversity.

Enhancing water security

Additional warming due to black carbon and dust in the atmosphere and their deposition on glaciers and snowfields in the Hindu Kush-Karakorum-

Himalayan-Tibetan area is strongly linked to accelerated melting of glaciers and snowfields in the region. A reduction in particulate emissions from implementing the top 25 clean air measures will slow the melting of glaciers and snowfields, reduce the risk of disasters related to glacier lake outburst floods, and help mitigate water insecurity for billions of people.

Mitigating climate change

Implementing the top 25 clean air measures will benefit efforts to mitigate climate change. It could reduce carbon dioxide emissions in 2030 by almost 20 per cent relative to baseline projections and potentially decrease the expected warming by a third of a degree Celsius by 2050. This would be a significant contribution to the Paris Agreement target of keeping global temperature rise this century well below 2ºC.

Contributing to the Sustainable Development Goals

The top 25 clean air measures will aid countries in their efforts to achieve the SDGs. Implementing them will improve air quality and mitigate climate change, directly contributing to the realization of SDG 3: Good Health and Well-being, SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production and SDG 13: Climate Action. Measures applied individually or in groups will also contribute directly or indirectly to the achievement of all the other 13 SDGs and their linked targets.

MAKING IT HAPPEN

Providing options for Asia and the Pacific

The top 25 clean air measures are not equally appropriate across the whole region. While the measures are a package, the diversity of sub-regions and countries in the region will mean tailoring the prioritization and implementation of the measures to national realities.

Requiring a small share of the region's future growth

Implementation of the top 25 clean air measures across the region is projected to cost US$ 300–600 billion per year, only about one twentieth of the increase of US$ 12 trillion in annual gross domestic product (GDP) that is projected by 2030. In addition to delivering substantial benefits to human health, food production, environmental protection and climate change mitigation, a basket of co-benefits will accrue, including savings on pollution control.

Financing the clean air measures

Several of the top 25 clean air measures are aligned with national development priorities and could be supported from domestic public finance. The private sector and businesses are ready to invest in cleaner technologies, provided a favourable enabling environment is in place. Concessional or low-interest loans can support governments and other stakeholders in implementing the measures, while climate finance mechanisms are available for measures that reduce air pollution and mitigate greenhouse gas emissions. Multilateral and bilateral funding institutions could align their air pollution strategies to the top 25 clean air measures, with research institutes and networks helping build the additional technical capacity needed to introduce and effectively implement the measures.

Mobilizing partnerships for multiple benefits

Continued economic growth will remain critical, but economic growth alone will not be enough to lead to the successful adoption and effective implementation of the top 25 clean air measures. That will require concerted efforts and integrated action from governments, businesses and civil society. The introduction and successful implementation of the measures will entail building bridges between traditional decision-making structures and breaking down barriers to effective partnership. The careful choice and implementation of the 25 clean air measures could foster cooperation between a variety of ministries, local authorities, industries and civil society organizations. Multiple partners working together can implement change for the greater good and sustainable development of Asia and the Pacific.

TABLE A: THE TOP 25 CLEAN AIR MEASURES

Regional application of conventional measures	
Post-combustion controls	Introduce state-of-the-art end-of-pipe measures to reduce sulphur dioxide, nitrogen oxides and particulate emissions at power stations and in large-scale industry
Industrial process emissions standards	Introduce advanced emissions standards in industries, e.g., iron and steel plants, cement factories, glass production, chemical industry, etc.
Emissions standards for road vehicles	Strengthen all emissions standards; special focus on regulation of light- and heavy-duty diesel vehicles
Vehicle inspection and maintenance	Enforce mandatory checks and repairs for vehicles
Dust control	Suppress construction and road dust; increase green areas
Next-stage air quality measures that are not yet major components of clean air policies in many parts of Asia and the Pacific	
Agricultural crop residues	Manage agricultural residues, including strict enforcement of bans on open burning
Residential waste burning	Strictly enforce bans on open burning of household waste
Prevention of forest and peatland fires	Prevent forest and peatland fires through improved forest, land and water management and fire prevention strategies
Livestock manure management	Introduce covered storage and efficient application of manures; encourage anaerobic digestion
Nitrogen fertilizer application	Establish efficient application; for urea also use urease inhibitors and/or substitute with, for example, ammonium nitrate
Brick kilns	Improve efficiency and introduce emissions standards
International shipping	Require low-sulphur fuels and control of particulate emissions
Solvent use and refineries	Introduce low-solvent paints for industrial and do-it-yourself applications; leak detection; incineration and recovery

TABLE A: THE TOP 25 CLEAN AIR MEASURES (contd.)	
Measures contributing to development priority goals with benefits for air quality	
Clean cooking and heating	Use clean fuels – electricity, natural gas, liquefied petroleum gas (LPG) in cities, and LPG and advanced biomass cooking and heating stoves in rural areas; substitution of coal by briquettes
Renewables for power generation	Use incentives to foster extended use of wind, solar and hydro power for electricity generation and phase out the least efficient plants
Energy efficiency for households	Use incentives to improve the energy efficiency of household appliances, buildings, lighting, heating and cooling; encourage rooftop solar installations
Energy efficiency standards for industry	Introduce ambitious energy efficiency standards for industry
Electric vehicles	Promote the use of electric vehicles
Improved public transport	Encourage a shift from private passenger vehicles to public transport
Solid waste management	Encourage centralized waste collection with source separation and treatment, including gas utilization
Rice paddies	Encourage intermittent aeration of continuously flooded paddies
Wastewater treatment	Introduce well-managed two-stage treatment with biogas recovery
Coal mining	Encourage pre-mining recovery of coal mine gas
Oil and gas production	Encourage recovery of associated petroleum gas; stop routine flaring; improve leakage control
Hydrofluorocarbon (HFC) refrigerant replacement	Ensure full compliance with the Kigali Amendment

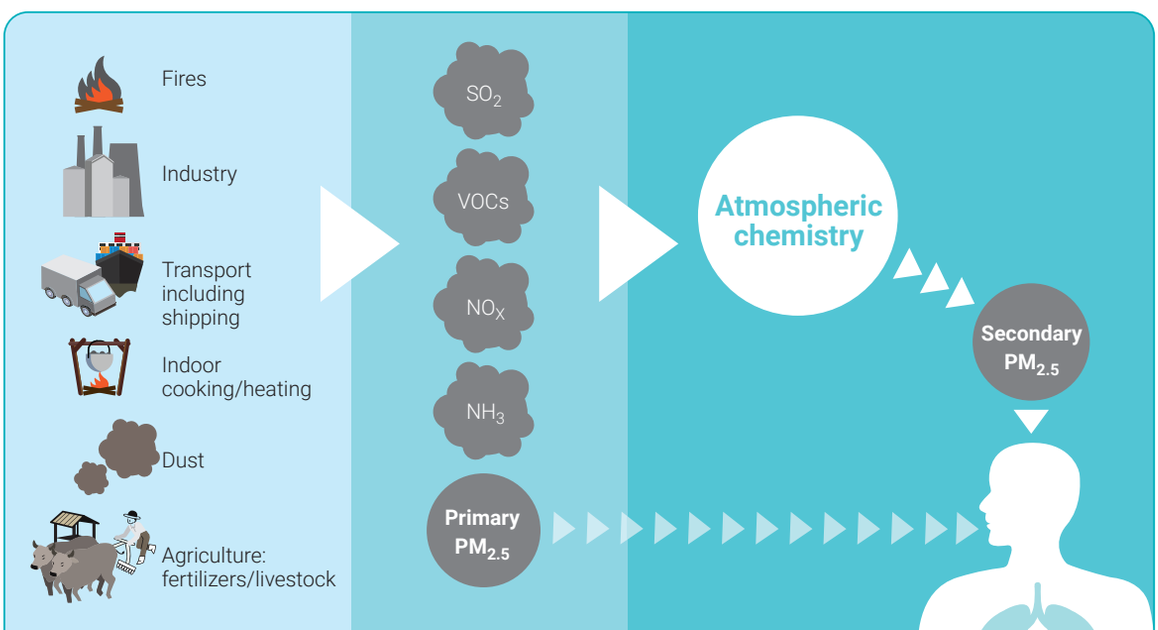
INTRODUCTION

AIR POLLUTIION IMPACTS ON HUMAN HEALTH

The impact of air pollution on human heath represents a serious public health crisis across Asia and the Pacific. Fewer than 8 per cent of the region's people are exposed to levels of air pollution that do not pose a significant risk to their health according to the World Health Organization (WHO) Guideline. There is now sufficient evidence from epidemiological studies in Asia and the Pacific that exposures to $PM_{2.5}$ and ground-level ozone are the most health damaging and account for large attributable health burdens.

Fine particulate matter

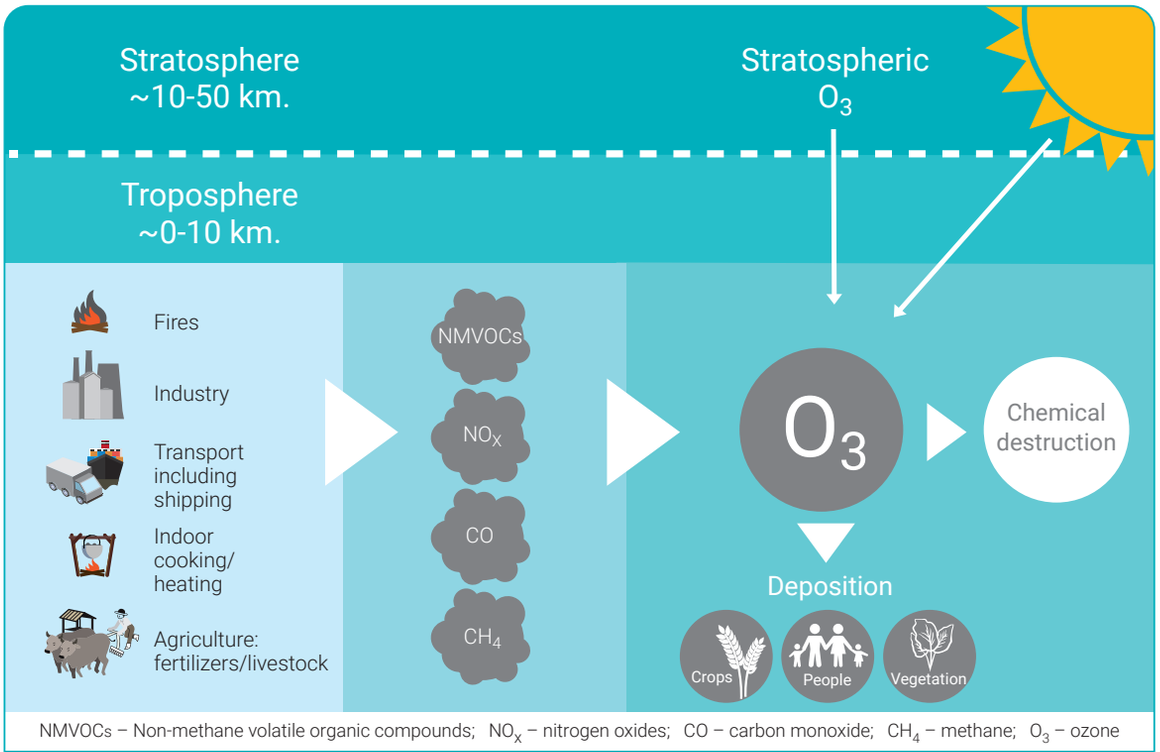
Fine particles are directly emitted during the combustion of fossil fuels and biomass including forest and peat fires, and from industrial processes; these particles include fly ash, various metals, salts, and carbonaceous species including black and organic carbon (Figure 1). Particle emissions also originate from natural sources such as soil dust and sea salt. Another substantial fraction of fine particles is formed in the atmosphere through chemical reactions involving gaseous emissions. Sulphur dioxide, nitrogen oxides and volatile organic compounds from fuel combustion and industrial processes, and ammonia from agricultural activities are the main contributors to the formation of fine particulates in this way. In this report, fine particulate matter is considered to be $PM_{2.5}$ – particles with an aerodynamic diameter equal to or less than 2.5 micrometres (µm). There is a variable relationship with PM_{10}, particles with an aerodynamic diameter equal to or less than 10 µm, that may depend on the sources as well as the physics and chemistry of the atmosphere.The relationship may vary with location, season and weather conditions.



SO_2 – sulphur dioxide; VOCs – volatile organic compounds; NO_x – nitrogen oxides; NH_3 – ammonia; $PM_{2.5}$ – particulate matter with an aerodynamic diameter equal to or less than 2.5 micrometres (µm)

Primary inorganic and organic $PM_{2.5}$ particles are those released directly to the atmosphere and inhaled by the population; these include dust from roads and black carbon from combustion sources. Secondary inorganic and organic $PM_{2.5}$ particles, on the other hand, are formed in the atmosphere from chemical reactions involving primary gaseous emissions: nitrogen oxides and sulphur dioxide mainly from cities and industrial areas; ammonia mainly from agricultural sources; and volatile organic compounds from solvent use. Because of their small size, both primary and secondary particles can be transported over large distances.

FIGURE 1: SOURCES AND COMPOSITION OF $PM_{2.5}$



NMVOCs – Non-methane volatile organic compounds; NO_x – nitrogen oxides; CO – carbon monoxide; CH_4 – methane; O_3 – ozone

FIGURE 2: SOURCES OF GROUND-LEVEL OZONE

Ground-level ozone

Ground-level ozone causes serious damage to human health and vegetation. It is formed in the atmosphere by reactions between carbon monoxide, nitrogen oxides, and volatile organic compounds, including methane, in the presence of sunlight (Figure 2). The substances that contribute to the formation of ozone are emitted from a wide range of sources including vehicles, industrial production, fuel combustion, natural emissions from vegetation and soils, vegetation fires including wildfires, controlled burns and agricultural burning, and solvents, as well as emissions from waste disposal. Nitrogen oxides reduce ozone close to their emission sources, usually within urban areas, but enhance its formation downwind. Emissions of volatile organic compounds are potent contributors to ozone formation at the urban scale, and ozone has a lifetime in the atmosphere of the order of several weeks, sufficiently long for it to be transported over longer distances.

World Health Organization guidelines

The WHO has established air quality guidelines to protect human health, with a value for $PM_{2.5}$ of 10 micrograms per cubic metre (µg/m³) as an annual mean concentration in ambient air (Table 1).

TABLE 1: WORLD HEALTH ORGANIZATION AIR QUALITY CRITERIA FOR $PM_{2.5}$

Annual mean $PM_{2.5}$ concentration		WHO Air Quality Criteria
35 µg/m³		WHO Interim Target 1
25 µg/m³		WHO Interim Target 2
15 µg/m³		WHO Interim Target 3
10 µg/m³		WHO Guideline

While based on scientific evidence of health impacts, this level may seem aspirational, and even out of practical reach for some countries given their current positions. As a result, the WHO has established Interim Targets as milestones along the way towards an end-goal of achieving the WHO Guideline value.

Looking forward

Fortunately, governments in the Asia and Pacific region have successfully adopted and implemented policies that have reduced pollution levels and will continue to do so in future. Without them, population-weighted exposure to harmful particulate matter would have been expected to grow by more than 50 per cent by 2030, based on the region's projected 80 per cent economic growth. Although current policies deliver clear and significant improvements in air quality and provide health benefits, a considerable achievement, further action is needed to achieve the WHO Guideline and protect public health.

Air Pollution in Asia and the Pacific: Science-based Solutions

Air Pollution in Asia and the Pacific: Science-based Solutions, the first comprehensive, solution-oriented, interdisciplinary scientific assessment of the air pollution outlook and policy measures in Asia and the Pacific, and this summary, have been prepared in response to Resolution 1/7 of the First Session of the United Nations Environment Assembly in 2014, which called for UNEP to prepare regional reports on air quality issues.

This report is the product of close collaboration between the Asia Pacific Clean Air Partnership (APCAP) and the Climate and Clean Air Coalition (CCAC). The assessment process was chaired by three Co-Chairs from the Asia and Pacific region: Professor Jiming Hao, Tsinghua University, China; Professor Yun-Chul Hong, Seoul National University, Republic of Korea; and Professor Frank Murray, Murdoch University, Australia, and was coordinated by: APCAP; CCAC Secretariat; Institute for Global Environmental Strategies (IGES); Stockholm Environment Institute (SEI); UN Environment, Asia and the Pacific Office; and International Institute for Applied Systems Analysis (IIASA).

Aims

The report and its summary aim to support efforts to address air pollution in Asia and the Pacific by providing options for tackling air pollution in the context of the SDGs. To this end, it brings together evidence of historical trends with future development perspectives and provides detailed analyses of past and future economic trends and their implications for ambient and indoor air pollution.

From there, the report identifies a detailed portfolio of 25 cost-effective measures for technological and policy interventions that would contribute to the achievement of the SDGs while delivering the greatest benefits for human health, crop yields, climate and the environment, as well as socio-economic development.

The report provides a clear picture of the benefits to be gained by adopting the measures and offers some implementation guidance through real-life case studies. It is also hoped that the report will act as a platform to share experiences with practical actions to prevent and control atmospheric pollution across the Asia and Pacific region.

Structure

Section 1 assesses from a regional perspective the many impacts that poor air quality can have, not only on human health, but on the environment, climate and development priorities.

Section 2 identifies the priority measures that most effectively reduce health impacts across the region and help to meet other development goals. This includes the benefits of taking action on air pollution for mitigating climate change.

Section 3 explains how these measures can be implemented and provides examples of where they have been successfully applied in the region. It also identifies enabling environments and factors supporting their implementation at scale across the region.

Target audience

The main report, *Air Pollution in Asia and the Pacific:*

Science-based Solutions, is intended to be used by professionals and practitioners to inform policy and decision makers working in the areas of air pollution and climate change. This summary document is intended to assist policy and decision makers in developing national policies and strategies to address air pollution using proven, cost-effective, readily implementable measures, and it summarizes the findings and conclusions of the main report.

References

This summary is entirely based on the main report, *Air Pollution in Asia and the Pacific: Science-based Solutions.* Thus, for ease of reading, all references to other works and diagram sources appear only in the main report.

Asia and the Pacific

In the report, results are presented as aggregates for four Asia and the Pacific sub-regions (Figure 3). While based on the sub-region components practically defined by the UN Environment Asia and the Pacific Office and the World Bank, countries were re-grouped for the purposes of modelling to take account of the availability of data and ensure the scientific consistency of the modelling results. These sub-regions are used for scientific convenience and have no official or administrative significance.

The modelling studies were conducted using available data on emissions and ambient concentrations of the relevant pollutants in Asia, but such data were obtainable for only a few countries in the Pacific area. The absence of data of a suitable quality for large parts of the Pacific prevented modelling to the necessary level of reliability in the Pacific.

As a result, the sub-regions used in the report are composed as follows:

- **East Asia** (modelled East Asia) includes China, Democratic People's Republic of Korea and Mongolia (and excludes Japan and Republic of Korea);
- **Southeast Asia** (modelled Southeast Asia) includes Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Thailand and Viet Nam (and excludes Brunei Darussalam and Singapore);
- **South Asia** (modelled South Asia) includes Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan and Sri Lanka; and
- **High-income countries** (modelled high-income countries) includes Brunei Darussalam, Japan, Republic of Korea and Singapore.

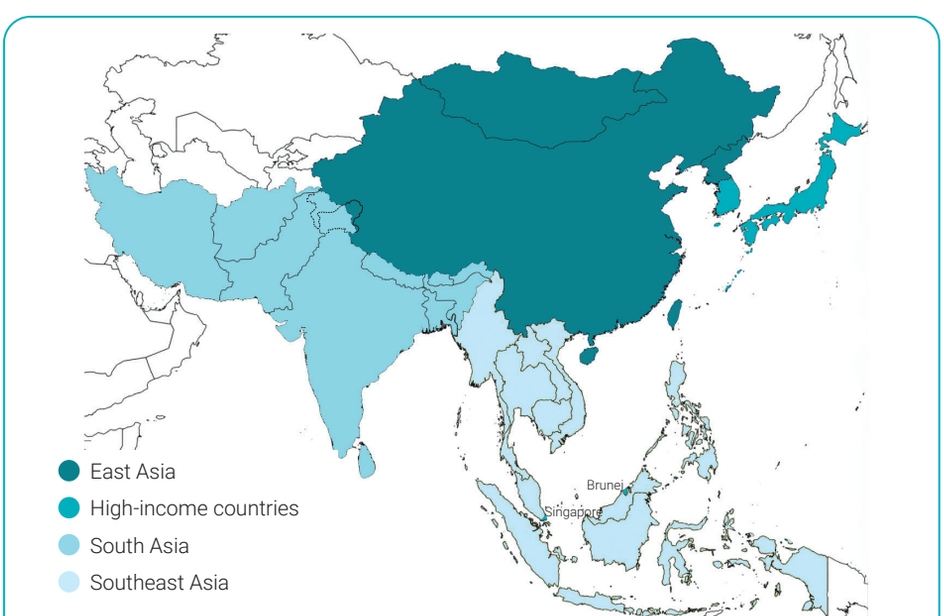


FIGURE 3: MODELLED SUB-REGIONS OF ASIA

SECTION 1

Why decisive action is needed to combat air pollution in Asia and the Pacific

HEALTH IMPACTS

Air pollution is a serious public health crisis across Asia and the Pacific – and the health risks affect everyone

Air pollution is an important risk factor for global disease burdens. It has a major impact on human health, particularly among the poor and vulnerable such as the aged and children. According to estimates in 2016 by the World Health Organization (WHO), exposure to air pollution causes 7 million premature deaths annually worldwide. Nearly 90 per cent of these premature deaths occur in low- and middle-income countries, with close to two out of three in Asia and the Pacific.

Rapidly developing countries in Asia and the Pacific bear much of this burden. While ambient air pollution is especially severe in some of the fastest-growing urban regions, indoor air pollution from cooking and heating with solid fuels is still a considerable concern. Almost 1.9 billion people depend on burning solid fuels such as wood, charcoal, coal and dung in their homes for cooking and heating, resulting in very high levels of indoor air pollution.

Consequently, the health risk posed by air pollution in Asia and the Pacific impacts urban and rural communities across several socio-economic strata. The total mortality burden from indoor and ambient air pollution is ranked only fourth behind dietary risks, tobacco and high blood pressure. In 2013, it was estimated that exposure to ambient and indoor air pollution cost the world's economy about US$ 5.11 trillion in welfare losses. In South and East Asia this cost is equivalent to 7.4 and 7.5 per cent of their gross domestic product (GDP) respectively.

Only 8 per cent of people in Asia and the Pacific are exposed to air pollution levels that do not pose a significant risk to their health, according to the WHO Guideline

While air quality monitoring data do not exist for all cities and locations in Asia and the Pacific, the available data provide ample evidence that international guidelines and national air quality standards are currently widely exceeded. Air quality across the region can be modelled with atmospheric chemistry transport models using the best available information on emissions and meteorological conditions.

Calculations using the Greenhouse gas–Air pollution Interactions and Synergies (GAINS) model that cover all of Asia indicate that, in 2015, $PM_{2.5}$ concentrations in ambient air exceeded the international WHO Guideline value of 10 micrograms per cubic metre (µg/m^3) over large areas, and essentially in all populated regions (Figure 1.1). Furthermore, concentrations exceeded the highest WHO Interim Target (35 µg/m^3) in many areas.

In 2015, less than 8 per cent of the Asian population could breathe air within the WHO Guideline for $PM_{2.5}$ of 10 µg/m^3 (Figure 1.1). Moreover, more than half, about 2.3 billion people, were exposed to $PM_{2.5}$ levels exceeding even the highest WHO Interim Target of 35 µg/m^3. Between 2005 and 2015, population-weighted mean exposure, which is considered more representative of exposure to $PM_{2.5}$ than monitoring data, increased by about 10 per cent and reached 43 µg/m^3, more than four times the WHO Guideline value.

In addition, in 2015 almost 1.9 billion people suffered from exposure to indoor pollution as a consequence of burning solid biomass or coal for cooking or heating.

For 2015, particularly high levels were calculated for urban and heavily industrialized areas with high population densities – for example in many cities in the northeast of China and in the Ganges valley. In addition, high concentrations occurred in areas with large sources of windblown dust from drylands, such as the Gobi Desert and large parts of Iran.

Emissions from household cooking and heating will need to be reduced to greatly improve ambient and indoor air quality

In addition to the direct impacts on human health of indoor emissions from cooking and heating using solid fuels, these indoor emissions can add to ambient air pollution. In India, for example, the contribution of indoor air pollution to ambient air pollution is estimated to vary between 22 and 52 per cent. A number of studies indicate that reducing emissions from household cooking and heating may be required to substantially improve ambient air quality in some parts of Asia and the Pacific.

The relationship between ambient and indoor air pollution and urban and rural centres emphasizes the importance of multiple stakeholders cooperating and using an integrated approach to improve air quality (Box 1.2).

Air pollution episodes

A considerable amount of epidemiological research, mostly time-series studies on acute exposure to air pollution ranging from days to weeks, has been done in the region, showing similar effects on premature mortality to the studies performed in North America and Europe. However, the health effects of acute episodic events such as forest fires or dust storms in the region are yet to be fully understood by solid scientific research.

There is overwhelming evidence from health studies around the world supporting urgent action to reduce air pollution

There is sizable and consistent global evidence base from short-term health-effects studies – conducted across Asia, Europe and North America – and newly reported long-term cohort studies from China, showing a large health burden from ambient and indoor air pollution in the region. The variations between different modelling approaches are minor in the face of the large burdens that confront populations.

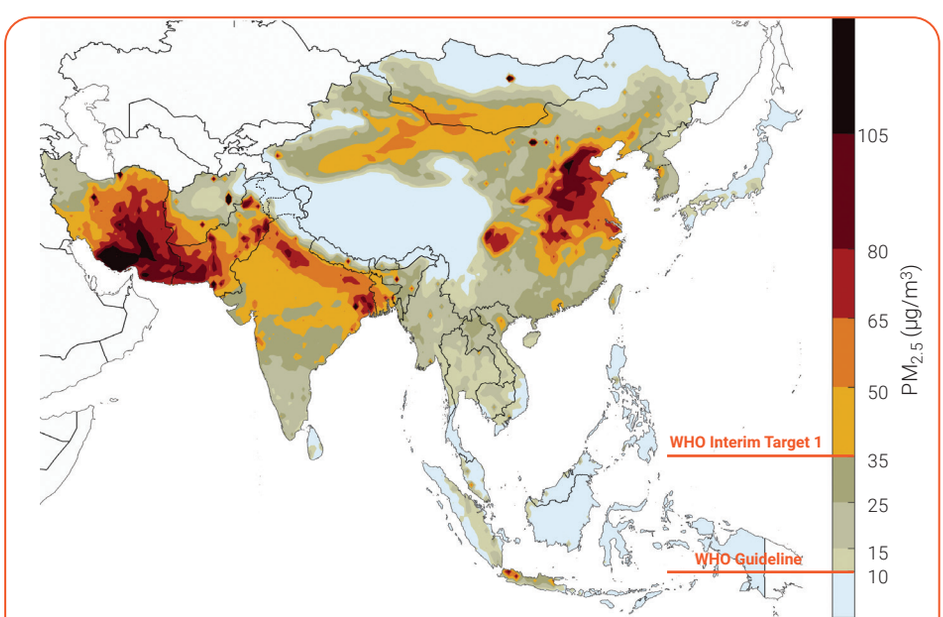


FIGURE 1.1: AMBIENT LEVELS OF $PM_{2.5}$ IN ASIA IN 2015

Note: data were available for all of Asia, but data of adequate quality were unavailable for most of the Pacific

Air pollution affects crop yields, food security and important ecosystems in Asia and the Pacific

CROP-YIELD IMPACTS

Air pollutants have harmful effects on ecosystems, including crops. Ground-level ozone is the most damaging air pollutant to vegetation due to its toxicity and prevalence at high concentrations over rural and agricultural regions downwind of emission centres. Exposure to relatively low levels of ozone damages crops and natural ecosystems. Ozone, particulate matter and related pollutants, including those involved in long-range transport (sulphur dioxide, nitrogen oxides, ammonia, methane and carbon monoxide), can directly or indirectly affect ecosystems in Asia and the Pacific adversely, which can influence crop production and important ecosystem services.

Global photochemical models project that parts of the region will experience further significant increases in ozone concentrations by 2030. High emissions of substances that contribute to the formation of ozone coupled with favourable meteorological conditions enhance ozone formation. The mixed land-use pattern commonly observed in developing countries in Asia and the Pacific, where agricultural land is adjacent to urban areas, increases the exposure of crops to ozone.

Ground-level ozone is increasing in large urban areas in Asia and the Pacific. The potential impact of elevated ozone on agricultural productivity threatens food security in the region, which is home to approximately 60 per cent of the world's undernourished people. High ozone concentrations during the crop growing season lead to substantial reductions in the productivity of a variety of crops, including legumes, maize, rice and wheat. For 2005, yield losses for maize and rice in the region were estimated to be 50 kilogrammes per hectare.

Elevated ground-level ozone also reduces the quality of crops. Visible damage to leafy crops reduces their economic value, while elevated ozone concentrations also decrease starch, protein and nutrient contents in rice and wheat grains.

Ecosystems provide a number of critical services, including supplying food, fibre, timber, water and medicines, and are damaged by air pollution in many parts of Asia and the Pacific. Ecosystems also have important roles in water regulation and purification, erosion control, protection from extreme climate events, recreation and tourism, amongst others. All these are damaged by ground-level ozone, acidification, excessive nutrient enrichment and other factors related to air pollution.

Many air pollutants also influence climate

IMPACTS OF AIR POLLUTION ON AREAS WITH ICE AND SNOW

The impacts of air pollution on areas of ice and snow in Asia and the Pacific are important because the glaciers and snowfields serve as a natural reserve of water for the more than 1.3 billion people living in downstream river basins.Deposition of atmospheric pollution over the glaciers can darken the snow, absorbing more heat and shortening the snow season.

Mineral dust and black carbon are the two most important light-absorbing particles that can be deposited on snow and ice surfaces. These particles significantly enhance absorption of solar radiation and accelerate snow melting. This is the reason that black carbon is thought to play an important role in the rapid retreat of Himalayan-Tibetan glaciers.

AIR POLLUTION EFFECTS ON THE ASIAN MONSOON

Monsoon rains are considered to be the main source of water for arable land in India and Pakistan. The unpredictable nature of the monsoon can cause extensive financial losses, the destruction of farmland and damage to livelihoods and property.

Increasing air pollution levels over these monsoon regions can alter long-term rainfall patterns. The presence of $PM_{2.5}$ in the atmosphere may affect precipitation patterns during the summer monsoon season. For example, a weaker trend in the Indian monsoon precipitation and a north-south shift in precipitation in East Asia have been observed and linked to changes in the emissions of particles

and other pollutants from within and outside Asia. However, there are still uncertainties in estimating the impacts of air pollution on the Asian monsoon due to the complex topography, diverse emission sources, and a wide range of pollutants with potentially complex impacts.

CLIMATE CHANGE IMPACTS

Air quality is closely related to climate change. Global climate change is primarily caused by anthropogenic carbon dioxide emissions, and air pollutants are produced by many of the same emission sources. In turn, many air pollutants influence not only air quality but also climate – ozone and black carbon, for example, warm the atmosphere, while sulphates and organic carbon cool the atmosphere. Improving air quality can make a sizeable contribution to tackling climate change. The impact of mitigation measures on cooling and warming the atmosphere depends on the strategies adopted, which has led to a focus on

BOX1.1: NATIONAL AIR QUALITY AND GLOBAL GUIDELINES FOR $PM_{2.5}$

The WHO developed air quality guidelines to protect human health, with a value for $PM_{2.5}$ of 10 µg/m^3 as an annual mean concentration in ambient air. While based on scientific evidence of health impacts, this level may seem aspirational, and even out of practical reach for some countries, given their starting points today. Taking this view, the WHO developed Interim Targets as milestones along the way towards an end-goal of achieving the Guideline value. These Interim Targets have been taken up in national air quality legislation with a number of countries in the region having put $PM_{2.5}$ standards in place.

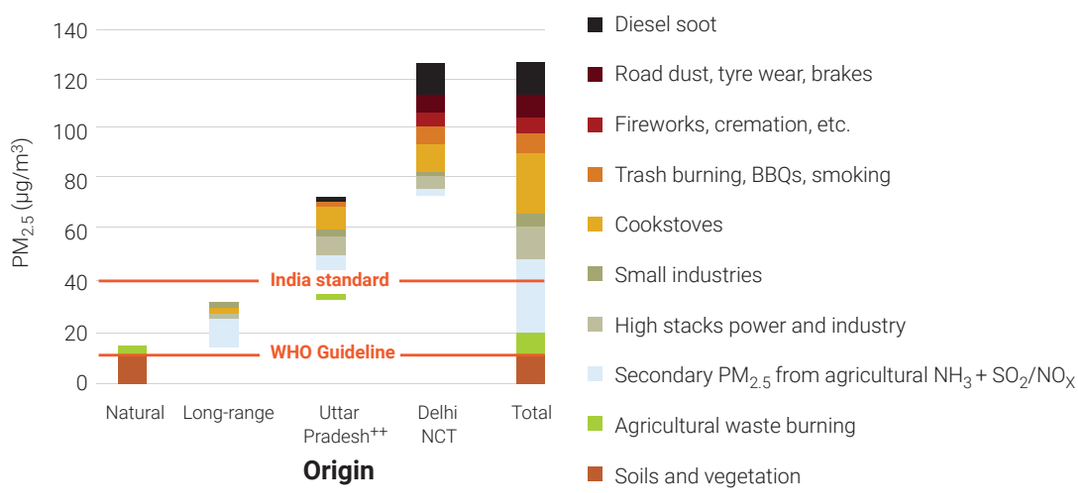
	Annual mean $PM_{2.5}$ concentration	WHO Air Quality Criteria	National air quality standards
	40 µg/m^3		India
	35 µg/m^3	WHO Interim Target 1	China Grade II Malaysia
	25 µg/m^3	WHO Interim Target 2	Mongolia Philippines Republic of Korea Sri Lanka Thailand Viet Nam
	15 µg/m^3 12 µg/m^3	WHO Interim Target 3	Bangladesh China Grade I Indonesia Japan Pakistan Singapore
	10 µg/m^3	WHO Guideline	
	8 µg/m^3[a]		Australia

[a]maximum concentration

BOX 1.2: WHY URBAN AND RURAL AGENCIES NEED TO COOPERATE TO ACHIEVE CLEAN AIR

Poor air quality is often regarded as an urban problem to be addressed by urban authorities. However, the physical and chemical features of $PM_{2.5}$ and ozone add an important spatial challenge to managing air quality as they can remain in the atmosphere for days to weeks respectively and be transported over hundreds of kilometres. Consequently, $PM_{2.5}$ and ozone found at any specific location may originate from distant sources, often beyond the jurisdiction of urban local authorities.

Even in large cities, a substantial proportion of the $PM_{2.5}$ found in ambient air originates from regional and rural sources, while at the same time urban emissions are transported to surrounding rural areas. In smaller cities the inflow of air pollution from neighbouring areas is even more dominant.



++ including Haryana; NCT – National Capital Territory;
NH_3 – ammonia; SO_2 – sulphur dioxide; NO_x – nitrogen oxides

SPATIAL AND SECTORAL SOURCES OF AMBIENT $PM_{2.5}$ IN DELHI, INDIA

The figure shows the contributions of different emission sources to ambient $PM_{2.5}$ in Delhi. The horizontal axis shows the sources of the emissions, including natural sources, long-range transport, the neighbouring provinces (Uttar Pradesh and Haryana), and emissions from within the Delhi National Capital Territory. Colours indicate the sectoral origin of emissions. Solutions for achieving clean air need to take into account these spatial source emission factors and ensure effective governance based on collaboration between urban and rural administrations.

measures for addressing the air pollutants collectively known as short-lived climate pollutants (SLCPs). Methane and ozone, both SLCPs, are important greenhouse gases in their own right. Methane and other substances that contribute to the formation of ground-level ozone also influence the climate, albeit indirectly. Particles in the atmosphere such as black carbon and mineral dust impact the climate both directly, by scattering and absorbing radiation, and indirectly, by changing the reflective properties of clouds and reflective surfaces such as snow and ice.

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 to slowing global warming and reducing air pollution. These policies should, however, complement not replace those reducing carbon dioxide.

The links between air quality and climate change are complex and an active area of scientific research. Understanding the interplay between air quality and climate change is key for integrated policy making that can maximize air quality and climate benefits.

Hydrofluorocarbons are also known to have a considerable impact on climate forcing and are emitted in significant quantities (Box 1.3). They are considered further in Section 2.

Climate change will have an effect on local and regional air quality

Future changes in climate will affect air quality by influencing the formation and removal processes of ground-level ozone and $PM_{2.5}$ through changes in temperature, precipitation, other meteorological conditions, and concentrations of substances that contribute to the formation of ozone and $PM_{2.5}$.

Changes in climate affect air quality through several different mechanisms, the most relevant of which include:

BOX 1.3: HYDROFLUROCARBONS

Hydrofluorocarbons (HFCs) are a group of powerful factory-made greenhouse gases used primarily for refrigeration and air conditioning. Production, consumption and emissions of HFCs have been growing at a rate of 10–15 per cent per year, causing a doubling every five to seven years. This rapid growth is due to their use as replacements for ozone-depleting substances, which are being phased out under the Montreal Protocol on Substances that Deplete the Ozone Layer, as well as increasing demand for consumer air conditioning and refrigeration. The Asia and Pacific region is one of the most significant drivers of both the demand for and supply of HFCs globally.

The use of HFCs in residential air conditioning systems has experienced significant growth over the past decade. Under current trends, an additional 700 million air conditioning units will be added to the global stock by 2030, and 1.6 billion by 2050. This rapid growth has important implications for future HFC emissions as well as energy security and air pollution from energy generation, as air conditioning accounts for a sizable percentage of peak energy loads in hot climates.

Many HFCs remain in the atmosphere for less than 15 years. Though they represent a small fraction of current total greenhouse gases (less than 1 per cent), their warming impact is particularly strong and, if left unchecked, they could account for nearly 20 per cent of climate pollution by 2050. A recent study concluded that replacing HFCs that have high global-warming potential (GWP) with low-GWP alternatives could avoid 0.1°C of warming by 2050.

1. changes in temperature affecting chemical production and loss rates and natural emissions;
2. changes affecting wind speed and mixing in the atmosphere;
3. changes in precipitation; and
4. changes in emissions due to variation in energy consumption patterns.

A strong correlation is observed between temperature and elevated ozone concentrations in polluted areas. In the case of China, models predict that the future change in ozone concentrations is most dependent on precursor emissions. For Japan, with lower emission densities, changes in ozone concentrations depend more on climate change.

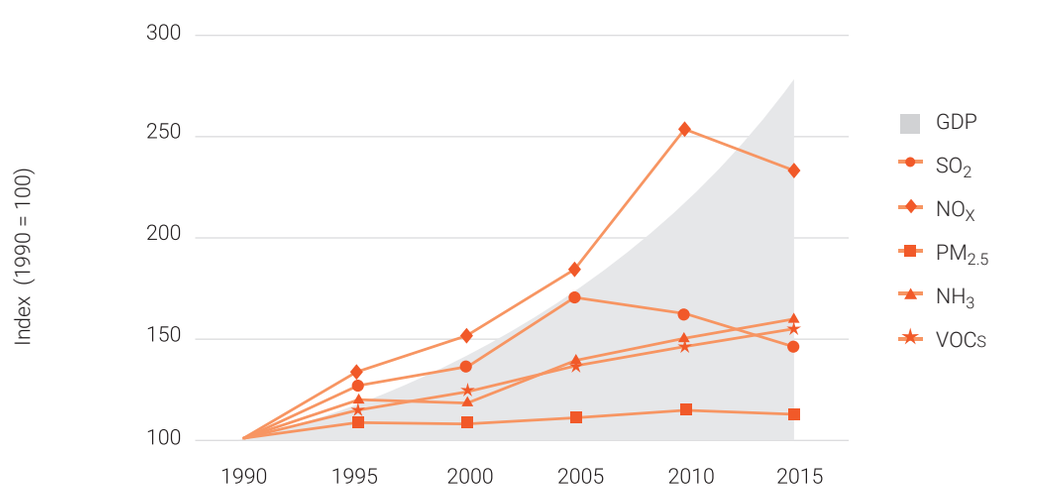
Understanding how particulate matter pollution will alter in a changing climate is complex and more uncertain than in the case of ozone. Changes in precipitation are also expected to have a large impact on particulate matter concentrations because particles are removed from the atmosphere by precipitation.

A recent study of Beijing predicts that climate change will cause a 50 per cent increase in the frequency of weather conditions conducive to winter haze episodes, which have become a worsening problem in the past decades. In addition, the persistence of weather conditions favourable to haze formation is predicted to increase. These local effects are attributed to large-scale circulation changes induced by climate change, including a weakening of the East Asian winter monsoon.

Considerable reductions in pollution have been achieved in Asia and the Pacific, where policy interventions have helped break the historical link between economic growth and pollution

POLICY INTERVENTIONS

From 1990 onwards, all emissions of pollutants that contribute to the formation of $PM_{2.5}$ in the region showed steady growth. Particularly large increases occurred for sulphur dioxide and nitrogen oxides, which closely followed the expansion of economic activities as measured by GDP. Other emissions for which non-industrial sources are more important, such as residential burning of biomass as a source of volatile organic compounds and primary emissions of $PM_{2.5}$, or agricultural activities as a source of ammonia, developed along a less steep growth path (Figure 1.2).



SO_2 – sulphur dioxide; NO_x – nitrogen oxides; NH_3 – ammonia; VOCs – volatile organic compounds

FIGURE 1.2: THE EVOLUTION OF GROSS DOMESTIC PRODUCT AND THE POLLUTANTS THAT CONTRIBUTE TO $PM_{2.5}$ FORMATION IN ASIA, 1990–2015

Policy interventions after 2005, especially sulphur controls for power plants in China and the introduction of emissions standards for vehicles, have, however, led to a decoupling of emissions of sulphur dioxide and nitrogen oxides from economic growth, while $PM_{2.5}$ emissions have remained relatively flat (Figure 1.2). In contrast, in the absence of policy interventions, emissions of ammonia, also a precursor of $PM_{2.5}$, have continued to grow as a consequence of increasing agricultural production.

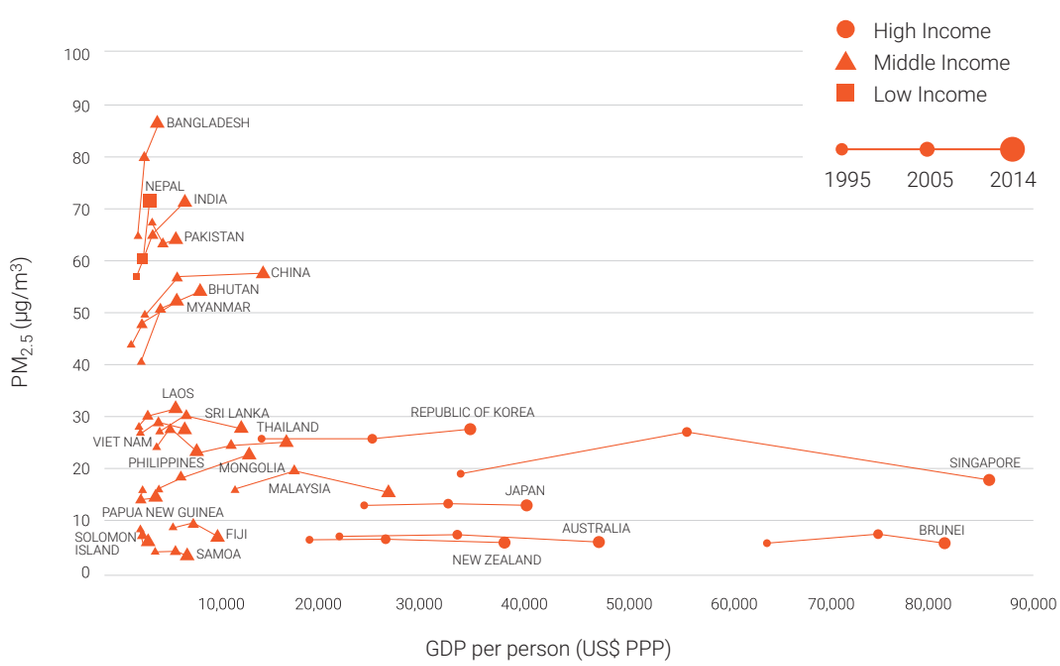
Governments in Asia and the Pacific have successfully adopted and implemented policies to reduce pollution levels. Without these, population-weighted exposure to harmful $PM_{2.5}$ would be expected to grow by more than 50 per cent by 2030 based on projected economic growth of 80 per cent. These policies deliver clear and significant air quality and health benefits, a considerable achievement.

Further action is still needed to move towards air quality levels within the WHO Guideline for public health protection. These guidelines are aligned with the national air quality standards adopted by countries in Asia and the Pacific (Box 1.4). Further action should reflect the diversity of the region in terms of stages of development, levels of capacity and availability of resources.

BOX 1.4: DIVERSITY OF DEVELOPMENT IN ASIA AND THE PACIFIC

The economic development of the region's 41 countries varies widely, with national GDPs ranging from hundreds of dollars per person per year to more than US$ 80,000. The data suggest that high-income countries in the region have annual population-exposure air pollution levels below 30 μg/m³ of $PM_{2.5}$ and that trends from 1995 to 2014 are stable. There are few data available on low-income countries. Middle-income countries have quite variable $PM_{2.5}$ concentrations, ranging from about 5 μg/m³ to more than 85 μg/m³.

There are some differences between modelled sub-regions (Figure 3). The (modelled) high-income countries tend to have lower levels of $PM_{2.5}$ and in most countries these concentrations have stabilized or are declining (see figure). Some large (modelled) East Asian middle-income countries have very high $PM_{2.5}$ concentrations and these increased between 1995 and 2014. In many (modelled) Southeast Asian middle-income countries, $PM_{2.5}$ concentrations are between these other two categories and are mostly stable, largely due to successful measures to control emission sources.



$PM_{2.5}$ CONCENTRATIONS AND GROSS DOMESTIC PRODUCT PER PERSON BY COUNTRY, AND PATHWAYS OF $PM_{2.5}$ CONCENTRATION AND ECONOMIC DEVELOPMENT BY COUNTRY, 2014

Note: $PM_{2.5}$ mean is the annual weighted population exposure from the 2015 Global Burden of Disease study. The exposure is calculated by weighting mean annual $PM_{2.5}$ concentrations by population in both urban and rural areas.

PPP = purchasing power parity

SECTION 2

Priority measures to reduce health impacts and meet development goals

INTRODUCTION

The measures that have been successful in decoupling economic growth from pollution in the past will not be sufficient to achieve clean air in the future

Energy policy and the enforcement of strengthened pollution control measures will remain the key determinants for a further decoupling between economic growth and air pollution. Many Asian[1] countries have established ambitious targets for reducing the energy intensity of their economies through energy efficiency policies and a restructuring of production towards less energy-intensive products. This suggests that energy consumption trends will decouple from economic growth even more than in the past. In addition, these policies aim to transform energy systems, with a smaller role for fossil fuels such as coal and oil. As a consequence, the recent projections of future energy use published by the International Energy Agency estimate that total primary energy consumption will grow by 25 per cent between 2015 and 2030, much less than the 80 per cent increase in gross domestic product (GDP) projected for the same period.

Despite these energy policies, however, 25 per cent higher energy consumption will further enhance the pressure on air quality in many countries of the region. Technical means exist to reduce emissions, and important measures already included in legislation should lead to lower emissions if they are effectively implemented. In addition, many further measures, often for sources that are not addressed by current legislation, are available that could deliver substantial additional emission reductions throughout Asia.

Energy policy and the enforcement of pollution control measures will remain the key determinants for further decoupling of economic growth from air pollution

The effectiveness of the implementation and enforcement of control measures will have a crucial impact on future emission levels. By 2030, without the policies and measures that have been put in place and enforced over the last decade, sulphur dioxide emissions in Asia would likely be almost three times larger compared with 2015, given the expected 80 per cent increase in GDP. However, the measures that have already been implemented cut emissions by about 40 per cent by 2015, and will continue to do so in the future if effectively enforced. Together with current policy measures to reduce energy intensity and phase out solid fuels, they would limit the emissions increase by 2030 to about 20 per cent compared to 2015. If all countries enforced the emission controls that they have already included in their legislation but that are not yet fully implemented, Asian sulphur dioxide emissions would shrink by 20 per cent from 2015 levels. Full application of all available controls could cut sulphur dioxide emissions by 60 per cent (Figure 2.1).

A similar picture emerges for emissions of nitrogen oxides, which would be 100 per cent higher by 2030 compared with 2015 levels in the absence of any emission controls. Energy policy measures together with existing emission controls would limit the increase to 25 per cent above 2015 levels, while a timely enforcement of recent legislation would

[1] This section focuses on Asia as data are available on emissions and ambient concentrations of the relevant pollutants in Asia but are only available for a few countries in the Pacific. The absence of data of a suitable quality for large areas of the Pacific prevents modelling to the necessary level of reliability.

deliver a 15 per cent reduction in emissions compared with 2015 levels. Overall, there is scope for a 50 per cent reduction in emissions of nitrogen oxides compared with emissions in 2015.

Primary emissions of $PM_{2.5}$ would double by 2030 compared with 2015 levels in the absence of any measures. The already implemented controls, together with energy policies that promote less polluting fuels in the household sector, will reduce the growth to 5 per cent, and an enforcement of all recent legislation should deliver a 10 per cent reduction in emissions compared with 2015 levels. Emissions could be cut by 75 per cent by 2030 with the full application of all available measures.

In contrast, population growth and dietary change will lead to an increase in agricultural production, especially of livestock, which will increase ammonia emissions in the absence of policies stimulating and enforcing emission controls. In addition, persistent over-fertilization and strong reliance on urea and ammonium bicarbonate mineral fertilizers will result in significant losses of nutrients to soil and

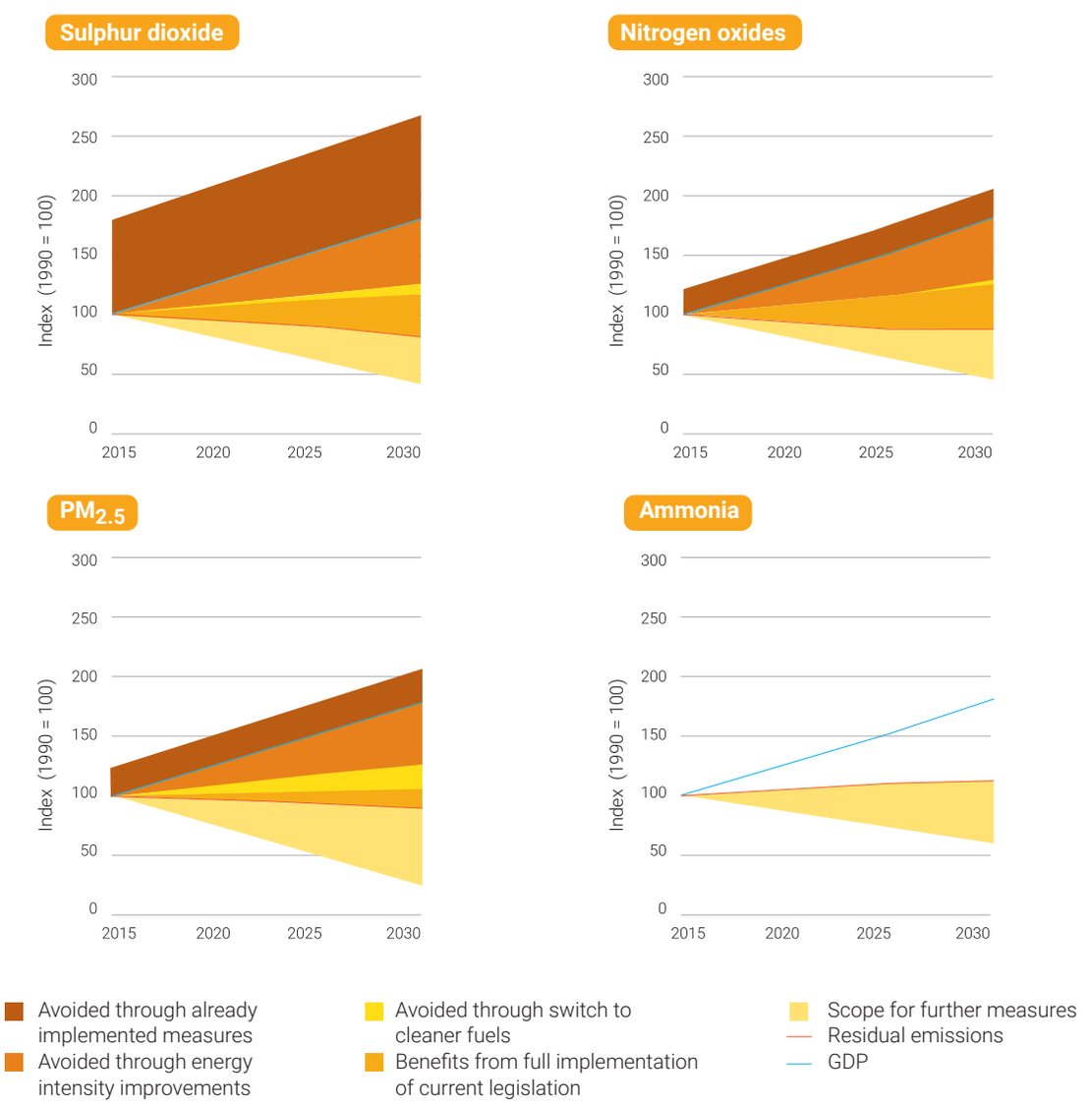


FIGURE 2.1: THE ROLE OF POTENTIAL POLICIES IN DECOUPLING $PM_{2.5}$ EMISSIONS AND POLLUTANTS CONTRIBUTING TO ITS FORMATION (BASED ON INTERNATIONAL ENERGY AGENCY PROJECTIONS AND AGRICULTURAL DATA TRENDS)

groundwater and ammonia and nitrous oxide emissions to the atmosphere. However, technical measures are available that could cut ammonia emissions by up to 40 per cent by 2030.

Policy decissions are not only influence future emissions but also air quality. Hypothetically, without any policy interventions, population-weighted mean exposure to $PM_{2.5}$ would grow by almost 50 per cent by 2030 – from 43 micrograms per cubic metre (µg/m^3) in 2015 to about 62 µg/m^3. This could be a consequence of higher emissions of pollutants that contribute to the formation of $PM_{2.5}$ combined with continued urbanization, which will increase the share of the urban population in Asia.

The already implemented measures would reduce the hypothetical growth of $PM_{2.5}$ by about 10 µg/m^3 by 2030, and a further 9 µg/m^3 reduction would result from the effective enforcement of all recently agreed emission control legislation. Consequently, current policies are expected to maintain population-weighted mean exposure at the current levels, and thereby compensate for the impacts of the 80 per cent economic growth.

Current policies will avoid further large-scale deterioration but will not achieve air quality standards

Current policies, however, will not be sufficient to improve air quality enough for national and international air quality standards to be met. Despite some decline of ambient $PM_{2.5}$ in (modelled) East Asia, large exceedances of air quality standards will remain in heavily industrialized areas with high population density (Figure 2.2). In Iran, ambient $PM_{2.5}$ levels would grow further, adding to the high load from natural sources (soil dust).

2.3 billion people, about 55 per cent of the population, will suffer from $PM_{2.5}$ levels above the highest WHO Interim Target, and 1.3 billion will remain exposed to indoor air pollution

Overall, current policies will deliver limited improvements in air quality but will not significantly reduce total population exposure to harmful $PM_{2.5}$ pollution compared to today, and by 2030, population exposure will be generally similar to 2015. Only 8 per cent of the Asian population will live with air quality that complies with the World

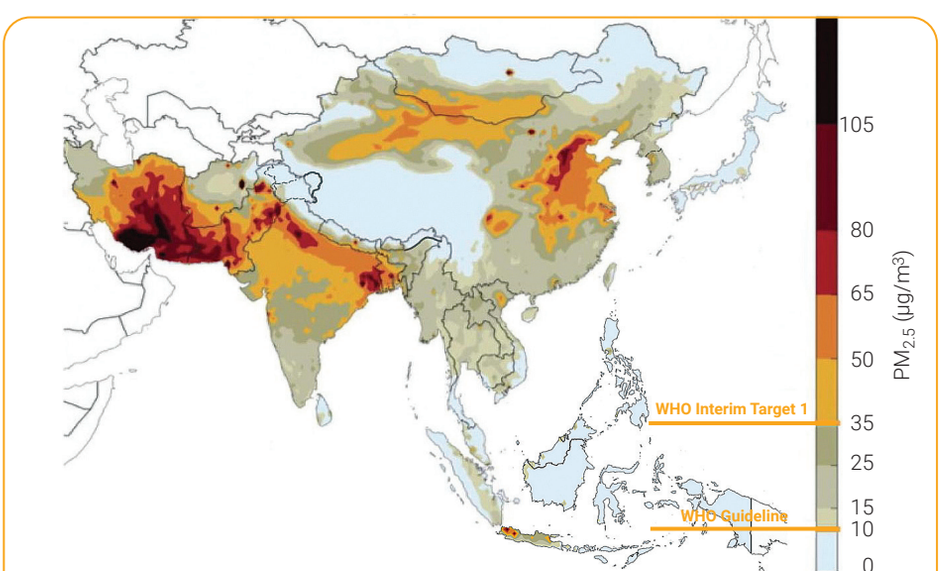


FIGURE 2.2: AMBIENT LEVELS OF $PM_{2.5}$ IN 2030 COMPUTED FOR THE CURRENT LEGISLATION BASELINE SCENARIO

Health Organization (WHO) Guideline while 2.3 billion people, 55 per cent of the total population, will still face $PM_{2.5}$ levels in excess of the highest WHO Interim Target (35 µg/m³). In addition, 1.3 billion people will remain exposed to dangerous levels of indoor air pollution.

THE TOP 25 CLEAN AIR MEASURES

By 2030, in the absence of appropriate policy interventions, population-weighted mean $PM_{2.5}$ in Asia would increase by about 50 per cent due to population growth, urbanization and economic development. However, current air pollution policies and measures deliver significant benefits on population exposure to $PM_{2.5}$, compensating for the negative impacts of future economic growth. Especially effective are post-combustion emission controls at large plants in the power and industry sectors, emissions standards for diesel and gasoline vehicles, and measures to control emissions from industrial processes, including steel, cement and glass production. Additionally, where implemented, effective vehicle inspection and maintenance schemes avoid substantial exposures. Alone, however, these policies will not be sufficient to achieve clean air in Asia.

A set of 25 measures that could deliver substantial improvements in air quality, many of which have already been implemented in some parts of Asia and the Pacific, has been identified by this study. These measures can be grouped into three categories (Table 2.1).

Conventional measures

An Asia-wide application of the conventional measures summarized in Table 2.1, especially in countries that have not yet developed more advanced air quality control regimes, such as in parts of modelled Southeast Asia, and the extension of current laws to smaller industrial sources, for example in some countries in modelled East Asia, can deliver additional air quality improvements and reduce population exposure to $PM_{2.5}$ by 6 µg/m³ – down to about 35 µg/m³. However, the conventional measures will not be sufficient to reduce exposure levels to national and international air quality standards, and will not protect people exposed to indoor air pollution.

The implementation and enforcement of the conventional emission controls that have already been introduced in recent legislation would essentially compensate the impacts of economic growth and keep population exposure at today's level. Full implementation of these conventional measures across Asia could reduce mean exposure to $PM_{2.5}$ by up to 15 per cent. However, as this would result in a mean $PM_{2.5}$ exposure of more than 35 µg/m³, these measures alone would fail to meet current air quality standards by a wide margin.

Next-stage measures

The current portfolio of policy measures in Asia focuses mainly on emission sources that are growing rapidly with economic development, including large industrial and power plants, and road transport. However, these measures inadequately address small and dispersed sources including agriculture, waste burning, and forest and peat fires. More important in Asia than on other continents, these sectors produce considerable amounts of primary emissions of $PM_{2.5}$ as well as gases such as nitrogen oxides and ammonia that contribute to and control the formation of secondary particles in the atmosphere.

Measures are available and proven that can reduce these emissions, including the more efficient use of fertilizers, the prevention of forest and peat fires, the enforcement of bans on open burning of agricultural residues and household waste, improved manure management, and control of solvent emissions in industry. Although these measures are not yet effectively applied at a large scale in Asia, they are important elements of today's air quality management portfolios in Europe and North America.

A portfolio that includes these measures, in addition to the conventional measures, could reduce $PM_{2.5}$ exposure by another 20 per cent compared to 2015. These measures require action in sectors such as agriculture and households that are currently not actively involved in air quality management. Furthermore, enhanced governance mechanisms need to be developed to achieve these emission reductions. However, by 2030 it is unlikely that even full implementation of such measures, in addition to the conventional measures, would bring mean

TABLE 2.1: THE TOP 25 CLEAN AIR MEASURES	
Regional application of conventional measures	
Post-combustion controls	Introduce state-of-the-art end-of-pipe measures to reduce sulphur dioxide, nitrogen oxides and particulate emissions at power stations and in large-scale industry
Industrial process emissions standards	Introduce advanced emissions standards in industries, e.g., iron and steel plants, cement factories, glass production, chemical industry, etc.
Emissions standards for road vehicles	Strengthen all emissions standards; special focus on regulation of light- and heavy-duty diesel vehicles
Vehicle inspection and maintenance	Enforce mandatory checks and repairs for vehicles
Dust control	Suppress construction and road dust; increase green areas
Next-stage air quality measures that are not yet major components of clean air policies in many parts of Asia and the Pacific	
Agricultural crop residues	Manage agricultural residues, including strict enforcement of bans on open burning
Residential waste burning	Strictly enforce bans on open burning of household waste
Prevention of forest and peatland fires	Prevent forest and peatland fires through improved forest, land and water management and fire prevention strategies
Livestock manure management	Introduce covered storage and efficient application of manures; encourage anaerobic digestion
Nitrogen fertilizer application	Establish efficient application; for urea also use urease inhibitors and/or substitute with, for example, ammonium nitrate
Brick kilns	Improve efficiency and introduce emissions standards
International shipping	Require low-sulphur fuels and control of particulate emissions
Solvent use and refineries	Introduce low-solvent paints for industrial and do-it-yourself applications; leak detection; incineration and recovery

TABLE 2.1: THE TOP 25 CLEAN AIR MEASURES (contd.)

Measures contributing to development priority goals with benefits for air quality	
Clean cooking and heating	Use clean fuels – electricity, natural gas, liquefied petroleum gas (LPG) in cities, and LPG and advanced biomass cooking and heating stoves in rural areas; substitution of coal by briquettes
Renewables for power generation	Use incentives to foster extended use of wind, solar and hydro power for electricity generation and phase out the least efficient plants
Energy efficiency for households	Use incentives to improve the energy efficiency of household appliances, buildings, lighting, heating and cooling; encourage roof-top solar installations
Energy efficiency standards for industry	Introduce ambitious energy efficiency standards for industry
Electric vehicles	Promote the use of electric vehicles
Improved public transport	Encourage a shift from private passenger vehicles to public transport
Solid waste management	Encourage centralized waste collection with source separation and treatment, including gas utilization
Rice paddies	Encourage intermittent aeration of continuously flooded paddies
Wastewater treatment	Introduce well-managed two-stage treatment with biogas recovery
Coal mining	Encourage pre-mining recovery of coal mine gas
Oil and gas production	Encourage recovery of associated petroleum gas; stop routine flaring; improve leakage control
Hydrofluorocarbon (HFC) refrigerant replacement	Ensure full compliance with the Kigali Amendment

exposures to $PM_{2.5}$ in Asia below the WHO Interim Target level 2 of 25 µg/m³ (Figure 2.3).

Development priority measures

The portfolios of conventional and next-stage measures presented in Table 2.1 have been compiled with a specific focus on air quality. Typically, such measures can be decided by the authorities that are dealing with air quality management in discussion with other relevant stakeholders, including other government agencies, vehicle producers, power companies, refineries, and industrial and agricultural organizations.

However, there are additional measures that offer further means of improving air quality, even if they are not primarily targeted at air pollution. Often, they fall under the jurisdiction of different authorities and are discussed in different policy frameworks in which air quality managers are often not represented. These include, amongst others, measures that are closely related to energy or agricultural policies, or urban management.

In particular, measures aiming to contribute to development priority goals eliminate, or at least reduce, some of the most polluting activities, and will thereby bring additional emission reductions that are usually beyond the immediate jurisdiction of environmental authorities.

This analysis explores measures aimed at those development priorities that affect the pollutants that contribute to the formation of $PM_{2.5}$, and for which the potential reduction in the polluting activity has been quantified in the International Energy Agency (IEA) World Energy Outlook study. Assuming the implementation rates in the IEA energy scenario collectively, these measures could reduce population-weighted mean exposure to $PM_{2.5}$ in Asia by up to 8 µg/m³ in 2030 and, with progressive implementation, correspondingly more thereafter.

Addressing ground-level ozone

Exposure to ground-level ozone is the second-largest risk factor for human health from ambient pollution, albeit current quantifications suggest much lower impacts than for $PM_{2.5}$. In addition, ground-level ozone causes significant damage to vegetation, including crops.

As previously discussed, emissions of pollutants that contribute to the formation of ground-level ozone include nitrogen oxides, volatile organic compounds, carbon monoxide and methane. The top 25 clean air measures target $PM_{2.5}$, and also affect three out of the four pollutants that contribute to the formation of ground-level ozone – nitrogen oxides, volatile organic compounds and carbon monoxide – and reduce them by 50 per cent, 60 per cent and 70 per cent, respectively, compared to the baseline.

These measures will lead to substantial reductions in the high (peak) ozone concentrations in Asia, with large benefits to human health. However, background ozone levels at the hemispheric scale have increased in the last decades (including in Asia), with significant impacts on crops and ecosystems. Methane is one of the key contributors to hemispheric background ozone, and according to the World Bank about 45 per cent of the methane emissions in the Northern Hemisphere occur in Asia[2]. In addition, to helping reduce concentrations of tropospheric ozone, the reduction in methane emissions also forms an integral part of sustainable development goal (SDG) 13: Climate Action and the nationally determined contributions (NDCs) under the Paris Agreement.

Overall, measures that are already widely applied in Asia, especially post-combustion emission controls in power plants and industry as well as for road transport, offer the largest improvements. Beyond these, key measures include access to clean cooking fuels, enhanced use of renewable energy, prevention of forest and peat fires and improved agricultural practices (Figure 2.4).

Current air quality criteria

Implementation of the top 25 clean air measures would deliver air quality that conforms to current national air quality criteria over large areas of Asia in 2030, but not everywhere. In particular, they will not be sufficient in some megacities surrounded by industrial areas, for example Beijing or Delhi,

[2] https://data.worldbank.org/indicator/EN.ATM.METH.KT.CE?view=chart

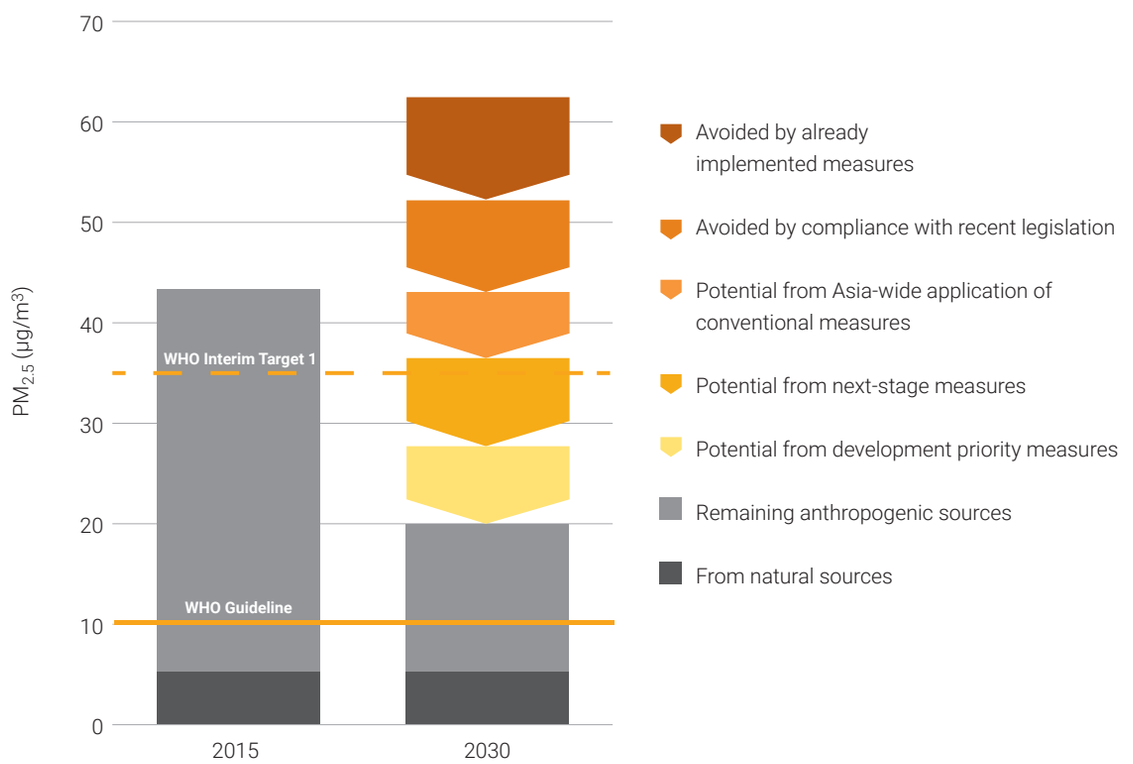


FIGURE 2.3: POTENTIAL CONTRIBUTIONS OF THE THREE PORTFOLIOS OF MEASURES TO POPULATION-WEIGHTED MEAN EXPOSURE TO $PM_{2.5}$

although standards are likely to be within reach with additional local measures. Furthermore, $PM_{2.5}$ levels will remain high in regions that are heavily affected by soil dust (Figure 2.5).

The top 25 clean air measures involve a wider perspective than the scope of current air quality management approaches. As additional benefits, the measures that contribute to national development priorities provide further emission reductions that could deliver another 20 per cent improvement in population exposures to $PM_{2.5}$ in Asia by 2030. In addition to their other benefits, if taken together with the conventional and next-stage measures discussed above, they could bring $PM_{2.5}$ exposure down to about 20 µg/m³, which, although still falling short of the global WHO Guideline, will achieve national air quality standards over large areas of Asia.

Implementation of the top 25 clean air measures will provide clean air to 1 billion people and reduce the number of people facing exposure above the highest WHO Interim Target by 80 per cent

Population exposure to $PM_{2.5}$ will greatly improve from implementation of the top 25 clean air measures. Most importantly, 1 billion people, or 22 per cent of the Asian population, will enjoy air quality in line with the WHO Guideline of 10 µg/m³, compared to less than 8 per cent in 2015. In addition, the number of people exposed to pollution above the highest WHO Interim Target level will decline from 2.3 billion in 2015 (55 per cent of the Asian population) to 430 million, a reduction of 80 per cent, and leave only 10 per cent exposed to the highest pollution levels (Figure 2.6).

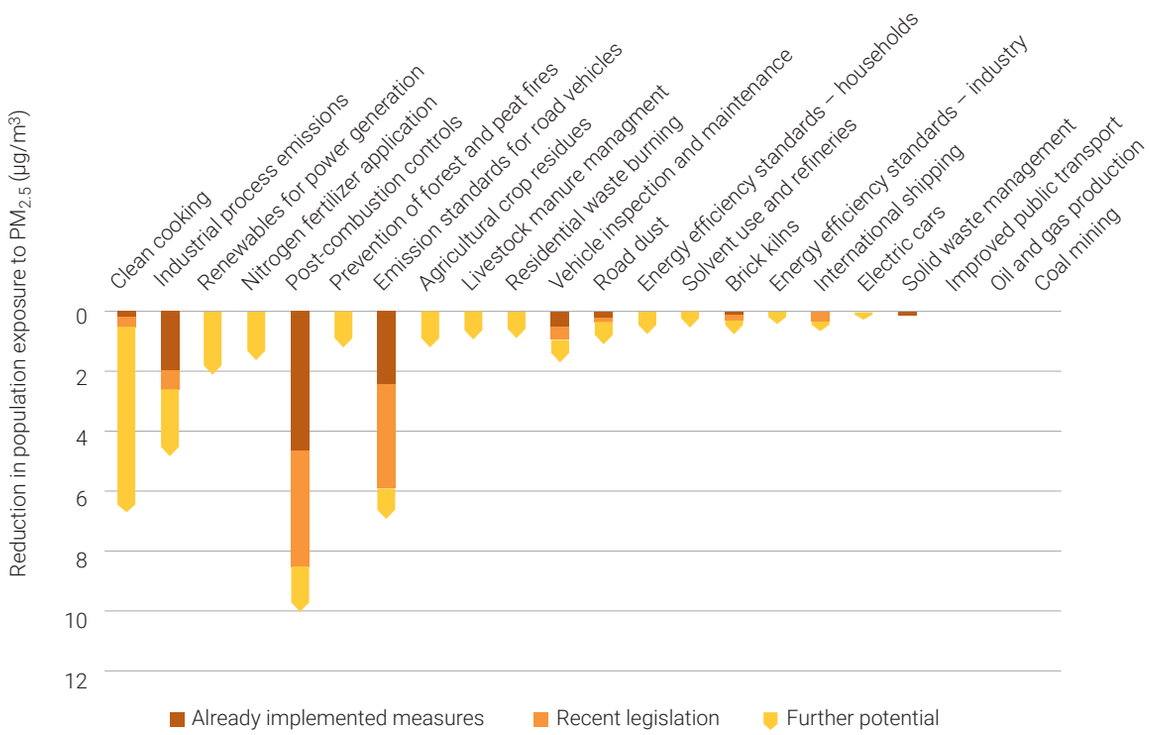


FIGURE 2.4: IMPACTS ON POPULATION-WEIGHTED EXPOSURE TO $PM_{2.5}$ IN 2030 FROM IMPLEMENTATION OF 22 CLEAN AIR MEASURES, RANKED BY FURTHER POTENTIAL

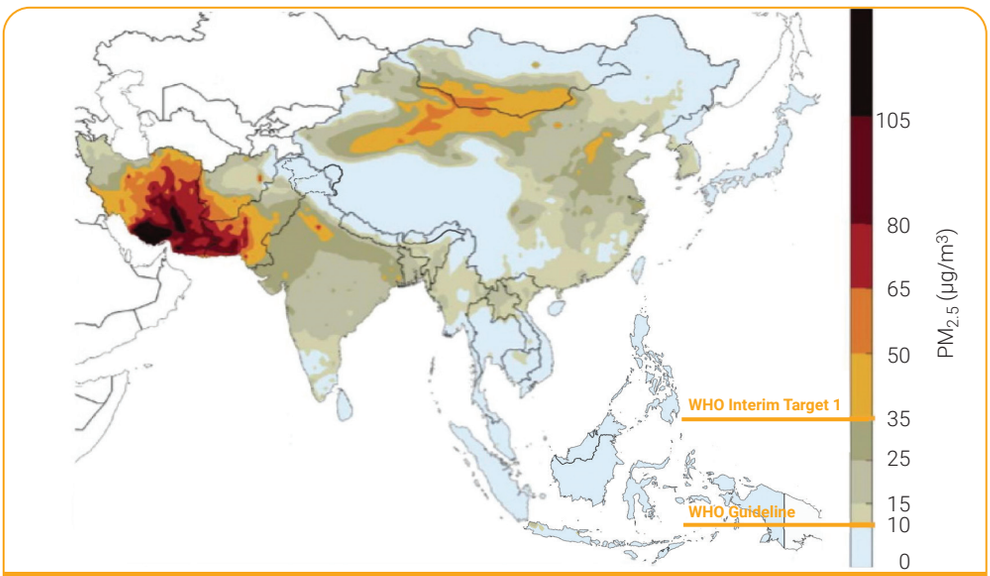


FIGURE 2.5: $PM_{2.5}$ CONCENTRATIONS IN 2030 AFTER IMPLEMENTATION OF THE TOP 25 CLEAN AIR MEASURES

HEALTH, ENVIRONMENTAL AND OTHER DEVELOPMENT BENEFITS

The top 25 clean air measures would avoid several hundred thousand premature deaths from ambient $PM_{2.5}$ pollution and about 2 million from indoor air pollution every year

Based on identical patterns of population exposure to $PM_{2.5}$, the two different quantifications of the health impact assessment methodology used in the 2010 and 2013 Global Burden of Disease studies result in estimates of 3.1 and 1.9 million cases of premature death in 2015, respectively. In the current legislation baseline case, the health burden could increase to 4.0 and 2.5 million cases by 2030, despite the slight downwards trend in population exposure. This divergence is caused by:

a) The population growth that is expected for this period; and
b) Population ageing, which will increase the number of old people, who are more susceptible to air pollution.

The top 25 clean air measures would lead to a 60 per cent lower $PM_{2.5}$ exposure in 2030 compared to 2015. Premature mortality is estimated to decline by 31–37 per cent, depending on the assumptions of the health impact assessment method.

Effective implementation of the top 25 clean air measures would also lead to a drastic reduction in the number of people using solid fuels (biomass and coal) for cooking, from about 1.9 billion people in 2015 to about 0.3 billion in 2030. This scenario assumes that access to clean cooking fuel will not be fully achieved throughout Asia by 2030 and that the remaining population in rural areas will use advanced biomass cookstoves or replace coal with briquettes. This transition could cut the estimated number of premature deaths attributable to exposure to indoor pollution by 1.7–2.6 million cases per year, depending on the assumptions used for the health impact calculations.

Reducing ozone-associated health impacts

The top 25 clean air measures also deliver substantial reductions in emissions of the pollutants that contribute to ozone formation – nitrogen oxides, volatile organic compounds, carbon monoxide and methane.

Using ozone concentrations from two global atmospheric chemistry transport models and applying a health impact methodology used previously to quantify ozone health impacts globally, it was estimated that more than 330,000 premature deaths were associated with ozone exposure in 2015 across Asia. The largest burden was in modelled South Asia, followed by East,

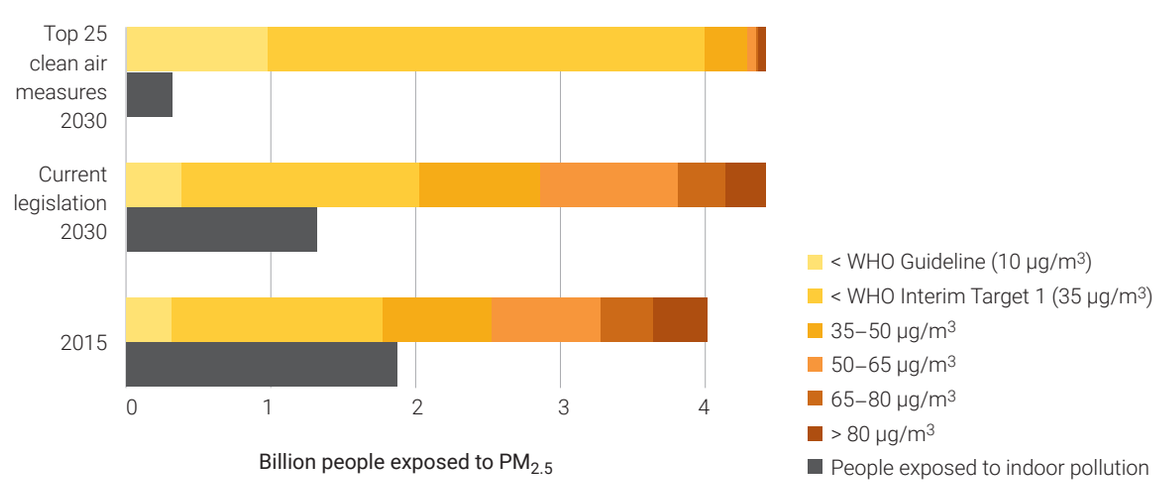


FIGURE 2.6: ASIAN POPULATION EXPOSURE TO $PM_{2.5}$ FOR 2015 AND 2030

Southeast and high-income countries (Figure 2.7). For the baseline case, the estimated ozone health burden increases in all regions by 2030, driven by a larger and older population as well as changes in ozone concentrations. The top 25 clean air measures reduce this estimated health burden by 40 per cent compared to the 2030 baseline across Asia. The relative reduction in estimated ozone health impacts as a result of the introduction of the top 25 clean air measures is largest in modelled Southeast Asia, a 58 per cent difference from the 2030 baseline, followed by high-income countries (44 per cent), East Asia (36 per cent) and South Asia (30 per cent).

Reducing ozone-induced crop losses

In addition to the impacts of air pollution on human health, ambient ozone concentrations can also damage vegetation including crops, resulting in reduced yields and injury to natural vegetation such as forests and grasslands. Applying appropriate methods used previously to estimate ozone-induced crop yield loss globally, crop loss resulting from elevated ozone concentrations was estimated to reduce yields by 10 per cent for maize, 4 per cent for rice, 22 per cent for soy and 9 per cent for wheat across Asia in 2015 (Figure 2.8). This is equivalent to a reduction in crop yield of 51 million tonnes across all four crops, the majority of which is yield loss in rice and wheat.

Implementation of the top 25 clean air measures could reduce estimated ozone-induced crop loss by 45 per cent compared to the 2030 baseline scenario. The largest relative reductions in ozone-induced crop loss would occur in modelled Southeast Asia (56 per cent), followed by East Asia (48 per cent), high-income countries (46 per cent) and South Asia (38 per cent). Estimating ozone crop impacts is uncertain due to differences in crop responses between Asia and other regions and because these estimates do not include the impacts of ozone on all crops, or its impacts on

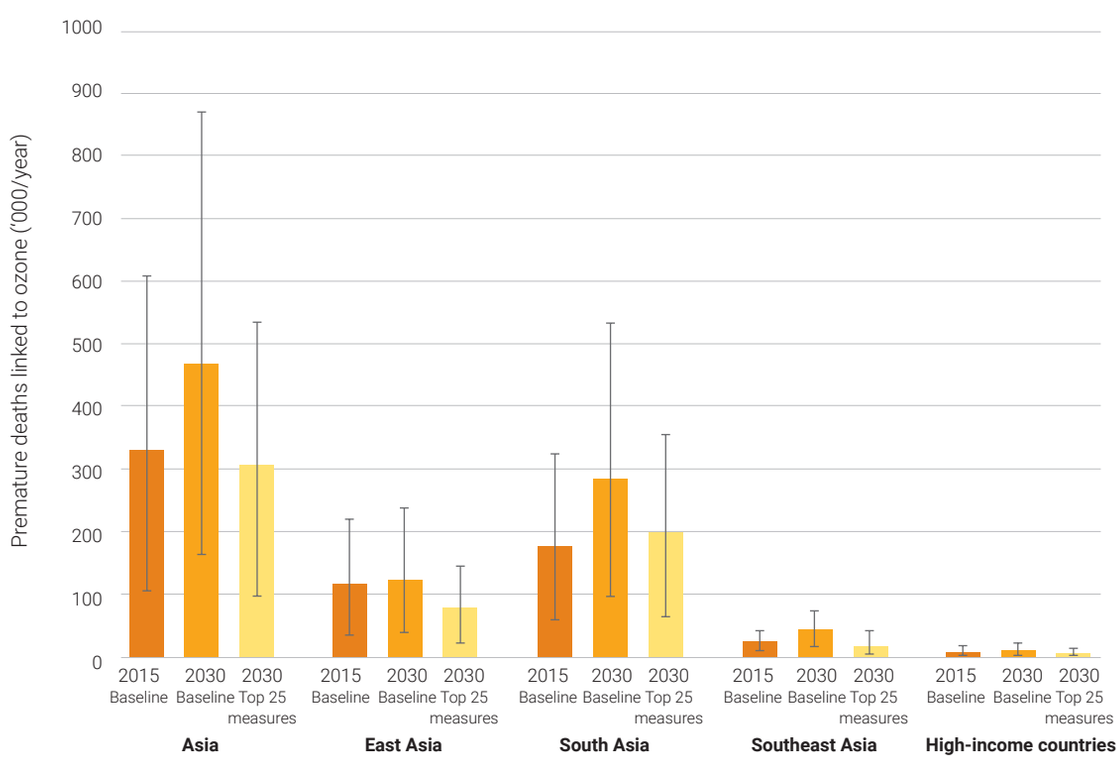


FIGURE 2.7: ESTIMATED NUMBER OF PREMATURE DEATHS ASSOCIATED WITH EXPOSURE TO OZONE IN 2015, AND IN 2030 FOR THE BASELINE AND THE TOP 25 CLEAN AIR MEASURES FOR THE MODELLED SUB-REGIONS OF ASIA

forests and other natural vegetation. However, the implementation of measures focused on reducing $PM_{2.5}$ concentrations, as well as measures targeting methane emission reductions, will likely also result in substantial co-benefits to agricultural crop yields through reductions in ozone concentrations.

Benefits for multiple Sustainable Development Goals

The measures identified in this report are examples of action that simultaneously contributes to multiple outcomes relevant to development (Figures 2.9 and 2.10). Many of the measures identified in the top 25 relate to specific SDGs such as SDG 7: Affordable and Clean Energy; SDG 11: Sustainable Cities and Communities; and SDG 13: Climate Action. Measures that improve air quality and reduce exposure to air pollution directly contribute to multiple SDGs and air quality is specifically mentioned in three SDG targets: 3.9, 11.6 and 12.4. However, many of these measures, for example clean cooking, also provide meaningful direct and indirect benefits for other SDGs, including those relating to poverty, gender and inequality.

Reducing pollutants that influence climate and temperature

While this report analyses policy measures from the perspective of protecting human health by ensuring air quality within WHO guidelines, the emission reductions that emerge from the top 25 clean air measures will also affect climate change in various ways (Figure 2.10). Air pollutants such as components of $PM_{2.5}$, as well as ground-level ozone, affect radiative balance and influence temperature increase, especially in the near and medium term. Different substances act in different ways: some are warming, including black carbon, methane and ozone, while others such

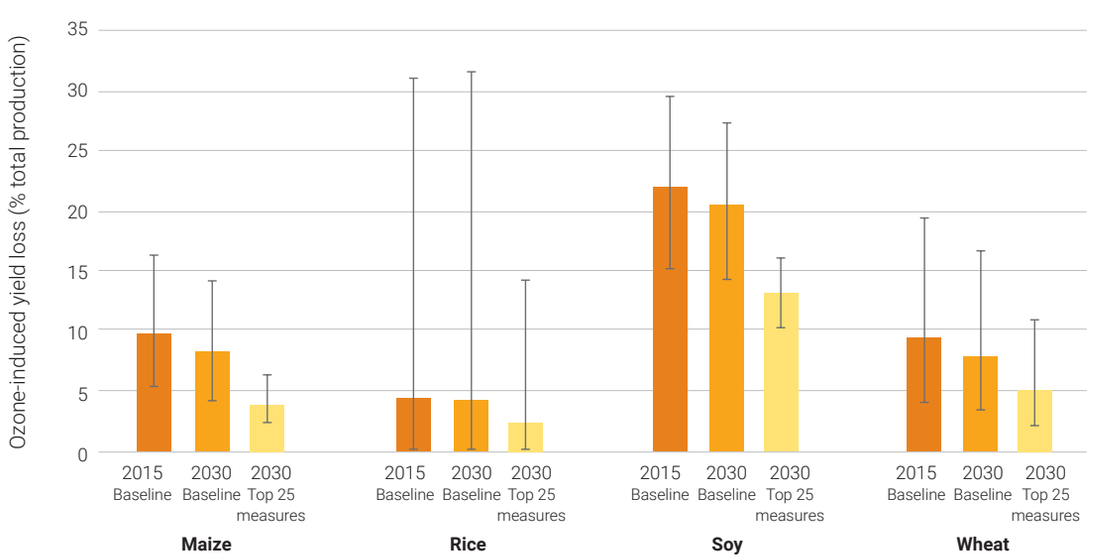


FIGURE 2.8: ESTIMATED OZONE-INDUCED CROP LOSSES FOR MAIZE, RICE, SOY AND WHEAT IN 2015 AND 2030 FOR THE BASELINE AND THE TOP 25 CLEAN AIR MEASURES IN ASIA

as organic carbon, sulphur dioxide and nitrogen oxides are cooling. This has regional impacts on temperature as well as the transport of heat over long distances, for example to the Himalayas and the Arctic as discussed previously.

The top 25 clean air measures will provide a net reduction in the rate of global temperature increase and will contribute significantly to the Paris Agreement target

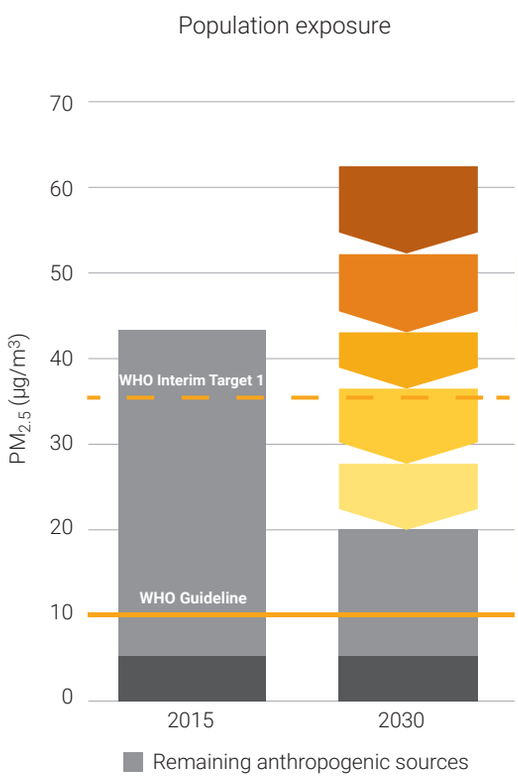
The analysis clearly demonstrates that any meaningful move towards national and international air quality standards in Asia must involve substantial reductions in emissions of pollutants that contribute to the formation of secondary particles, specifically sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds. As many of these substance, apart from VOCs such as methane, normally act to cool the atmosphere, the reductions imply an increase in temperature due to the reduced cooling effect. However, it is also clear that the top 25 clean air measures also affect emissions that contribute to temperature increase.

Calculations of the impact of Asian emission scenarios on global mean temperature[3] suggest that the anticipated baseline changes in global emissions will result in an increase in global mean temperature of about 0.6°C by 2040–2050 relative to 2015. The development priority measures applied in Asia could decrease this warming by about 0.3°C (Figure 2.11).

This net temperature change emerges from several factors. Reductions in emissions of the air pollutants sulphur dioxide, nitrogen oxides, ammonia and organic carbon, but excluding black carbon, will

[3] using the absolute global temperature potential method.

FIGURE 2.9: THE RELATIONSHIP BETWEEN AIR QUALITY AND THE SUSTAINABLE DEVELOPMENT GOALS



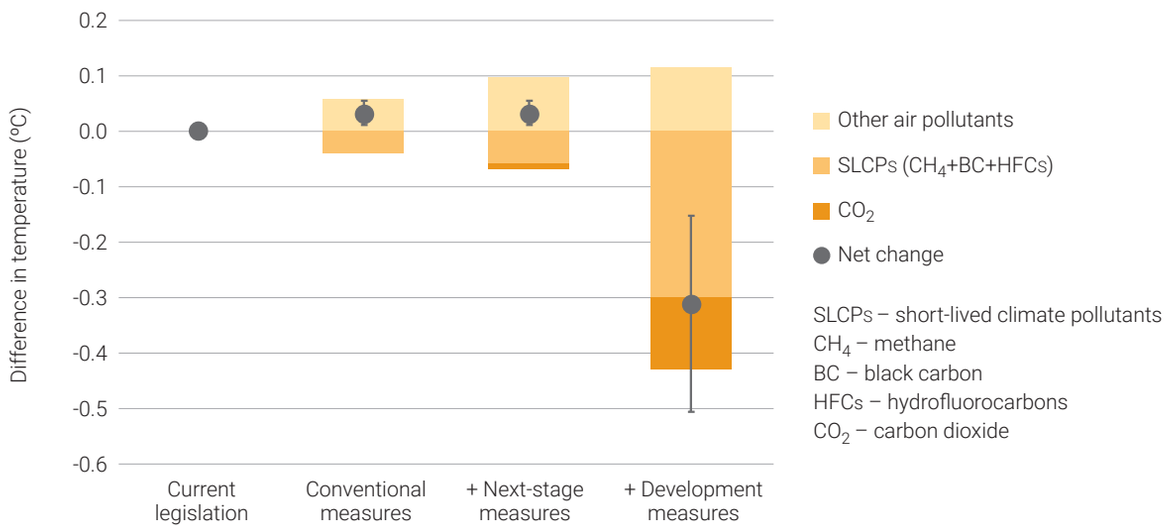
	SDG benefits	Climate forcers		
		CO_2	CH_4	BC
Post-2015 legislation relative to 2015	Goal 3	+16%	+17%	-24%
Conventional measures relative to 2030 baseline	Goals 3, 15	0%	0%	-8%
Next-stage measures relative to 2030 baseline	Goals 2, 3, 15	0%	-29%	-56%
Development priority measures relative to 2030 baseline	Goals 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15	-19%	-44%	-72%

FIGURE 2.10: IMPACT OF THE TOP 25 CLEAN AIR MEASURES IN REDUCING POPULATION EXPOSURE TO $PM_{2.5}$, AND BENEFITS FOR CLIMATE AND THE SUSTAINABLE DEVELOPMENT GOALS

cause a warming of 0.12°C. However, this is more than offset by the lower emissions of methane and black carbon, which would reduce warming by 0.3°C. In addition, the lower carbon dioxide emissions that emerge from the development priority portfolio will reduce temperature increase by 0.13°. Implementation of the Kigali Amendment on the phase-down of HFCs by Asian countries will reduce temperature by another 0.02°C (Box 2.1).

Additional multiple benefits from hydrofluorocarbon management

One final measure that can contribute to sustainable development is the replacement of HFC refrigerants with environmentally friendly alternatives, through full ratification of and compliance with the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. These powerful manufactured greenhouse gases are primarily used as replacements for ozone-depleting substances currently being phased out under the Montreal Protocol, and are the fastest-growing group of greenhouse gases in many countries due in part to rapidly increasing consumer refrigeration and airconditioning markets. In addition to the direct benefits from HFC mitigation, the measure can also catalyse improvements in the energy efficiency of the refrigerators, air conditioners and other products and equipment that use HFC refrigerants, which is a critical part of SDG 7: Affordable and Clean Energy.



Note: Other air pollutants include sulphur dioxide, nitrogen oxides, ammonia, organic carbon and carbon monoxide.

FIGURE 2.11: CHANGES IN GLOBAL MEAN TEMPERATURE FROM THE THREE PORTFOLIOS OF MEASURES, IN 2050 RELATIVE TO THE 2030 BASELINE PROJECTION

Box 2.1: THE KIGALI AMENDMENT

The Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer aims to reduce concentrations of HFCs in the atmosphere by phasing down their production and consumption. As they have no impact on the ozone layer, HFCs have been used as replacements of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which are both ozone-depleting and greenhouse gases. However, HFCs are powerful greenhouse gases in their own right. The Kigali Amendment will enter into force on 1 January 2019, making the Montreal Protocol an even more powerful instrument against global warming. Full compliance with the amendment will reduce HFC consumption and production by more than 80 per cent by 2047. The impact of the amendment will avoid up to 0.5°C of increase in global temperature by the end of the century and provide significant additional climate benefits by catalysing improvements in the energy efficiency of appliances.

ECONOMIC IMPLICATIONS OF THE MEASURES

Implementation of the top 25 clean air measures requires only a small share of the resources gained by future economic growth

It is estimated that Asia currently spends about 1 per cent of its economic output (US$ 160 billion per year) on emission controls, with significant although often hidden benefits to air quality, the environment and human well-being human well-being. By 2030, while compensating for the additional pollution that will come from the 80 per cent enlarged economic activities, full implementation of current legislation will increase pollution control costs to 1.2 per cent of GDP (Figure 2.12). Full application of the conventional measures across Asia would require emission control costs of 1.55 per cent of GDP and would reduce population exposure by one third. At a cost of 1.85 per cent of GDP (about US$ 500 billion per year), the inclusion of next-stage measures could reduce population exposure by half.

While the top 25 clean air measures cut population exposure by 60 per cent, the associated costs of air pollution controls decline to approximately 1.5 per cent of GDP, due to the lower consumption of polluting fuels requiring less pollution control equipment. Additional costs for implementing the development priority measures are outside the scope of this air pollution-centred assessment; however, the development priority portfolio would save about US$ 75 billion per year on air pollution controls, in addition to delivering substantial air quality benefits.

Although air pollution control costs may seem high in absolute terms at US$ 300–600 billion per year in 2030 for all of Asia, they constitute a rather small share, about 5 per cent, of the increase in GDP of US$ 12 trillion per year that is projected for Asia by 2030.

Presently, the largest share of pollution control costs is spent on technically advanced emission controls for vehicles, and this share is expected to grow further along with the increasing car fleet. Extension of the conventional pollution controls across all of Asia would double costs in the power and industrial sectors. The next-stage measures would direct additional pollution controls to the residential and agricultural sectors, although the cost shares of these sectors would remain small in the overall context, as many measures can be implemented at low cost.

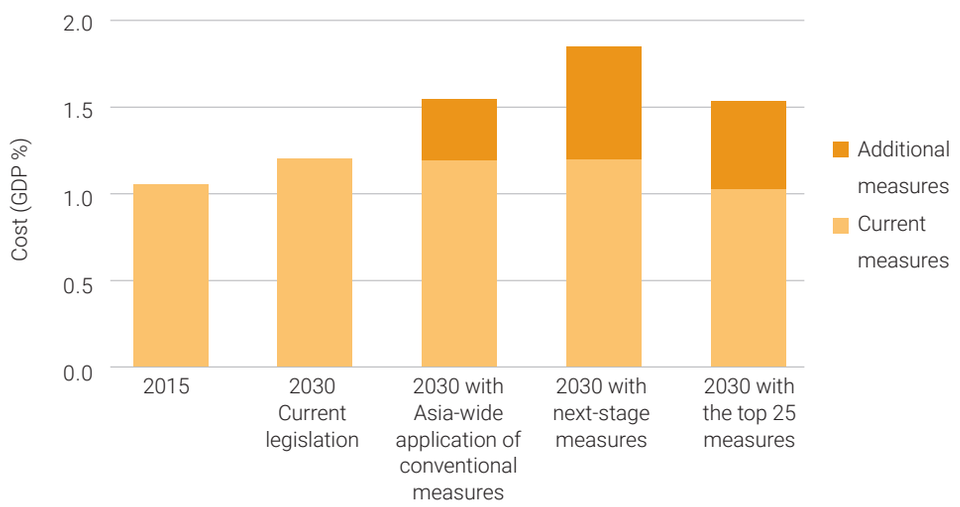
ASIA'S DIVERSITY CALLS FOR TAILORED APPROACHES

Clean air strategies will vary in approach based on the context of each country and city, as well as their capacity to develop and implement them. There is no uniform policy prescription for air quality that is applicable to all cities, countries and regions; such an approach would be neither possible nor desirable for a problem that varies with local conditions.

Benefits differ across Asia

The impacts of the top 25 clean air measures on air quality and population exposure differ across Asia. Figure 2.13 shows that they will bring population exposure down to or below the WHO Guideline in modelled Southeast Asia and high-income countries, and below the WHO Interim Target 1 in modelled East Asia and South Asia.

Figure 2.14 shows the reduction in the number of people exposed to different levels of $PM_{2.5}$ in ambient and indoor air and how it varies across the region. The top 25 clean air measures would eliminate exceedance of the WHO Interim Target 1 (35 μg/m^3) in modelled Southeast Asia and high-income countries. A much smaller percentage of the population would remain exposed to concentrations above the WHO Interim Target 1 in modelled South Asia and East Asia. Indoor air pollution is substantially reduced in modelled South, East and Southeast Asia and is not a significant issue in high-income countries.



Note: Costs for SDG action are not included.

FIGURE 2.12: AIR POLLUTION CONTROL COSTS FOR 2015 AND THE 2030 CURRENT LEGISLATION PROJECTION AND THREE PORTFOLIOS OF MEASURES IN 2030

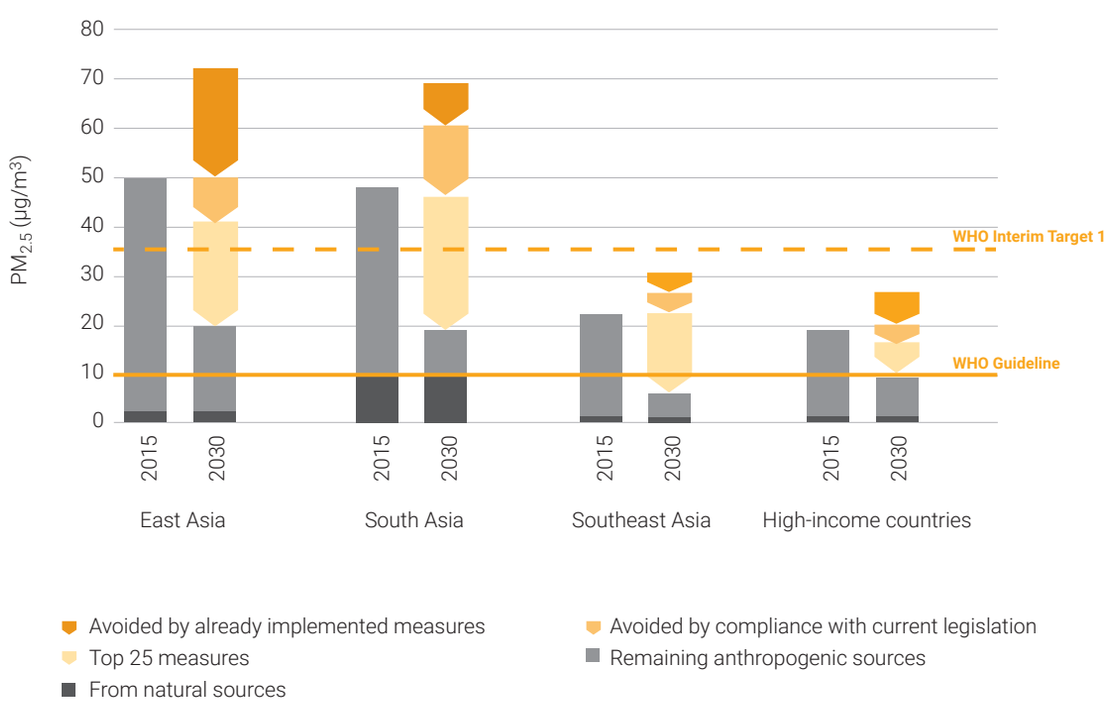


FIGURE 2.13: CHANGES IN POPULATION-WEIGHTED EXPOSURE TO $PM_{2.5}$ BETWEEN 2015 AND 2030: BENEFITS OF IMPLEMENTING THE TOP 25 CLEAN AIR MEASURES AND REMAINING EXPOSURE IN THE MODELLED SUB-REGIONS OF ASIA

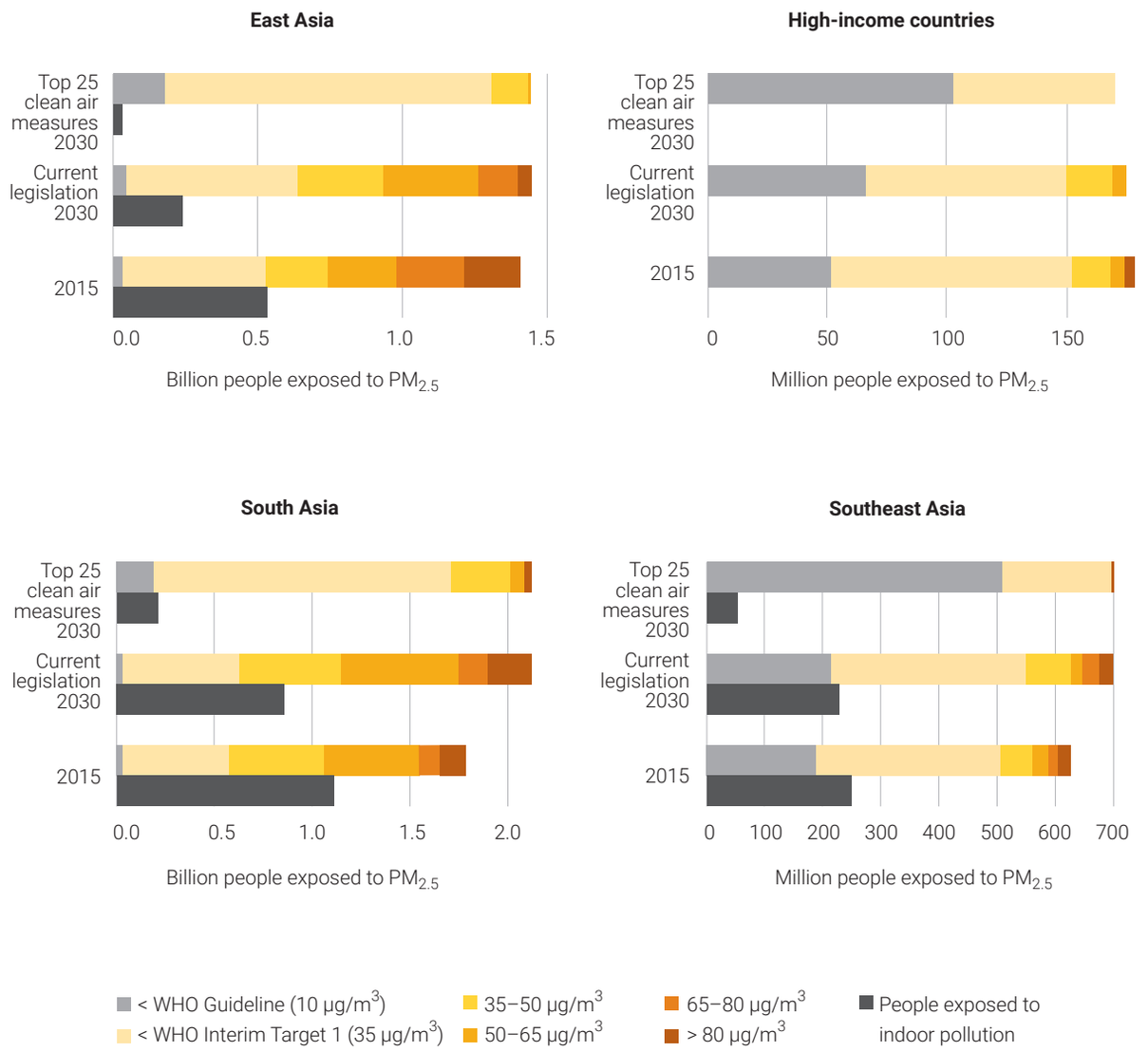


FIGURE 2.14: NUMBERS OF PEOPLE EXPOSED TO DIFFERENT LEVELS OF $PM_{2.5}$ IN AMBIENT AND INDOOR AIR IN THE MODELLED SUB-REGIONS OF ASIA

SECTION 3

Successful implementation of measures

INTRODUCTION

Millions of people in Asia and the Pacific could enjoy longer, healthier lives if measures to control and prevent air pollution were successfully implemented

Section 2 used state-of-the-art modelling approaches to identify measures that could significantly reduce air pollution in Asia and the Pacific. The modelling suggested that effectively implementing 25 measures could prevent exposure to dangerous levels of air pollution, help millions of people enjoy longer and healthier lives, and achieve other environmental development goals. This section assesses how countries in the region have already implemented those measures, highlighting factors contributing to varying degrees of success. The section concludes by underscoring the important role of governance and finance in boosting compliance with the chosen measures.

Before reviewing cases from the region, it should be emphasized that the top 25 clean air measures offer a menu from which countries can select nationally appropriate options. Though the actual choice and timing of those options will inevitably vary across the region, countries are likely to go through a relatively similar process that builds on increasingly robust science to select measures. That process frequently begins with environmental agencies acquiring initial air quality monitoring data to identify and recognize air pollution problems. This initial phase sets the stage for improved monitoring data and emissions inventories that can contribute to formulating policies to reduce emissions. Following the development of inventories, analyses of the sources of emissions will tend to form the basis for policies meant to enhance overall air quality. A final stage will frequently consist of the development of health-impact, cost-effectiveness and/or cost-benefit analyses to determine which interventions maximize the health and other benefits of clean air (Figure 3.1). Though this report presents regional results, national-level data are available on request to help decision makers interested in moving through this process.

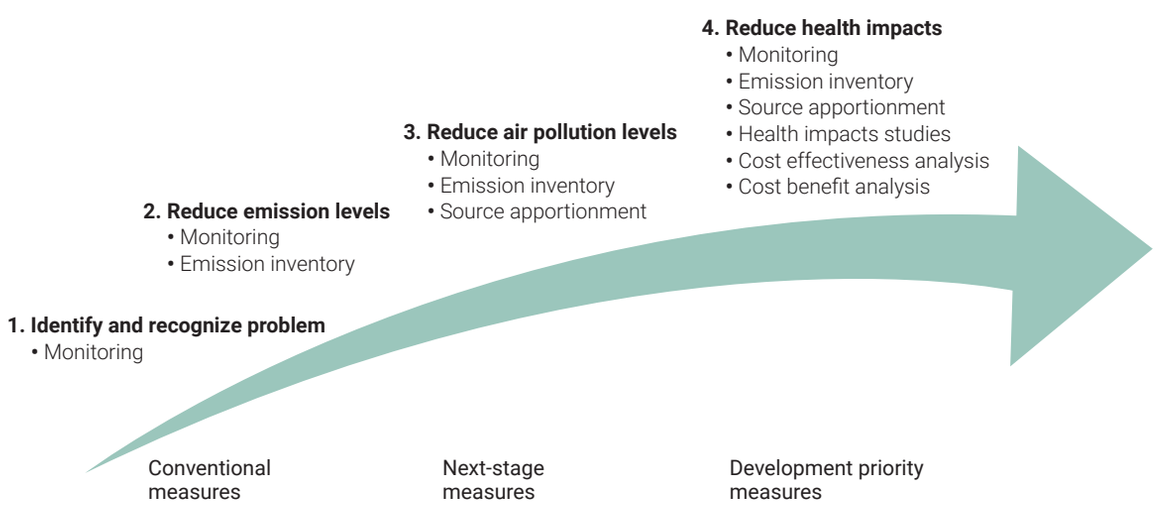


FIGURE 3.1: STRENGTHENING THE SCIENTIFIC BASIS FOR AIR QUALITY MANAGEMENT OVER FOUR STAGES

CONVENTIONAL MEASURES

Strengthening compliance with conventional emission controls can substantially improve air quality in Asia and the Pacific

One of the key findings from Section 2 is that, with economic growth of about 80 per cent by 2030, effective implementation of the conventional measures could at best maintain mean exposure to air pollution at current levels and only reduce exposure in some areas. For many countries in Asia and the Pacific, ambient air quality standards are the starting point in an effort to encourage power plants, industries and other sources to adopt these controls. As they enter this process, environmental agencies across a growing number

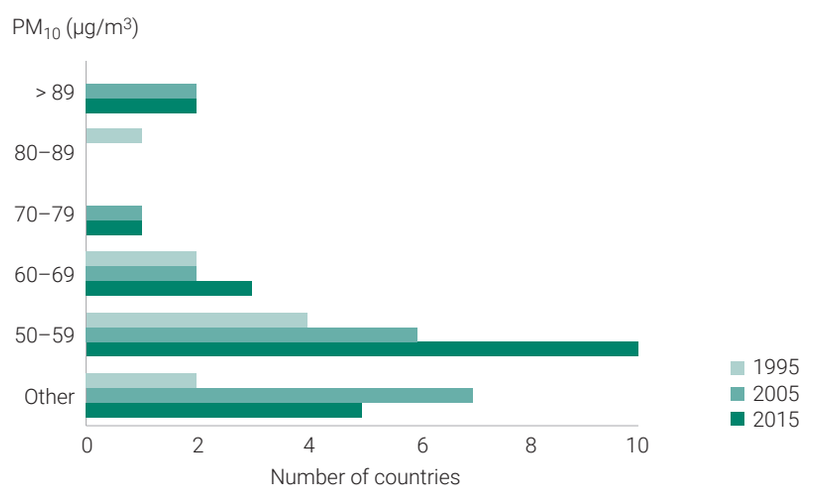


FIGURE 3.2: NUMBER OF COUNTRIES WITH DIFFERENT LEVELS OF AMBIENT AIR QUALITY STANDARDS FOR PM_{10}

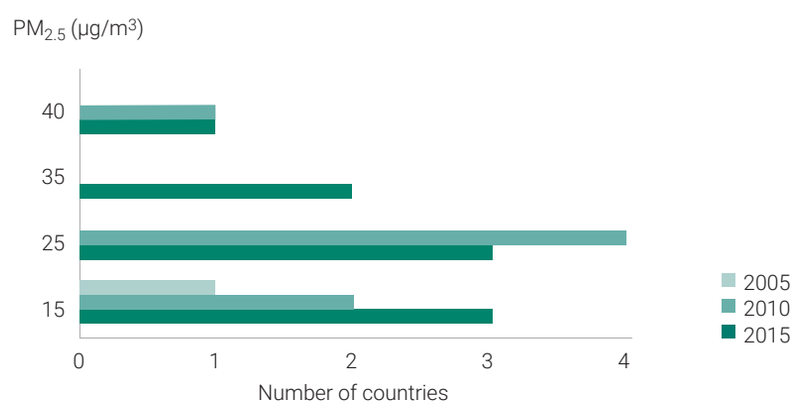


FIGURE 3.3: NUMBER OF COUNTRIES WITH DIFFERENT LEVELS OF AMBIENT AIR QUALITY STANDARDS FOR $PM_{2.5}$

of countries in Asia and the Pacific have become better at making the case for introducing and then tightening standards. This is evident in both the increasing overall quantity of countries adopting some level of standards and in the number of countries with the more stringent levels of standards (Figures 3.2 and 3.3). There is also scope, however, for countries to bring standards in line with the World Health Organization (WHO) Guideline.

Many countries in Asia and the Pacific could adopt conventional controls at early stages of development

In addition to ambient standards, some governments have tightened production and emissions standards and encouraged technical or process changes to reduce emissions for energy and industrial sources. For countries ranging from the Republic of Korea to Thailand, these regulatory changes have encouraged power plants to install flue gas desulphurization and other emission control technologies. Meanwhile, in an example of leapfrogging, India has recently moved towards energy-efficient supercritical technologies, due in part to the ongoing implementation of increasingly stringent standards on old and new coal-fired power plants. In other instances, as occurred in India's capital of Delhi, phasing in stringent standards has resulted in the shut-down of power plants or a shift to gas. While tighter standards can encourage investment in pollution control technologies or broader structural changes, there is often a need for legally backed financial incentives that bring about these shifts. In countries including China and Mongolia, legislation that provides for air pollution fees has created those incentives.

Clean air action plans are additional mechanisms that governments employ to control and prevent air pollution. In some instances, these plans start with national governments responding to emerging policy priorities. In 2012, China's national government released new ambient air quality standards and technical regulations for an air quality index as part of a wide-ranging effort to curb $PM_{2.5}$. More recently, India's government adopted the National Clean Air Programme which, amongst other things, is expanding the air monitoring network, improving the dissemination of data and public outreach, and calling for plans for the prevention, control and abatement of air pollution. Clean air action plans do not always start at the national level. Cities, such as Can Tho, Viet Nam, have also developed action plans to target locally relevant sources of air pollution.

Regulation of the transport sector, particularly diesel engines, offers another conventional control with potential benefits for the region. Often improvements in the transport sector come from more stringent vehicle emissions standards. In many parts of the region, environmental agencies have become more adept at working with transport agencies, vehicle manufacturers and the fossil fuel industry to tighten standards. Cooperation with oil refineries is particularly important since attaining higher standards requires lowering the sulphur concentration in fuel to 50 parts per million (ppm) or even 10 ppm. Assuring the availability of such fuel requires the regulation and commitment of refineries. Fuel switching, another solution to mobile-source pollution, has also been practised in some parts of the Asia and Pacific region. Further, the impetus for regulatory change sometimes comes from institutions outside government agencies. India's Supreme Court, for example, issued a decision that required the entire Delhi public transportation fleet – buses, taxis and auto-rickshaws – to switch to compressed natural gas (CNG). There are currently 1,094 CNG stations in India due to this landmark decision.

Non-technical solutions can help reduce emissions from heavy-duty commercial vehicles. For example, effective logistics and route planning for freight vehicles can avoid unnecessary travel. There can also be effective combinations of measures; for instance, replacing older buses can open a window of opportunity for route rationalization and optimization that offer complementary improvements in service quality. For many countries in developing Asia and the Pacific, much of the air pollution comes from older second-hand cars imported from developed countries. To help reduce its emissions, Mongolia introduced an excise tax policy to favour hybrid and electric vehicles that has changed the second-hand car purchasing behaviour of low- and middle-income families.

Apart from technical solutions, inspection and maintenance programmes that remove the highest emitters are a critical component of a well-designed diesel control strategy. In Tokyo, Japan, a well-publicized and staffed effort to inspect vehicles helped remove the city's highest emitters. For the 13,000 buses in Jakarta, Indonesia, the roll-out of inspection and maintenance programmes reduced emissions of diesel soot by 30 per cent and fuel consumption by 5 per cent.

Most of the conventional controls are reinforced by relevant legislation. For some countries in Asia, legislation has become more coherent across government agencies. For example, there are provisions in several sector-specific laws in India related to pollution. India's Air Prevention and Control of Pollution Act of 1981 depends on the performance of its Motor Vehicles Bill of 1988 (amended in 2007), the Auto Fuel Policy of 2002, the National Environment Policy of 2006, and the National Green Tribunal Bill of 2009.

A source that contributes to air pollution but is not covered in many of the above policies is fugitive dust. This fugitive dust can arise from unpaved roads and infrastructure development and is a serious air pollution problem in areas with expanding transport and construction networks. For example, some cities in India attribute more than half of their $PM_{2.5}$ to this dust. Several technical options are available to policy makers to address these problems, including resurfacing unpaved surfaces and dust suppression using water and suitable chemicals. In some cases, such as the city of Rajhashi in Bangladesh, forward-looking politicians and citizens engaged in a concerted effort to plant more trees and shrubs to suppress the dust. On existing paved surfaces, pressurized sprays and street cleaning with mechanical equipment can vacuum the dust or wash it into drainage systems.

NEXT-STAGE MEASURES

The implementation of conventional pollution controls and prevention programmes will help avert a deterioration in air quality despite 80 per cent economic growth in Asia by 2030, but other measures will be required to reduce the health impacts of air pollution further. This section focuses on a more diverse collection of measures than conventional emission controls. Interventions range from cookstove programmes to industrial controls on solvents. Diversity is also evident in the types of stakeholders involved in crafting and implementing these controls.

Changes in the agricultural and land-use sectors will require incentives to change behaviour and established practice

Agricultural residues

Open-field burning of agricultural residues is still common in many countries in Asia and the Pacific and is a particularly large source of air pollution in Southeast Asia, accounting for 5–30 per cent of total anthropogenic emissions. Crop residue burning has strong seasonality, significantly increasing $PM_{2.5}$ concentrations in the dry season and occasionally contributing to local and regional pollution episodes. While the law in most countries prohibits open burning, the effectiveness of bans without engaging affected communities is questionable. To make bans more successful, working with farmers to provide alternatives for the use of crop residues is needed. For example, widespread use of mechanical rice-straw baling machines can convert above-ground biomass into compressed straw bales for off-site use, help farmers quickly prepare land for the next crop cycle, and derive additional income from selling the bales. In India, the government has taken a cross-sectoral approach, asking power companies to buy agricultural waste from farmers and convert it into biomass pellets that can be co-fired with coal. In addition, India is exploring the potential for biomass gasification, the use of seed drills that incorporate residues as a mulch (happy seeders), and bio-methanation processes that could put agricultural residues to productive use and make open burning bans more effective.

Prevention of forest and peat fires

Forest and peat fires are a serious and persistent problem in Asia and the Pacific. Many of the largest fires have occurred in Southeast Asia due to aggressive land-clearing practices that have grown

more common with the creation and expansion of plantations for rubber, palm oil and paper production. Economics is the main driver behind the burning: clearing land mechanically can cost between 1.5 and, at the highest estimate, 40 times as much as clearing land with fire and chemicals.

Promoting no-burn methods in the agricultural sector as a whole may decrease forest fires by up to 90 per cent in some countries. In other cases, where land-clearance activities cause the majority of fires, creation of a market for useful agricultural-residue products may provide greater incentives for no-burn clearing methods. These measures can be introduced independently, with support for the purchase or leasing of clearance equipment or through the outright monetizing of conserved forest regions as carbon sinks. Much of the attention has focused on regional arrangements to help solve these problems, particularly the the Association of Southeast Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution. In recent years, Indonesia's decision to ratify this agreement has given rise to a Haze-free Roadmap and greater enthusiasm for implementing measures that would help support provisions in the roadmap.

Manure management

Animal manure is a key source of ammonia, which acts as an important component in the formation of secondary particles in the atmosphere, but it is rarely managed systematically in Asia and the Pacific. Most individual farms have small open pits where manure is dumped and composted for field application later. Many of the large industrial livestock farms are not in crop-producing areas and therefore treat manures as waste rather than an organic fertilizer resource. Manure that is applied on land is typically spread widely (often called broadcasting) and is seldom quickly incorporated into soil. Such storage and application practices are associated with high losses of nitrogen volatilized as ammonia.

Improving manure management practices, including the use of closed storage tanks and the quick incorporation of manure into soil following application, are effective means of reducing the release of ammonia. There is also potential in many countries to utilize anaerobic digestion of manure in farms and community projects for the production of biogas for cooking or electricity generation and the use of the resultant slurry as fertilizer.

More efficient fertilizer application

At present, total mineral nitrogen fertilizer consumption in Asia accounts for 60 per cent of global use; China and India are the largest producers and consumers of nitrogen-based fertilizers, especially urea. However, inefficiency in nitrogen-based fertilizer use results in a significant release of nitrogen compounds to the atmosphere and ecosystems. Several governments have adopted measures to reduce these losses, while curbing environmental impacts and the cost of subsidies. For example, India introduced an initiative that requires coating urea-nitrogen with neem oil, a nitrification inhibitor that can reduce nitrogen loss by 10–15 per cent. Other promising techniques such as the split application of nitrogen, the use of slow- and controlled-release fertilizers, promoting speciality fertilizers, and using leaf colour charts to determine crop nitrogen needs, could prevent wastage of 20–25 per cent of nitrogen-based fertilizers by 2030 in India. Bangladesh has introduced innovative approaches to increase the efficiency of nitrogen-based fertilizer use with urea super granules, deep placement of urea, bio-organic fertilizers and low-input crop varieties, resulting in increases in rice yields of 15–20 per cent and reductions in the use of nitrogen-based fertilizers of 20–30 per cent.

Small and medium-sized enterprises and infrastructure development may require innovative management approaches to reduce emissions

Brick kilns

Brick kilns are a major source of air pollution in many parts of Asia. For countries suffering from their emissions, one way to reduce the pollution involves shifting from relatively energy-intensive fixed chimney kilns to more efficient zig-zag, vertical shaft brick and tunnel kilns. The overall impacts of these shifts depend upon fuel type,

technologies, and the operation and maintenance of the new technologies. Perhaps the greatest variable in determining the effectiveness of new technology is the degree to which long-standing production practices can be changed. Countries have sought to revise those practices through the phasing out of fixed chimney technologies (Bangladesh) or sustainable building policy that aimed to improve efficiencies in brick production (Viet Nam). In a recent successful case in the Kathmandu Valley in Nepal, kiln operators worked with a team of experts to shift to zig-zag kilns with modest changes to kiln design at a reasonable cost (an average of about US$ 100,000) that resulted in a 60 per cent decrease in particulate matter, a 40–50 per cent reduction in coal consumption, and an increase in high-quality A grade bricks to 90 per cent of production. Brick kiln entrepreneurs from many parts of Bangladesh, India, Nepal and Pakistan are visiting the new kilns with a view to adopting similar approaches.

Shipping emissions

The control of shipping emissions is important to air quality management and public health improvement in coastal port cities and regions with significant marine traffic. Owing to concerns about port competitiveness and trade opposition, port cities in Asia have been slow to introduce regulations on marine fuels. Indeed, a lack of information about shipping emissions as a pollution source has hampered a better appreciation of its implications in air pollution policy, public health burden evaluation and climate change strategies. This is unfortunate because some studies suggest that increased shipping emissions lead to large adverse health impacts and climate issues in the East Asia region.

Hong Kong (Special Administrative Region of the People's Republic of China) is one of the world's top 10 international container ports and has been proactive in reducing shipping emissions in the past decade. The Ocean Going Vessels Fuel at Berth Regulation, implemented since July 2015 in Hong Kong, is the first marine fuel control regulation for ocean-going vessels in Asia. The key part of this regulation has been adopted nationally by China for the establishment of three domestic emission control areas (DECAs) in its coastal waters; it will come into force in 2019. The latest estimates suggest that without control measures, both sulphur dioxide and particulate emissions were expected to increase by 15–61 per cent in the three DECAs in China during 2013–2020.

Solvents in industries and refineries

There is growing concern about air pollution emissions from the production and use of paints, cosmetics, rubber and chemicals as well as cleaning products in both industries and households. The sharp increase in the use of these substances has led to calls for a greater effort to target solvents in air pollution policies. Recent efforts are included in China's Action Plan for Air Pollution Prevention and Control, released in 2013. Illustrating a different regulatory style, Japan's government worked with industrial associations to design voluntary programmes that have led to declines in emissions of volatile organic compounds from several key industries where leak detection, repair and/or solvent recovery were implemented. In India, Delhi's government is aggressively pushing for installation of vapour recovery systems at petrol pumps to reduce emissions of volatile organic compounds; in 2017, about 60 per cent of Delhi's fuel stations had been fitted with systems that not only reduce these emissions but also save fuel.

DEVELOPMENT PRIORITY MEASURES

Development priority measures usually aim to achieve other development priorities beyond improved air quality

Although the implementation of conventional and next-stage policies to prevent air pollution will provide significant health benefits, the additional implementation of the development priority measures could reduce population exposure to $PM_{2.5}$ by up to 60 per cent by 2030 relative to 2015. One billion people, about 22 per cent of Asia's population, could enjoy air quality within the WHO Guideline, compared to only 8 per cent in 2015. Additionally, the number of people exposed to pollution above WHO's Interim Target 1, the highest level, will decline by 80 per cent, from 2.3 billion in 2015, to 430 million people by 2030. The development priority measures offer a

further means for air quality improvements, even if they do not primarily target air pollution. Often, they fall under the jurisdiction of different authorities in areas such as energy, agriculture or transport.

The implementation of measures to control emissions from indoor solid fuel stoves, kerosene lamps and heating is a development priority for many countries

Clean cooking, heating and lighting

In several parts of Asia, residential stoves burn firewood, animal dung and other biomass for heating and cooking while inefficient kerosene lamps provide lighting for energy-poor regions. The unevenness of the fuels' combustion coupled with poor ventilation generates indoor air pollution. This is particularly detrimental to women and children who spend more time near cookstoves and are most exposed to cookstove emissions.

The country that has received the greatest attention for its national cookstove programme is China. From the late 1970s to the early 1990s, several Chinese government agencies collaborated on the National Improved Stove Program (NISP) to bring cleaner stoves to 129 million households, covering approximately 65 per cent of China's population. The programme benefited from the sustained effort of the Ministry of Agriculture and the assistance of other agencies to identify locally relevant solutions. This flexibility allowed agencies to start small and build to scale, and for rural energy companies to create markets for improved products. For example, in 2007, the Chinese government launched the One Solar Cooker and One Biomass Stove Program specifically in Tibetan regions and distributed almost 80,000 biomass stoves and a quarter of a million solar cookers over four years. However, the NISP brought only modest improvement in indoor air quality, as other unimproved cookstoves were often also present in the kitchen. China's cookstove programme has undergone reforms more recently, with new technologies, better programme oversight, and stronger links to overarching development policies.

India has also introduced several cookstove programmes to help the approximately 100 million (out of 240 million) households lacking access to modern cooking options. These efforts began with the National Programme for Improved Chulhas, a programme that in its most recent form, known as the National Biomass Cookstoves Initiative, is focusing on developing and promoting efficient (including fan-assisted), cost-effective, durable and easy-to-use biomass cookstoves. Other recent high-profile initiatives include an ambitious scheme called Pradhan Mantri Ujjwala Yojana. India's Ministry of Petroleum and Natural Gas launched this initiative in 2016 and has facilitated access to 35 million liquid petroleum gas (LPG) connections for 100 million energy-poor households. The scheme involves convening meetings or *Ujjwala Panchayats* that allow users to connect with each other, express their concerns and experiences, and share information on LPG use and safety. Other smaller-scale activities in India have sought to draw on indigenous knowledge and customize cookstoves to user needs.

Programmes to reduce household sources of air pollution have largely focused on replacing the stoves and fuels used for cooking. In many places, however, wood, coal and other biomass are used for home heating as well. In some developed countries, residential wood-burning stoves are commonly used for home heating, and because they are subject to regulation and design guidelines, lead to relatively low emissions. Heating stoves that burn coal are often used in places where space heating is required and coal is readily available, such as parts of China and Mongolia. Coal heating stoves in these regions are typically older, have low efficiency and are unregulated, with the exception of some urban areas where bans have been introduced on solid-fuel use for residential heating.

Many stoves are used for both cooking and heating, especially in the winter or in high-latitude or high-altitude regions where there is a greater need for space heating. Combined-purpose cooking and heating stoves may be particularly important since they may be used daily for long periods of time, such as overnight for heating, as well as for cooking two to three meals a day. Several mitigation opportunities exist for combined cooking and heating stoves. These include emissions standards, testing and labelling; ecolabelling;

technology development of advanced low emission stoves; fuel switching; district heating; upgrading biofuels and transition to pellet stoves; improving household energy efficiency; separating cooking and heating appliances and fuels; stove exchange programmes; policy and regulatory instruments; and financing approaches.

Renewable energy

Policies that encourage the use of renewable energy and energy-efficient technologies can reduce energy consumption and improve air quality

The adoption of policies that encourage the use of renewable energy and energy-efficient technologies can simultaneously reduce energy consumption and air pollution. Many countries in Asia and the Pacific have adopted policies – from renewable standards to feed-in tariffs – that have contributed to declines in the costs and increases in the generation of solar and wind power (Figure 3.4). The clearest example is China, where solar power generation reached 28 terawatt hours (TWh) and wind power generation reached 55 TWh in 2016, respectively constituting 36 per cent and 42 per cent of the global totals for these sources of energy. The declining costs and increased consumption of solar and wind power seem likely to continue in India, Indonesia, Japan, the Philippines, Thailand and other countries of the region. Growth in clean energy consumption and energy efficiency may also occur for reasons beyond proactive national governments. In the Republic of Korea, Seoul's municipal government, for instance, introduced a variety of demand-driven energy-saving measures that also improve urban air quality as part of its One Less Nuclear Power Plant project.

Energy efficiency standards – households and industry

Energy efficiency standards for households and industry often pay for themselves over the lifetime of an investment. This potential has been recognized by the Chinese government, as illustrated by the inclusion of ambitious energy efficiency targets in its 11th, 12th and 13th Five-Year Plans. China has also introduced an energy efficiency programme that initially relied on a series of training, auditing and better reporting measures to improve energy efficiency in the country's 1,000 most energy-intensive companies. This programme was later expanded to

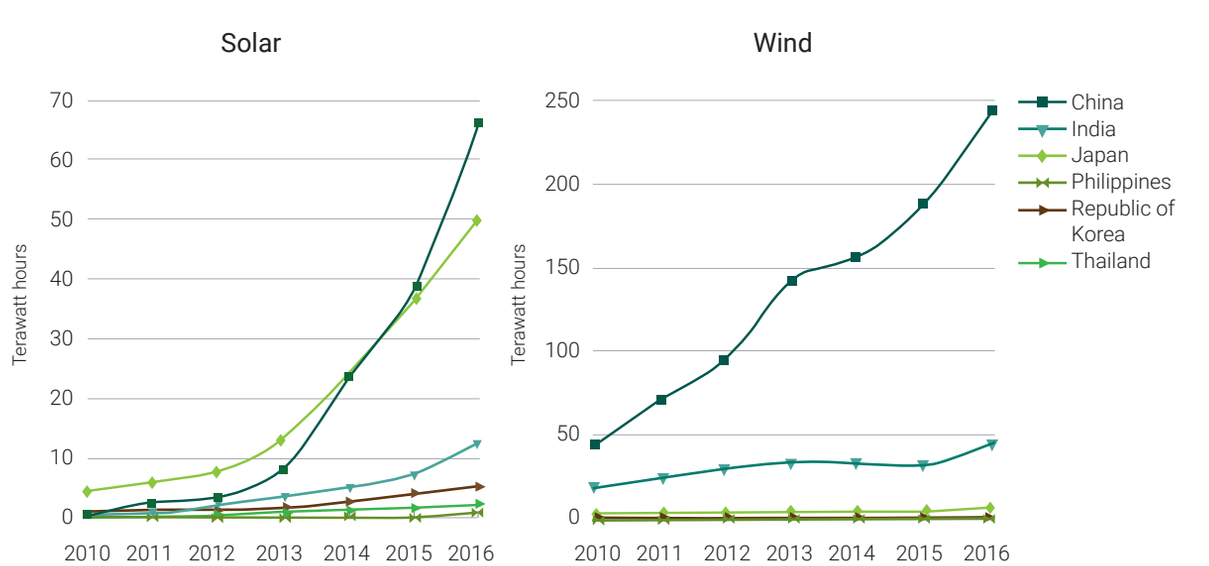


FIGURE 3.4: TRENDS IN SOLAR- AND WIND-POWERED ELECTRICITY GENERATION IN SELECTED COUNTRIES OF ASIA AND THE PACIFIC

encompass the top 10,000 most energy-intensive companies. To enlarge the programme, more responsibilities were delegated to sub-national provincial governments to support training and reporting. India has also been proactive on energy efficiency. Under the Energy Conservation Act 2001, the country established the Bureau of Energy Efficiency (BEE) to advance energy conservation and efficiency agendas through a variety of mechanisms. For households, the BEE has implemented a labelling programme for appliances which provides information to consumers about energy savings. The BEE has introduced mandatory energy-information labels on appliances such as air conditioners, without which they may not be sold. Across Asia and the Pacific, there have also been attempts to introduce pre-paid cards for energy use that can raise household awareness of what they use and motivate residents to purchase energy-efficient appliances.

Improved public transport

Many developed countries in Asia and the Pacific have relatively well-developed public transport systems that help reduce demand for personal transport. Often these systems are most effective when combined with other measures that discourage the purchase of motor vehicles. Singapore has received the most attention in this regard, based on a carefully designed transport demand management strategy that charges cars for entering key parts of the city. Some smaller cities have also enjoyed success in combining public transport with urban planning interventions – the city of Toyama, Japan, for example, sought to counter a trend for residents to move to the suburbs. To bring people back, the city invested considerable effort in making the city more compact and introducing a tram system.

Electric vehicles

China has been a global leader in the supply of and demand for electric vehicles. This position is partially attributable to a government strategy of providing subsidies for the purchase of electric vehicles, and removing some restrictions on these vehicles in some cities. The government of India is also aggressively promoting the introduction of electric vehicles. Meanwhile, the city of Shimla and part of Mumbai have introduced some electric buses for commercial use. There have also been efforts from the private sector, with Ola, a taxi company in the city of Nagpur, launching a pilot to operate a multi-modal electric fleet.

Solid waste management

There is a diverse range of waste management technologies and practices in Asia and the Pacific, making it virtually impossible to identify a single waste management solution in the region. On balance, the region's developed countries tend to employ more advanced technologies such as incineration with energy recovery based on waste-to-energy technology, and systematic recycling of recyclable materials. In contrast, developing countries tend to rely more on direct landfill, often associated with open, and sometimes illegal, dumping and burning, and informal recycling as well as environmentally sound intermediate treatment. The burning of solid waste is one of the major sources of air pollution in the Pacific islands.

The national differences in waste management approaches appear at different junctures in the waste stream, starting with the transport of waste. Advanced economies such as Australia, Japan, the Republic of Korea and Singapore deploy technology-oriented solutions for waste collection and transport, including motorized vehicles and compactor and transfer stations, along with source separation and collection of recyclable wastes. Emerging economies including Indonesia, Malaysia and Thailand also operate systematic collection and transport of wastes, at least in large cities, but the collection of recyclables is still often informal or achieved through community-based approaches such as waste banks. Recycling is often associated with the large informal sector in developing economies. Although some countries promote recycling as a government policy, market-based recycling (often informal) is very common in Bangladesh, Cambodia, China, India, Indonesia, the Philippines and Thailand. Thus, to promote recycling systematically in the region there is a need for governments to collaborate with the informal sector.

For much of Asia and the Pacific, burning offers a relatively easy and low-cost way of disposing of waste and refuse. The practice is common among households with limited access to waste management facilities. It also occurs in communities with rudimentary landfill sites, which are prone to spontaneous combustion. Many parts of the region have introduced laws forbidding waste burning that include fines and other penalties levied on those caught burning. For example, the Philippines' Ecological Solid Waste Management Act includes provisions that forbid the practice and stipulate penalties. At the same time, awareness and enforcement of these legal prohibitions are often limited or altogether lacking. Not surprisingly, the most effective solutions tend to combine technical solutions with information campaigns. Fiji, for example, has adopted a reduce, reuse, recycle awareness programme that has reduced both the amount of waste generated and the practice of burning. More generally, the Pacific island nations have begun to work together to develop regional strategies that can enhance waste management and limit the need for burning.

Rice paddies

The decay of organic matter in rice paddies under anaerobic conditions generates methane. Drainage and intermittent aeration during the planting season interrupt this anaerobic fermentation and can reduce emissions of methane. Many farmers in Asia and the Pacific have adopted the practice of drainage to save water and boost crop yields, achieving methane reductions as a desirable side effect. As there are many effective approaches, there is a need to spread information about successful drainage schemes. In Japan, farmers have adopted the practice of draining their rice paddies for 10 days during the middle of the planting season to increase crop yields. China has more recently and dramatically embraced drainage – between 1980 and 2000, the percentage of farmers using the practice rose from approximately 25 per cent to 80 per cent.

Wastewater treatment

Inadequate wastewater treatment systems are a significant source of methane emissions in Asia and the Pacific. In most developed countries, centralized aerobic wastewater treatment systems, which reduce the amount of methane emitted compared with less advanced systems, are commonly used to treat municipal wastewater. Due to a lack of wastewater infrastructure and technical, institutional and financial capacity, especially in developing countries, up to 89 per cent of Asia's domestic wastewater is discharged directly into nearby water bodies without treatment, causing severe contamination to both surface and groundwater. Systems in developing countries tend to be low cost and less energy intensive, utilizing the process of anaerobic digestion of organic matter.

Typical systems in use include biogas digesters; lagoon, medium and large-scale anaerobic digesters; and septic tanks and other types of latrines. In Asia and the Pacific, the production of biogas from anaerobic digestion is also widely used for treating livestock manure and sewage sludge. A number of proven technological approaches to wastewater methane mitigation and recovery have been applied successfully. These include installing anaerobic sludge digestion; installing biogas capture systems at existing open-air anaerobic lagoons; installing new centralized aerobic treatment facilities or covered lagoons; installing simple degassing devices at the effluent discharge of anaerobic municipal reactors; and optimizing existing facilities and systems that are not being operated correctly while ensuring proper operation and maintenance.

Oil and gas

Methane emissions occur in all sectors of the oil and natural gas industry, from production through processing and transmission to distribution. They result chiefly from normal operations, routine maintenance, fugitive leaks and system upsets. Numerous technologies exist to control the emissions generated during these processes (Figure 3.5). Analyses of the top 10 opportunities to capture unintended and unnecessary methane emissions from oil and gas production, including shale gas, show that if implemented they could reduce methane emissions by around 88 per cent. The oil and gas industry understands the need to

reduce methane emissions: eight of the world's largest oil and gas companies agreed in 2017 to act to reduce them. BP, Total, ExxonMobil, Royal Dutch and four others have agreed to implement guiding principles to minimize leaks from energy infrastructure. Some countries in the region have also illustrated the feasibility of using control technologies. In India, for example, a recovery system was installed to help recycle and recover flare gases that are piped in from Mumbai High offshore field. Meanwhile, Indonesia has adopted a zero-flaring policy as part of its climate change strategy.

Coal mining

Methane can be released into the atmosphere during the process of mining coal. The amount of methane released from this activity is predicted to increase sharply in Asia and the Pacific due to enhanced productivity of mining techniques and the extraction of more coal from deeper, gassier seams. Rather than releasing the methane into the atmosphere, it is possible to capture and use it to generate energy, operate industrial boilers or for other productive purposes. This can be accomplished by the installation of degasification systems that capture methane. In some cases, enhanced degasification systems are needed to capture methane that has been diluted with air (known as ventilated air methane) to safeguard against mine outbursts and explosions. While it is common for mines in developed countries to have recovery systems, the high upfront costs of investing in the necessary technologies have made it less common in developing countries. About a decade ago, China began to use resources from the Clean Development Mechanism to overcome this barrier and facilitate the transfer of recovery technologies. Since then, it has adopted several other domestic enabling policies that have provided regulatory and financial incentives, such as tax relief, for investors in methane recovery projects.

Hydrofluorocarbons

Reduced energy use and pollutant emissions can be achieved with options that cut emissions of hydrofluorocarbons (HFCs). One such set of options involves retrofitting large and medium-sized facilities with low global-warming-potential (GWP) refrigeration, air conditioning, or other manufacturing processes. These changes are occurring in Indonesia with nearly 1,000 Alfamidi convenience stores installing energy-saving refrigeration systems. Yet another positive sign involves India's appliance manufacturer, Godrej & Boyce, which leapfrogged high-GWP HFCs and moved directly to lower GWP alternatives, selling more than 100,000 HC-290 room units with support from the German development agency GIZ and India's Ministry of Environment. As

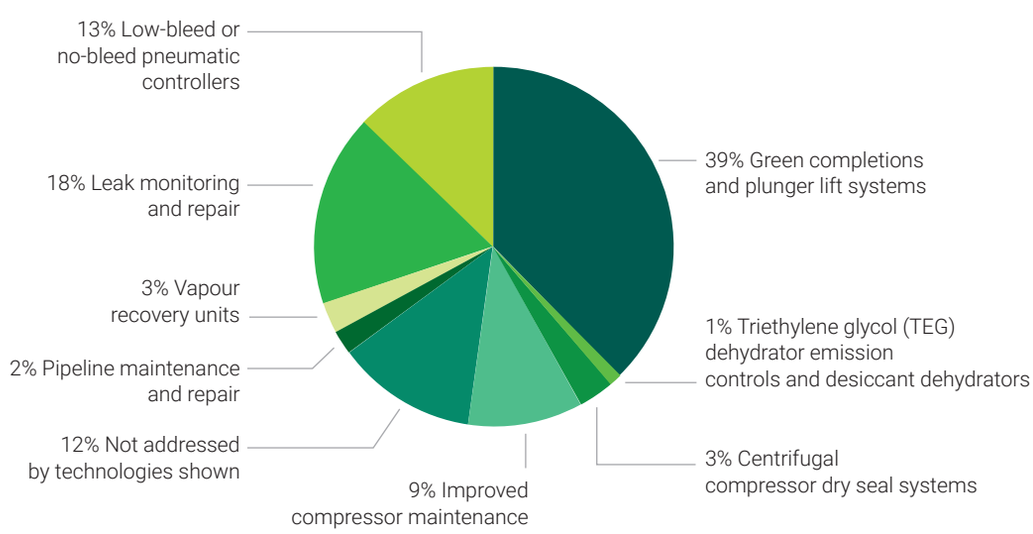


FIGURE 3.5: TECHNOLOGIES WITH THE GREATEST POTENTIAL TO REDUCE METHANE EMISSIONS IN THE OIL AND GAS INDUSTRY

the majority of Asia imports HFC products, policy makers and standard-setting organizations need clear market signals to avoid the accumulation and dumping of HFC technologies. Japan's Revised Fluorocarbons Recovery and Destruction Law, which entered into force in 2015, offers a clear signal with measures that require manufacturers to dispose of gases as well as regulating products that use fluorocarbons.

Sub-regional priorities

Several measures that are important at a sub-regional level are not the highest priorities at a regional level but could lead to significant reductions in emissions in sub-regions or particular countries. For instance, in Bangladesh the government has identified rice parboiling units as an important source of air pollution and introduced remedial measures to curb emissions.

AIR POLLUTION EPISODES

In response to episodes of high concentrations of air pollution that attract considerable public attention, governments in Asia and the Pacific are increasingly aiming for short-term interventions that should either reduce the severity of an envisaged pollution episode or minimize the exposure of people to polluted air during these episodes.

Most pollution episodes are caused by high emissions across a large area upwind of cities and are enhanced by unfavourable meteorological conditions, for example low wind speeds and limited atmospheric mixing.

The emissions responsible for the pollution – $PM_{2.5}$, sulphur dioxide and nitrogen oxides, amongst others – remain in the atmosphere for about a week. During that time, upwind emission sources contribute to pollution in the target area. For a short-term action plan to be effective, emission controls need to begin about a week before the predicted event, and should cover upwind sources over a distance of up to 1,000 kilometres due to the low wind speeds that are typical for pollution episodes. Uncertainties about weather forecasts for such periods extend this emissions region.

Many techniques have been adopted to manage and mitigate the effects of these episodes. Some focus on raising awareness of the severity of air pollution and encouraging people who might be especially vulnerable to stay indoors. This can involve the establishment of alert systems and public communication plans. Other methods focus on temporary restrictions on vehicles and the halting of construction. Many of these approaches were implemented in China following a series of heavy pollution episodes that attracted policy-maker attention in 2013. In modelled Southeast Asia, these episodes frequently involve transboundary emissions, which have led to efforts to strengthen the ASEAN Agreement on Transboundary Haze Pollution.

There are examples of successful short-term policy interventions, notably in China, which relies on strong authority to enforce drastic emission reductions over very large areas. In other cases, where governments have less authority to temporarily suspend a wide range of economic activities over a sufficiently large area, interventions have been less successful.

In addition, the economic effectiveness of such disruptive interventions remains questionable. Long-term strategies that reduce emissions from the most polluting activities in a planned and scheduled manner are considered to be more cost-effective than policies that repeatedly require the shut-down of entire production processes, restrict the mobility of people and goods, or reduce labour productivity.

TAILORING THE TOP 25 CLEAN AIR MEASURES TO NATIONAL CONTEXTS

The top 25 clean air measures offer a range of options for governments to consider in their own contexts. There is no uniformly applicable set of solutions. Priorities will differ across and within countries. Decision makers will therefore need to tailor selected options to their own national contexts. In addition, there is no set sequence they should follow. Decision makers may want to place a greater emphasis on agriculture before turning to industrial sources; or they may concentrate on transport and a transition to

a different fossil fuel, for example from diesel to CNG. Though the order is likely to vary from one country to the next, one of this report's main messages is that decision makers should aim to strengthen the scientific basis for their solutions (Figure 3.1). In so doing, they should be aware that all of the 25 measures have been implemented in the region with some level of success. The solutions are grounded in both science and experience.

The next logical question is what are the factors behind the more successful experiences? Table 3.1 summarizes successful implementation and describes some important reasons behind it. It demonstrates that the factors leading to exemplary action often include growing awareness of the magnitude and severity of air pollution, again underlining the importance of building a sound scientific basis for decisions. The success factors

TABLE 3.1: FACTORS ENABLING THE SUCCESS OF CLEAN AIR MEASURES

Regional application of conventional measures		Relevant experiences/ case studies	Enabling/success factors
Post-combustion controls	Introduce state-of-the-art end-of-pipe measures to reduce sulphur dioxide, nitrogen oxides and particulate emissions at power stations and in large-scale industry	Thailand's installation of flue gas desulphurization technologies	Tightening of standards based on health impact studies (WHO guidelines) that stimulate investment in pollution control/cleaner technologies
Industrial process emissions standards	Introduce advanced emissions standards in industries, e.g., iron and steel plants, cement factories, glass production, chemical industry, etc.	China's adoption of waste heat recovery technologies	Tightening of production, performance and emissions standards that stimulate investment in pollution control/cleaner technologies
Emissions standards for road vehicles	Strengthening all emissions standards; special focus on regulation of light- and heavy-duty diesel vehicles	Regional tightening and updating of mobile-source emissions standards	Collaboration between environmental agencies, transport agencies, oil companies and vehicle manufacturers
Vehicle inspection and maintenance	Enforce mandatory checks and repairs for vehicles	Tokyo's (Japan) diesel control strategy	Centralized inspection and maintenance systems developed through multi-agency collaboration; self-funding mechanism for regular audits at test centres
Dust control	Suppress construction and road dust; increase green areas	Bangladesh's (Rajhashi) tree-planting scheme	Forward-looking politician and general public support

TABLE 3.1: FACTORS ENABLING THE SUCCESS OF CLEAN AIR MEASURES (contd.)

Next-stage air quality measures that are not yet major components of clean air policies in many parts of Asia and the Pacific		Relevant experiences/ case studies	Enabling/success factors
Agricultural crop residues	Manage agricultural residues including strict enforcement of bans on open burning	Thailand's open burning controls	Growing policy-maker and public awareness of pollution sources/ impacts; complementing burning bans with other use options with the involvement of farmers, alternative off-site use of crop residues, technologies that plough residues into fields
Residential waste burning	Strictly enforce bans of open burning of household waste	The Republic of Korea's waste management policies	Regulation on engineered landfills and incineration; collaboration with informal sector for recycling
Prevention of forest and peatland fires	Prevent forest and peatland fires through improved forest, land and water management and fire prevention strategies	Indonesia's cooperation with Malaysia/Singapore	ASEAN Agreement on Transboundary Haze Pollution
Livestock manure management	Introduce covered storage and efficient application of manures; encourage anaerobic digestion	China's agricultural policies	Combination of regulation, policy and programmes for covering compost; incorporating manure into soil; changing to modified ammonium nitrate fertilizer
Nitrogen fertilizer application	Efficient application, urease inhibitors, use of ammonium nitrate	Bangladesh's use of urea super granules	Cost-benefit analysis of the efficient application of nitrogen fertilizer
Brick kilns	Improve efficiency and introduce emissions standards	Kathmandu's (Nepal) shift from bull trench to zig-zag kilns	Clear presentation of the benefits of the retrofit; collaboration with kiln owners and technical experts in the kiln redesign
International shipping	Require low-sulphur fuels and control of particulate emissions	Hong Kong's rules on port emissions	Support from the International Maritime Organization
Solvent use and refineries	Introduce low-solvent paints for industrial and do-it-yourself applications; leak detection; incineration and recovery	China's volatile organic compound control policy	Growing public concern over particulate pollution; comprehensive reduction targets

TABLE 3.1: FACTORS ENABLING THE SUCCESS OF CLEAN AIR MEASURES (contd.)

Measures contributing to development priority goals with benefits for air quality		Relevant experiences/ case studies	Enabling/success factors
Clean cooking and heating	Use clean fuels – electricity, natural gas, liquefied petroleum gas (LPG) in cities, and LPG and advanced biomass cooking and heating stoves in rural areas; substitution of coal by briquettes	China and India cooking and heating programmes	Growing policy-maker awareness of the impacts of cooking on health; lessons learned from the design of previous programmes
Renewables for power generation	Use incentives to foster extended use of wind, solar and hydro power for electricity generation and phase out the least efficient plants	China, India, Indonesia, Japan, Thailand, and the Philippines' renewable programmes Seoul's (Republic of Korea) One Less Nuclear Power Plant project	Including renewable power generation in energy and climate policies; public pressure to switch from fossil fuels and nuclear to renewables
Energy efficiency standards for households	Use incentives to improve energy efficiency of household appliances, buildings, lighting, heating and cooling; encourage roof-top solar installations	India's household energy programmes Australia's rooftop solar incentives	Creation of bureau of energy efficiency
Energy efficiency standards for industry	Introduce ambitious energy efficiency standards for industry	China's Five-Year Development Plans	Including energy efficiency targets in Five-Year Plans
Electric vehicles	Promote use of electric vehicles	Mongolia's excise tax that favours electric and hybrid vehicles	Policy that supports and promotes the use of electric vehicles
Improved public transport	Encourage a shift from private passenger vehicles to public transport	Japan's (Toyama) Compact City Planning	Integration with Compact City Planning
Solid waste management	Encourage centralized waste collection with source separation and treatment, including gas utilization	Pacific islands and Small Island Developing States' waste management	Regional waste management policy and strategy

TABLE 3.1: FACTORS ENABLING THE SUCCESS OF CLEAN AIR MEASURES (contd.)

Measures contributing to development priority goals with benefits for air quality		Relevant experiences/ case studies	Enabling/success factors
Rice paddies	Encourage intermittent aeration of continuously flooded paddies	Viet Nam's agricultural practices	Established tradition of irrigation and drainage policy
Wastewater treatment	Introduce well managed two-stage treatment with biogas recovery	Japan's treatment technologies	Promotion of decentralized wastewater treatment units
Coal mining	Encourage pre-mining recovery of coal mine gas	China's methane recovery programme	Use of existing economic incentives, tax; incentives, well-defined gas property rights unsubsidized free gas market education and information dissemination
Oil and gas production	Encourage recovery of associated petroleum gas; stop routine flaring; leakage control	India's flare gas recovery systems	Collective corporate action
Hydrofluorocarbon (HFC) refrigerant replacement	Ensure full compliance with the Kigali Amendment	Indonesia's HFC reduction policies	Government mandate to shift to low-GWP coolants; clear presentation of the cost savings from technology change

also highlight the significant role of enabling policies – from regulatory standards to tax incentives – that create conditions that make it easier to introduce the measures. Finally, the list of successful measures underlines the crucial role of different stakeholders, both within and beyond the government, in introducing enabling policies, financial incentives and other resources to make implementation possible.

The next section concentrates on the kinds of governance and financial arrangements that could help implement a portfolio of different options and improve compliance with policies promoting the top 25 clean air measures.

GOVERNANCE AND FINANCE

Multi-stakeholder partnerships can help improve compliance, delivering cleaner air and other benefits

A persistent problem with environmental policies is that what is written on paper is often not implemented in practice. Unfortunately, the lack of compliance remains a significant hurdle to progress on air pollution prevention and control in much of Asia and the Pacific. This section discusses the governance and financing arrangements that can help overcome that hurdle and close longstanding implementation gaps.

The term governance refers to the exercise of authority in the pursuit of publicly desirable goals. When considering how governance can help increase policy compliance, an important initial consideration is whether a relevant agency possesses a mandate to control air pollution. Because the enforcement of environmental policies can be complicated by different legal and governance frameworks, having a government agency with a clear mandate of air pollution regulation is essential for successfully adopting many of the top 25 clean air measures. Most countries in Asia and the Pacific have established air quality management agencies or divisions in environmental agencies; many have seen their staffing and budget grow in recent years. For example, the number of employees working in sub-national environmental protection bureaus in China doubled between 1998 and 2014. These are promising trends that need to continue – and be considerably strengthened in many countries – to achieve the goals presented in this report.

Another issue is whether environmental agencies have the *de facto* authority to regulate emission sources. Though environmental agencies have seen their status rise across the Asia and Pacific region, they may struggle to advance their agenda when other more powerful agencies have conflicting objectives. Coordination across or within agencies is essential. This is particularly the case because more integrated air pollution and climate change policies and coordination across government agencies could simultaneously improve air quality, mitigate climate change and yield a range of other benefits. Fortunately, there are signs of changing agency power relations and better coordination. Examples include the inclusion of air pollution in nationally determined contributions (NDCs) that have been pledged to the United Nations Framework Convention on Climate Change (UNFCCC).

Other considerations involve the devolution of authority from central government. Over the past two decades, governance has become multi-tiered or polycentric, with power increasingly shared among different stakeholders beyond central governments. Reflecting this redistribution of authority, cities have been delegated many new responsibilities for air pollution. While devolution or vertical integration can be problematic if local governments are not sufficiently strict or lack capacity, subnational governments can also be an important source of innovation. This is clearly evident in the reforms to public transport and urban planning found throughout Asia and the Pacific. In some cases, central governments can encourage innovation through fiscal policies that transfer resources or grants to help local governments finance new solutions to air pollution.

In some countries, for example some Pacific island nations, traditional leaders may have more influence on the behaviour of communities than government authorities. Giving traditional leaders authority to enforce some directives, such as bans on burning domestic and agricultural waste or forests, has been more effective in Fiji than government directives.

Reliable, accurate and timely monitoring data, though not formally part of the governance system, is also essential to improving governance. Most air quality monitoring stations measure PM_{10}, $PM_{2.5}$ and total suspended particulates. Coverage is typically more extensive in developed countries and the capital cities of developing ones. Most large cities in Japan, the Republic of Korea, Singapore and Thailand observe stringent monitoring procedures while many other cities are faced with limits on equipment, monitoring and siting procedures, and quality assurance and control procedures.

Civil society is also an increasingly vital source of support for environmental policies and ambient air quality monitoring. Countries are establishing institutional channels allowing civil society organizations and the general public to articulate concerns about pollution. Both the public and civil society organizations can also play an important role in monitoring air pollution by notifying regulatory authorities of a lack of compliance. The growing affordability of monitoring equipment may also make it possible for citizens to generate their own policy-relevant data.

One of the main reasons behind the compliance gaps is a lack of financial resources for pollution prevention and control. Most Asian countries allocate financial resources for environmental management

as part of annual nationally appropriated funds. One way to help boost those outlays is to ensure that urban development planning prioritizes air pollution control measures, and hence funds for the enforcement of such measures are allocated at the local level. Private-public partnerships can help support cleaner infrastructure. Special funds can also be set up by the government to finance air pollution control projects. The Philippines established the Special Vehicle Pollution Control Fund as a seed fund emission reduction initiative in the transport sector. The funds are generated from a charge on all motor vehicles, paid by the owners.

The private sector, particularly financial institutions, can complement government efforts by supporting investment that reduces air pollutants. Several of the top 25 clean air measures are consistent with national development priorities and could be supported from annual nationally appropriated funds. At the same time, the private sector and businesses can help fund cleaner technologies, provided a favourable enabling environment is in place. Currently, a number of innovative instruments are also available to finance green projects (Box 3.1). Green bonds, in particular, can be a major source as they are estimated to increase to a value of US$ 100 billion in 2018. Commercial banks can be required to lend a certain percentage of their investment portfolio for green projects. This strategy was successfully implemented in Fiji and even exceeded its targets. It may also be possible for development banks working in Asia and the Pacific to employ these instruments to help overcome financing barriers, such as high upfront costs, for some of the top 25 clean air measures. In a similar vein, development banks may consider aligning their strategies with some of the measures. Last but not least, there may be growing opportunities to tap climate finance mechanisms such as the Green Climate Fund for activities that mitigate greenhouse gases and prevent air pollution.

A final set of participants at the national level is business and industry. Industries can assist or prevent changes in the design and implementation of air pollution regulations. This is particularly the case if they work with regulatory agencies to change pollution-intensive development patterns. However, businesses are recognizing the advantages of moving first on the environment and investing in new energy and cleaner production technologies. This is especially true for publicly traded firms which fear that negative media attention from environmental pollution will cause an adverse reaction among investors and customers. Improvements in emissions performance by industry are accomplished most easily when the government and the public push for them and financial markets move in the same direction. In such cases, inadustry has incentives to clean up, especially for financially viable enterprises that are targeting a global market or first-mover status in an emerging market.

BOX 3.1: TROPICAL LANDSCAPES FINANCE FACILITY – LEVERAGING PUBLIC FINANCE TO SUPPORT GREEN GROWTH

In line with the SDGs and the Paris Climate Agreement, the Indonesian government, together with UN Environment, the International Centre for Research in Agroforestry (ICRAF), BNP Paribas and ADM Capital, officially launched the Tropical Landscapes Finance Facility (TLFF) in October 2016. The TLFF, as the first private-sector landscape financing facility at scale, aims to pool financial resources for supporting sustainable agriculture and land management, renewable energy and overall rural livelihood. The TLFF mobilizes capital through its loan and grant funds. The TLFF Loan Fund seeks to provide long-term loans of at least 10 years to projects that comply with zero-deforestation criteria and environmental, social and governance standards. The TLFF Grant Fund focuses on building the capacity of farmers and rural communities, land rehabilitation and the availability of renewable energy in rural areas.

As organizations within and beyond governments work together, efforts become less about government agencies dictating what should be done, and more about collaborative partnerships generating mutually agreeable solutions. These partnership models are not limited to those working solely at the national or local level; rather, air pollution is also gaining attention at regional and international levels. This is partially due to recognition of the links between air pollution and climate change. It is also due to the growth of international and regional networks and initiatives that could provide the knowledge needed for action. This could be achieved with technical assistance and well-designed capacity building. City networks such as Clean Air Asia and ICLEI–Local Governments for Sustainability may be particularly well placed to transfer knowledge between countries and cities, in part because they are more flexible than formal government-to-government arrangements.

The Asia and Pacific region has several existing air pollution and environmental collaborating networks that have helped to share scientific understanding, strengthen monitoring and, in some instances, promote collective action. These include the Asia Pacific Clean Air Partnership (APCAP), which is co-financing this report together with the Climate and Clean Air Coalition (CCAC), the global network, which is also helping to advance an action-oriented agenda through a better understanding of science, and a series of initiatives targeting a particular sector or cross-sectoral concern. Both APCAP and CCAC are potentially useful hubs to carry forward some of the capacity building and action that could follow from this report. In so doing, they could help to meet the provisions in the United Nations Environment Assembly (UNEA) resolution that gave life to this report. Last but not least, they could support countries in implementing these solutions and assist progress on several SDGs, including SDG 3: Good Health and Well-being, SDG 11: Sustainable Cities and Communities and SDG 13: Climate Action, in which air pollution control or air quality improvement is directly mentioned as well as those such as SDG 5: Gender Equality, where the link is more indirect. In the process, they could help bring cleaner air to the region and address one of the world's most serious public health crises.

Conclusion

Policy action taken in Asia and the Pacific in the last decade has led to a clear decoupling of some emission trends from economic growth, notably for sulphur dioxide and nitrogen oxides, confirming world-wide experience that pollution controls do not prevent economic development. Hypothetically, without the current policies, population-weighted exposure to harmful particulate matter ($PM_{2.5}$) would grow by about 50 per cent by 2030 given the region's forecast economic growth of 80 per cent. Thus, while current policies deliver clear and significant returns on air quality and health benefits, improving air quality requires further action to reduce emissions that lead to the formation of $PM_{2.5}$ and ground-level ozone which, together, damage human health and well-being as well as food crops and the environment.

The adoption of the top 25 clean air measures (Table A) will cut population exposure to $PM_{2.5}$ and ground-level ozone by 60 per cent by 2030 and increasingly more thereafter, at a cost of approximately 5 per cent of the increase in gross domestic product of US$ 12 trillion per year that is projected for Asia by 2030.

The benefits to human health and well-being of implementing the top 25 clean air measures will be significant. Most importantly, 1 billion people, 22 per cent of the region's population, will enjoy air quality in line with the World Health Organization (WHO) Guideline, compared to just 8 per cent in 2015, while the number of people exposed to pollution above the highest WHO Interim Target level will fall by 80 per cent, leaving only 10 per cent of the population, 430 million people, exposed to high pollution levels. Additionally, annual premature mortality associated with indoor air pollution could decline by 75 per cent, avoiding about 2 million premature deaths each year.

The implications for food production are similarly encouraging. Implementation of the top 25 clean air measures would reduce estimated ozone-induced crop losses by 45 per cent for maize, rice, soy and wheat combined.

Furthermore, implementing the top 25 clean air measures will benefit efforts to mitigate climate change. They could reduce carbon dioxide emissions in 2030 by almost 20 per cent relative to baseline projections and potentially decrease the expected warming by a third of a degree Celsius by 2050. This would be a significant contribution to the Paris Agreement target of keeping global temperature rise this century well below 2°C on pre-industrial levels and contribute to the development agenda.

Continued economic growth will remain critical to lifting tens of millions of people out of poverty, raising levels of health and improving general well-being. But, growth alone will not lead to the successful adoption and effective implementation of pollution control measures. Rather, that will require action by governments, businesses and civil society.

Each of the top 25 clean air measures offers different potential air quality improvements, not only for the whole of the region but even more so for specific countries, owing to differences in social, economic, technological and geo-physical conditions. The top 25 clean air measures are not equally appropriate across the whole region. While the measures are a package, the diversity of sub-regions and countries in the region will mean tailoring the prioritization and implementation of the measures to national realities.

Abbreviations

APCAP	Asia Pacific Clean Air Partnership
ASEAN	Association of Southeast Asian Nations
BC	Black carbon
BEE	Bureau of Energy Efficiency (India)
^{o}C	Degree Celsius
CAA	Clean Air Asia
CCAC	Climate and Clean Air Coalition
CFCs	Chlorofluorocarbons
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
DECAs	Domestic emission control areas (China)
GAINS	Greenhouse gas – Air pollution Interactions and Synergies model developed by the International Institute for Applied Systems Analysis (IIASA)
GDP	Gross domestic product
GIZ	German Corporation for International Cooperation (Gesellschaft für Internationale Zusammenarbeit)
GWP	Global warming potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
ICLEI	International Council for Local Environmental Initiatives
ICRAF	International Centre for Research in Agroforestry
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
IIASA	International Institute for Applied Systems Analysis
LPG	Liquefied petroleum gas
NDCs	Nationally determined contributions
NH_3	Ammonia
NISP	National improved stove program (China)
NO_X	Nitrogen oxides
NRDC	Natural Resources Defence Council (USA)
O_3	Ozone
OC	Organic carbon
$PM_{2.5}$	Particulate matter with an aerodynamic diameter equal to or less than 2.5 micrometres (µm)
PM_{10}	Particulate matter with an aerodynamic diameter equal to or less than 10 micrometres (µm)
PPM	Parts per million
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SLCPs	Short-lived Climate Pollutants, i.e., black carbon, methane and hydrofluorocarbons
SO_2	Sulphur dioxide
TEG	Triethylene glycol
TLFF	Tropical landscapes finance facility (Indonesia)
TWh	Terawatt hours
UNEP	United Nations Environment Programme (UN Environment)
UNEA	United Nations Environment Assembly
UNFCC	United Nations Framework Convention on Climate Change
VOCs	Volatile Organic Compounds
WHO	World Health Organization
µm	micrometres
$\mu g/m^3$	micrograms per cubic metre