NEACAP POLICY ANALYSIS REPORT

SUCCESSES AND CHALLENGES IN ADDRESSING AIR POLLUTION IN NORTH-EAST ASIA

A Call to Strengthen Regional Collaboration

ESCAP
Economic and Social Commission for Asia and the Pacific

NEASPEC North-East Asian Subregional Programme for Environmental Cooperation

*The shaded areas of the map indicate ESCAP members and associate members.**

The Economic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations. The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-oriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

The North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC) is a comprehensive intergovernmental cooperation framework established in 1993 by six member States: China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, and the Russian Federation. The Senior Officials Meeting (SOM) is held annually and serves as the governing body and principal mechanism for the development of NEASPEC. The East and North-East Asia Office of ESCAP functions as the NEASPEC secretariat.

The North-East Asia Clean Air Partnership (NEACAP) is a regional cooperation mechanism under NEASPEC for enhancing coordinated action among North-East Asian countries to address air pollution. Established in 2018 in response to growing environmental and public health concerns related to air pollution, NEACAP fosters collaborative approaches to improving air quality and advancing sustainable development across the subregion through its inclusive platform of government representatives, technical centres, and experts.

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ACRONYMS AND ABBREVIATIONS

ACBSP	Asia Clean Blue Skies Program
ADB	Asia Development Bank
AQGs	Air Quality Guidelines
AQI	Air Quality Index
BaP	Benzo(a)pyrene
BATs	Best Available Techniques
BC	Black Carbon
CCUS	Carbon Capture, Utilization and Storage
CFORS	Chemical weather FORecasting System
CH4	Methane
CHOCHO	Glyoxal ($C_2H_2O_2$)
CMAQ	Community Multiscale Air Quality Modeling system
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DPF	Diesel Particulate Filters
DSS	Dust and Sandstorm
EANET	Acid Deposition Monitoring Network in East Asia
EDGAR	Emissions Database for Global Atmospheric Research
ESCAP	Economic and Social Commission for Asia and the Pacific
EV	Electric Vehicle
FICAP	Forum for International Cooperation on Air Pollution
GCAM	The Global Change Analysis Model
GEMS	Geostationary Environment Monitoring Spectrometer
GHG	Greenhouse Gas
GUIDE	Greenhouse Gases and Air pollutants Unified Information Design System for Environment
HCHO	Formaldehyde
HOBs	Heat-Only Boilers
HTAP	LRTAP Convention Task Force on Hemispheric Transport of Air Pollution
IAM	Integrated Assessment Model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LRTAP	Long-Range Transboundary Air Pollution (UNECE Convention)
LTP	Long-range Transboundary Air Pollutants

MEIC	Multi-resolution Emission Inventory for China
NEACAP	North-East Asia Clean Air Partnership
NEASPEC	North-East Asian Sub-Regional Programme for Environmental Cooperation
NEV	New Energy Vehicles
NH_3	Ammonia
NMHC	Non-methane Hydrocarbons
NMVOC	Non-methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
O_x	Photochemical Oxidants
PAN	Pandora Asia Network
PGN	Pandonia Global Network
PM	Particulate Matter
PM_{10}	Particulate Matter with a Diameter less than 10 Micrometers
$PM_{2.5}$	Particulate Matter with a Diameter less than 2.5 Micrometers
R&D	Research and Development
RAPAP	Asia-Pacific Regional Action Programme on Air Pollution
RCP	Representative Concentration Pathways
REAS	Regional Emission inventory in Asia
RSD	Remote Sensing Device
SACEE	Satellite Application Centre for Ecology and Environment
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides
SPM	Suspended Particulate Matter
SSP	Shared Socioeconomic Pathways
TEMM	Tripartite Environment Ministers Meeting
TSP	Total Suspended Particles
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNICEF	United Nations International Children's Emergency Fund
VNR	Voluntary National Review
VOCs	Volatile Organic Compounds
WHO	World Health Organization

EXECUTIVE SUMMARY

This report examines recent progress and challenges in managing air pollution in North-East Asia, focusing on China, Japan, Mongolia, and the Republic of Korea. It highlights those countries in the region that have made significant strides, not only in improving air quality, but also in public health and ecosystem services. Much of this progress is due to increasingly strong domestic air pollution policy and regulatory frameworks; regional efforts to share information and experiences may have also played a constructive role. While this progress is notable, continuing the forward momentum will require addressing several emerging challenges. Key hurdles range from challenges in urban pollution; struggles with agricultural emissions and ozone; difficulties achieving Sustainable Development Goals (SDGs) and updated WHO air quality guidelines; frequently reinforcing implementation barriers; the potentially negative impacts of climate change on air quality. The report concludes that many of these challenges can be turned into opportunities in the region by, for instance, leveraging synergies between air quality, climate, and other development priorities to craft more cost-effective policies. Strengthening regional collaboration on environmental data management and other agreeable need areas can also build upon the recent foundation of success and ensure North-East Asia's future generations enjoy clean air.

Achievements

Air quality has improved significantly over the past decade. North-East Asia has made significant strides in reducing key pollutants like $PM_{2.5}$ and NO_2 through robust policies targeting emissions from industrial, transportation, and residential sectors. The degree of improvement has varied across countries in the region, with China and Mongolia (Ulaanbaatar) experiencing the most significant reductions over the last decade as $PM_{2.5}$ levels fell by over 60%. In Japan and the Republic of Korea, $PM_{2.5}$ concentrations decreased by approximately 45% and 30% respectively, as both countries strengthened compliance with national air quality standards. Major economic and political centers in each country, including capital cities, often introduced ambitious policies that achieved a significant reduction in pollution, paving the way for similar policies introduced recently at the national level.

Over the same period, emissions of key precursors of $PM_{2.5}$ and ozone were reduced. The largest reductions were achieved for SO_2, NO_X, and primary $PM_{2.5}$ driven by the implementation of policies and measures aimed at controlling emissions from power plants, large industrial facilities, road transport, and household cooking and heating. However, emissions of ammonia and non-methane volatile organic compounds (NMVOCs) have stagnated or even increased in most countries.

Air quality monitoring and remote sensing capacity has been extended, allowing a better understanding of air pollution and its trends, as well as supporting policy enforcement. Most of the countries in the region have expanded air quality monitoring and remote sensing networks, enhancing their capacities to observe and track key air pollutants. The research of comprehensive emission inventories and atmospheric models has supported effective policymaking and enhanced regional collaboration.

Such progress would not have been possible without well-designed legislation and supporting governance and institutional arrangements. All countries have set ambient air quality standards, aiming to align them with WHO guidelines, and source-oriented emission regulations that have been progressively updated, considering economic conditions across the region. The focus of many of these efforts has been on controlling key emerging pollutants such as $PM_{2.5}$ and ozone. Regulations have covered both stationary and mobile sources, addressed emissions of SO_2, NO_X, and PM, and been supported by strong legal enforcement frameworks.

China, Japan, and the Republic of Korea established cooperation channels and strengthened policy and scientific research collaboration. Several bilateral and trilateral initiatives, focusing on policy collaboration in specific areas and joint research, monitoring, and capacity building, have been established. These initiatives have facilitated knowledge sharing and established communication channels that support efforts to address common environmental concerns across North-East Asia.

The clean energy transition – marked by increased shares of renewables in energy supplies, improved access to clean fuels, and the growth of new energy vehicles (NEVs) – has contributed to air quality improvement in recent years. Renewable energy has increased rapidly, now representing a significant percentage of China's energy supply and other countries in the region making commitments to harness renewables. An important part of the energy transition is investment in the development and availability (and affordability) of NEVs. Advancements in renewable energy and NEVs demonstrate a commitment to moving the clean energy transition forward.

Policies and plans have been developed and implemented across the region to address the Sustainable Development Goals (SDGs). Progress has been made towards the attainment of SDGs and this has been driven by a combination of many of the previously mentioned developments (e.g., establishing policy frameworks, environmental regulation, energy transformation).

Emerging challenges

The region faces increasing ozone concentrations in recent years. While $PM_{2.5}$ concentrations have been falling, ozone levels remain high, especially in the cities, resulting in greater health impacts and economic burdens, including crop loss due to reduced yields. Increasing ozone levels are driven by changes in atmospheric composition, driven by policies that reduced ozone precursors like NO_X, VOC, while failing to satisfactorily address emissions of NMVOCs. Additionally, continued growth of global concentrations of methane (CH_4) as well as changing meteorological and climate conditions (frequent high temperature) have, and will in the future, affect ozone formation substantially.

Despite air quality improvements, urban air pollution remains a challenge. A significant proportion of urban residents continue to be exposed to pollution levels that exceed national air quality standards and are well above the WHO guidelines for $PM_{2.5}$ and ozone. A significant proportion of urban pollution originates from sources outside of city boundaries, necessitating collaboration with neighboring provinces or prefectures and multiple stakeholders on domestic pollution sources.

Emissions from agriculture are a growing concern. Agricultural emissions of ammonia have not declined and their contributions to the formation of secondary $PM_{2.5}$ have been increasing. Additionally, ammonia also plays an important role in the eutrophication of ecosystems and reduced biodiversity, both of which could be addressed by improved nitrogen management. To date, policies addressing ammonia emissions are either lacking or very limited.

Efficient implementation of current policies and development of further action are hampered by several barriers. There are several economic, technological, institutional, and social barriers to the effective implementation of air pollution policies. These include financing shortfalls, fragmented institutions, and struggles scaling up innovative solutions. There is some, albeit limited, success overcoming these barriers.

Climate change is expected to adversely impact air quality, potentially leading to higher levels of ground-level ozone and $PM_{2.5}$. Climate change already causes increased frequency and intensity of heatwaves, wildfires, and leads to more favourable conditions for sustained high pollution episodes, which adversely impact air quality. There is an urgent need to better understand and develop policies to deal with these emerging threats; strengthening science collaboration within the region can help in this regard and should be prioritized.

Major challenges remain with respect to progress on SDG13 (on Climate Action). Only moderate progress has been made thus far to achieve SDG13. Other key relevant SDGs, addressing air pollution health impacts (SDG3) and sustainable cities (SDG11), have shown some improvement and might be hampered in the future by challenges originating from increasing ozone, urban/rural interactions, links with climate change, and, last but not least, institutional and other challenges.

Looking ahead

Support for technical collaboration and assistance needs to be continued and strengthened. Collaborative efforts aimed at enhancing technology transfer and expertise sharing across local, national, and regional levels can lead to more effective and efficient policies. Robust monitoring, particularly by maintaining existing capacity and extending $PM_{2.5}$ monitoring networks beyond urban centers, can be crucial in this regard.

Addressing urban pollution should be a regional priority. Promoting regional and stakeholder cooperation (across jurisdictions and stakeholders associated with key pollution sources) to address both local and regional (provinces/prefectures) sources of pollution needs to be a focal point for collaboration.

Integrated policies that address air quality at the same time as climate change and other development priorities should also be a focal point for collaboration. Integrating air quality, climate and policies can yield co-benefits, enhancing the near-term cost effectiveness and long-term sustainability of responses. International collaboration on integrated approaches can help to achieve air quality and climate targets while reducing health, ecological, social, and economic burdens across North-East Asia.

Existing collaborative programmes should be strengthened to support knowledge exchange and specific projects. Existing collaborative platforms should be strengthened to foster knowledge exchange, build capacity, overcome implementation barriers, and tackle emerging issues. Joint projects aimed at enhancing scientific research on emerging issues such as the interconnected nature of air quality and climate change should receive particular attention.

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CHAPTER 1
BACKGROUND AND SCOPE

Air pollution is a critical environmental issue that significantly impacts health, the environment, and the economies of nations worldwide. In North-East Asia, the challenges posed by air pollution are particularly acute due to rapid industrialization, urbanization, and the high population density of the region. Effective collaboration at all levels is essential to effectively address and mitigate these adverse effects.

The North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC), was established with the vision of fostering regional cooperation to address environmental challenges shared by its member countries: China, the Democratic People's Republic of Korea, Japan, Mongolia, the Republic of Korea, and the Russian Federation. A key initiative of NEASPEC is the North-East Asia Clean Air Partnership (NEACAP), launched in 2018 as a flagship programme to spearhead efforts in tackling air pollution.

NEACAP aims to provide a collaborative platform for member countries to share knowledge, exchange best practices, and implement joint actions to combat air pollution. By facilitating regional cooperation, NEACAP endeavors to reduce air pollutant emissions, improve air quality, and improve public health across North-East Asia.

Over the past decade, member countries in North-East Asia have made significant strides in addressing air pollution through a variety of measures. These include the adoption of stricter emission standards, the development of green technologies, the promotion of sustainable urban planning, and the enhancement of air quality monitoring systems. These efforts have yielded tangible outcomes, and the countries are ready to share their achievements through partnership.

As air pollution continues to pose significant challenges, NEACAP remains committed to advancing its mission through strengthened cooperation on information exchange and collaboration on scientific, technical, and policy issues. The partnership seeks to build on past achievements by fostering the integration of environmental policies and promoting sustainable development practices. Continuous exchange of knowledge and technology among member countries is crucial for sustaining progress and achieving long-term air quality goals.

1.1 Scope

This report aims to highlight the key achievements of four countries – China, Japan, Mongolia, and the Republic of Korea (ROK) – in their efforts to tackle air pollution, showcasing the progress made and the lessons learned over the past decade. By documenting these successes, the report supports the process of strengthening policy exchange and collaboration between countries of North-East Asia. Further, it reviews policy progress as well as existing and emerging challenges in each country and eventually, underscores the value of regional cooperation and provides a roadmap for future initiatives to ensure cleaner air and a healthier environment for the people of North-East Asia.

The report also considers the important national and regional conditions, including both common and different elements, and:

- Focuses on NEACAP priority pollutants, including PM_{10}, $PM_{2.5}$, and ozone & their key precursors,
- Provides a broad overview of air pollution, air quality trends, and air quality policies and legislation,
- Reviews development and progress in addressing air quality,
- Reviews the institutional capacity and effectiveness in the implementation of air pollution policies and legislation,
- Identifies key successes and emerging challenges, and;
- Discusses opportunities and scope for further exchange and collaboration within the region.

Based on inputs received from national experts nominated by member States, the report:

- Analyzes the official reporting on the status and progress in implementation of air pollution/quality by reviewing key facts and figures based on the environmental assessment studies/reports,
- Analyzes the national environmental policy (and science-policy) settings,
- Conducts an overview of the available science literature focusing on North-East Asia, rather than a review, since the goal is to identify key high-level science findings supporting the assessment of and future scope for, air quality policy, and;
- Analyzes jointly how a regional collaboration framework could be strengthened by involving science in support of the policy process and discusses the way forward.

CHAPTER 2

AIR POLLUTION AND AIR QUALITY TRENDS

Key findings

- Over the past decade, North-East Asia has seen significant improvements in air quality, marked by a decrease in concentrations of key pollutants such as $PM_{2.5}$ and NO_2. These improvements reflect the success of ambitious policies and regulatory measures aimed at reducing emissions from industrial, transportation, and residential sectors.
- Despite success in curbing primary aerosol emissions like SO_2, $PM_{2.5}$, and NO_x, and consequent improvement of air quality, large share of urban populations face ambient $PM_{2.5}$ levels above WHO guidelines and even national standards.
- Ozone concentrations have not declined and even increased in the last years, especially in the cities. This trend is driven by increasing emissions of NMVOC as well as CH_4, which is not adequately addressed by current policies.
- Emissions from agriculture, particularly ammonia, show no decline or are on the rise, yet there is a lack of, or only limited, targeted policies addressing this sector's contributions to air pollution and climate change.
- Most of the countries in the region have expanded air quality monitoring and remote sensing networks, enhancing their capacities to observe and track all key air pollutants.
- The research of comprehensive emission inventories and atmospheric models has supported effective policymaking and enhanced regional collaboration.
- Uncertainties remain in estimates of emissions for several sources, especially for agriculture as well as transport, where emission factors, typically, poorly represent real-life driving conditions.

Recommendations

- Given the rising ozone levels, strengthen polices addressing NMVOCs and methane.
- Further develop dedicated policies addressing emissions from agriculture, going beyond the ban of open residue burning. Efforts should focus on stimulating improvements in nitrogen use efficiency, increasing composting and biogas capacity, and imposing emission regulation for large livestock farms.
- Maintain and enhance monitoring networks, especially for rural and less-developed areas, to provide a more comprehensive understanding of regional air quality dynamics and support effective policy interventions.
- Efficient enforcement of current policies is crucial to deliver expected emission reduction and improvements of air quality.

Over the past decade, North-East Asia has exhibited a decreasing trend of air pollution and steady improvement of air quality. Concentrations of fine particulate matter, a major concern in the last decade, have been consistently declining across the region (Figure 1). The degree of improvement varied, with largest changes observed for China and Mongolia where average concentrations of $PM_{2.5}$ decreased by over 60% in the last decade. While this shows impact of ambitious and successfully implemented policies, there is still much room for improvement in the current ambient $PM_{2.5}$ levels (see further discussion of regional distributions in Section 2.1).

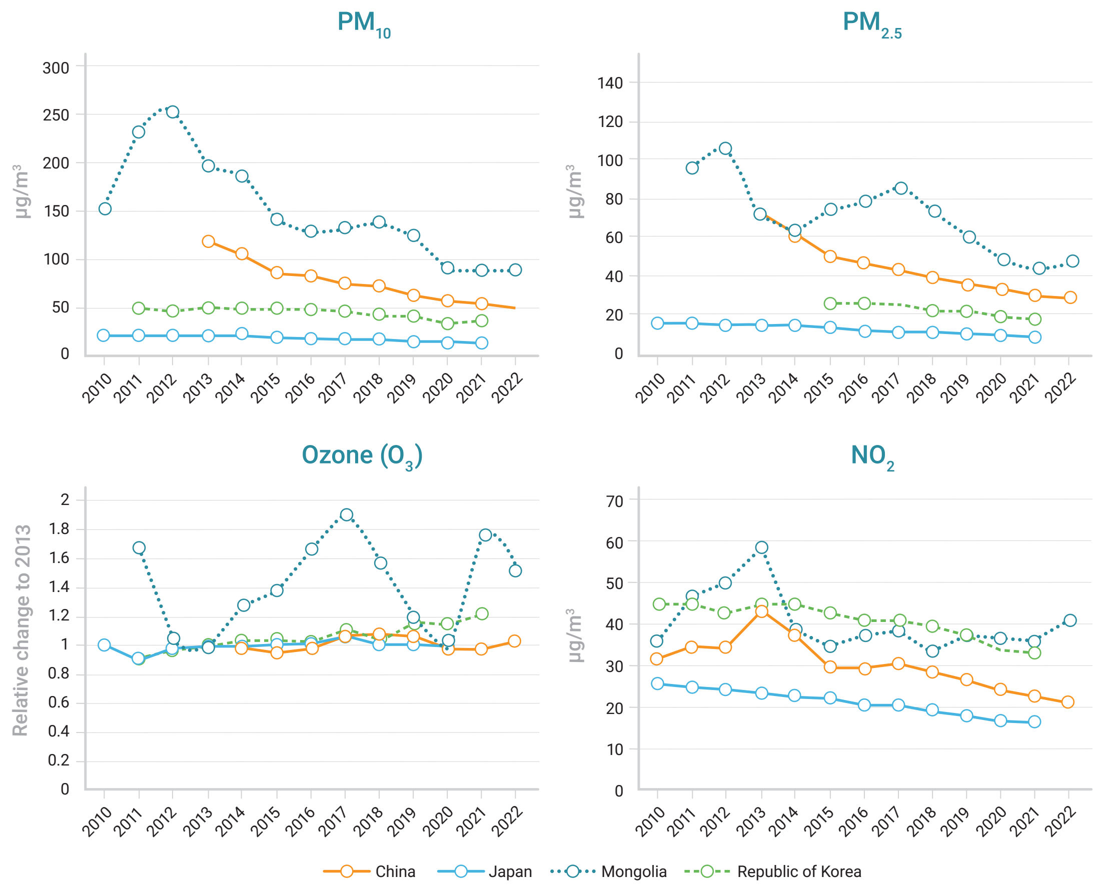
Owing to the earlier onset of environmental regulation and structure of industrial production, as well as role of natural emissions (e.g., desert dust), ambient $PM_{2.5}$ levels in the Republic of Korea (hereinafter ROK) and Japan have been much lower in the past but they have been reduced further in the last decade by about 30% in ROK and nearly 45% in Japan, ensuring consistent compliance with national air quality standards (Table 5). PM_{10} concentrations declined in the region at nearly the same rate as $PM_{2.5}$, while the ratio of its concentrations to $PM_{2.5}$ varies across the region owing to a contribution of natural sources and role of fugitive sources; note the scale in Figure 1 with a factor two on the PM_{10} axis compared to $PM_{2.5}$.

A consistent downward trend has been observed in all countries for nitrogen oxides (NO_2) concentrations (Figure 1), and since 2018 the national standard of 40 μg/m^3 has been met, with the exception of Japan, yet to achieve the WHO air quality guideline of 10 μg/m^3 (WHO, 2021). NO_2 is one of the precursors of ground level ozone (others include non-methane volatile organic compounds – NMVOC, methane – CH_4, and carbon monoxide – CO) and while its concentrations have been declining, as well as those of CO (not shown), the continued increase of NMVOC emissions in most countries (Figure 2) and global increase of CH_4 concentrations (e.g., Tollefson, 2022) led to lack of similar reductions in ozone concentrations.

In fact, an increase has been observed over the last decade (Figure 1); note that for ozone, change in concentrations related to 2013 (first year for which all countries reported ozone) is shown, rather than the absolute values (see Table 13 in the Annex) since different indicators are used and also the averaging period might vary. This increase is mostly visible for cities (Chatani et al., 2023; Ito et al., 2021; Lee et al., 2021; Maji et al., 2019) where strong titration effect and VOC-limited regimes led to increased production of O_3, an effect measured during the COVID-19 lockdown (Wang et al., 2022). Figure 3 illustrates development in the capital cities of the four countries; note that ozone concentrations shown in Figure 3 have been reported using different methods and indicators, including either maximum daily one-hour or eight-hour means, and the averaging periods may vary too – Table 13 (Annex) provides more detailed information about methods for measuring and reporting used by different reporting agencies.

Effective policies to reduce emissions of sulfur dioxide (SO_2), primarily from power plants and industry, brought continued decline of SO_2 concentrations in most countries in the region, and resulted in consistent compliance with the national standards (see sources of data shown in Figure 2). However, this is not yet the case for Mongolia, where SO_2 concentrations in Ulaanbaatar kept growing (http://agaar.mn/index?lang=en) and are still above the national 24-hour average standard of 50 μg/m^3 and WHO guideline value of 40 μg/m^3. The SO_2 trend for Ulaanbaatar is also reflected in the evolution of SO_2 emissions, which have increased in recent years (Figure 2).

Figure 1: **Annual average concentrations and trends of key air pollutants (PM_{10}, $PM_{2.5}$, ozone, and NO_2) for the period 2010-2022 in China, Japan, Mongolia, and Republic of Korea.**



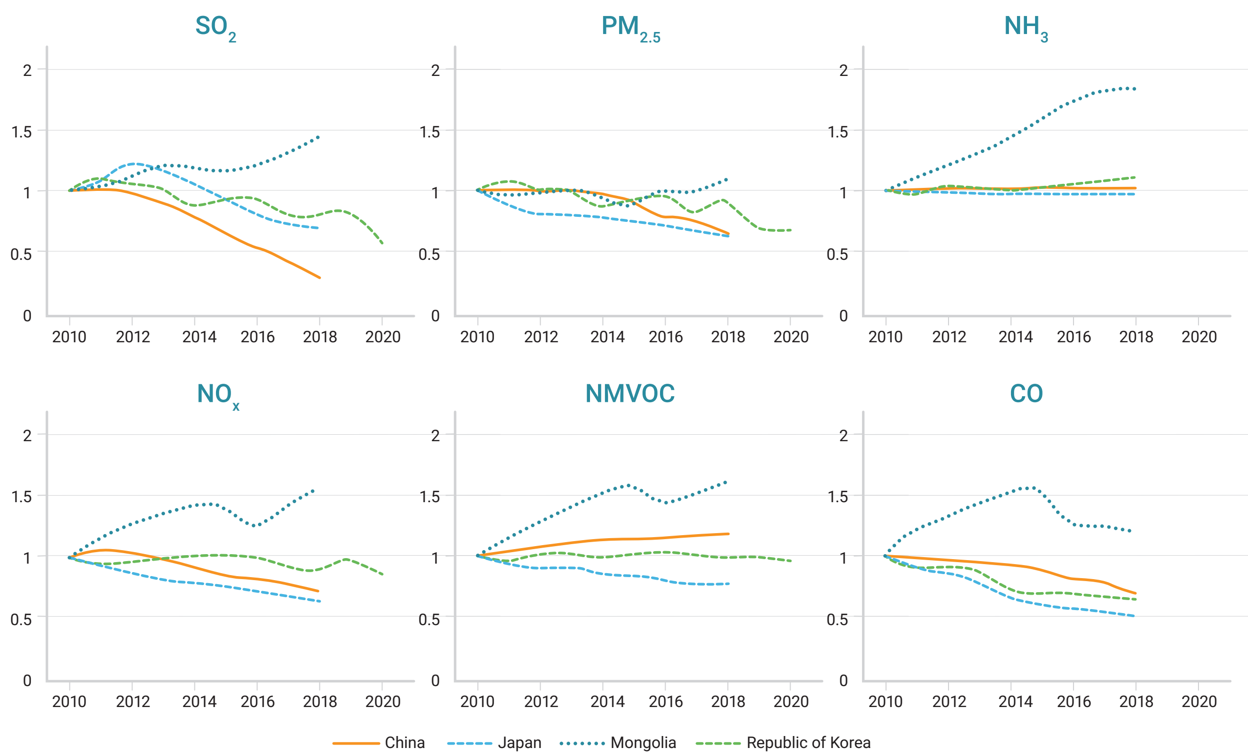
Sources: China: Ministry of Ecology and Environment[1], Japan: National Institute for Environmental Studies (NIES))[2], [3], Mongolia: Meteorological and Environmental Analysis Department of Mongolia[4], and Republic of Korea: Air Korea[5]

Note: For Mongolia (*), the concentrations are for the capital city of Ulaanbaatar and ozone (O_3) is reported as a relative change from 2013 (first year for which all countries report ozone) to highlight the trend since the reported values (maximum daily one-hour or eight-hour means) are not directly comparable. For China, the number of monitoring stations and the range of cities covered, changed significantly in both 2013 and 2015. Additionally, the meteorological conditions under which the published pollutant concentration monitoring values were estimated were adjusted in 2019. Ozone indicators vary across countries, e.g., Japan reports O_x and China 90th percentile of mean ozone concentrations.

The trends in air quality are consistent with the available information shown in the reported as well as estimated, scientific literature and national emissions from anthropogenic sources (Figure 2). Emissions of key $PM_{2.5}$ precursors ($PM_{2.5}$, NO_X, SO_2) have shown a decline since 2010, while emissions of ozone precursors (NO_X, NMVOC, CO) exhibit diverse trends across the regions with, typically, declining NO_X and CO and stagnating or increasing emissions of NMVOC. Mongolia, however, shows different trends from the other countries, since all precursor emissions have continued to increase. Another source of emissions for which no significant trend has been observed, is the open burning of agricultural residues, although all countries have introduced legislation prohibiting such practices (Table 18; in the Annex).

1 *Report on the State of the Ecology and Environment in China*. Available at: https://english.mee.gov.cn/Resources/Reports/soe/index.shtml
2 https://tenbou.nies.go.jp/download/
3 https://tenbou.nies.go.jp/download/
4 http://agaar.mn/index?lang=en
5 https://www.airkorea.or.kr/web/detailViewDown

Figure 2: Trends in anthropogenic emissions of key precursors of ambient $PM_{2.5}$ ($PM_{2.5}$, SO_2, NH_3, NO_x) and ozone (NMVOC, NO_x, CO).



Source: Crippa et al. (2023).

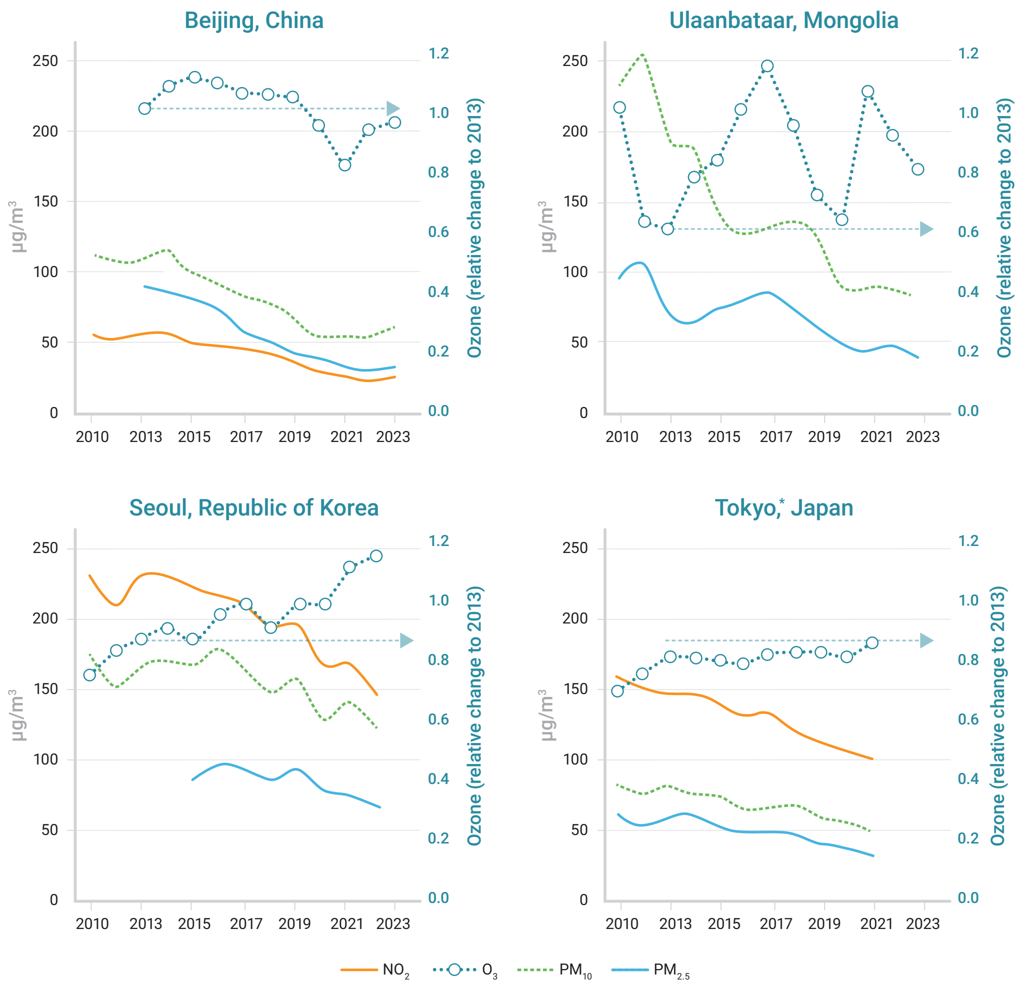
The role of ammonia in the formation of $PM_{2.5}$ has been increasing (Bai et al., 2019; Wang et al., 2013; Xu et al., 2022) and so far, no, or only limited, efforts were made to reduce these emissions in North-East Asia, and comparison of trends reveals that emissions remain constant or slightly increased (Kurokawa and Ohara, 2020; Liu et al., 2019b; Sase et al., 2022; Zhang et al., 2010). The trends shown in Figure 2 draw on the harmonized estimates developed by Crippa et al. (2023), which is based on data from the national inventories, including MEIC for China (MEIC, 2022), CAPSS for Korea (Kim et al., 2023), $PM_{2.5}$EI[6], J-STREAM (Shibata and Morikawa, 2021) (Chatani et al, 2023) for Japan, and EDGAR or REAS (Kurokawa and Ohara, 2020). These trends are consistent with other available scientific emission inventories developed for the region (Kurokawa and Ohara, 2020; Li et al., 2017a, 2017b; Saikawa et al., 2017; Zheng et al., 2018) as well as the national estimates shown in the following section. Comparing various inventories, including official national figures, where available, shows that the source coverage (sectors included), extent of time series, as well as the methods used varies (although this is not always well documented, making a direct comparison challenging.

The concentrations and trends shown in Figure 1 are not necessarily attained in all areas across the countries, especially in many larger cities. While more details are presented in the next sections, where particular aspects of regional development in selected countries are discussed, here trends in concentrations of key pollutants are shown for the capital cities of the four countries (Figure 3).

6 https://www.env.go.jp/air/osen/pm/info.html

The capitals show higher levels of air pollution than the national average and this is common for most larger cities in the region. Rural areas experience typically lower overall pollution levels. The trends are generally similar to the national air quality trends, except for ozone where most capital cities measure steady increase, and this is also the case for several other cities in the region (Lee et al., 2021; Maji et al., 2019; Wang et al., 2022). In fact, only Beijing reported a slight decline in ozone (increasing in the last years though), contrary to the national overall trend. With the exception of NO_2 (and SO_2, not shown) there is much room for improvement in meeting national standards for other pollutants over the past 10 years.

Figure 3: Average annual concentrations of key air pollutants in capital cities.



Sources: China: Beijing Municipal Ecology and Environment Bureau[7], Mongolia: Meteorological and Environmental Analysis Department of Mongolia[8], Republic of Korea: Air Korea[9], Japan: National Institute for Environmental Studies (NIES).[10]

Note: Shown ozone concentrations are not directly comparable across cities since they are reported as either 90th percentile of maximum daily eight-hour mean (Beijing) or eight-hour mean (Ulaanbaatar, Seoul, Tokyo); additionally, for Tokyo (*) O_x is reported as ozone and SPM is shown as PM_{10}. For Beijing, the number of monitoring stations taken into account changed significantly in both 2013 and 2015; additionally, the meteorological conditions under which the published pollutant concentration monitoring values were estimated were adjusted in 2019.

7 https://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/sthjlyzwg/1718880/1718881/1718882/326119689/index.html
8 http://agaar.mn/index?lang=en
9 https://www.airkorea.or.kr/web/detailViewDown
10 https://tenbou.nies.go.jp/download/

The development of air quality modelling and monitoring capacity has been essential in understanding the implications of actions taken to reduce emissions and validating the progress in improvement of air quality. This is important for policy-making and public perception, as it provides evidence and further supports ongoing efforts, including those at the international level where joint efforts to address data gaps and consider various modelling approaches will help to better assess, understand and reduce uncertainties in the modeling results. As elaborated later, all countries in the region have enhanced their monitoring capacity, expanding from a handful of stations to several thousand stations in some countries, primarily in urban areas but also including several background stations. More details are provided in the following sections.

2.1 National and Regional Review

2.1.1 Emissions and air quality trends

This section provides further details about the air quality trends, also at the subnational level where relevant and available, and discussion of key factors affecting the observed changes. Further, brief account of key policies as well as their impact on emissions of $PM_{2.5}$ and ozone precursor species are discussed. The measurement methods, reporting standards, averaging times, and even choice of stations to derive various air quality indicators, differ between the countries, therefore, a direct comparison of pollutants concentrations must be done with care, while the trends are likely more comparable and robust.

2.1.1.1 China

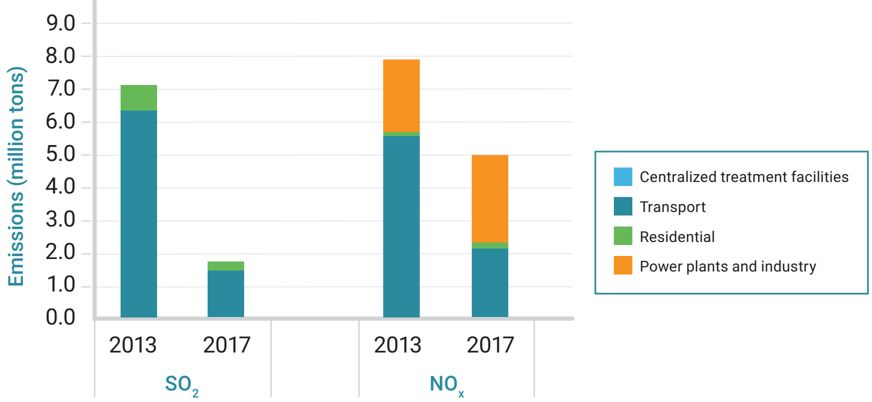
The air quality in China has generally improved throughout the past decade according to the Ministry of Ecology and Environment of China. The ambient concentration levels of PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO have been declining in the last decade; compared to the 2015 levels, these dropped by about 38, 40, 64, 23 and 48% by 2021, respectively. On the other hand, ambient levels of O_3 have not been showing a significant trend in the last decade, while in the last few years slightly increased (see Figure 1 for selected pollutants). According to the *2020 Report on the State of the Ecology and Environment in China*, 202 out of the 337 cities included in this report, met the national air quality standards in 2020 (MEE, 2021a). This is a 13.3% increase from that of 2019.

BOX 1

COORDINATED AIR POLLUTION CONTROL IN BEIJING AND ITS SURROUNDING AREAS, CHINA

Beijing-Tianjin-Hebei (Jing-Jin-Ji cluster) is the biggest urban agglomeration region in North China with a population of over 110 million people, making them collectively, one of the largest metropolitan areas in the world. In recent years, Beijing has actively coordinated air pollution control efforts with neighboring areas through collaborative planning, unified standards, joint emergency response, and information sharing. Accordingly, major air pollutant emissions in Beijing and its surrounding areas—namely Tianjin, Hebei, Henan, Shandong, Shanxi, and Inner Mongolia—experienced significant reductions between 2013 and 2017. Specifically, SO_2 and NO_x emissions dropped by 75%, 42%.

Figure 4: Changes in major air pollutant emissions in the areas surrounding Beijing (including Tianjin, Hebei, Henan, Shandong, Shanxi and Inner Mongolia), 2013 and 2017 (unit: million tonnes).



Source: Statistical Yearbook of the Ministry of Ecology and Environment of China.

Policy measures for effective air quality management in Beijing a its surrounding Areas:

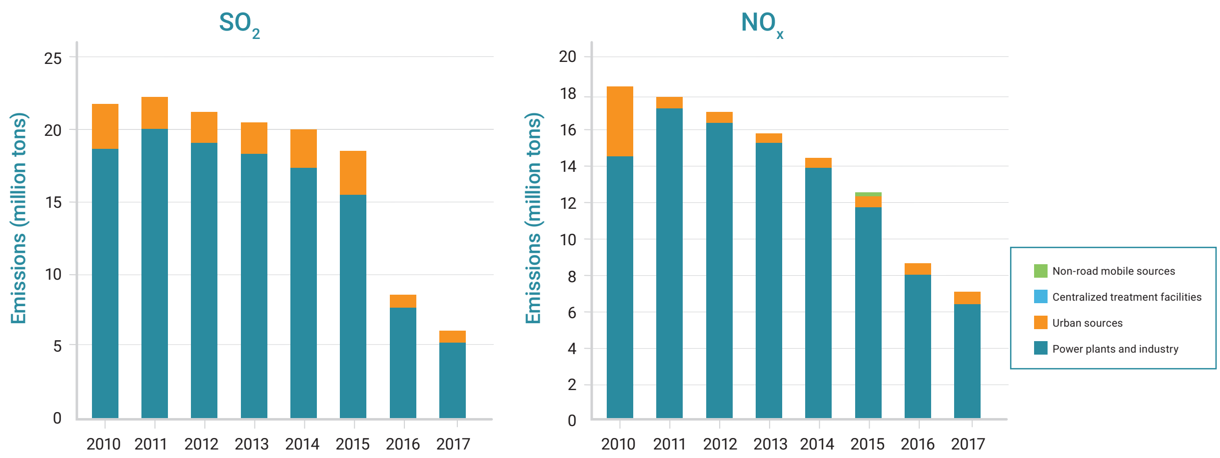
1. **Legal framework**: In 2013, the *Beijing Clean Air Action Plan 2013–2017* was launched in accordance with the National Action Plan for Air Pollution Prevention and Control, and annual work plans were developed for the following 5 years under this framework. To enhance regional coordination efforts, additional plans were introduced, including the Beijing Plan for Implementing the Strengthened Measures for Air Pollution Prevention and Control in the BTH region 2016–2017, and the Beijing Detailed Plan for Implementing the Action Plan for Comprehensive Prevention and Control of Autumn and Winter Air Pollution in BTH and Surrounding Areas 2017–2018.
2. **Coordination agency**: With the support of China's State Council, the Coordination Group for Air Pollution Prevention and Control in BTH and Surrounding Areas was established in 2013. In 2017, based on the pollutants transport patterns, Ministry of Environmental Protection (MEP) designated Beijing, Tianjin, and another 26 cities in Hebei, Shanxi, Shandong, and Henan provinces (collectively referred to as '**2+26**' cities) as the key cities in the region, prioritizing them for air quality control efforts.
3. **Implementation of key policies and mitigation measures**: The Coordination Group and relevant ministries have successively rolled out multiple policies and mitigation measures to achieve air quality goals.
   - **Twinning cities**: Beijing partnered with neighboring Baoding and Langfang city of Hebei province, providing financial and technical assistance to phase out small coal-fired boilers and manage large coal-fired boilers, thus setting an example for regional cooperation on air pollution control.
   - **Unified heavy pollution episode response**: A joint forecasting and early earning mechanism was also established. In 2016, Beijing, Tianjin, and Hebei unified their alert thresholds for severe air pollution emergencies. By 2017, these standards were extended to include the '2+26' cities, and the procedures for issuing, adjusting and lifting alerts were standardized, paving the way for a unified regional response to heavy air pollution in BTH and Surrounding Areas.
   - **Joint mobile source control**: A specialized mechanism was also created to enhance regional cooperation in tackling vehicle pollution. In 2016, Beijing, Tianjin, and Hebei put into effect the China V emission standards for motor vehicles and fuel quality. Subsequently, in 2017, the '2+26' cities began supplying fuels that comply with China VI standards.

The observed air quality improvement is a result of introduced policies (see Chapter 3) that brought in a reduction of precursor emissions (Figure 5). According to the MEIC emission inventory developed by Tsinghua University, China's overall anthropogenic emissions showed a substantial downward trend from 2010 to 2020. According to data from MEE, from 2010 to 2020, SO_2 emissions reduced by 85%, NO_X emissions reduced by 45%. The primary driving force behind these emissions reductions was the objective of continuously mitigating $PM_{2.5}$ pollution in China.

Overall, these efforts reflect China's commitment to combatting air pollution and improving air quality, and the substantial reductions in emissions demonstrate the positive impact of the implemented policies (Li et al., 2017a; McDuffie et al., 2020; Tong et al., 2018). These policies addressed primarily the implementation of stricter industrial emission standards in key sectors such as the power, iron and steel industries. Notably, these sectors have successfully transitioned into an ultra-low emission phase. Currently, China boasts the world's largest clean coal power supply system and clean steel production base. As reported by MEE, as of the end of 2022, approximately 1,060 million kilowatts (or 1.06 TW) of coal-fired units had undergone ultra-low emission transformation, accounting for 94.6% of the total installed capacity of coal-fired plants. Similarly, heavy industries were transformed and while crude steel production continued to grow, a significant share of capacity applied ultra-low emission standards and has been equipped with flue gas desulphurization and denitrification. Similarly, cement production has undergone structural changes eliminating outdated and excess capacity. These changes resulted in decoupling heavy industry production from emissions (Clean Air Asia, 2022a, 2022b; Kurokawa and Ohara, 2020; Zheng et al., 2018) and jointly, power plant sector reductions continue to contribute to an estimated decline in SO_2, NO_X, and $PM_{2.5}$ emissions (Figure 5).

Transport sector emissions appear constant in the period presented in Figure 5, but owing to the strong growth in transport activity, the regulation allowed to offset the potential increase. The impact of the additional regulatory action is illustrated also by presenting emission trajectory when either activity data or further development of environmental policy is stopped (frozen). One also clearly sees that the NMVOC emissions continue to increase and legislation is not able to offset the activity growth, while for ammonia (NH_3) some change is visible and also some legislation has been introduced in the last decade. For example, in terms of the policies addressing ammonia emissions, the Chinese government has made significant efforts in controlling atmospheric ammonia emission. The revised Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution in November 2018 proposed the implementation of synergistic control of ammonia, aiming to reduce emissions from agricultural sources. In 2023, the *Action Plan for Continuous Improvement of Air Quality* was released, proposing the steady advancement of atmospheric ammonia pollution prevention and control. The First Biennial Transparency Report on Climate Change of the People's Republic of China, issued in December 2024, detailed the nitrogen loss from ammonia volatilization in agricultural land. In 2024, China introduced pilot projects for ammonia emission control in livestock and poultry farming in Beijing-Tianjin-Hebei region and its surrounding areas, specifically targeting large-scale intensive farms for ammonia emission control management.

Figure 5: Sectoral emissions of SO_2 and NO_X.



Source: Statistical Yearbook of the Ministry of Ecology and Environment, China.

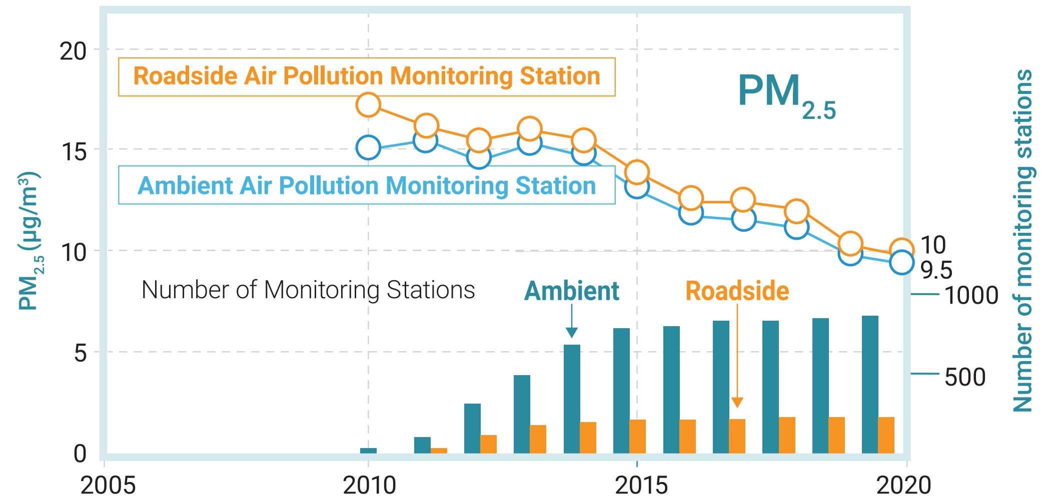
The use of solid fuels, primarily coal and wood, for cooking and heating has been an important source of air pollution. During the '13th Five-Year Plan' period, a key focus of the energy revolution in rural areas was the promotion of clean heating in northern regions. According to MEE, by the end of 2022, approximately 37 million rural households had successfully transitioned from using scattered coal to cleaner heating alternatives. This transition has had a significant positive impact on the quality of life for rural residents, including indoor air quality, reduced costs, and contributed to a reduction of emissions of many air pollutants including SO_2, $PM_{2.5}$, and black carbon. The impact of this policy has been also measured, showing how black carbon emission declined and what role residential sector transformation played in this (Kanaya et al., 2020, 2021).

2.1.1.2 Japan

Air quality in Japan has been steadily improving over time and trends remained consistent over the last decade. The mean annual concentrations of key air pollutants (SPM [shown as PM_{10} in Figure 1], $PM_{2.5}$, SO_2, NO_2, and CO) have been declining in the period considered in this analysis, with only ozone continuing to show marginal growth (see Figure 1, Figure 6, and Figure 7 for selected species and (MoEJ, 2023b; Morikawa et al., 2023). Compared to 2015 values, average annual concentrations of SPM, $PM_{2.5}$, SO2, NO_2, and CO in 2021 decreased by 54%, 58%, 100%, 36%, and 100%, respectively.

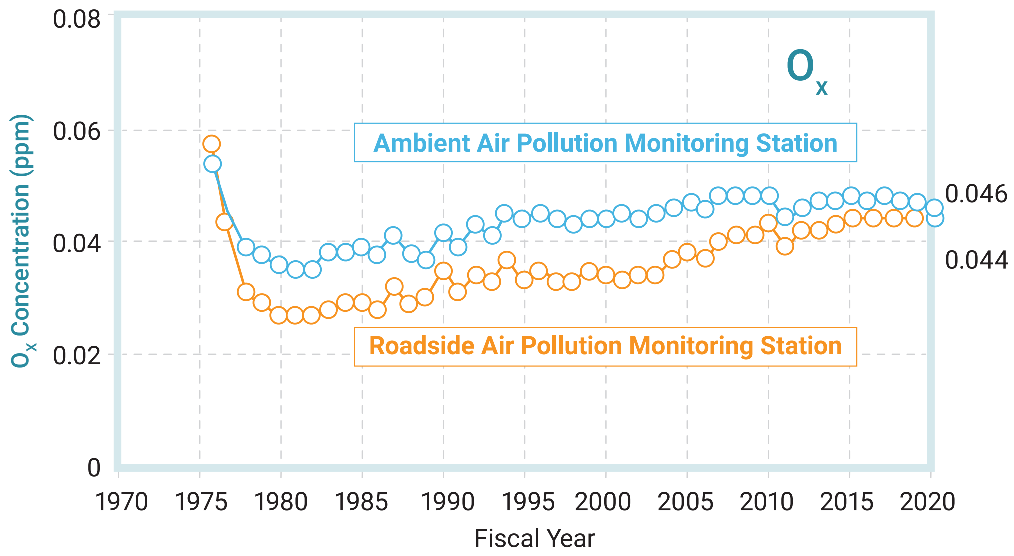
Japan has been increasing efforts to monitor key pollutants like $PM_{2.5}$ and ozone by continuously expanding its network of monitoring stations across roadside, urban, and rural areas (Figure 6, Figure 7). This enhanced a further understanding of pollution levels and human exposure, which supports the validation of air quality models, and demonstrates the impact of policies that have led to reductions in most air pollutant concentrations. For ozone (Figure 7), Japan reports O_X (photochemical oxidants), which represents mostly ozone. Contrary to all other air pollutants, where the annual average concentrations are based on one-hour, average concentrations, for O_X, the national average was calculated using the effective measurement station data of at least 6,000 hours per year at each station. In the case of oxidants, the period from 5:00 a.m. to 8:00 p.m. was defined as daytime, and the national average was calculated using the effective measurement station data when the number of daytime measurement days was 250 or more.

Figure 6: Monitoring of $PM_{2.5}$ in ambient air.



Source: Morikawa et al (2023)

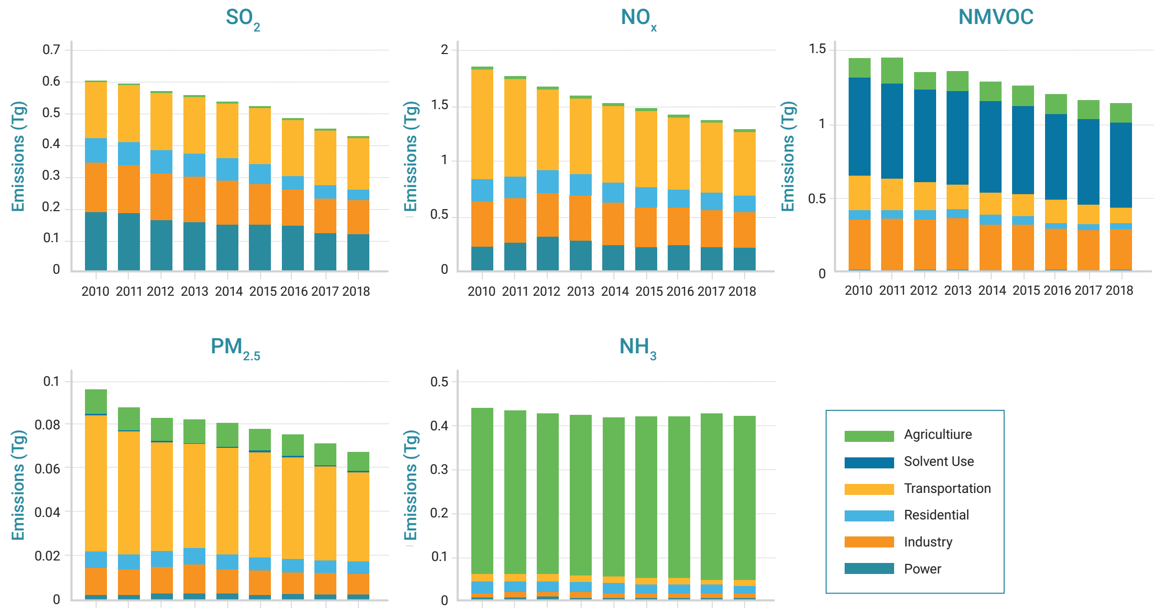
Figure 7: Average concentration of O_x.



Source: Morikawa et al, 2023; and https://tenbou.nies.go.jp/download)

Trends in emissions of air pollutants since 2000 are presented and discussed in Chatani *et al.* (2023). This study developed a long-term emission inventory, which explicitly represent changes in precursor emissions caused by emission controls and variations in activities for past years from 2000 to 2019 in Japan. This inventory is intended for use in an atmospheric model to evaluate the effectiveness of emission controls on ambient pollutant concentrations, and can be used in conjunction with the recent study evaluating emissions across the Asian continent (Kurokawa and Ohara, 2020) which has been performed under the Model Inter-Comparison Study for Asia (MICS-Asia). For the global inventory (Crippa et al., 2023), for use in the HTAP experiments, results of the national inventory of Japan were used and are shown in Figure 8.

Figure 8: Sectoral emissions of key precursors of $PM_{2.5}$ and ozone between 2010 and 2018.



Source: Crippa et al., (2023).

According to recent findings, emissions of all key species, except NH_3, declined during the 2000-2019 period as a result of strengthened emission control measures (Chatani *et al.* (2023). The anthropogenic emissions of NO_X, NMVOC, CO, SO_2, NH_3, and $PM_{2.5}$ in 2019 were 56%, 50%, 56%, 74%, 20%, and 59% lower than those in 2000, respectively. Reductions in the transport sector were among the most important and demonstrate the impact of effective regulation. In addition, the voluntary actions suppressed emissions from fugitive NMVOC sources including those from fuel evaporation and solvent use. These results are consistent with results shown in Figure 8. A challenge of reducing emissions of NH_3 remains; primary sources of NH_3 (livestock and fertilizer use) are difficult to control and a long-term strategy would require enabling transformational changes, i.e., reducing meat protein consumption for example. Beside targeted policies addressing key pollutant sources, the change in energy supply structure following the Great East Japan Earthquake, and the economic crisis around 2008 affected changes in emission.

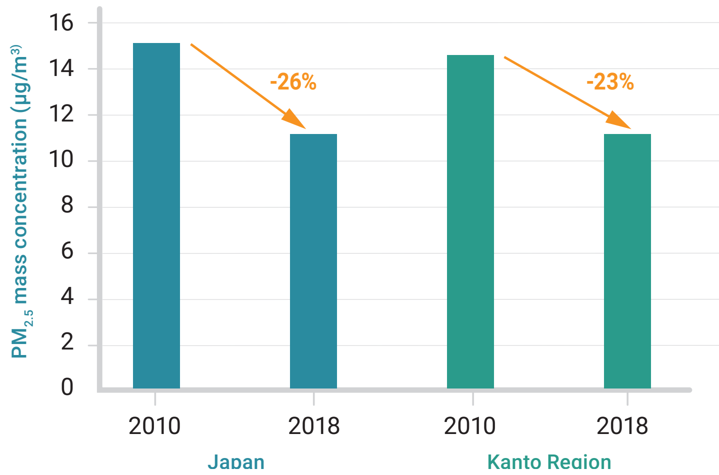
Kanto region, and especially Tokyo Metropolitan Government (TMG), have been developing ambitious policies addressing emission from transport and industry (Box 2). The impact of these policies also stimulated application of similar action at the national level.

BOX 2

COORDINATED AIR POLLUTION CONTROL IN THE KANTO REGION

The Kanto region, home to over 43 million people, includes the Tokyo Metropolis and the prefectures of Chiba, Gunma, Ibaraki, Kanagawa, Saitama, and Tochigi, making it the most densely populated region of Japan. Although air quality in the region has significantly improved during the past decades, $PM_{2.5}$ and photochemical oxidants remain key challenges. The Tokyo Metropolitan Government has been especially proactive in reducing $PM_{2.5}$ levels, taking institutional steps even before the national government. From 2010 to 2018, $PM_{2.5}$ concentrations in the Kanto region decreased by 23%, closely mirroring the national reduction of 26%.

Figure 9: $PM_{2.5}$ concentrations (microgram per cubic metre) in Japan and the Kanto region, 2010 and 2018



Source: Ito, A. et al (2021)

Mechanism for effective air quality management in the Kanto Region:

1. **Legal framework**: For the past decade, the Tokyo metropolitan government (TMG) has been promoting innovative environmental measures that are often ahead of efforts by the national government. In 1969, TMG first introduced the Tokyo Pollution Control Ordinance, which set environmental standards and required factories to report activities that might cause air pollution.This inspired other municipalities to adopt similar ordinances, prompting the national government to establish environmental laws. In 2000, Tokyo enacted its own ordinance regulating diesel vehicle emissions, followed by the prefectures of Saitama, Chiba and Kanagawa. Subsequently, Japan revised the Automobile NO_x Control Law to include PM alongside NO_x.
2. **Implementation of key policies and mitigation measures**: TMG has successively rolled out multiple policies and mitigation measures to achieve air quality goals.
   - **Measures against diesel emissions**: Since 2003, Saitama, Chiba, Tokyo, and Kanagawa prohibited diesel vehicles that did not meet PM emission standards in the metropolitan area, requiring non-compliant vehicles to be replaced, upgraded, or equipped with certified PM filters.
   - **Vehicle Emission Regulation Program**: In addition to enforcing regulations against non-compliant diesel vehicles, TMG is now making the transition to hybrid buses and trucks. Businesses with 30 or more vehicles (approximately 1,600 as of FY 2019) are required to submit a Vehicle Emission Reduction Plan to achieve further reductions in greenhouse gas and exhaust emissions.
   - **Clear Sky Supporters Program**: By enlisting businesses that work on NOx or VOC emission reduction measures as Clear Sky Supporters and publicly showcasing their efforts, TMG promotes voluntary emissions reductions while raising awareness among residents and providing them with relevant information.
   - **Formulation of the Zero Emission Tokyo Strategy in 2019**: TMG will accelerate efforts to leverage co-benefits by integrating climate change strategies into air quality management.

2.1.1.2 Mongolia

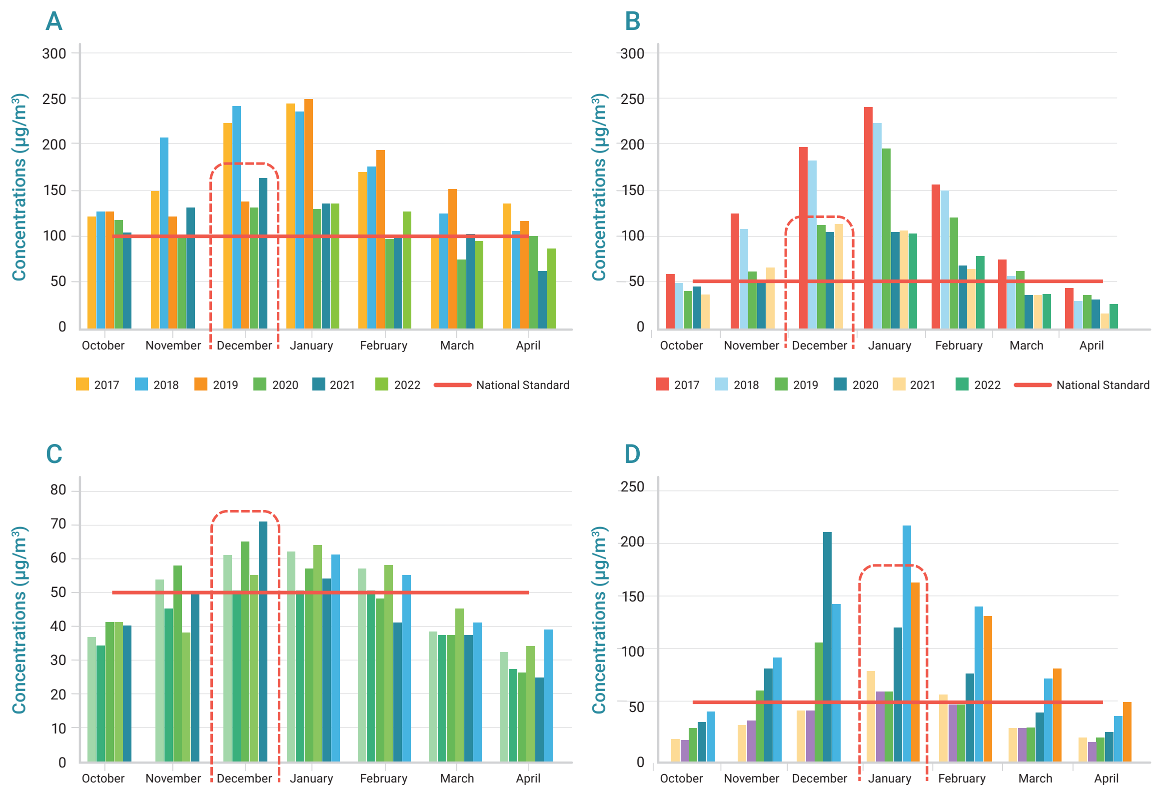
As shown in Figure 1, the trends in air quality in Mongolia are more diverse than in other countries, however, overall they show a decline with key reduction achieved for particulate matter (for both PM_{10} and $PM_{2.5}$). Ozone levels have not changed much and show recent increases which is a common feature for all countries in the region. NO_2 reductions are smaller than for other countries, but the current concentrations are in compliance with the national standard for the annual average of 40 μg/m^3. The reported air quality trend analysis focuses on Ulaanbaatar only, and while it is the largest city, the trends are not necessarily representative for the whole of Mongolia. Contrary to other countries, the measurements of SO_2 in the past five years show an upward trend reaching a record-high of 66 μg/m^3 as the annual average concentration in 2021. Similarly, concentrations of CO exhibit an increasing trend in the past decade (the SO_2 and CO are not shown but can be retrieved from the environmental analysis data section at http://agaar.mn/index?lang=en. Based on the average concentrations of key air pollutants in Ulaanbaatar in the past decade, national efforts to control emissions, particularly SO_2, NO_2, and CO seem to be necessary and immediate. The available data from the existing measurement network does not currently indicate trends for $PM_{2.5}$ or ozone for other cities in Mongolia since monitoring stations across the country do not yet include these measurements for $PM_{2.5}$, except those from Ulaanbaatar (see Section 2.2). Looking forward, extending monitoring capacity to have a country-wide coverage for all key species should be a priority.

Concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 are disproportionately high in the winter season (especially in December and January) in Ulaanbaatar (Figure 10). Due to its unique topographic characteristic that causes extremely cold air in the winter season to be trapped in the city by the surrounding mountains, the city requires extensive coal combustion for heating in residential 'Ger' areas. In virtually all cases, the national standards continue to be exceeded between November and February. For particulate matter (PM_{10} [A] and $PM_{2.5}$ [B]) there is a declining trend in recent years, while for SO_2 [C] the interannual concentration variability seems to reflect the meteorological conditions. For NO_X [D] a strong increase is observed which is likely linked to a growing number of vehicles in Ulaanbaatar, many of which might not meet the highest environmental standards resulting in relatively high emissions during cold conditions.

Coal is the dominant energy source due to the country's vast coal reserves, comprising about 80% of the total primary supply. Similarly, the heating sector relies almost entirely on coal (ESCAP, 2023). This heavy reliance on coal results in significant emissions of SO_2, NO_X, and $PM_{2.5}$ (Figure 10) at the national level as well as in Ulaanbaatar. In 'Ger' areas, most households burn raw coal (or solid waste, for the poorest) for heating and cooking. Government and private buildings mostly use highly polluting and inefficient coal-fired heat-only boilers. These energy systems are the primary sources of air pollution, contributing to a large share of $PM_{2.5}$ emissions and an estimated 80% of the ambient concentrations of $PM_{2.5}$ in Ulaanbaatar. Apart from power generation and solid fuel use for heating and cooking in households, it is transport that plays an important and increasing role for NO_X and NMVOC emissions. In Ulaanbaatar, the number of private vehicles and highly polluting public transport buses has been increasing. These sources are estimated to account for 10% of the $PM_{2.5}$ emissions. Coal burning in the combined heat and power plants, which generate heat and electricity for the city, contributes 5%-6% of $PM_{2.5}$. Additionally, the resuspension of unpaved ger road dust and fly ash from heat and power plant add 4%-5% (ADB, 2020).

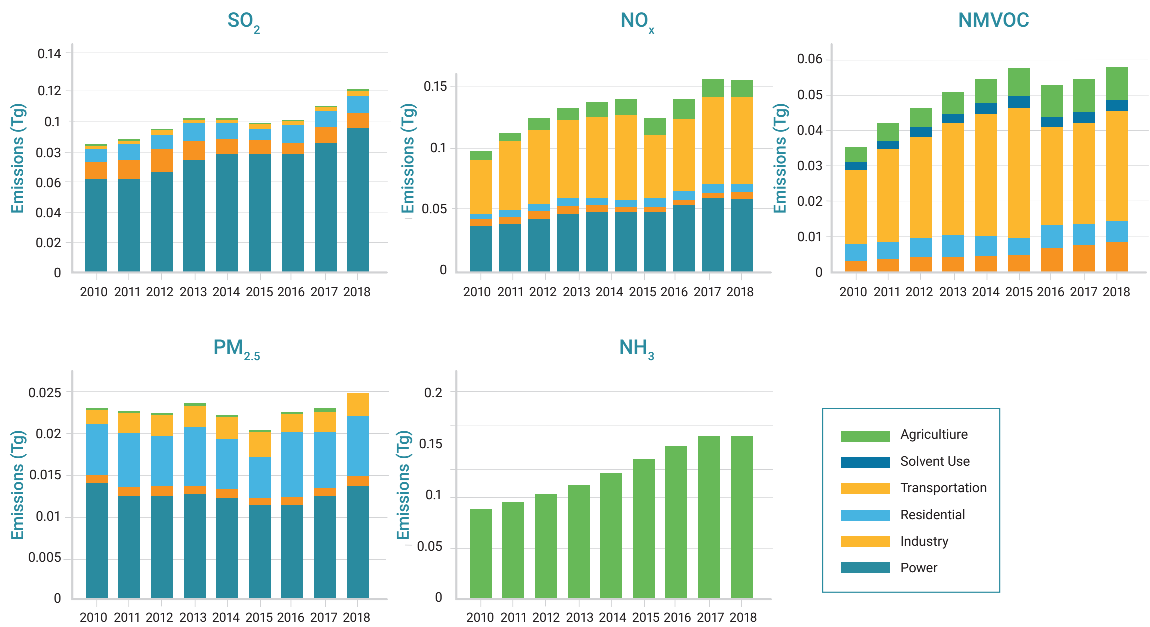
Compared to other countries, solvent use emissions of NMVOC are much lower, barely a few per cent of the total, indicating the lesser role of the chemical industry in the economy and, owing to current economic status, also consumption of solvent containing products.

Figure 10: Monthly averaged concentrations of (A) PM_{10}, (B) $PM_{2.5}$, (C) SO_2, and (D) NO_2 (μg/m³) in Ulaanbaatar, Mongolia in the heating seasons (October – April), 2017–2022.



Source: The Ministry of Environment and Tourism of Mongolia. Available at http://agaar.mn/index?lang=en, accessed on July 15th, 2023.

Figure 11: Sectoral emissions of key precursors of $PM_{2.5}$ and ozone between 2010 and 2018 in Mongolia.



Source: Crippa et al., (2023).

Emissions presented above refer to the whole country and have been estimated using a consistent methodology documented in Kurokawa and Ohara (2020) and used in HTAP_v3 inventory (Crippa et al., 2023). Similar air pollution emission trends are shown in modelling studies for Ulaanbaatar where emission inventories were developed by international teams like Japan International Cooperation Agency (JICA), e.g., (JICA, 2017), Figure 11. While the importance of emission sources is similar (compare Figure 10 and Figure 11 in the Annex), the absolute values as well as relative changes over time need further analysis.; few initial thoughts are provided in the Annex.

2.1.1.4 Republic of Korea

Similarly, compared to other countries in the region, air quality has been improving, however, ozone levels have been rising in the last decade (Figure 3). The annual concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO have steadily decreased[11] (see also Figure 1 for selected air pollutants). The observed improvement in the national air quality highlights the impact of successfully implemented air pollution policies and regulations. On the other hand, the increasing trend of annual concentration levels of O_3 suggests that further efforts in controlling emissions of non-methane volatile organic compounds (NMVOCs), which is one of the precursors of $O_{3,}$ and potentially also support of regional and global mitigation of methane (CH_4) are necessary. In spite of the observed decline for most species, the ambient air quality standards remain exceeded for $PM_{2.5}$ and ozone.

Since 1999, ROK has developed the Clean Air Policy Support System (CAPSS), a national air pollutant emission inventory to estimate air pollutant emissions at the administrative district level. Through CAPSS, emission inventories and calculation-related data from approximately 150 organizations and 260 basic statistics have been systematically collected and managed, providing data to produce emissions statistics by roughly categorizing them into 13 sources. The inventory provides information on emissions of $PM_{2.5}$, SOx, NOx, VOCs, NH3, CO, TSP, PM_{10}, and BC from 250 cities, counties, and districts throughout the ROK since 1999 (Kim et al., 2023). The National Air Emission Inventory and Research Center (NAIR), which was established in December 2019 under the Special Act in the Reduction and Management of Fine Dust, releases the National Air Pollutant Emissions every year.

According to the national inventory, key sources include power plants and industry for SO_X, transport for NOx and $PM_{2.5}$, solvent use for NMVOC, and agriculture for NH_3. Through long-term efforts to improve air quality, air pollutant emissions in ROK have been continuously reduced or remained at the similar level despite economic growth (see also Figure 12). The greatest reductions were estimated for SO_x, i.e., about 42% in the period from 2016 to 2020 (National Air Emission Inventory and Research Center (2023), followed by NOx and $PM_{2.5}$ (27% and 16% between 2016 and 2020), while only a small reduction or increase is shown for VOCs and NH_3. The primary source of emissions reduction for SO_x is the power generation sector, while for NO_X power generation and transport, reflecting the introduction of stricter emission limit values as well as ongoing adjustments in the energy source mix. The stricter limit values for power and industry as well as transport sector led to a decline of $PM_{2.5}$ emissions in the shown period.

Figure 12 shows emission trends by sector for key precursors of ambient $PM_{2.5}$ and ozone for the period 2010-2018. These estimates originate from the HTAP inventory (Crippa et al., 2023) which use earlier CAPSS inventory (Kim et al, 2023) but modified for better representation of interannual trend of ROK and harmonized for all countries, globally. The most significant discrepancy is for $PM_{2.5}$, where HTAP inventory has higher emissions from industry and agriculture, however, it is not clear if allocation of sources is the same,

11 Air Korea, Ministry of Environment, ROK. Available at: https://www.airkorea.or.kr/web/

e.g., to what extent use of liquid fuels in industrial engines is allocated to industry or non-road transportation, where open burning of agricultural residues is included, and it seems that PM emissions from livestock are not included in the national CAPSS estimates. For other pollutants, differences are smaller and can be linked to lack of estimates for soil NO_X and NMOVC from crops and livestock in the national data. Such differences demonstrate the difficulty of comparing the national estimates across many countries, unless there is a harmonized approach.

Figure 12: Sectoral emissions of key precursors of $PM_{2.5}$ and ozone between 2010 and 2018.

Source: Crippa et al., (2023)

Overall, since 2010, there is a significant reduction of some of the pollutants, especially for SO_2 where emissions were reduced from about 400 kt to below 300 kt by 2018 and about 180 kt in 2020. Some of the significant year to year deviations are associated with methodological changes that include: changes in the definition of statistics, consideration of previously not estimated sources like fugitive dust and biomass burning, changes to the construction equipment emissions calculation method in 2012, updates to activity data and VOCs emission coefficients for food and beverage processing (alcohol sector, e.g., whiskey), the inclusion of fishing and leisure ship emission sources in 2014, and the application of updated NO_X emission coefficients in 2016 to reflect actual road driving conditions of diesel vehicles for both post EURO-4 and pre-EURO-3 categories. Additionally, improvements were made to PM_{10} and $PM_{2.5}$ emission coefficient for gasoline and LPG vehicles.

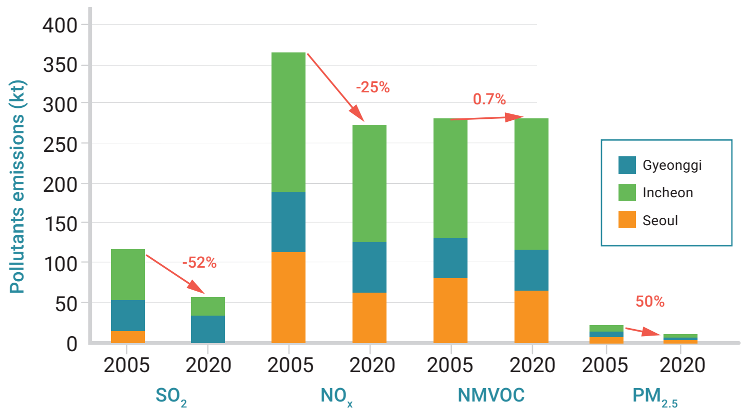
As illustrated for other countries, the high population density and strong economic regions often implement policies that are more stringent than the existing national rules (Box 3), while at the same time enabling such more ambitious action nationwide at the later stage.

BOX 3

COORDINATED AIR POLLUTION CONTROL IN SEOUL, INCHEON AND GYEONGGI, REPUBLIC OF KOREA

Seoul, Incheon and Gyeonggi (SIG) are three regions in the northwest of the Republic of Korea with a population of 26 million, which represents more than half of the country's total population. From 2005 to 2020, air quality in SIG, saw significant improvements due to a combination of a robust policy and governance framework alongside the implementation of effective emission reduction measures in major source sectors. During this period, primary $PM_{2.5}$ emissions decreased by 19.3 % nationwide, with even larger reductions in SIG (50%) as shown in the table below.

Figure 13: Changes in major air pollutant emissions in SIG region, 2005 and 2020 (unit: thousand tonnes)



Source: UNEP 2023

Policy measures for effective air quality management in Seoul, Incheon and Gyeonggi

1. **Legal framework:** In 2003, the *Special Act on Air Quality Improvement in the Seoul Metropolitan Region (SMR)* was established, followed by the introduction of the *1st and 2nd Basic Plan for Air Quality Management in the SMR* in 2005 and 2014, respectively. Local governments in SIG are required to develop implementation plans under the central government's Basic Plan to achieve the goals outlined in each Governing Act. *The enactment of the Special Act on the Reduction and Management of Fine Dust in 2018* further strengthened a legal framework for air quality management in SIG, facilitating emergency mitigation measures and comprehensive fine dust control strategies.
2. **Coordination agency**: In accordance with the Special Act on Air Quality Improvement in the Seoul Metropolitan Region (SMR), the Metropolitan Atmospheric Environment Office under the Ministry of Environment, and SIG have established the Metropolitan Atmospheric Environment Management Committee to collaborate on data sharing through integrated environmental management systems and the assessment of air quality management performances.
3. **Implementation of key policies and mitigation measures**: SIG has developed and implemented various policies and mitigation measures tailored to its regional characteristics to achieve air quality goals.

- **Fine dust forecast and warning system and emergency mitigation measures**: Along with the introduction of fine dust forecast and warning systems, the emergency mitigation measures, put into effect since 2017, aim to reduce air pollution through prompt responses during times of elevated concentration levels.
- **Seasonal Management Scheme (SMS)**: The seasonal management scheme, established in 2019, is a targeted preventive strategy for managing particulate matter within SIG, focusing on enhanced reduction measures during periods of high concentrations, specifically from December to March (winter to early spring) every year. This system addresses the shortcomings of emergency mitigation measures, which are activated only after PM levels rise. The seasonal management framework includes additional emissions reduction strategies, such as restrictions on the use of Grade 5 vehicles, the alternate no-driving day programme for public agencies, etc.
- **Mandatory installation of eco-friendly boilers in households**: In 2015, Seoul began supplying eco-friendly boilers as part of a special PM management plan, targeting reductions in both air pollution and heating costs, followed by Incheon and Gyeonggi adopting similar initiatives in 2017.
- **Introduction of eco-friendly buses and restrictions on driving pollutant-emitting vehicles**: Eco-friendly buses powered by clean fuels are currently in operation in SIG. In 2016, the Ministry of the Environment entered into agreements with the local governments of Seoul, Incheon and Gyeonggi to develop plans to restrict high-emission vehicles from entering air quality management zones.

2.2 Air Quality Monitoring Networks

The continuous development of air quality monitoring capacity has been essential in understanding not only the current pollution situation but even more importantly, the impact of actions taken to curb emissions and improve air quality. All countries in the region have enhanced their monitoring capacity, expanding from a handful of stations to several thousand stations in some countries, primarily in urban areas but also including several background stations. The latter are essential for validation of models and assessments, which allows, in addition, robust estimation of regional and local sources on urban air quality in each member state. The available evidence has been supporting development of informed policy at local, national, and regional level. However, some gaps exist in spatial and pollutant (e.g., $PM_{2.5}$, chemical speciation) coverage, especially outside urban centers, and further investments shall be encouraged, including exchange of information across the North-East Asia region.

2.2.1 China

Since 2013, the air quality monitoring network has expanded rapidly. At present, China's ambient air quality monitoring system consist of four levels: state, provincial, city, and district (county), with more than 5,000 monitoring sites. According to the China Ecological and Environmental Status Bulletin 2023 obtained from the China National Environmental Monitoring Centre, the state-level air quality monitoring network operates 1,734 monitoring stations across 339 prefectural level cities (Table 1). This network conducts continuous online monitoring of pollutants such as SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3. This system also serves other purposes including monitoring background air quality, acid rain, dust, particulate matter composition, photochemistry, and greenhouse gases. In addition to the state monitoring network, local air quality monitoring sites have been established throughout China. Provinces such as Hebei, Shandong, and Henan have made efforts to build monitoring sites that cover all their townships, further enhancing the coverage and effectiveness of the air quality monitoring system.

Table 1: National air quality monitoring network of China

Scope of monitoring	Number of Monitoring Centres	Range of pollutants monitored
Urban area air quality	1,734 air quality monitoring stations across 339 prefectural level cities	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2, CO, meteorological parameters, visibility, etc.
Regional (incl. rural area) air quality	96 regional monitoring centres	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2, CO, meteorological parameters, visibility, etc.
Background air quality	16 monitoring centres	PM_{10}, $PM_{2.5}$, O_3, SO2, NO2, CO, meteorological parameters, visibility, acid deposition, GHG, black carbon, VOCs, etc.
Atmospheric particle composition and photochemical substances	38 monitoring spots across 2+26 cities	$PM_{2.5}$, VOCs

Source: China National Environmental Monitoring Centre. Available at: cnemc.cn/gzdt/wjtz/202407/P020240712489012988272.pdf, accessed on October 11th, 2024.

2.2.2 Japan

The distribution and number of air quality monitoring sites operated by local governments in Japan is shown in Table 2. As the monitoring stations belong to an internationally coordinated network, the monthly average air pollution concentrations of the EANET monitoring stations are shown in a public website and can be downloaded. These include annual average concentrations and seasonal concentration changes, averaging every five years, for a total of 12 monitoring sites, including remote, rural, and urban stations.

There are approximately 1,900 monitoring stations nationwide, categorized into two types based on their location. The first type represents ambient air quality monitoring stations (AAQMS) situated in general environments like residential areas. The second type includes roadside air quality monitoring stations (RsAQMS) located in areas directly impacted by road transport. The real-time local air quality data of PM_{10}, $PM_{2.5}$, SO_2, NO_X, NO_2, photochemical oxidants (O_X), CO, and non-methane hydrocarbon (NMHC) is synchronized to the National Government data and published in real-time from Atmospheric Environmental Regional Observation System (AEROS: https://soramame.env.go.jp/).

Table 2: Nationally monitored air pollutants and the number of monitoring stations in Japan.

Pollutants	Number of monitoring stations as of 2018		
	Total	AAQMS	RsAQMs
SPM (PM_{10})	1,703	1,314	389
$PM_{2.5}$	1,088	849	239
Ozone (O_3)	1,193	1,165	28
Nitrogen Oxides, Nitrogen Dioxide (NOx, NO_2)	1,658	1,260	398
Sulfur Dioxide (SO_2)	1,010	960	50
Carbon Monoxide (CO)	293	60	233

Source: Ito, A. et al. (2021). https://www.mdpi.com/2073-4433/12/8/1072.

2.2.3 Mongolia

The Government of Mongolia has established a network of 40 ambient air quality monitoring (AAQM) sites across the country, including 15 sites in Ulaanbaatar. These AAQM sites monitor six air pollutants (SO_2, NO_X, CO, O_3, $PM_{2.5}$, PM_{10}) and collect weather data, however, not all parameters are measured at all stations; for details see Table 16 in the Annex. The National Agency for Meteorology and Environmental Monitoring (NAMEM) operates the AAQM stations. The 16 sites in Ulaanbaatar which are managed by both NAMEM and the Air Pollution Reduction Department (APRD) of Ulaanbaatar City are located in industrial (UB1 and UB7), residential (UB4, UB5 and UB13), ger area (UB3, UB11, UB12, APRD1, APRD2, APRD3, APRD4, APRD5, and APRD6), roadside (UB2), and remote areas (UB8) (Soyol-Erdene et al., 2021). Most of the stations in Ulaanbaatar measure all key species, with only a few not covering $PM_{2.5}$ and ozone. Stations in other cities do not measure $PM_{2.5}$ or ozone but consistently include SO_2 and NO_X and few also include measurements of PM_{10}.

Table 3: **Air quality monitoring stations and monitored pollutants in Mongolia.**

Region	Number of monitoring stations	Pollutants measured	Name of air quality monitoring stations*
National	40	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2, CO	–
Ulaanbaatar	15	PM_{10}	UB-1, UB-2, UB-3, UB-4, UB-5, UB-7, UB-8, UB-12, Zuragt, Tolgoit, Nisekh, Amgalan, Bayankhoshuu
		$PM_{2.5}$	UB-2, UB-3, UB-4, UB-12, Zuragt, Tolgoit, Nisekh, Amgalan, Bayankhoshuu
		O_3	UB-1, UB-4, UB-5, UB-8, Zuragt, Tolgoit, Nisekh, Amgalan, Bayankhoshuu
		SO_2	All stations
		NO_2	All stations
		CO	UB-1, UB-2, UB-4, UB-5, UB-7, UB-8, Zuragt, Tolgoit, Nisekh, Amgalan, Bayankhoshuu

*UB refers to Ulaanbaatar

Source: Air Quality Monitoring in Mongolia (Davaanyam, E. and Gantsetseg, B., 2020). Available at: https://www.unescap.org/sites/default/files/9.%20Air%20Qulaity%20Monitoring%20in%20Mongolia_IRIMHE.pdf.

2.2.4 Republic of Korea

Assessment of the status and trends of ambient air pollution has been supported by the national air pollution monitoring network that as of June 2024, consisted of 958 stations throughout the country. Since 2011, the Ministry of Environment expanded the monitoring network by nearly doubling the number of air quality stations (463 stations in 2011). This was done in response to increased public concern regarding urban air pollution and implementation of new standards for $PM_{2.5}$ in 2015. It is composed of several air monitoring networks, including urban (530 stations), suburban (27 stations), national background (11stations), ship monitoring (35 stations), roadside (62 stations), marine port (31 stations), hazardous air pollutants (63 stations), heavy metals (81 stations), acid deposition (43 stations), photochemical air pollutants (20 stations), global atmosphere (1 station), speciated measurement of $PM_{2.5}$ (43 stations), and an intensive monitoring network (11 stations). The urban, suburban, and national background monitoring network measure SO_2, CO, NOx, PM_{10}, $PM_{2.5}$, and O_3.

Table 4: **Nationally monitored air pollutants and number of monitoring stations in the Republic of Korea.**

Scope of monitoring		Number of Monitoring Stations	Range of pollutants monitored
Urban Air Monitoring Network		530	SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, O_3
Suburban Air Monitoring Network		27	SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, O_3
National background	Urban area	11	SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, O_3
	Ship monitoring	35	$PM_{2.5}$, BC
Roadside Air Monitoring Network		62	SO_2, CO, NO_2, PM_{10},$PM_{2.5}$, O_3
Port Air Monitoring Network		31	SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, O_3
HAPs Monitoring Networks		63	VOCs (17 types), PAHs (16 types)
Air Heavy Metal Monitoring Network		81	PM_{10}, Pb, Cd, Cr, Cu, Mn, Fe, Ni, As, Be, Al, Ca, Mg
Acid Deposition Monitoring Network		43	Dry: $PM_{2.5}$, Moisture: pH, Mercury

Table 4: **Nationally monitored air pollutants and number of monitoring stations in the Republic of Korea.**

Scope of monitoring	Number of Monitoring Stations	Range of pollutants monitored
Photochemical Assessment Monitoring Stations	20	PM_{10}, $PM_{2.5}$, O_3, NOx, VOCs (56 types)
Global Atmosphere Monitoring Network	1	CO_2, CFC (-11,-12,-113), N2O, CH4
$PM_{2.5}$ Components Network	43	$PM_{2.5}$, carbon, ion, Metals
Intensive monitoring network	11	SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, O_3
TOTAL	**958**	

Source: Air Korea, Ministry of Environment, ROK. Available at https://www.airkorea.or.kr/web/, accessed on October 11th, 2024.

2.3 Remote Sensing and Modelling

This section provides a brief overview of the existing regional and national remote sensing and modelling capacity that is actively used to support the monitoring and evaluation of air quality. Remote sensing data allows to extend the monitoring capacity and has been used by scientists and environmental agencies supporting the evaluation of trends and even compliance with existing legislation. Remote sensing and monitoring data are essential for validation of the progress of the implementation of policies/measures as well as for various models used in support or discussions with the policy community.

While atmospheric modelling capacity goes hand in hand with monitoring data supporting evaluating of current situation, it also has a potential, once models are validated with robust monitoring information, to support assessment of implications/impact of air quality policy in the future and can be employed in the policy process at national and even regional level. For the latter, there is a need for transparent information sharing and building trust between science and policy community across the nations within the region.

2.3.1 Remote sensing programmes used to monitor air quality

Satellite observations enhance ground-based networks by providing data across wider areas of the globe. This is particularly useful in regions without surface monitors, making them essential for evaluating air quality models and improving inventories. Monitoring air quality from satellites has become crucial in understanding pollution levels and trends from regional to global scale, offering quantitative data on pollutant amounts, emissions and transport.

2.3.1.1 The Geostationary Environment Monitoring Spectrometer (GEMS)

The Geostationary Environment Monitoring Spectrometer (GEMS), launched by the Republic of Korea in February 2020, is the world's first geostationary satellite dedicated to air quality monitoring. It enables hourly tracking of air pollution levels across nearly 20 Asian countries, from India to Japan, and Indonesia to Mongolia. GEMS allows the monitoring of O_3, aerosols, and their precursors of NO_2, SO_2, formaldehyde (HCHO), and CHOCHO as column density and possibly vertical profiles. It also supports various applications like surface concentration conversion, UV index, emission characteristic indicator, etc. with data visualization available on homepage (https://nesc.nier.go.kr).

The United Nations Economic and Social Commission for Asia and Pacific (ESCAP) and the National Institute of Environmental Research (NIER) of the Republic of Korea launched the *Pan Asia Partnership for Geospatial Air Pollution Information*. This partnership leverages GEMS data and a network of ground-based remote sensing instruments, the Pandora Asia Network (PAN), to harmonize and enhance the use of GEMS data across Asian countries. By integrating with the Pandonia Global Network (PGN), which uses the Pandora spectrometer instrument for 3-D air quality monitoring, the initiative validates satellite data with ground data through regional cooperation. Combining government-collected ground data with calibrated GEMS and Pandora data, this effort aims to fill information gaps and support evidence-based policymaking to address air quality issues.

2.3.1.2 National programmes

China has made significant strides in developing nationally supported remote sensing programmes for air quality monitoring. According to the official website of the Satellite Application Centre for Ecology and Environment (SACEE), an affiliate of the MEE, remote sensing monitoring of NO_2, HCHO column concentrations, and ozone precursor indicator values (HCHO/NO_2) was conducted from June to September 2020. This effort identified key regions with high ozone precursor values, providing valuable support for remote and on-site supervision as well as assistance in ozone pollution prevention and control. In October 2021, the Atmospheric Environment Remote Sensing Innovation and R&D Base, jointly established by SACEE and the University of Science and Technology of China (USTC), successfully obtained the first batch of global monitoring products for NO_2, SO_2, HCHO, and O_3 concentrations using a fully self-developed hyperspectral remote sensing algorithm for atmospheric pollutants. These products, derived from China's hyperspectral observation satellites, possess the highest spatial resolution among morning transit time pollution gas satellite monitoring products worldwide. The development of the hyperspectral observation satellite, led by the MEE, represents a significant advancement in comprehensive environmental observation satellites with operational capabilities. It holds great significance in supporting the co-control of $PM_{2.5}$ and O_3 and plays a crucial role in the battle against pollution prevention and control.

Further, China has established an integrated monitoring system known as the 'sky-earth-space', which is designed to meet the requirements of routine monitoring of the atmospheric environment and incorporates advanced online technologies for monitoring ground particulate matter composition, VOCs, and ground-based remote sensing. The MEE now has access to near real-time monitoring results for various pollutants, including $PM_{2.5}$, SO_2, NO_2, as well as dust storm and open biomass burning events. This system utilizes data from the domestic environment monitoring satellite system and foreign remote sensing data sources. Furthermore, there is a cross-verification process in place to compare satellite remote sensing data with ground environment monitoring data, ensuring the accuracy and reliability of the measurements (MEE, 2019b).

As a remote sensing monitoring network, DSS (Dust and Sand Storm)[12] is being implemented by the Ministry of the Environment, Japan. Predicted distribution of DSS in East Asia, based on the CFORS (Chemical weather FORecasting System) model using lidar data, is always available as part of a joint research project between the National Institute for Environmental Studies and Kyushu University.[13]

Since 1987, Mongolia has been receiving digital data from US polar-orbiting NOAA and MODIS satellites, and in recent years, satellite data has been used for research and development in the areas of snow cover, vegetation cover, forest fire monitoring, land use, environment, and natural resource assessment. However, so far there is a lack of research on the optical state of the atmosphere and air pollution.

12 http://www2.env.go.jp/dss/kosa/en/index.html
13 https://www-cfors.nies.go.jp/~cfors/index-j.html

2.3.2 Modelling capacity

This section provides brief information about existing modelling capacity and collaboration in the region. There is no intention to show and discuss specific results but rather highlight the national and community efforts to develop and operate air quality modelling infrastructure. Strong atmospheric modelling capacity is essential for better understanding of pollution sources and implications and benefits of their control. The models are typically used to provide short term air quality forecasts or support assessment of current status and projections of implications/impact of air quality policy. Validated models are important for the processes of establishing common language and trust with the policy community. In the longer term they could provide an important element of continuous discussion about both evaluation of current policies and planning for next steps.

Atmospheric modelling is practiced at the universities where both locally developed and community-based models such as CMAQ – the Community Multiscale Air Quality Modeling System (https://www.epa.gov/cmaq) – are applied in research work and sometimes also in support of regulator authorities for impact assessments of specific industrial facilities. Development and application of such tools is an essential part of capacity development establishing strong local modelling community working with monitoring networks as well as emission inventory teams.

A more recent activity, linked to the development and application from the national and regional to the global level, is large scale integrated assessment models that are either developed within the region or jointly with foreign teams. For example, in **China**, GCAM-China – its development based on the GCAM model[14] – provides a detailed and refined analysis specific to the Chinese region. It offers province-level approaches, which provides comprehensive examination of the interdependences between energy, agriculture, forestry and other land use, water, emissions, and climate systems. The model covers 31 provinces, further divided into specific grid regions, from the present day up to the year 2100, using 5-year time periods. The input data for GCAM-China consists of scenario assumptions encompassing socioeconomic factors (such as population, labor participation, and labor productivity), characteristics of energy and agricultural technologies, energy, and other resource data. For output, the model generates key scenario results, including analysis of the energy system, prices and supplies of agricultural and forest products, land use and land use change, water demands and supplies for all agricultural, energy, and household uses, and emissions of 24 greenhouse gases and short-lived species (CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, and SO_2). GCAM-China has been instrumental in assessing the deployment of carbon capture, utilization, and storage (CCUS) across different provinces, which enables the realization of a low-carbon energy mix and the achievement of local air quality goals (Yu et al., 2019b). In addition to the estimation of energy efficiency and benefits of reduced air pollution resulting from low-carbon energy mix, GCAM-China assesses benefits of air pollutant control strategies on public health as well (Dong et al., 2023; Li et al., 2020).

The Asian-Pacific Integrated Model (AIM) is a large-scale computer simulation model developed by the National Institute of Environmental Studies (NIES) of **Japan**. The AIM evaluates policy options for addressing climate change, specifically in the Asia-Pacific region. Its main goals are to reduce greenhouse gas emissions and mitigate the impacts of climate change. The Asia-Pacific Integrated Modeling/Computable General Equilibrium (AIM/CGE) model, an extension of AIM, focuses on analyzing climate change mitigation and its effects. While its primary purpose is to address climate change, the AIM model can also be applied to tackle other environmental issues such as local air pollution issues and short-lived climate forcers (SLCFs) extending its capacity to analyze co-benefits of climate and air quality policies. The air pollutant modules within AIM follow a bottom-up approach (Hanaoka and Masui, 2018). Benefits of air quality improvement from carbon mitigation were also assessed in ROK (Kim et al., 2020).

14 The Global Change Analysis Model (GCAM) is an open-source community model developed by the Joint Global Change Research Institute (JGCRU)

The ADAM-Haze air pollution distribution model was installed in the **Mongolian** Meteorological Service in 2017. Starting from September 2019, the internal network of the Institute of Hydrometeorology began to be tested with 1x1 km resolution in the city of Ulaanbaatar. The ADAM-Haze model is based on a multidimensional coupled model of air quality (CMAQ). The CMAQ model works on the principle of taking the initial weather data from the regional WRF model's climate parameters such as temperature, precipitation and humidity, and making the first calculation from 9×9 km, then making the second at a 3×3 km calculation, and finally down to a 1×1 km scale. For the model's input emission data, the HTAPv2 emission dataset (Hemispheric Transport of Air Pollution) with a resolution of 10x10 kilometres was downloaded from the 2010 release and further refined using 1x1 kilometre resolution data provided by the JICA expert team.

GHGs and Air pollutants Unified Information Design System for Environment (GUIDE) has been developed by the Graduate School of Environmental Studies (GSES), Seoul National University (**Korea**) consortium since 2016 (Woo et al., 2020). Based on economy and energy mitigation and projection, air quality simulation with emission reduction regulations, and cost-benefit analysis, GUIDE models strategies to effectively manage GHGs and air pollutants. Using Response Surface Model (RSM) for air quality and BenMAP model for health impact, GUIDE provides an integrated air quality assessment, including 7 air pollutants (CO, NO_x, NH_3, SO_2, PM_{10}, $PM_{2.5}$, VOCs) and six Kyoto GHGs (CO_2, CH_4, N_2O, 3 F-gases), for 17 regions in ROK. The GUIDE model is used for national policies and academic research of the integrated management system of GHG and air pollution emission in ROK. GUIDE serves as a scientific foundation of the national climate change adaptation and the Cleaner Air in Seoul plans (Woo et al, 2024). Furthermore, the GUIDE model is also used with other IAMs in the Northeast Asia region, GCAM-China, and GAINS-Asia, as in the Air Quality in North-East Asia (AQNEA) project to project future emission levels, control strategies and concentration-health impact of ROK (Woo et al, 2023a). The Seoul National University consortium is currently expanding the GUIDE IAM to a global level (GUIDE-Global) to support global GHG mitigation and adaptation (i.e., air pollution) with a focus on Northeast Asia. Simultaneously, a local level IAM of GUIDE (GUIDE-Local) is under development to support local implementation plans of GHG and air pollutant mitigation in ROK (Woo et al., 2023b).

Another type of activity includes predicting/forecasting short term air quality. Since 2013, **China** has made significant advancements in establishing regional forecasting centers to monitor and forecast air quality. These centers cover six major regions: the Beijing-Tianjin-Hebei region and nearby areas, the Yangtze River Delta, South China, Northeast China, Northwest China, and Southwest China. The forecasting system operates at national, regional, provincial and city levels, ensuring cooperation and support between different levels. The system integrates long-term and short-term forecasts, as well as nowcasts, and operates steadily. According to MEE, China has achieved daily air quality forecasts for the next 7 days for 31 provinces and 339 prefecture-level and above cities. Additionally, air quality forecasts for the next 7-10 days are available for key regions, while trend forecasts for air quality are provided for the next 15 days at both national and regional levels. At the national level, daily forecasts are made for the national air quality over the next 5 days, and a national forecast consultation is conducted every two weeks to release the air quality forecast for the next 15 days. At the regional level, daily forecasts are provided for the air quality changes in major regions. At the provincial level, daily releases include air quality changes and day-by-day air quality level forecasts for 3-7 days. At the city level, the mobile app provides daily forecasts of the Air Quality Index (AQI) range, air quality level, and primary pollutants for the next 7 days. These efforts in air quality forecasting ensure timely and accessible information to the public, aiding in understanding and managing air pollution across various regions in China (MEE, 2019b).

In **Japan**, the National Institute for Environmental Studies (NIES) developed the Visual Atmospheric Environment Utility System (VENUS) simulating $PM_{2.5}$ and ozone for the next seven days in Japan (https://venus.nies.go.jp/) that has functions such as visualizing selected areas and showing graphs of temporal variation. NIES also developed a system for supporting experts (especially in local government) related to air pollution control measures and policies to conduct air quality model simulations.

2.4 Health, Environmental, and Crop Impacts Due to Air Pollution

Air pollution has been a serious environmental and public health issue worldwide, particularly in Asian countries. Recent studies have indicated that $PM_{2.5}$ and ozone are the most detrimental air pollutants to human health, resulting in substantial disease burdens for Asian populations (Du et al., 2024; Lanzi et al., 2022; UNEP, 2019). Additionally, ozone affects crop yields (Feng et al., 2022) and deposition of sulfur and nitrogen contributes to acidification and eutrophication of natural ecosystems.

2.4.1 Health benefits from improved air quality

More than three decades of epidemiological research have established robust associations between long-term exposure to ambient and indoor air pollution and premature mortality. Among others, ischemic heart disease, stroke, chronic respiratory diseases and lung cancer contribute to substantial reduction of life expectancy. Furthermore, morbidity linked to e.g., chronic respiratory symptoms, including bronchitis and asthma, belong to some of the most deleterious effects of air pollution. And a growing body of literature points to the vulnerability of children to air pollution, with premature deaths from pneumonia. Ambient and household air pollution continues to be the leading environmental risk factor for disease burden (IHME, 2024). While most of the attention has been drawn by exposure to $PM_{2.5}$ with an estimated 2 million premature deaths in East Asia, exposure to ground-level ozone has also been associated with mortality and respiratory diseases independent of exposure to $PM_{2.5}$. Premature deaths in East Asia from ozone exposure have been estimated at about 100,000 in 2015 (UNEP, 2019).

A report related to the economic benefits of international cooperation in improving air quality in Northeast Asia, released by the Organization for Economic Co-operation and Development (OECD), highlights those significant reductions in $PM_{2.5}$, BC (black carbon), and SO_2 (sulfur dioxide), achieved through the transition to cleaner fuels used in cooking and heating, particularly in households. The report notes that nearly 70% of the reduction in $PM_{2.5}$ can be attributed to the Chinese strategy of replacing coal and biomass with cleaner alternatives such as gas and electricity (Lanzi et al., 2022). There is vast literature assessing China's efforts to improve air quality and the resulting health benefits. These include assessment of the impact of the Action Plan of Air Pollution Prevention and Control (Action Plan) (2013-2017) leading to reduced long term exposure and number of heavily polluted days (Xue et al., 2019). Further study evaluated impacts of the 2018-2020 Three-Year Action Plan for Winning the Blue-Sky Defense Battle (the Three-year Plan) (Xiao et al., 2022). Another study showed how the longer term reduction of pollution in the period 2002-2017 brought significant health benefits (Geng et al., 2021b). Overall, China's progress in its 'battle against pollution' has been remarkable, particularly when placed in a global context. According to the reports released by EPIC (Greenstone et al., 2022) the rate at which China has reduced pollution surpasses that of the United States and Europe, however, the current levels of $PM_{2.5}$ in the US and most of Europe are comparable to those in Japan and are still lower than in China, Mongolia, or Korea.

Strategies addressing air quality through measures like access to clean fuels and improving the efficiency of residential appliances for cooking and heating, will also bring significant benefits for indoor pollution and exposure with strong benefits for children and women who typically spend more time indoors.

2.4.2 Environmental impacts associated with the deposition of sulfur and nitrogen

Atmospheric ammonia plays important roles in fine particle pollution, acid deposition, and nitrogen deposition. The abatement of NH_3 emission can effectively mitigate $PM_{2.5}$ pollution and nitrogen deposition in China. Quantitatively, a 50% reduction in NH_3 emissions achievable by improving agricultural management, along with a targeted emission reduction (15%) for sulfur dioxide and nitrogen oxides, can alleviate $PM_{2.5}$ pollution by 11-17% primarily by suppressing ammonium nitrate formation. Meanwhile, nitrogen deposition is estimated to decrease by 34%, with the area exceeding the critical load, shrinking from 17% to 9% of China's terrestrial land, which indicates that mitigation of NH_3 emissions should be a priority to tackle serious nitrogen deposition in China. Moreover, during 2013-2018 in mainland China, the annual NO_2 dry deposition ranged between 2.1 and 3.1 kg N $ha^{-1}yr^{-1}$, with an annual reduction rate of 0.21 kg N $ha^{-1}yr^{-1}$ over this period. The annual SO_2 dry deposition ranged between 7.5 and 18.4 kg S $ha^{-1}yr^{-1}$, with the annual reduction rate at 2.4 kg S $ha^{-1}yr^{-1}$. The reduced emissions attributed to the national action on air pollution control were identified as an important reason for the declining deposition. However, reducing deposition is not as simple as merely reducing its precursor emissions, the design of future policies to reduce associated risks may need to vary by region and species, accounting for their evolving interactions over time (Xu et al., 2018; Yu et al., 2019a; Zhao et al., 2022; Zhou et al., 2021).

A reduction of atmospheric deposition in forested areas has been suggested based on long-term observational studies (Chiwa, 2021; Sase, 2019; Sase et al., 2021; Wang et al., 2023; Zhigacheva, 2022) Accordingly, recovery of lake/stream water from acidification and/or nitrogen saturation has been observed in forested areas in Japan (Chiwa, 2021; Sase, 2019; Sase et al., 2021). However, sulfur derived from atmospheric deposition is still accumulated in forest soil in a high-deposition area (Tanikawa et al., 2022). Additionally, it has been reported that changes in climatic/meteorological conditions influenced nitrogen leaching processes to stream water (Ding et al., 2022; Zhigacheva, 2022). In a forest catchment in Far East Russia, it was suggested that changes in meteorological conditions enhanced leaching of sulfur and nitrogen, resulting in stream water acidification (Zhigacheva et al., 2022). Therefore, possible disturbance of air-pollution legacy pools by a changing climatic/meteorological condition should carefully be monitored in recovery processes. A regional risk assessment was conducted using the critical load approach in the whole EANET region (Yamashita et al., 2022) and the EANET database holds a long-term monitoring data of acid deposition in East Asia (https://monitoring.eanet.asia/document/public/index). Eutrophication (nitrogen saturation) risks were found not only in East Asia but also in tropical Asia.

2.4.3 Crop impacts related to ozone

Near-surface ozone has increasingly, become an important atmospheric pollutant globally and as indicated earlier in this report, the ozone concentrations have been increasing across the region. High concentrations of ozone enter the leaves of crops through stomata to produce oxidative stress, which negatively affects food growth and threatens global food security. Estimates provided in the UNEP study (UNEP, 2019) for 2015, indicated ozone induced crop losses of about 30,000 million tons, split about equally between wheat, maize, and rice with only small share of soy. In relative terms, however, soy losses were estimated to be about 20% of the yield, maize and wheat at about 10%, and rice at about 5%. A strong mitigation policy, beyond what is currently committed, addressing sources of tropospheric ozone in Asia could constitute about half the overall losses by 2050 (UNEP, 2019). According to recent analysis, further reduction in ozone pollution could bring significant increases in crop yields, ranging from a few per cent to over 20% for wheat, rice and corn across East Asia. (Feng et al., 2022).

A reduction of CO_2 uptake due to ozone exposure was assessed for Japanese tree species (Kinose et al., 2020). The estimated reduction rates for Japanese beech (*Fagus crenata*) and birch (*Betula platyphylla var. japonica*) were 14.0% and 15.4%, respectively. A review paper showed changes in possible causes of tree decline symptoms in Asian countries (Takahashi et al., 2020). Possible causes have been changing from SO_2 to ozone and climate change with economic growth. Capturing mechanisms of PM (especially black carbon) have been studied for Japanese tree species (Hiroyuki Sase, 2022; Ohta et al., 2023). These studies will contribute to improvement of urban air quality using green infrastructure.

CHAPTER 3
REGULATIONS AND POLICIES

Key findings

- All countries have established ambient air quality standards to manage air pollution, which vary based on pollution intensities and economic contexts. The standards have been updated over time aiming to align with the WHO guidelines in the long-term.
- Regulations and emission limit values, for both stationary and mobile sources, have been implemented to control emissions of SO_2, NOx, PM, CO, and recently NMVOC for sources of fugitive emissions.
- Each country has a robust legal framework to enforce air pollution control, with specific laws targeting atmospheric pollution and environmental impact assessments.

Recommendations

- Continue aligning air quality standards with WHO guidelines, particularly for pollutants like $PM_{2.5}$ and ozone.
- Promote the adoption of advanced emissions control technologies in industries and vehicles to meet more stringent standards.
- Enhance enforcement of existing legislation and sharing experiences to bolster institutional capacity.
- Integrate air quality management with broader climate change policies to leverage co-benefits and improve overall environmental sustainability presenting an opportunity for regional collaboration.

Recognition of the impacts of air pollutants on human health and environment led to the development and gradual strengthening of national air quality standards across the world. Countries in North-East Asia have been establishing institutions and air quality related standards since the 1960s, although the pace has varied across the region. Established standards and respective laws, including monitoring capacity, have enabled the governments to analyze and keep track of air pollution and develop specific strategies and further regulations to address their unique air pollution challenges, reflecting their economic, environmental and social contexts. This chapter provides an overview of recent regulations and policies in four countries implemented in response to the country-specific issues and circumstances.

3.1 National Air Quality Standards

The ambient air quality standards form a crucial basis for national and local governments to manage air quality by development of respective plans, including setting typically national and source specific pollution emission standards; often such standards can vary also from region to region within the country, exemplifying the local circumstances and pollution intensities that need to be managed. An overview of current air quality standards across the region and their comparison to the latest WHO air quality guidelines is summarized in Table 5.

In China, ambient air quality regulation began in 1982, initially setting limits for Total Suspended Particulates (TSP), SO_2, NO_2, lead, and Benzo(a)pyrene (BaP). These standards were strengthened and expanded in 1996 under National Standard GB3095-1996. The standards were updated in 2000 (MEP Announcement 2000 No.1). In February 2012, China released a new standard, GB3095-2012, which sets limits on $PM_{2.5}$ for the first time. China's Air Quality Standards have different timelines for metropolitan areas where pollution is more severe and are divided into classes: Class 1 for special regions (like national parks) and Class 2 for all other areas. The current standard was fully implemented nationwide by 2016.

Japan's ambient air quality standards, known as Environmental Air Quality Standards (EQSs), are formulated under the authority of the Air Pollution Control Law. Last amended by Rule No. 32 in 1996, these standards have been expanded to include additional pollutants. The EQS for $PM_{2.5}$ was officially announced and took effect on September 9, 2009.

In Mongolia, ambient air quality standards were legislated in 1998 through the adoption of standard MNS 204585-98, updated in 2007 (MNS 4585:2007) and amended in 2016 (MNS 4585:2016) (UNDP, 2019) specifying the maximum permissible levels of pollutants in ambient air.

Korea's ambient air quality standard was initially established in 1978 for SO_2. Standards for particulate air pollutants were established for total suspended dust (TSP) in 1983. In 1993, a new environmental standard for PM_{10} was introduced with an annual average not exceeding 80 μg/m^3, reflecting the human health risks associated with particulate matter. The focus shifted to PM_{10} with the elimination of the TSP standard in 2001. In 2007, as expectations for air quality heightened, the annual and 24-hour standards for PM_{10} were set at 50 μg/m^3 and 100 μg/m^3, respectively. Concurrently, NO_2 standards were also strengthened. In 2012, recognizing the health risks from fine particulate matter, Korea introduced new $PM_{2.5}$ air quality standards. As of 2012, the standard has been expanded to eight pollutants to include NO_2, CO, O_3, PM_{10}, $PM_{2.5}$, Pb, and Benzene.

The comparison presented in Table 5 reveals that despite significant progress in ambition of the national air quality standards across the region, there remains a gap to the WHO air quality guidelines (AQG). The national standards are typically better aligned with the WHO Interim Target-4 and as has been illustrated in Chapter 2, for several of them most countries are on track or already comply with the IT-4 recommendations. The biggest challenges relate to $PM_{2.5}$, ozone, and also NO_2, especially for compliance at urban sites. For $PM_{2.5}$, an additional challenge is associated with the contribution of natural sources, e.g., dust storms, which in some locations contribute more than the WHO AQG value. For ozone, the continued increase of concentrations of methane (CH_4) globally adds to the background ozone creating additional challenges from the perspective of regulation, while also offering an opportunity when aligning air quality and climate policies that would lead to a reduction of methane emissions. However, an increase of urban ozone (see discussion in Chapter 2) is strongly associated with policies addressing, in the first instance, sources of NOx, while leaving behind strong control of NMVOC.

Table 5: National Air Quality Standards and WHO Guidelines.

Pollutant	Sampling time	China		Japan	Mongolia	ROK	WHO	
		Class I	Class II				AQGs	IT-4
PM_{10} (µg/m³)	Hourly	–	–	200	–	–	–	–
	24h average	50	150	100	100	100	45	50
	Annual mean	40	70	–	50	50	15	20
$PM_{2.5}$ (µg/m³)	24h average	35	75	35	50	35	15	25
	Annual mean	15	35	15	25	15	5	10
O_3 (µg/m³)	Hourly average	160	200	0.06 ppm (117.8 µg/m³)	–	0.1 ppm (196.3 µg/m³)	–	–
	8h max	100	160	–	100	0.06 ppm (=117.8 µg/m³)	100	120**
	Peak season	–	–	–	–	–	60	70**
SO_2 (µg/m³)	10 minutes						500	
	20 minutes	–	–	–	450	–	–	–
	Hourly average	150	500	0.1 ppm (262.3 µg/m³)	-	0.15ppm (393.4 µg/m³)	–	–
	24h average	50	150	0.04 ppm (104.8 µg/m³)	50	0.05ppm (131µg/m³)	40	50**
	Annual mean	20	60	–	20	0.02ppm (52.4 µg/m³)	-	-
NO_2 (µg/m³)	Hourly average	200	200	–	-	0.1 ppm (187.5 µg/m³)	200	-
	24h average	80	80	0.04-0.06 ppm (75–113 µg/m³)	50	0.06 ppm (113 µg/m³)	25	50**
	Annual mean	40	40	–	40	0.03 ppm (=56 µg/m³)	10	20***
CO (mg/m³)	15 minutes	–	–	–	–	–	–	–
	20 minutes	–	–	–	60	–	–	–
	Hourly average	10	10	–	30	25 ppm (28.6 mg/m³)	35	–
	8 hours average	–	–	20 ppm (22.9 mg/m³)	10	9 ppm (10.3 mg/ m³)	10	–
	24h average	4	4	10 ppm (11.5 mg/m³)		–	4	7*

Sources: China: Ministry of Ecology and Environment of People's Republic of China (Available here), Japan: Ministry of Environment of Japan(Available here), Mongolia: Meteorological and Environmental Analysis Department of Mongolia (Available here), ROK: Ministry of Environment of ROK (Available here), and WHO guidelines (Available here). (7)

Notes: (1) Class I refers to areas which require special protection (i.e. more stringent environmental standards), such as natural reserves and scenic spots; Class II refers to residential areas, commercial-traffic-residential mixed area, cultural districts, industrial areas and rural areas;
(2) AQGs refer to WHO's air quality guidelines;
(3) IT-4 refers to interim target – 4;
(4) IT-4 were not set for some pollutants; * refers to IT-1; ** refers to IT-2; *** refers to IT-3;
(5) Differences in sampling and measurement techniques are not considered in the table;
(6) Peak season of Ozone standards refers to an average of daily maximum 8-hour mean concentration in the six consecutive months with the highest six-month running average O_3 concentration, and;
(7) In Japan, AQSs values for PM_{10} as given in this table are for Suspended Particulate Matter (SPM) that is particles left after particles with aerodynamic diameter larger than 10 um have been completely separated.

3.2 Emission Standards

National ambient air quality standards have been set to protect public health and the environment in all concerned countries. To achieve these standards, a range of policies have been proposed and implemented encompassing emission standards for industries and automobiles, by setting emission limit values for all key sources of pollution including both existing and newly constructed installations and new vehicles. This section provides an overview of regulations for stationary and mobile sources and the key overarching national actions taken to implement these regulations. The focus is on SO_2, NO_x, and PM, although regulation for pollutants is mentioned where major polluting sources contributing to ozone and PM pollution are concerned.

3.2.1 Stationary sources

China began imposing progressively lower air pollutant emission limit values for power plants in 1991, eventually establishing the ultra-low emissions (ULE) standards that included also prescribed timing of implementation. The current standards (GB13223-2011) went into effect on 1 July 2014, limiting SO_2, NO_x and PM emissions from coal-fired power plants to 100, 100 and 30 mg/m^3, respectively. These levels are comparable or even lower than those currently in force the United States (136, 95 and 12 mg/m^3 for SO_2, NO_x and PM, respectively) and the European Union (150, 150 and 10 mg/m^3) at the standard oxygen level. These standards were tightened on 12 September 2014, when the ULE standards for new and upgraded coal-fired power-generating units were introduced, limiting SO_2, NO_x and PM emissions to 35, 50 and 10 mg/m^3, respectively. These emission levels are similar to those from gas-fired power plants. The ULE policy not only substantially reduced Chinese power emissions (e.g., Tang et al., 2019), but also led to considerable social benefits in terms of environmental improvement.

Beyond the power sector, heavy industries belong to key pollution sources and China has imposed a series of compulsory emission standards for several production sectors since 2012, for example, covering all production processes of iron and steel industry. In particular, for the sintering process, which is among the key polluting sources, the current standards prescribe emission limit values that are lower than the previous standards (GB 16297–1996) by about 90% and 60% for SO_2 and PM, respectively. This has resulted in a significant reduction of emissions and contribution of iron and steel industry to ambient $PM_{2.5}$ (Tang et al., 2020). Strong economic growth in the last decades has been fueling demand for cement which in turn resulted in a significant increase in emissions from this sector. The previous emission standards (issued in 2004) were updated in 2013 requiring that in-stack emission concentrations for PM and NO_x decline by about 40% and 50%, respectively, and strengthened them further in 2015. Moreover, a range of even stricter regional/provincial standards were designed and implemented in the provinces of Guangdong, Guizhou, Shandong, Hebei, Chongqing, Fujian, and Beijing between 2012 and 2016. These new standards led to significant reductions of emissions from cement production, ranging from over 30% for NO_x and 50% for PM. Current policies and trends also envisage the phasing out of small and older plants, which, together with the strict emission limit values, will likely reduce the impact of this sector on air quality in the future (Tang et al., 2022a). A more detailed information and overview of the industrial regulation for China are available from the Ministry of Ecology and Environment (MEE, 2019b).

In **Japan**, the Air Pollution Control Act, established in 1968, sets national emission standards specifically addressing SO_2, soot, and NO_x emissions for 33 types of facilities, including boilers, dryers and diesel combustion facilities. More stringent standards apply to newly established facilities in nine regions identified as having serious air pollution. Domestic emission standards for coal-fired power plants are set under the Air Pollution Control Law and vary depending on the location of the plant, sulfur content of the fuel used, and the height of the smokestack. In 2023, the Japanese government mandated that all new coal-fired power plants implement emissions reduction measures, mainly addressing CO_2. Plans are in place to close or suspend about 90% of existing coal-fired power plants deemed inefficient, approximately 100 facilities in total. An overview of the emission limit values in Japan for several sectors is available here (in Japanese).

Recognizing growing importance of ozone, since April 2006, the Ministry of the Environment of Japan (MOEJ) has employed a combination of regulatory controls and voluntary approaches to reduce VOC emissions, as a result, the goal to reduce VOC emissions by 30% from 2004 to 2010 was exceeded, with a further 20% reduction observed from 2010 to 2017 (Tripartite Policy Dialogue on Air Pollution Air Quality Policy Report, 2019). Concerning evaporative emissions from fuel retailers, Stage 2 certification was introduced in February 2018, allowing fuel stations that meet stringent emission reduction criteria to be certified. By September 2019, 302 fuel stations were certified. In March 2017, the fuel association adopted a plan to reduce VOC emissions by 30% by 2024 compared to 2004 levels.

The first emission standards for power plant boilers and heat only boilers (HOBs) in **Mongolia** were established in 2008[15]. These standards regulate SO_2, NOx, PM, and CO emissions from coal-fired power plants and HOBs. New emission standards[16] were introduced in 2011, prescribing emission limit values for both existing and new power plants, along with the governmental draft of a new energy conservation law.

Since the introduction of emission standards in the **Republic of Korea**, they have undergone several revisions, including in 1996, 2001, 2007, 2010, 2015, and finally 2020. Effective from January 2020, the Ministry of Environment of the Republic of Korea promulgated the Amendment to the Enforcement Rules of the Air Quality Conservation Act, strengthening emissions standards by 33% for PM, by 28% for NO_x, by 32% for SO_2, and by 39% for ammonia. Additionally, an Air Pollutant Emission-Cap Management System is in force setting a maximum quantity of air pollutants that can be emitted annually in each area. In cases of a business exceeding their assigned limit, a charge is levied and if a business's emissions are below their allocation, the remainder may be transferred to alternative sites of business, or the unused allocation can be saved until the next year (KECO). This emission cap management system has shown some success in reducing air pollutant emissions as has been shown in the real time monitoring data collected automatically at the respective business sites. The Air Pollutant Emission-Cap Management System targets air pollutants such as NOx, SOx, and total suspended particulates (TSP). A Tele-Monitoring System (TMS) has also been installed in the smokestacks of high emitting sources since 2002. Based on the information collected by TMS, the Ministry of Environment mandates improvements and imposes penalties (ex. closedown, charges, etc.) to those who exceed emission standards.

A comparison of emission limit values for power plants across the countries in the region is provided in Table 6, while further information about limit values for other industrial sources and incinerators is provided in the Annex.

15 MNS 5919:2008: Maximum acceptable level and measuring method of air pollutant in exhaust gases from the steam and hot water boilers of TPP and thermal stations

16 MNS 6928:2011: Maximum Acceptable Level and Measuring Method of Air Pollutants in the Exhaust Gases from Steam and Hot Water Boilers of Thermal Power Plants and Thermal Stations

Table 6: **Emission limit values for coal fired thermal power plants (unit: mg/m³).**

Country	Regulation	Types	SO_2	NO_2	PM
China	Emission standard of air pollutants for thermal power plants (GB13223-2011)	Ultra-low emission standard	35	50	10
		National standards (key areas)	50	100	20
		National standards (general area/new build)	100	100	30
		National standards (general area/existing)	200	100	30
Japan	Emission Limits for existing coal power plants	Emissions limits are set on the plant level (1)	200	376	46
Mongolia (4)	MNS 6298:2011	Maximum permissible levels in urban area (2)	400	1100 (V_{daf}<10%)	50
		Maximum permissible levels in rural area (3)	600	650 (10%<V_{daf}<20%)	200
				450 g/m³ (V_{daf}>0%)	
Republic of Korea (5)	Clean air conservation act and act on the integrated control of pollutants	Liquid fuels	20~140 (ppm)	50~250 (ppm)	10~20
		Solid fuels	25~140 (ppm)	15~90 (ppm)	5~20
		Gaseous fuels	10~200 (ppm)	10~180 (ppm)	10~20

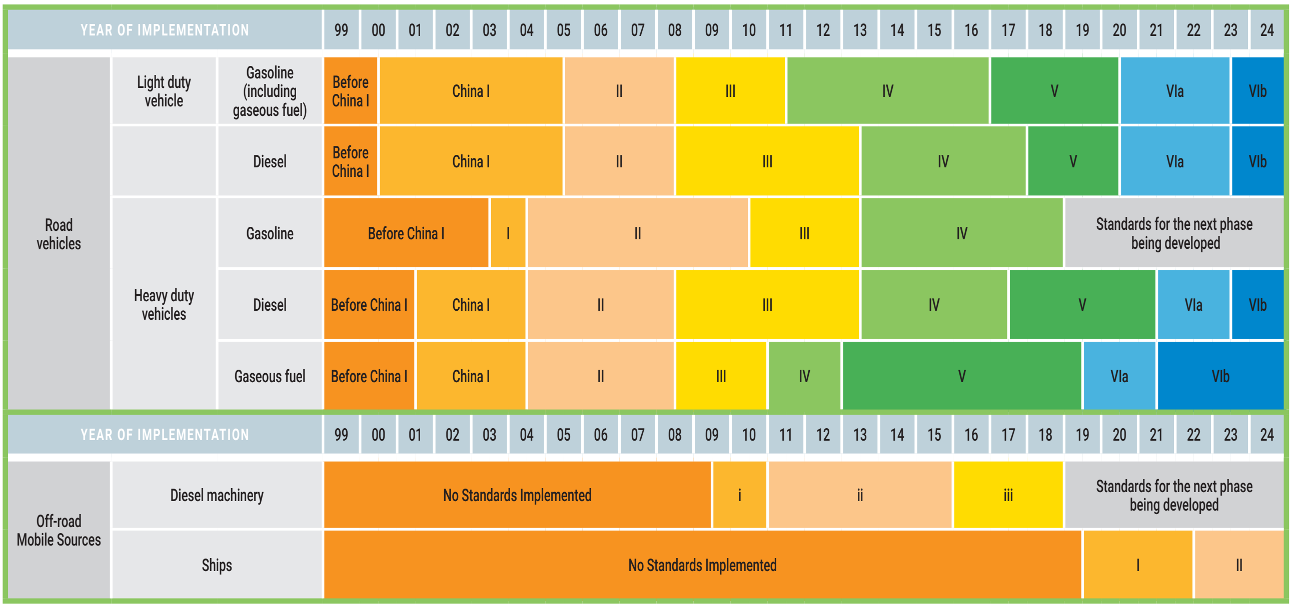
Sources: MEE China (here) MOE Japan (here), Mongolia (here), and ROK Enforcement Decree of the Act on the Integrated Control of Pollutant-Discharging Facilities (here).

Notes: (1) Limit values are based on compilation of actual emissions values – 90th percentile shown here; Mongolia;
(2) Defined as a region with population density between 10-1000/km²;
(3) Defined as a region with population density below 10/km²; (4) zzV_{daf} – volatile content in coal; (5) ROK emission standards apply after 2020.

3.2.2 Mobile sources

To reduce transport-related emissions, **China** has coordinated the 'fuel-vehicle-road' pollution control, conducted a series of effective work in optimizing the vehicle structure, tightened vehicle standards, upgrading the quality of oil products, and promoted development of railway transportation. When the National V standard was implemented for vehicle fuel in 2017, sulfur content was down to 10 ppm from 150 ppm for gasoline and 350 ppm for diesel in 2013. In less than two decades, China has moved from National I to National VI standard for vehicle emissions. In 2016, China unveiled the Limit Value and Measurement Method of Pollutant Emission from Light Vehicles (the sixth stage in China). This National VI standard also includes strict emission limit values for particulate matter, which are especially relevant for diesel vehicles, requiring about 99.5% reduction compared to the National I standard. An overview of the development of the regulation for transport sector in China is provided in Figure 14.

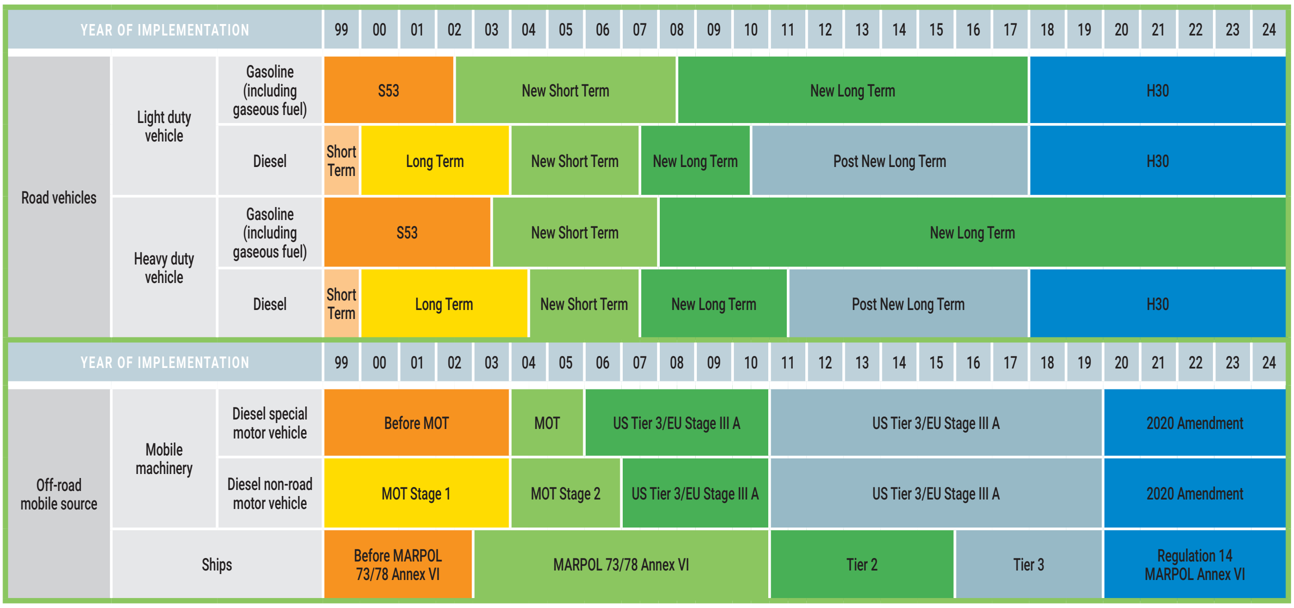
Figure 14: China's mobile source environmental standards system implementation process.



Note: Chinese emission standards for LDV, HDV up to China 6 are based on European regulations with some changes. China 6a and China 6b standards include the same emission limits, but China 6b introduces some more stringent testing requirements which are more stringent than EURO 6 standard.

Japan introduced its first vehicle exhaust emission controls in 1966, targeting CO emissions from gasoline cars. Japan introduced new engine emission standards for light-duty vehicles and heavy-duty engines in the late 1980s, which were relatively relaxed through the 1990s. In 2003, stringent 2005 emission standards were set, making Japan's diesel regulations the strictest globally at that time. These were further tightened in 2009 and aligned with US 2010 and EURO VI standards by 2016 (Dieselnet.com).

Figure 15: Japan's mobile source environmental standards system implementation process.



Source: Ministry of Land, Infrastructure, Transport and Tourism (2022) Emission regulations for new cars (in Japanese).

Note: Light duty vehicles include passenger cars and light vehicles, excluding light cargo vehicles. Special motor vehicles: off-road vehicles registered for operation on public roads (e.g., agricultural tractors, forklifts, or wheel loaders). Non-road motor vehicles: a type of motor vehicle not intended for use on public roads, such as bulldozers or crawler cranes.

In the 1990s and early 2000s, two programmes were implemented to reduce emissions from in-use diesel vehicles: (i) the Law concerning special measures for total emission reduction of nitrogen oxides from automobiles in specified areas and (ii) the Tokyo Retrofit Programme. In 1992, to address NOx pollution from existing vehicle fleets, the MOEJ adopted the Motor Vehicle NOx Law, targeting the elimination of the oldest and most polluting vehicles in designated areas. This regulation was amended in 2001 to include PM emission requirements and was renamed Law concerning special measures for total emission reduction of nitrogen oxides from automobiles in specified areas. Additionally, the Tokyo government, along with several neighboring prefectures, enacted diesel emission regulations mandating either the retrofitting of older in-use diesel vehicles with PM control devices, or their replacement with newer, cleaner models. The retrofit requirements in Tokyo became effective in October 2003.

Currently, the **Mongolian** National Standard (MNS 217:2006) specifying liquid fuels quality for use in vehicles is similar to Euro 2 standard (see Table 7), but the sulfur content of diesel is four times higher than that of Euro 2 standard (Bayasgalan et al., 2018).

Table 7: **Vehicle fuel standard (Unit: ppm).**

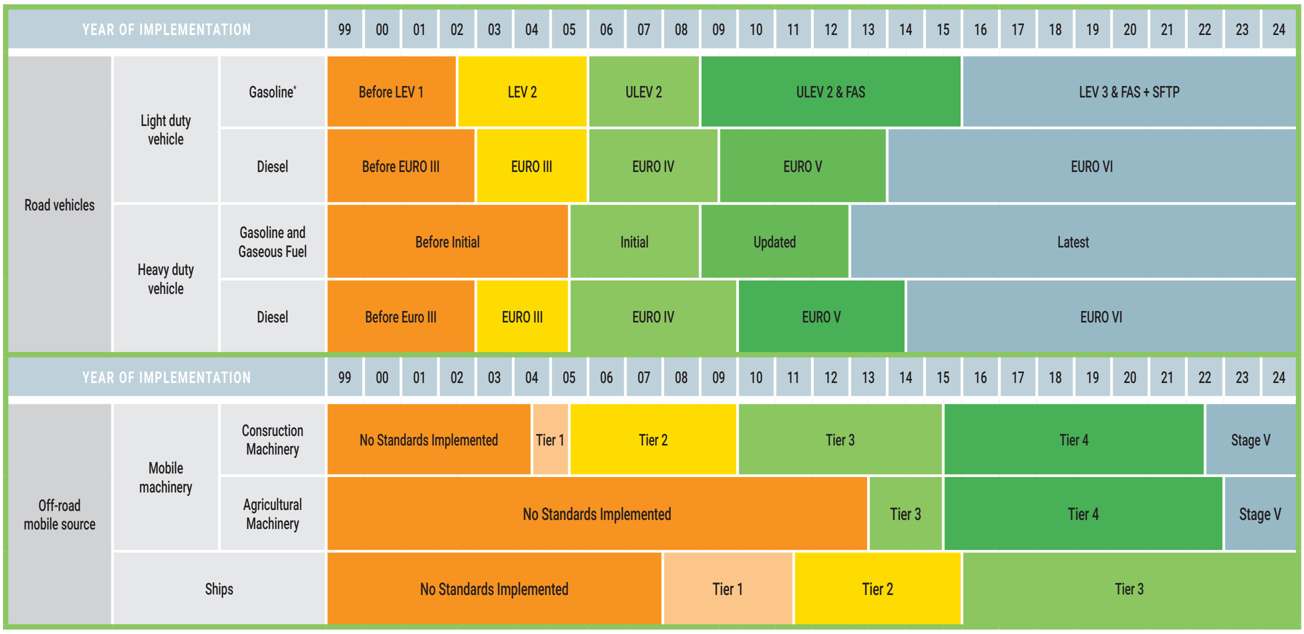
Type	Pollutant	Euro 2	Euro 3	Euro 4	Euro 5	MNS 217:2006
Gasoline	Pb (Lead)	13	5	–	–	10
	S (Sulfur)	500	150	50	10	500
Diesel	S (Sulfur)	500	350	50	10	2000

Source: Bayasgalan et al (2018).

The capital, Ulaanbaatar, is facing severe air pollution and heavy traffic congestion. The exhaust gases from road vehicles were estimated to contribute about 20% of the total air pollution in Ulaanbaatar. In this regard, the city government has tested some technical measures, including the installation of diesel particulate filters (DPF) in the diesel buses used in the capital's public transport services. The National Programme for Air and Environmental Pollution Reduction (2017) set comprehensive measures. These include promoting the import and use of EURO-5 standard fuel, gradually banning the import of non-standard fuels, and enhancing the fuel quality monitoring system.

The **Republic of Korea** has adopted stringent measures to control emissions from diesel vehicles, to encourage the use of eco-friendly cars, and expand restrictions on driving older diesel vehicles. Korea uses a mix of European and US-based standards, depending on the vehicle type: light-duty gasoline vehicles (small- and mid- sized gasoline vehicles) are applied with the US-based standards. For mobile, non-road diesel engines, US standards (Tier 1 ~ Tier 4) have been used for their control, but currently, the more stringent, European standard (Stage-4) has been introduced. Diesel vehicles and heavy-duty trucks and buses adhere to European standards.

Figure 16: Republic of Korea's mobile source environmental standards system implementation process.



Sources: Light duty vehicles, Heavy duty vehicles, Machinery, and Ships: Enforcement Decree of the Clean Air Conversation Act.

Note: Emission standards for light-duty gasoline vehicles are based on US/California standards. ROK diesel machinery engine standards are based on US standards from 2004(2013) and renewed based on European regulation (Stage V) in 2022. ROK regulates marine engine emission standards in Enforcement Decree of the Clean Air Conversation Act Attached Form 35 with NO_x emission only.

As of January 1, 2023, under the revised Enforcement Rules of the Clean Air Conservation Act in September 2022, the Seoul city government announced the Air Pollution Reduction Project, which includes an additional ban of Grade 4 diesel vehicles in central Seoul starting from 2025, with a city-wide to follow in 2030. Grade 5 diesel vehicles are currently banned across Seoul from December to March and year-round in central Seoul.

While more advanced standards have been introduced across the region, it has to be noted that the emission limit values fall short of representing real-life emissions since they only poorly reflect the actual driving conditions – which vary widely across cities and regions – and the detection of high emitting vehicles, including those that are malfunctioning or those that have been tinkered with for example, to increase performance, is not always warranted. Therefore, the actual trends in emissions from transport sources might be different and need to be continuously monitored and evaluated.

3.3 Legal Framework and Air Pollution Control Policies

3.3.1 Legal Framework

According to the **China** Air Quality Improvement Report (MEE, 2019b), since 2013, China has actively constructed a legal framework for air pollution prevention and control, revising and implementing key laws such as the Environmental Protection Law, the Law on the Prevention and Control of Atmospheric Pollution, the Law on Environmental Impact Assessment, the Environmental Protection Tax Law, the Law on Prevention and Control of Desertification, and the Law on Energy Preservation. In addition, local governments across 31 provinces, municipalities and autonomous regions on the Chinese mainland have also promulgated or revised supporting regulations with some regions like Zhejiang, Anhui and Chongqing releasing guidelines for the prevention and control of motor vehicle pollution.

MEE is working closely with the Supreme People's Court, the Supreme People's Procuratorate, the Ministry of Public Security and the Ministry of Justice for joint administrative and judicial enforcement at the national level.

Government departments have jointly issued the Interpretation of Issues Concerning Applicable Laws in Dealing with Criminal Cases of Environmental Pollution, stepping up efforts to crack down on pollution crimes. Since 2015, the amount of administrative penalty fines imposed has increased year by year. In 2018, China issued penalties in 186,000 administrative cases, 1.9 times the figure in 2015, with total fines of 15.28 billion yuan, 3.6 times the figure in 2015.

Japan has a comprehensive legal framework for air pollution control that has evolved significantly over the decades. The Basic Law for Environmental Pollution Control was enacted in 1967 and the Air Pollution Control Law was enacted later in 1968, while Japan's Environment Agency was formed in 1971 and the Ministry of the Environment was created out of the Environmental Agency in 2001 (Wakamatsu et al., 2013). The Japanese government set initial environmental quality standards (EQSs) in the early 1970s and then added standards for tetrachloroethylene (1997), dioxins (1999), and dichloromethane (2001); a standard on $PM_{2.5}$ was added in 2009 (MoEJ, 2023a). Most of the responsibility for implementing relevant air pollution laws and regulations falls to the Ministry of the Environment. However, in some instances, prefectural governments can make requests to the Ministry of Environment or the Cabinet to take actions on regionally important issues (Air Pollution Control Act, 1968).

The Government of **Mongolia** has made significant efforts to reduce air pollution, especially since 2010, when air pollution levels in the capital threatened public health (UNDP, 2019). In response, the Parliament adopted the Law on Air in the Capital City in 2011 and the Law on Air of Mongolia in 2012. The Law on Air Pollution Fee (2010) regulates fees for air polluters, including coal mining entities, organic solvent producers and importers, transport facilities, vehicle owners, and major stationary pollution sources. This law outlines fee items, rates, exemptions, and payment provisions across its 10 Articles, and has been amended multiples times.

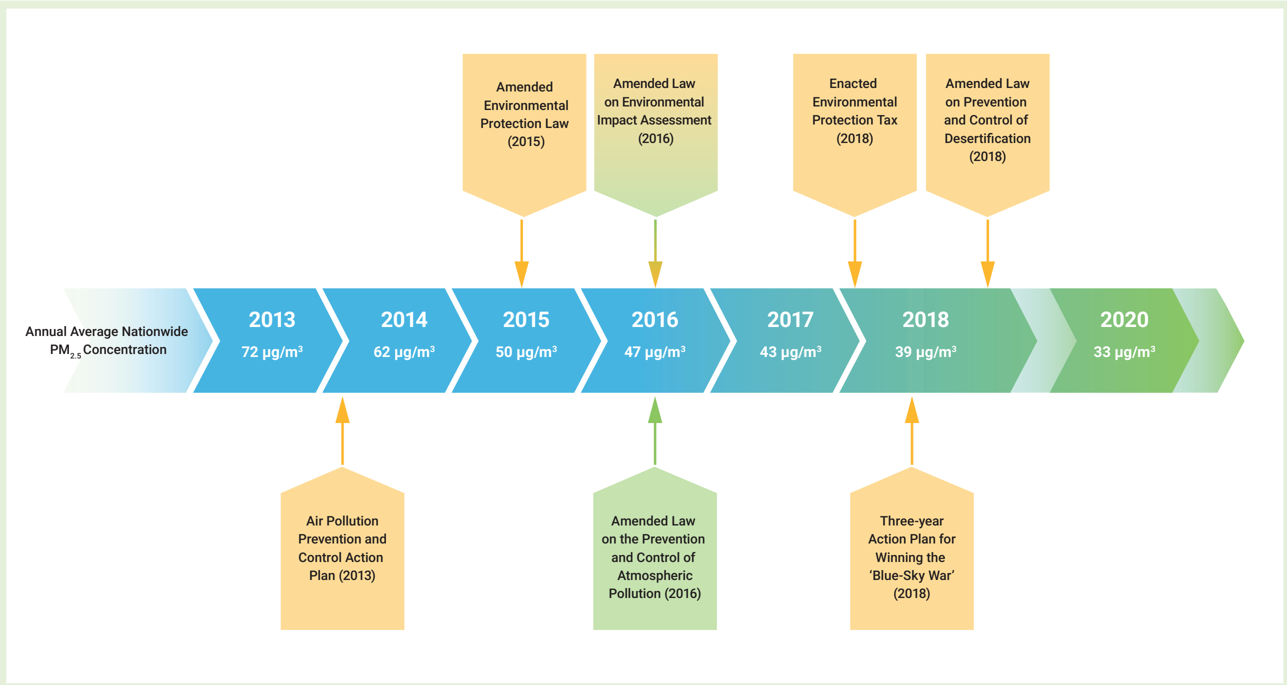
The revised Law on Air of 2012 serves as a primary legal instrument for air protection, pollution prevention, mitigation, and control. The Law on Air in the Capital City establishes fines for non-compliance and offers tax rebates to those who reduce pollution. Article 4 of this law details the phased action plan for reducing air pollution in Ulaanbaatar (Koo et al., 2020).

The **Republic of Korea**'s air quality management policy has evolved significantly from basic pollution control measures in the 1960s to comprehensive, integrated approaches in recent years. Key milestones include the enactment of the Air Quality Preservation Act in 1986, which provided a comprehensive legal framework for air quality management by introducing regulations on industrial emissions and establishing air quality standards. In 1991, the government introduced the Special Act on the Improvement of Air Quality in Seoul Metropolitan Area, targeting air pollution in this densely populated region. The Clean Air Conservation Act of 2005 further strengthened vehicle emission regulations and promoted the use of cleaner fuels and technologies. In 2013, the Special Act on the Reduction and Management of Fine Dust in 2013 focused on reducing $PM_{2.5}$ levels through stringent emissions standards and public awareness campaigns. The Special Law for Mitigating Particulate Matter Pollution in 2019 defined the PM pollution in Korea as a 'social disaster' and greatly increased the national budget for urgent PM control policies, raising the budget by about 1.6 billion USD in 2019 (Park et al., 2020).

3.3.2 Air Pollution Control Policies

The Chinese government has implemented a series of strict air pollution control policies since 2013, and the development of national air pollution control policies has been driven by explicit air quality objectives during this period. In September 2013, the State Council of **China** promulgated the **Air Pollution Prevention and Control Action Plan** (2013-2017), which pointed out that by 2017, the national concentration of respirable particulate matter in cities at the prefecture level and above would drop by more than 10% compared to 2012, and $PM_{2.5}$ concentration reductions of 25%, 20%, and 15% in 2017 compared to the level in 2013 were mandated in 3 key regions: The Beijing-Tianjin-Hebei region (BTH), the Yangtze River Delta (YRD), and the Pearl River Delta region (PRD), respectively. It is followed by the Three-Year Plan from 2018 to 2020, the second phase of the Action Plan, which required further nationwide air quality improvements, that is, compared with 2015, the concentration of $PM_{2.5}$ in non-compliant prefecture-level and above cities would drop by more than 18% by the end of 2020. The timeline, key legislative acts, as well as the change in annual average (nationwide) concentration of ambient $PM_{2.5}$ are shown in Figure 17. By 2020, the concentrations dropped to about 33 μg/m^3, i.e., more than a 50% reduction since 2013 and in compliance with the national standard. Moreover, the Chinese government has also set the target of reducing annual mean $PM_{2.5}$ concentrations by 10% between 2020 and 2025 in its 14th Five-Year Plan, which could be regarded as the third phase of the Action Plan.

Figure 17: Timeline of key steps in air quality legislation in China.

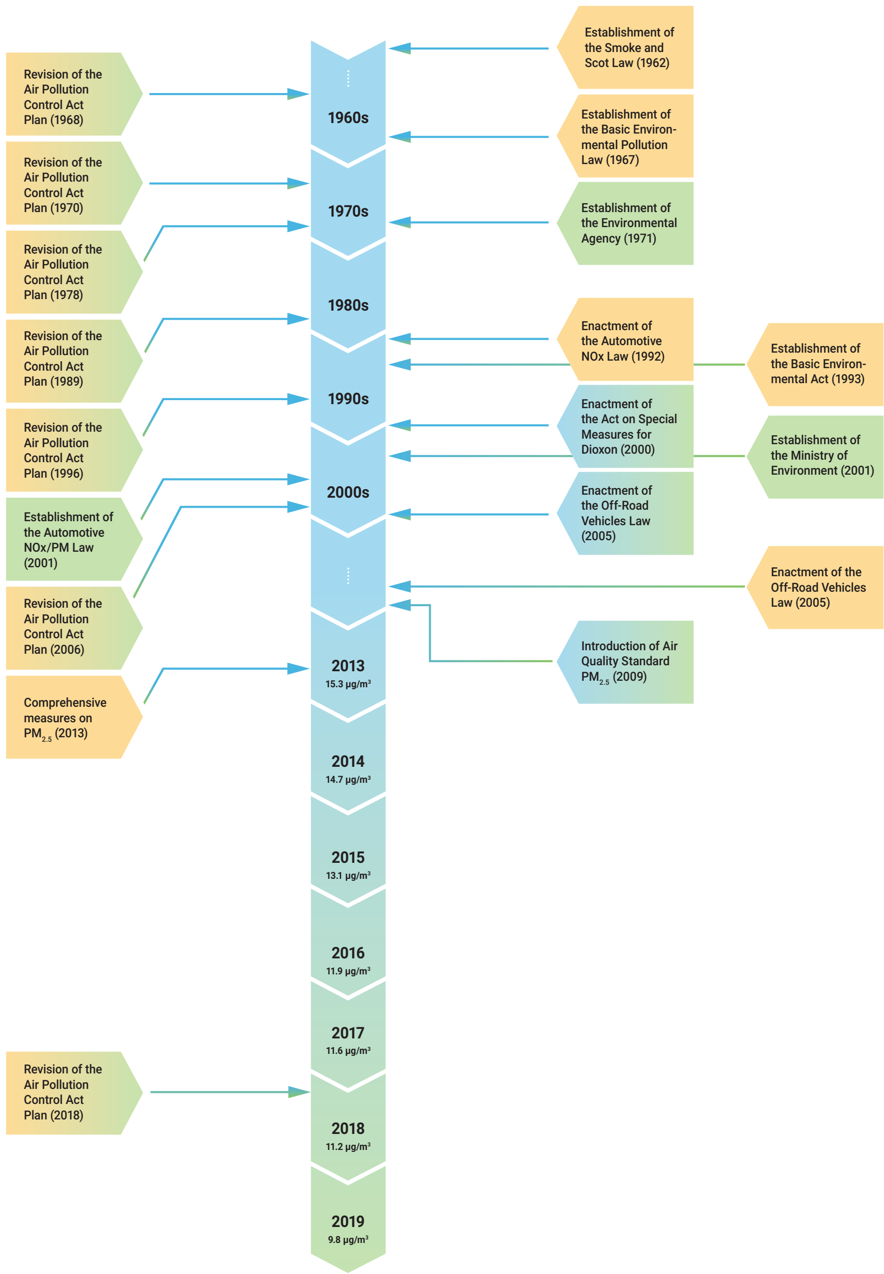


Through implementing **the Comprehensive Measures on $PM_{2.5}$ (2013) of Japan,** the rate of achieving the annual $PM_{2.5}$ standard (15μg/m^3) increased from 37.8 percent in 2014 to 93.5 percent in 2018. According to the Japanese Ministry of the Environment's press release[17] on the status of air pollution for FY 2020, the Ministry of the Environment Japan (MOEJ) will continue to comprehensively promote measures to control emissions from factories and workplaces, automobile emissions, and the spread of low-emission vehicles to achieve and maintain environmental standards.

With regard to $PM_{2.5}$ and Ox, based on the interim report (March 2015) of the Expert Committee on Fine Particulate Matter, etc. of the Atmosphere, Noise and Vibration Subcommittee of the Central Environment Council, the enhancement of emission control measures is being considered and implemented for various air pollutants that contribute to $PM_{2.5}$ and O_x. In January 2022, MOEJ formulated the 'Working Plan for Comprehensive Measures against Photochemical Oxidants to Cope with Climate Change and Improve the Atmospheric Environment' which appears necessary owing to the role photochemical oxidants play in air pollution and climate change. MOEJ will continue its efforts to clarify the phenomena and improve information that will serve as the basis for comprehensive measures and will consider additional measures according to the progress of these efforts. The timeline, key legislative acts, as well as change in annual average (nationwide) concentration of ambient $PM_{2.5}$ are shown in Figure 18.

17 https://www.env.go.jp/press/110805.html

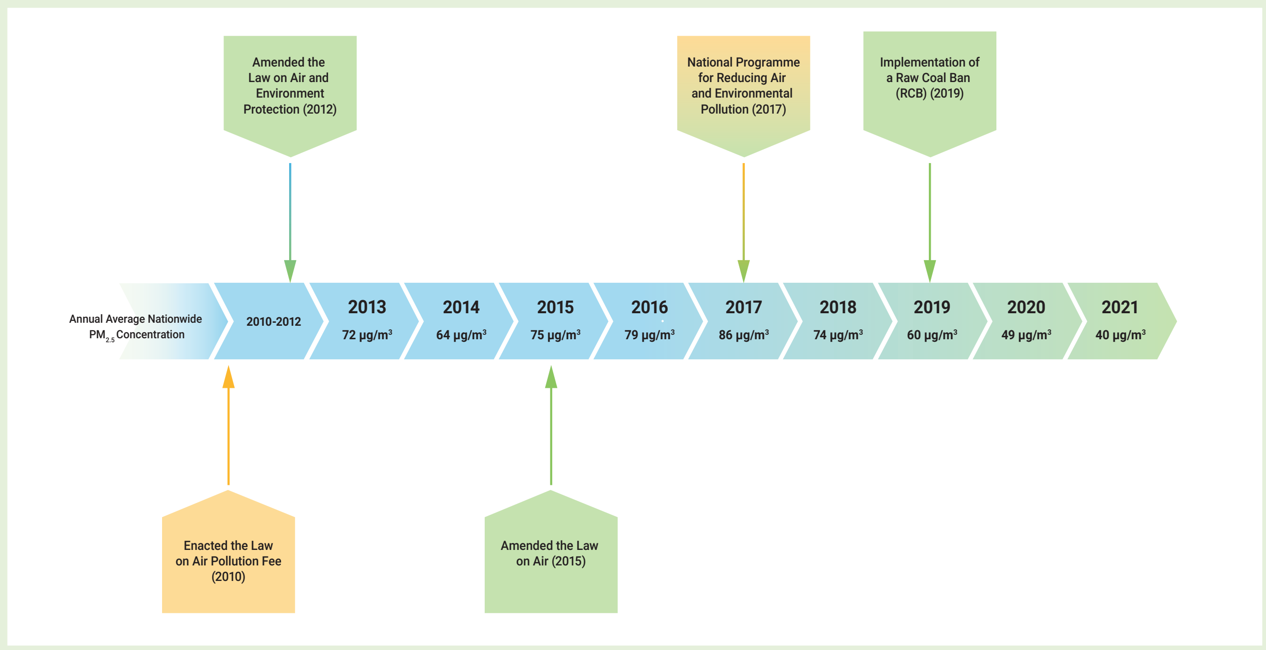
Figure 18: **Timeline of key steps in air quality legislation in Japan.**



Mongolia's air quality management policy has evolved in response to the growing recognition of air pollution as a significant environmental and health challenge, particularly in urban areas like Ulaanbaatar. Key initiatives include the adoption of the **National Programme for Air and Environmental Pollution Reduction (2017)**[18] to decrease air pollution by 80% by 2025 with measures including the prohibition of unprocessed coal use and enhancements in urban planning and infrastructure and the introduction of laws and regulations to regulate air quality and pollution, and the implementation of targeted programmes to reduce pollution and improve infrastructure. The timeline, key legislative acts, as well as the change in annual average (nationwide) concentration of ambient $PM_{2.5}$ are shown in Figure 19.

18 ХӨТӨЛБӨР БАТЛАХ ТУХАЙ /Агаар, орчны бохирдлыг бууруулах үндэсний хөтөлбөр/ (legalinfo.mn) (in Mongolian)

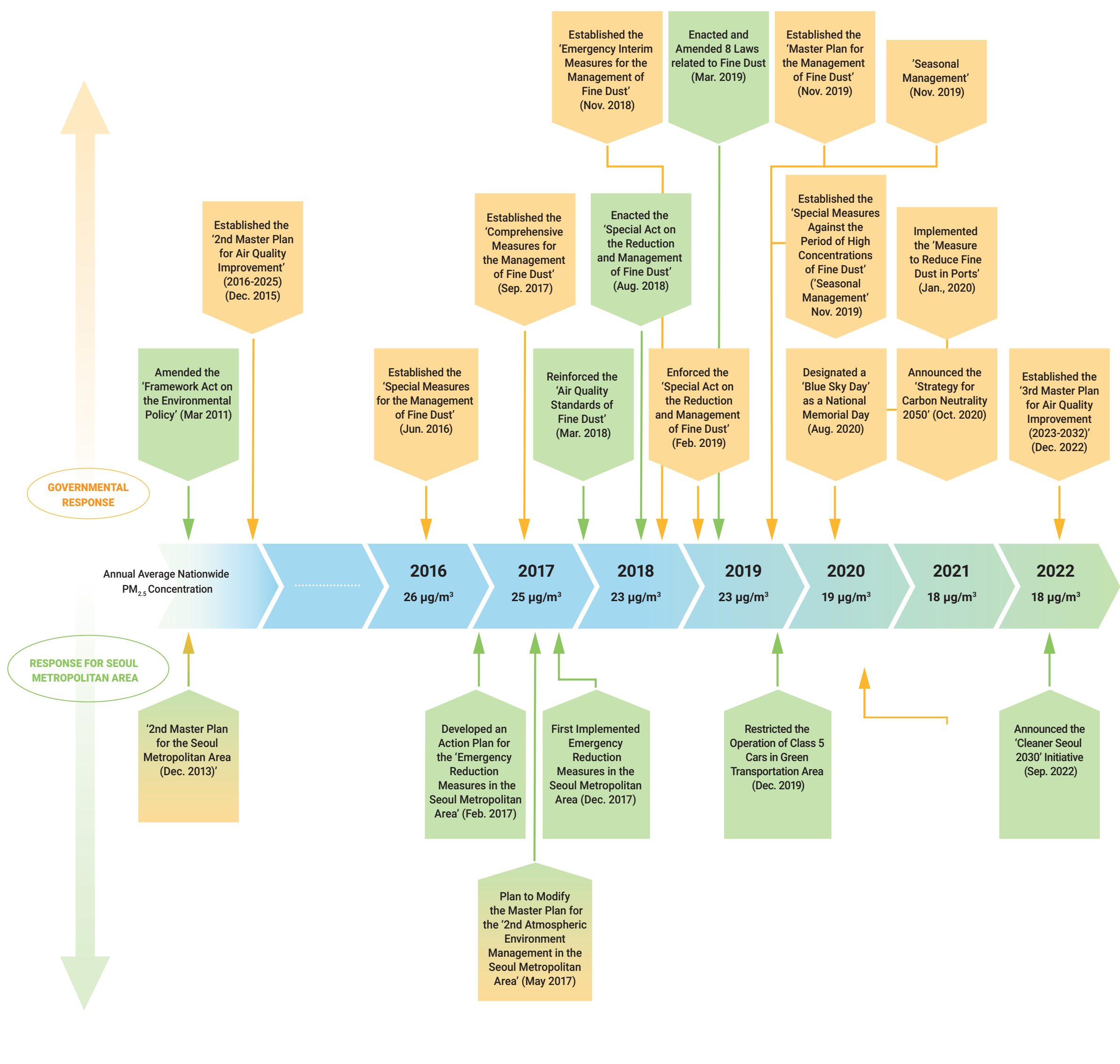
Figure 19: **Timeline of key steps in air quality legislation in Mongolia.**



To tackle air pollution in Ulaanbaatar, which is attributed to raw coal consumption, the government issued Resolution No. 62 in February 2018, banning the domestic use of raw coal. This ban became effective in six out of the nine districts in Ulaanbaatar in May 2019. As an alternative, the government introduced 'refined coal briquettes' at a 'subsidized price' comparable to the price of raw coal. Besides the raw coal ban, the government also subsidizes energy-efficient technology installations for HOBs and their chimney scrubbers and promotes public awareness about raw coal control and consumption and instructions for using briquette fuel (Ganbat et al., 2020).

In the **Republic of Korea**, the air quality management policy has evolved significantly from basic pollution control measures in the 1960s to comprehensive, integrated approaches in recent years. Key milestones include the establishment of legal and institutional frameworks, the introduction of specific regulations for major pollutants, the implementation of market-based mechanisms, and the integration of air quality management with climate change policies. The country's commitment to improving air quality is reflected in its continuous enhancement of regulations and adoption of advanced technologies. For instance, the introduction of the fine dust forecast and warning system in 2014 enabled citizens to directly check air quality information around their residences and workplaces. A combination of media focus on human health impacts from exposure to $PM_{2.5}$ and access to real-time data on air quality (in 2014 national $PM_{2.5}$ limit values were regularly exceeded), resulted in growing public interest and increasing public pressure on the government to take action to improve air quality. In response, the government has announced new fine dust policies every year from 2016 to 2019.

Figure 20: **Timeline of key steps in air quality legislation in Korea.**



Source: modified from a figure provided by Seungmin Lee (KEI).

In particular, the **Comprehensive Plan for the** Management of the Fine Dust[19] (2020-2024) (hereinafter referred to as the 'Comprehensive Plan') established in 2019, is a comprehensive and systematic mid- to long-term plan to improve air quality addressing fine particulate matter ($PM_{2.5}$). The Comprehensive Plan encompasses over 100 policy measures in each sector with the goal of achieving the concentration target for 2024 (nationwide annual average $PM_{2.5}$ concentration of 16 μg/m³). Thanks to the public interest and the government's efforts to reduce emissions, Korea's PM concentration has steadily decreased as shown in Chapter 2. As of 2021, it still falls short of the national air quality standards, but the situation has clearly improved in less than 10 years and if the trend continues, the standards will be met within the next few years. The timeline, key legislative acts, as well as the change in annual average (nationwide) concentration of ambient $PM_{2.5}$ are shown in Figure 20.

19 In Korean. For outline of the Comprehensive Plan, see Annex

CHAPTER 4

IDENTIFICATION OF CHALLENGES AND SUCCESSES

Key findings

- There are several economic, technological, institutional, and social barriers to progress implementation of policies addressing air pollution. There is limited and varying experience in overcoming these barriers.
- All countries struggle with managing emissions of VOCs and NO_X, which are crucial for ozone formation.
- Recent years have seen significant progress in implementation of the clean energy agenda, with a growing share of renewable energy and new energy vehicles (NEVs).
- Urban air pollution is significantly influenced by sources outside city boundaries, necessitating regional cooperation and integrated policies involving multiple stakeholders within the country.
- Despite the significant progress in the reduction of air pollution, levels still exceed WHO guidelines in many areas. Coordinated national policies integrating air quality, climate and energy goals are essential for achieving long-term targets.
- Climate change is expected to adversely impact air quality by increasing heatwaves and wildfires, leading to higher levels of ground-level ozone and $PM_{2.5}$.
- Frameworks addressing Sustainable Development Goals (SDGs) have been developed and are being implemented, offering potential solutions to address various challenges.

Recommendations

- Develop and implement further strategies to control ozone and $PM_{2.5}$, considering their complex photochemical interactions and mutual impacts.
- Establish collaboration among local and national stakeholders as well as among countries in the region, to efficiently address existing barriers in effective policy implementation.
- Promote regional and stakeholder cooperation (across jurisdictions and key stakeholders representing pollution sources and society) to address urban and rural pollution, taking into account both local and regional sources of pollution within the country.
- Develop integrated national policies addressing air quality and climate change challenges, exploring synergies and enhancing cost-efficiency.
- Strengthen international collaboration to achieve long-term air quality and climate targets, reducing health, ecological, social, and economic burdens across North-East Asia.

This chapter illustrates the challenges and successes countries in Northeast Asia have experienced regulating air pollution. In so doing, it sheds light on opportunities for mutual learning and knowledge exchange that can build a foundation for regional cooperation on air quality.

4.1 Understanding Common Challenges

The starting point for the chapter is that regulating air pollution is rarely easy. In fact, most countries encounter difficulties when controlling air pollution. This section begins by outlining some of the key economic, technological, institutional and social challenges to managing air quality. It then demonstrates how countries in Northeast Asia have overcome these challenges.

The first such set of challenges is **economic or financial** in nature. These challenges can stand in the way of investments in pollution abatement technologies or slow transitions to cleaner technologies. While economic challenges can be difficult for all emission sources, they may be particularly difficult for small and medium sized industries given the lack of operating capital to invest in emissions controls. They may also be challenging for operators of resource constrained vehicle owners, especially if the owners operate older vehicles with higher emissions.

A second set of challenges are **technological** in nature. Technological impediments involve a lack of access to pollution control technology. They may also involve limited information about what are sometimes known as the best available control technologies. A related point is that just because control technologies are available in one country does not mean they are available everywhere; access to technologies and constraints on technology transfer can hamper the diffusion of technologies. Last but not least, technological constraints may also apply to what are referred to as enabling technologies. These can include critical infrastructure such as charging stations for electric vehicles or continuous emissions monitoring systems for stationary sources.

A third set of challenges pertain to **institutional arrangements**. In this case, some of the more common barriers involve limits on interagency coordination—for instance, between agencies that are responsible for the environment, industry, and transport sectors. An additional layer of difficulties can involve coordination between levels of decision making. Most notably, some local governments may find it difficult to follow national policies, while some national level agencies may struggle to grasp on-the-ground implementation realities. Both vertical and horizontal coordination issues can be aggravated by shortages of capacity. In some cases, there may be a shortage of staff to working on air pollution. In other instances, the issue may be that assigned staff lack the technical training or experience to manage air pollution.

A final set of challenges could be classified as being **social**. Under this category falls the lack of knowledge of different social segments of the harms of air pollution. Social barriers may also include the lack of awareness raising mechanisms that would alert exposed populations to those harm. Yet another example of social barriers involves opportunities for different groups or the public to participate in air quality planning.

4.2 Barriers to Implementation of Policies

While China, Japan, Mongolia, and the Republic of Korea share common challenges in managing air quality, such as addressing O_3 pollution, balancing economic growth with environmental protection, and integrating air quality with climate change policies, they also face unique country-specific issues. These challenges include institutional frameworks, financial constraints, local governance, and urban planning. Effective air quality management in these countries requires both common regional (within country) strategies and tailored national approaches to address their distinct challenges.

This section further highlights institutional and financial barriers, emphasizing the importance of systematically understanding other challenges and barriers. These include, for example, the coupling of economic and environmental issues and the resulting priority setting. A better understanding of the implications of decisions made – and priorities set – (set priorities) at different levels, including their socio-economic dimensions, would be important. Collaboration between scientific and political institutions across the region could support open discussions and dialogue about the benefits of stronger environmental policies addressing current and emerging air quality and climate challenges. Although there are examples of knowledge informed policies at the regional level, they often focus on the capital cities/regions and are not adequately supported or shared with other regions within the countries. This lack of adequate support leads to a poor understanding of the role of economic activities in the formation of pollution and its impact, including social inequalities with respect to exposure.

Finally, the transition to a decarbonized energy sector is set in the national plans/visions to achieve carbon neutrality, however, institutional frameworks need further development for efficient policy implementation. Another challenge/barrier is addressing all greenhouse gases in policies, as CO_2 typically receives more focus, while the urgency of reducing methane is not fully recognized or implemented. Methane reduction is essential in the near term and must address all key sectors including fossil fuels, waste, and agriculture. Such an approach, also coupled with an understanding of its impact on air quality, would result in multiple co-benefits across pollution domains, economic sectors, and populations, and contribute to achieving a number of Sustainable Development Goals (SDGs).

4.2.1 Institutional barriers and challenges

China's approach features centralized target-setting and top-down implementation with policies enforced through vertical administrative lines (Wang, 2020). The central government has gradually decentralized its financial and planning systems, assigning law enforcement responsibilities to local governments. The Ministry of Ecology and Environment (MEE) replaced the former Ministry of Environment and Protection (MEP) in 2018 to enhance its authority in developing more coherent and integrated approaches to pollution prevention and control.

The command-and-control approach has delivered marked emission reductions and improvements in air quality, but they have come at a significant economic and social cost. China has an opportunity to place more emphasis on market-based approaches in order to sustainably reduce pollution at a lower cost and ensure the long-run durability of the actions (Greenstone et al., 2022). Such approaches have been successful in other parts of the world but still require political support demonstrating commitment and focus to 'clean air'.

The Ministry of the Environment (MOE) of **Japan** exclusively oversees the setting of both ambient air quality standards and emissions limit values, the formulation of the total emissions reduction policies, and the regulation of specific facilities (OECD, 2020a). Some policies are handled by multiple ministries.

For instance, the Ministry of Economy, Trade and Industry (METI) develops the Basic Energy Plan, which sets targets for the adoption of clean vehicles and renewable energy generation. The Central Environment Council (CEC), an advisory body to the MOE and other ministries, reviews all laws and programmes that may impact the environment. Local governments have limited policymaking authority regarding air quality and are primarily responsible for monitoring and enforcement. However, Tokyo has taken proactive measures to reduce air pollution by imposing diesel vehicle regulations ahead of the central government. Tokyo city has also implemented emissions controls for industrial plants and introduced a subsidy programme to encourage the purchase of electric cars.

Mongolia's air pollution control involves multiple institutions. Parliament oversees legislation and budget approval, while the Government executes programmes and coordinates policy through the National Committee on Reduction of Air and Environmental Pollution (NCRAEP). The Anti-Air Pollution Fund finances air protection activities and supports clean technology adoption. The Ministry of Environment and Tourism (MET) implements state policy, sets standards, manages monitoring, and controls emissions, with the National Agency for Meteorology and Environmental Monitoring (NAMEM) providing regular environmental quality updates. Until 2023, the NCRAEP coordinated and implemented activities at the ministerial level. Since then, its responsibilities have been transferred to the municipal level, where coordination faces challenges. Additionally, budgetary and financial difficulties complicate the implementation of comprehensive policies at both national and local levels.

The necessity for a comprehensive strategy involving stakeholders and local governments has been recognized, e.g., Ulaanbaatar shall be addressing its pollution by considering both the city and the surrounding residential areas, although the set of solutions/measures differs. While it has been recognized that only joint action can bring significant benefits, institutionalizing and financing such coordinated efforts remains a challenge. An example could be a lack of coordinated urban planning and transport management leading to mounting congestion and associated pollution problems as well as economic losses. Due to poor urban planning, the road infrastructure cannot handle the increased traffic and public transport is poorly developed. Another area where coordination across policy/stakeholder domains would be essential is related to the heating sector and sustainable energy supply; while electrification of 'Ger' areas is recognized as a priority, the higher costs of electricity supply (compared to coal), lack of additional plant capacity to produce more electricity, and the high levels of greenhouse gas emissions from Mongolia's coal-dominated electricity grid complicate the transition. A systematic approach is required to accelerate energy efficiency improvements in ger areas, pilot and deploy heat pumps, and better target electricity subsidies. Carbon emissions from electricity generation can be addressed in parallel through expanding wind and solar generation, adding energy storage, and using natural gas as a transition fuel (ADB, 2022).

Korea has a centralized system with significant devolution of policy implementation to provincial and local governments. The Ministry of Environment oversees policy development and supports local environmental management. Most local authorities lack fiscal autonomy and rely on financial transfers from the central government. The degree of fiscal autonomy is defined as the ratio between local tax revenue and the local budget, with the gap covered by central government subsidies. Despite improved local administrative capacity, funding and resource constraints hinder effective policy implementation, particularly outside the Seoul Metropolitan Area. Local governments, responsible for permits and enforcement, face challenges in balancing economic growth with environmental protection. Inspection quality and enforcement have improved through risk-based planning and cross-checks between central and local governments, though resource limitations persist (OECD, 2017).

Recognizing the problem of compliance with the national ozone standards and lack of sufficient monitoring data, especially for background areas, MOE developed incentives and announced strategies aiming at reduction of precursor emissions of NOx and NMVOC. However, smaller businesses and local governments have encountered technical and financial difficulties in managing these pollutants. There is a need for systematic management of business sites through inventory advancement. Practical reductions in emissions at workplaces are necessary through an emissions allowance system. Establishing a foundation for managing NOx and VOCs at workplaces in connection with ozone measures is also essential.

In the agricultural sector, the ROK government has increased enforcement measures against illegal opening burning activities. However, crop residue burning remains a common practice in the fields post-harvest to manage the large amounts of leftover crop material and to enrich the soil with nutrients, such as those found in ashes (Han et al., 2022).

Addressing emissions from non-road machinery, i.e., construction and agricultural machinery, has been recognized as a priority[20], however, the management of these pollution sources has been notably insufficient compared to road transport,[21] suggesting a significant impediment to achieving substantial reductions in overall mobile source emissions. According to the Third Comprehensive Plan (2023), the measures for non-road emission sources are currently limited to specific types of agricultural and construction machinery. It is therefore necessary to strengthen emission standards for these machines and expand support for the distribution of zero-emission vehicles to effectively reduce their impact on air quality.

Finally, inefficiencies in cap & trade mechanisms and emission facilities management are also linked to the institutional and technical setup of thereof. The cap-and-trade system allocates annual emission allowances for NOx and SO_x to large facilities, requiring them to stay within these limits and permitting the trade of any surplus allowances. The primary issue with the air pollutant cap-and-trade system was the excessive allocation of emission quotas to each business site, removing the incentive to reduce emissions and hindering the activation of emissions trading. During the first allocation period (2008-2012), over-allocation was so significant that allocated air emissions were about 50% higher, failing to motivate companies to lower their emissions.

4.3 Lessons and Good Practices

This section exemplifies how domestic policies and regulations have overcome the above hurdles. Nearly all the examples discussed herein involve the generation of energy for power, industry, and transport. While most of the examples were meant to improve air quality, many also mitigated climate change. In fact, this section shows scope to share experiences with co-benefits.

4.3.1 China

China has been regulating air pollution for close to four decades. For example, it passed its first Atmospheric Pollution Control Law in 1987. Since 2004, the Chinese government has provided subsidies to retrofit smokestacks in coal-fired power plants with equipment to remove sulfur dioxide (Lewis, 2023). The turning point in the air quality policy was, however, the 2013 National Air Pollution Prevention and Control Action Plan, which many provisions sought to transform the energy structure in China. This Plan featured the concept of 'total coal consumption control' that gave rise to a slate of complementary reforms and drove down coal use (MEE, 2021b). Those complementary reforms included coal consumption control targets in key areas, restrictions on low quality coal, and the shut-down of small-scale coal boilers.

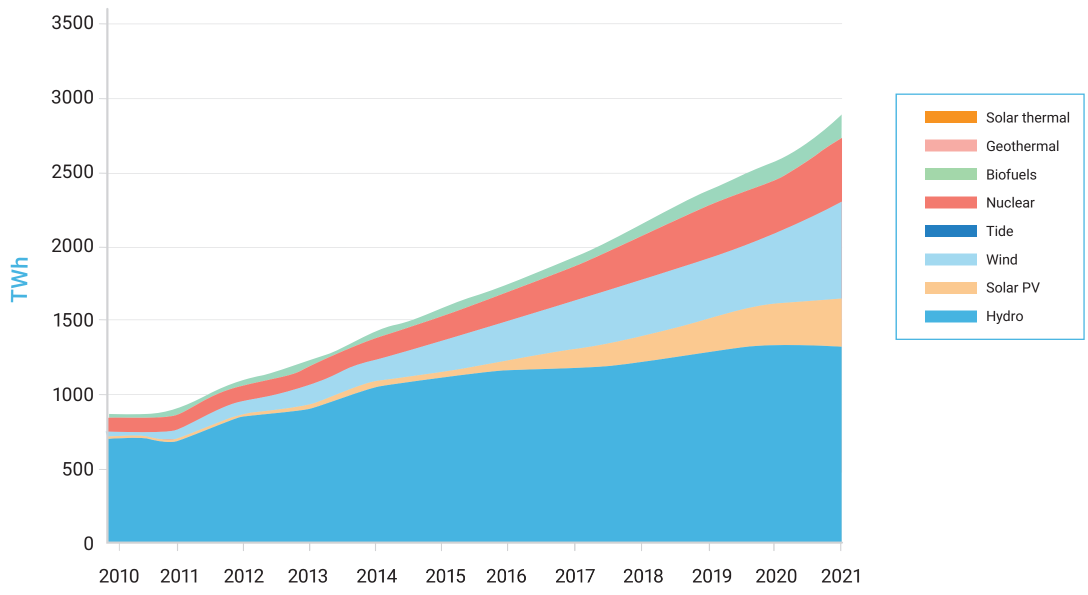
20 Analysis of Air pollutant emissions in ROK: https://www.kier.re.kr/tpp/tppBoard/view/23?menuId=MENU00962, accessed on 26th April 2024
21 Report of Ministry of Economy and Finance available at: https://www.korea.kr/archive/expDocView.do?docId=33457, accessed on 29th April 2024

The focus of the latter programme was to eliminate such boilers in built-up areas and to prohibit the installations of new small boilers. A few years later, China would follow these restrictions with standards on bulk coal for household use and briquettes as well as a clean heating programme in northern China (MEE, 2019b). The measures further tightened standards for industrial emissions, and shut down small, inefficient power generators and industrial operators (Lewis, 2023).

Some of the key policies following the National Action Plan and driving the reduction of air pollutants emissions in the period 2013 and 2017, primarily SO_2, NO_X, and $PM_{2.5}$, were ever stricter and gradually tightened industrial emission standards that required installation of efficient end of pipe measures in coal power plants and several key polluting industries, the phasing out of small and outdated industrial capacities as well as small coal power plants, promotion of clean fuels in the residential sector, and strengthened vehicle emission standards (e.g., Zhang et al., 2019). More details are provided in sections 3.2.1 and 3.2.2.

The National Air Pollution Prevention and Control Action Plan along with other policies also helped to support the diffusion of renewables and cleaner fuels. By the end of 2022, renewable energy capacity exceeded 1200 TW (terawatts), reaching 1213 TW and accounting for 47.3% of the country's total power generation capacity. Further, by the end of March 2023, China's installed non-fossil energy generation capacity accounted for slightly more than half of the total installed capacity. The strong growth of solar and wind capacity in the last decade has played an important role and represented in 2021 about a third of total non-fossil electricity generation in China (Figure 21) and a large share (about 30% in 2018) of total global capacity (see Figure 37 in the Annex). Supporting access to clean fuels, there has also been a growing reliance on natural gas due to the 150 billion cubic meters increase in one-time gas transmission capacity and expanding gas network.

Figure 21: Development of the low-carbon electricity generation in China since 2010.



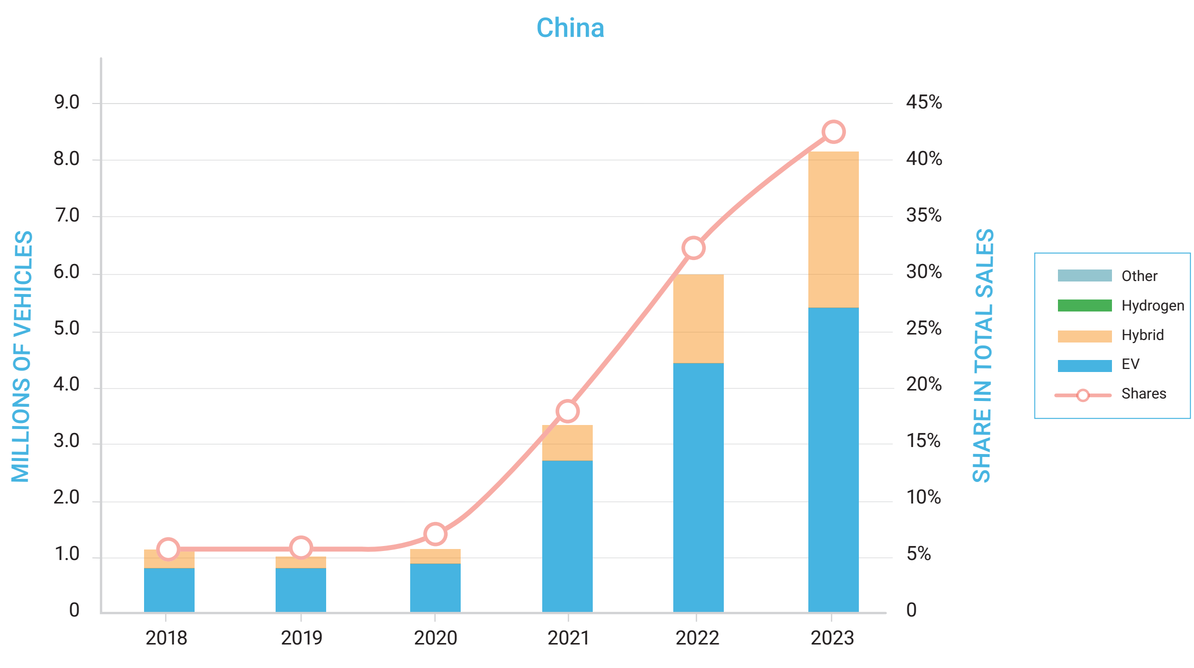
Source: IEA Electricity Information https://www.iea.org/data-and-statistics/data-product/electricity-information

China has prioritized the ultra-low emission and energy-saving coal-fired power plants (ULE). By the end of 2022, coal-fired plants had completed the ULE transformation of 1,060 TW, accounting for 94.6% of the installed capacity of coal-fired plants.

China has made efforts to tackle air pollution by transforming/upgrading industries and improving the industrial structure (MEE, 2019b). These efforts have led to the closure of backward production facilities and increased tertiary industry. Often the focus has been on larger industries. Between 2013 and 2017, for instance, steel production was slashed by 170 million tons. Some of these efforts have targeted small and scattered enterprises such as a cleanup and rectification campaign in Beijing-Tianjin-Hebei and neighbouring areas.

While introduction of fuel and emission standards for road and non-road vehicles is an important part of the efforts to improve air quality (see Chapter 3), policies addressing transformation in transport sector, including promotion of new energy vehicles (NEV)[22] and expansion of railway networks with increasing capacity of fast trains play key role in reducing both air pollutants as well as greenhouse gas emissions. By the end of 2012, only 17,000 NEVs were on the road in China. Since 2015, China has eliminated a total of more than 40 million old motor vehicles and has become the world's largest electric passenger car market, accounting for half of the global market. In 2023, China recorded 8.1 million NEV registrations (Figure 22). This surge in NEV sales was a key factor in the overall growth of China's car market, which saw a 5% increase despite an 8% decline in sales of conventional vehicles with internal combustion engines. Notably, 2023 was the first year China's NEV industry operated without the national subsidies that had supported it over a decade although tax breaks for EV purchases and other non-monetary incentives were extended. Local government support and investments also continued to significantly influence the EV market.

Figure 22: Growth of new energy vehicle ownership in China between 2015 and 2023.



Source: IEA (2024)

22 NEVs include here battery electric vehicles (EV), hybrid (including also plug-in hybrids) and hydrogen (fuel cell) vehicles.

4.3.2 Japan

Japan's effort to clean the air traces back several decades when a series of pollution crises set off public concerns that motivated the national government to adopt legal and regulatory reforms. Early evidence of this aggressive response can be found in the Basic Environmental Pollution Control Law in 1967. This foundational law sought to clarify which entities were responsible for emissions while also promulgating an initial set of environmental quality standards. A year later, Japan passed the Air Pollution Control Act—an amended version of the Smoke and Soot Regulation Law that had been passed just six years earlier. A few years later, Japan would adopt a revised version of the Air Pollution Control Act with uniform emission standards and non-compliance penalties. This would then be followed by yet another iteration of the Air Pollution Control Act that introduced controls on emissions from automobiles.

The cornerstone of these early reforms were regulatory provisions such as the K-Value. This regulation, which was intended to bring down ground level concentration of SO_2 set facility level emission limits based on a predefined criteria. The successful enforcement of this regulation along with the associated installation of pollution control technologies has led to a steady decrease in SO_2 emissions. These reductions have been particularly pronounced in industrial centers with clusters of heavy emitting industries.

In more recent years, there have also been efforts to expand the scope and further tighten regulations on harmful emissions. For instance, in 2006 Japan adopted standards related to volatile organic compounds (VOC) emission standards on fine particulates. This would also be joined in 2009 by the first air quality standard for $PM_{2.5}$. Even more recently still, Japan has introduced another revision of the Air Pollution Control Act requiring that best available technologies be adopted to control mercury emissions.

Interestingly, not all of Japan's efforts to regulate emissions have started at the national level. One of the more notable examples of regulation rooted in local concerns, involved the restrictions on diesel vehicles. In the early 2000s, the Tokyo Metropolitan Government (TMG) got behind a 'Say No to Diesel Vehicles' campaign. That campaign would not only ban the use of diesel vehicles but convince nearby prefectures to follow suit. It would also form the basis for the aforementioned national regulations on mobile source emissions.

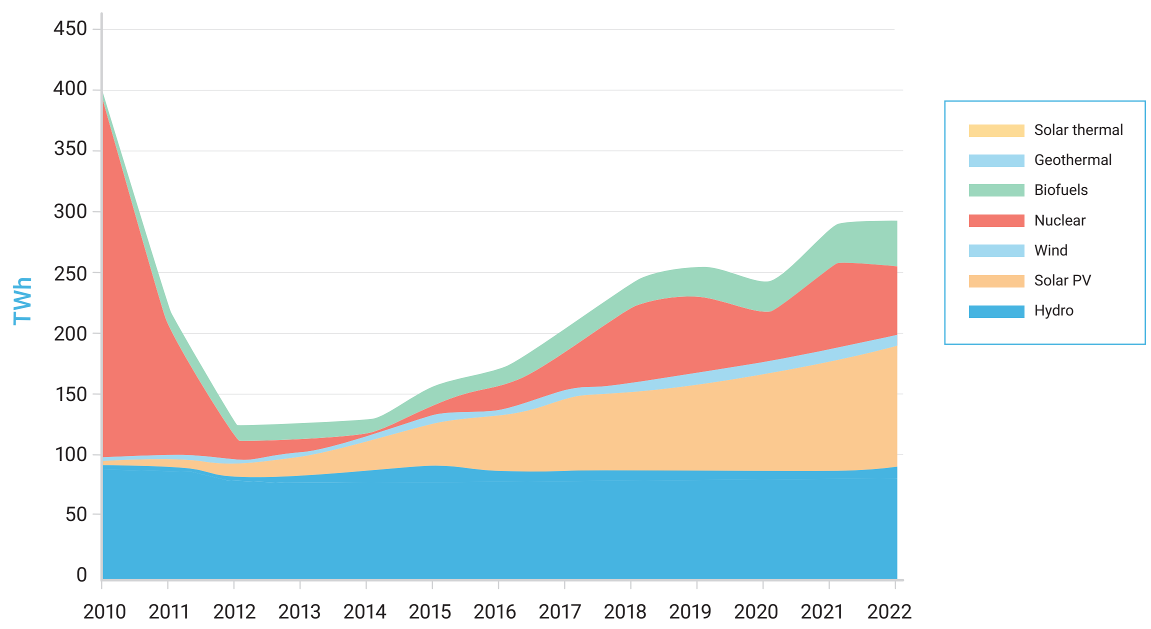
Another unique feature of Japan's efforts to control emissions has been the use of voluntary agreements. For example, in the case of controls on Volatile Organic Compounds (VOCs), Japan has encouraged industries to effectively self-regulate rather than use command and control mandates on particular technologies. More concretely, the aforementioned controls on VOCs illustrate case in point this more flexible approach to regulation.

Although not always mentioned as part of the air pollution strategy, Japan has also capitalized on a forward-looking approach to energy savings that has simultaneously helped lower emissions. One notable example of how energy policy has complemented Japan's pollution regulation has been the top runner programme. This programme in question has been in existence since the late 1990s (and has expanded to a variety of product categories) when the government required companies manufacturing energy intensive products to meet energy efficiency targets. However, rather than having those targets set by regulation, industries are expected to keep pace with companies that have offered the most efficient models. The companies that set the standard are rewarded with a label that marks them as top runners. In theory, the government can publicly call out companies that lag or mandate product changes. In practice, this has not happened as companies have found incentives in aiming to save energy.

Following the 2011 Fukushima nuclear accident due to the Great East Japan Earthquake and Japan's costly dependence on imported fossil fuels, the country implemented policies to boost renewable energy use and promote energy efficiency and conservation. The Sixth Strategic Energy Plan[23], released in October 2021, set a goal for renewables to constitute 36-38% of the energy mix by 2030. This plan sped up the deployment of solar, wind and hydropower, necessitating a 94 GW increase in installed capacity, primarily from solar power. Due to limited land for large-scale projects, Japan turned to floating solar power on inland lakes and reservoirs. In December 2022, Japan announced plans to restart nuclear power plants to address energy shortages and pursue low-carbon development (World Economic Forum, 2023).

In October 2020, Japan introduced its 'Green Growth Strategy Through Achieving Carbon Neutrality in 2050.'[24] This plan envisions that renewable energy sources will provide 50% to 60% of the country's electricity needs by 2050, with the rest coming from nuclear and thermal power plants equipped with carbon capture, utilization, and storage (CCUS) (30-40%), and 10% from hydrogen and ammonia generation (METI, 2021). Hydrogen is anticipated to be a key element in Japan's shift to clean energy. Japan was one of the pioneers in establishing a national hydrogen strategy, aiming to make hydrogen as cost-effective as natural gas. By 2030, Japan's goals include having 800,000 fuel cell vehicles, over 5 million residential fuel cells, and creating an international hydrogen supply chain. Additionally, Japan is testing large-scale hydrogen-based power generation, which will offer valuable insights to the global energy sector (International Energy Agency, 2021). All of the policies listed above led to a dramatic change in the structure of energy production in Japan since 2010 (Figure 23), leading to strong increase in solar PV capacity and biofuels, while the nuclear represents only about a fourth of the capacity before the Fukushima accident. Overall, the total energy demand has also declined owing to energy saving efforts.

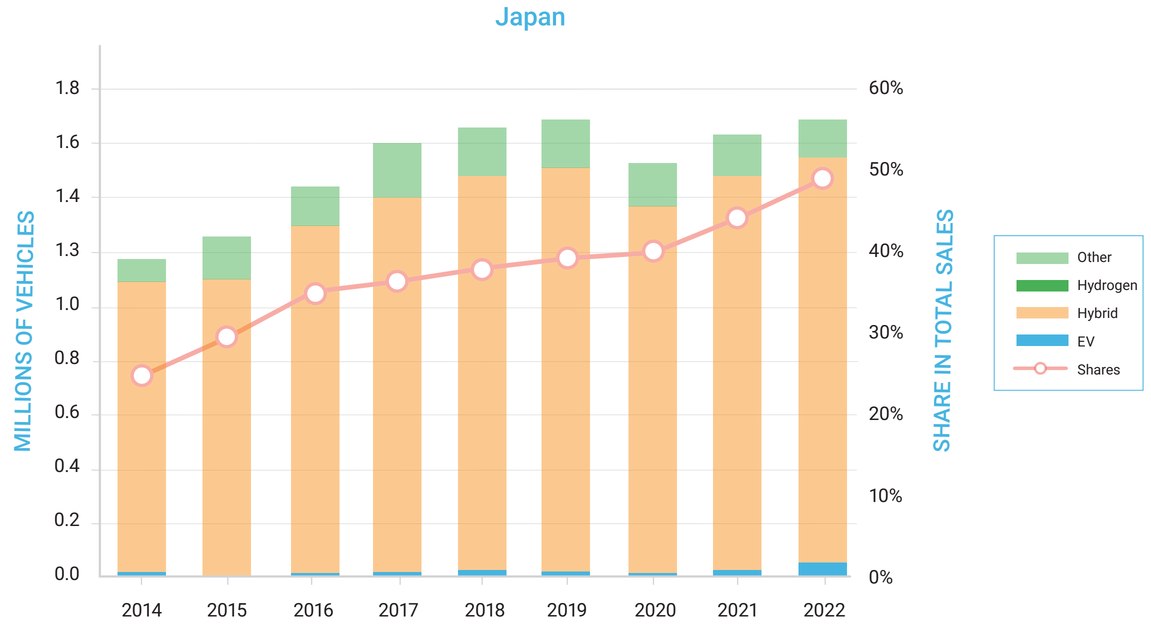
Figure 23: **Development of non-fossil (renewable and nuclear) energy sources since 2010.**



23 https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf
24 https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html

Since 2009, when the government of Japan introduced tax incentives and subsidies to encourage the purchase of eco-friendly vehicles, the number of new registrations for next-generation vehicles, such as hybrid, plug-in hybrid, electric, fuel cell, clean diesel, and other new-energy vehicles, has been steadily increasing in Japan (Figure 24). However, in 2020, new registrations of these vehicles decreased due to the COVID-19 pandemic. Despite this setback, each automaker's efforts to develop various models and the ongoing impact of the pandemic, the proportion of next generation of vehicles among new passenger car registrations has been steadily growing, reaching 48% in 2022 (Japan Automobile Manufacturers Association, Inc.).

Figure 24: New registrations of new energy vehicles as well as clean diesel.



Source: Japan Automobile Manufacturers Association

4.3.3. Mongolia

Over the past decade, Mongolia has also stepped-up efforts to control air pollution. To a significant degree, these efforts have been motivated by the recognition of the health damaging impacts of air pollution. They also reflect an expanded willingness to limit those impacts with tougher standards, cleaner fuels, and other targeted interventions.

In terms of important policy developments, in 2012 Mongolia adopted its Law on Air. This new law introduced a series of measures to improve ambient air quality while also calling for creation of emissions inventories and improved monitoring that would support science-based planning. The new law additionally introduced other notable controls. For instance, it calls for maximum allowable limits on stationery emission sources while delegating some of the authority for regulation to local governments (Law of Mzongolia on Air, 2012).

In more recent years, Mongolia also approved the National Programme for Reducing Air and Environment Pollution for the period 2017–2025 (National Programme).[25] The National Programme took an even more aggressive stance on air pollution by mandating 25% reductions in $PM_{2.5}$ and PM_{10} by 2019.

25 https://montsame.mn/en/read/132984

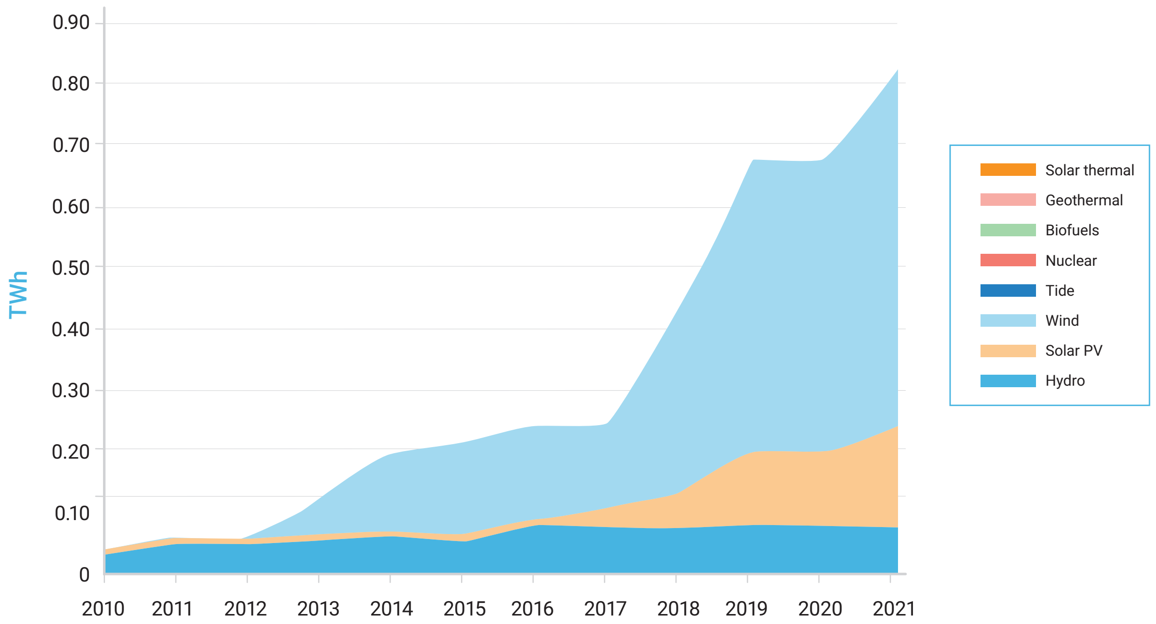
Importantly, that National Programme appears to have paid dividends. For example, less than two years after the National Programme was adopted, $PM_{2.5}$ concentrations fell by more than 40% (ADB, 2020).

To some extent, the success of the National Programme is attributable to other subnational efforts, including the ban on raw coal in six districts of Ulaanbaatar (Songinokhairkhan, Bayanzurkh, Chingeltei, Khan-uul, Sukhbaatar, Bayangol) issued in 2019, which is considered among key actions (ADB, 2020). The ban was intended to remove one of the dirtiest energy sources for household cooking and heating from the market, while simultaneously encouraging the use of cleaner burning refined briquettes. Though the ban had positive impacts, there were also less desirable and unanticipated side effects. For instance, the lack of training on how to use the briquettes resulted in carbon monoxide poisoning in some homes (Jun, 2021).

As a further pillar in achieving improved air quality and addressing climate challenges, the government supported the development of renewable energy, which resulted in increasing wind and solar generating capacity in the last decade (Figure 25). However, despite impressive growth rates and existing potential that still represents a small fraction of total electricity supply, i.e., 3.5% in 2021.

The vehicle fleet in Mongolia is growing fast but most of these vehicles are old, inefficient, and highly polluting. More than half of vehicles are registered in Ulaanbaatar (about 642 thousand or 57% of national total) which is a fourfold increase in the last decade.[26] Compared to other countries, the uptake of NEV vehicles in Mongolia has been very slow. as of December 2023, only about 1,061 NEV vehicles were registered, representing just 0.012% of the total vehicle fleet, which is estimated at about 1.2 million vehicles. Due to poor urban planning, the road infrastructure cannot handle the increased traffic and additionally, public transport is poorly developed.

Figure 25: Development of renewable energy capacity in Mongolia.



Source: IEA Electricity Information https://www.iea.org/data-and-statistics/data-product/electricity-information

26 https://asia.fes.de/news/mongolia-air-pollution.html

Mongolia has also featured its desire to clean the air in policies with a broader focus. One of the clearest indications was Mongolia's first Voluntary National Review (VNR) (Government of Mongolia, 2019). Mongolia's VNR underlines that cleaner air is essential to achieving other development priorities and it outlines a series of specific measures that can help improve air quality while delivering climate co-benefits – see further discussion in section 4.4.3.

4.3.4 Republic of Korea

The Republic of Korea has successfully reduced fine dust levels through a robust legal and policy framework. This framework includes distinct plans for both national and local levels, with clear roles and responsibilities assigned to various organizations at both the national and sub-national levels.

Through various measures, there has been a notable reduction in the average annual ultrafine dust concentration across the nation, decreasing from 26 $\mu g/m^3$ to 18 $\mu g/m^3$ in 2021. Nevertheless, during the winter months, the dispersion of emitted fine dust is hindered by low atmospheric mixing, compounded by the increase in fine dust carried by frequent westerly winds. Consequently, the concentration increases from December to March, requiring special measures. During these months, the monthly average concentration is typically 15-30 % higher than the annual average, ranging from 30-32 $\mu g/m^3$. To address seasonality issues, as preemptive measures under this scheme, driving grade 5 emission vehicles without high efficiency catalytic particle filters are restricted on roads in Seoul, Gyeonggi Province and Incheon, and some coal fired plants halt operations.

Thanks to the preemptive measures, fine dust concentration, after implementation of seasonal management scheme, showed a gradual decrease in ROK during the target period, reaching the lowest concentration after the 5th round (2023-2024). The number of 'good days' (concentrations lower than 15 $\mu g/m^3$) gradually increased, and 'bad days' (concentrations higher than 36 $\mu g/m^3$) decreased.

Special measures for improving metropolitan air quality include total air pollution load management, an emission trading system, and mandatory purchase of low emission vehicles. In 2015, 'diesel vehicles' were the largest emitters in the Seoul Metropolitan Area, accounting for 22% of the area's total emissions compared to 11% for the entire country. Significant investments have been made in the transportation sector to reduce emissions. Between 2007 and 2020, the three local governments of Seoul, Incheon and Gyeonggi in the Seoul Metropolitan Area invested USD 9 billion in air quality management, with 56 % of the funding focused on measures to reduce emissions from the transport sector. USD 3.2 billion was devoted to generating evidence and engaging the public on air quality issues (UNEP, 2023).

The Ministry of Environment's report on 'Low-Emission Measures for Grade 5 Diesel Vehicles in 2023' reveals that out of about 660 thousand Grade 5 diesel vehicles, nearly 330 thousand (or 50%) are now equipped with Diesel Particulate Filters (DPFs), a development supported by the scrappage subsidy programme for Grade 5 vehicles. In the Seoul metropolitan area, a higher uptake was recorded with nearly 85% of these vehicles equipped with DPFs (UNEP, 2023).

One of the significant factors contributing to ROK's success is the availability of long-term and real-time air quality data, which is made publicly accessible through air quality information websites – see Table 8. These websites allow researchers to identify trends and provide actionable information for government agencies.

Table 8: **Sources of publicly available information about air quality in Korea.**

Types	Name	Website
Real-time Air Quality	AirKorea	https://airkorea.or.kr/eng/
Air Pollutant Emission-Cap regulation	CleanSYS	https://www.stacknsky.or.kr/eng/index.html
Re-suspended dust concentration	Clean Road	https://www.cleanroad.or.kr/index.do (Korean only)
Satellite data	GEMS	https://nesc.nier.go.kr/en/html/index.do

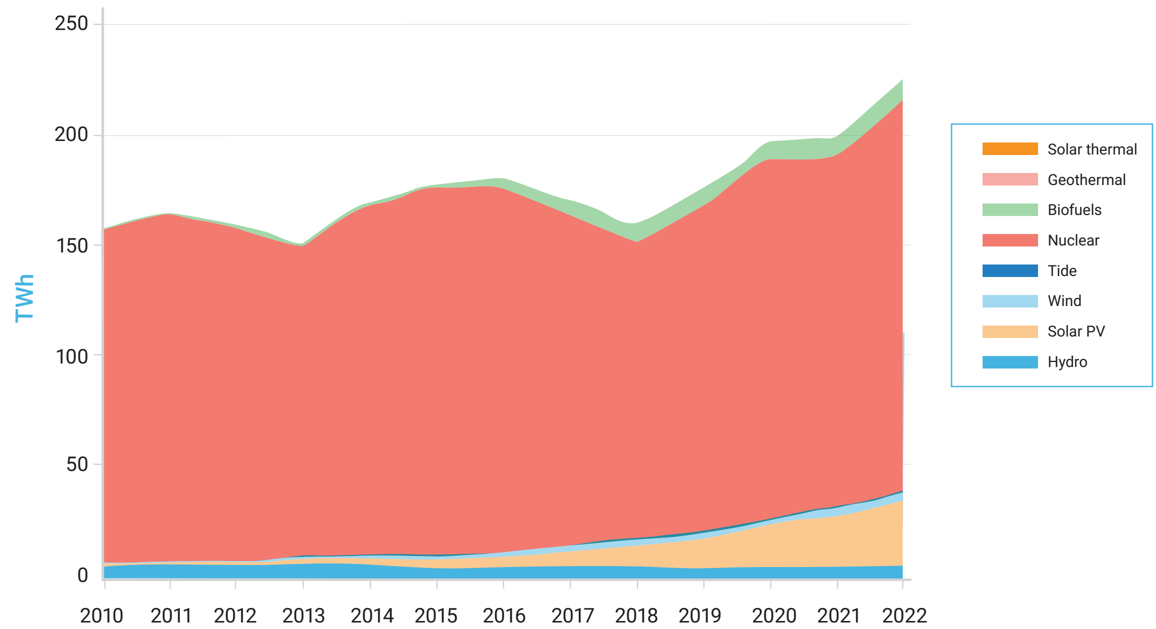
Overall, the combination of a strong legal framework, significant investments in air quality management, real-time data accessibility, and targeted measures have enabled ROK to make substantial progress in reducing fine dust levels and improving air quality.

The Republic of Korea set the carbon neutrality goal for 2050 that includes a comprehensive strategy significantly increasing renewable energy sources, phasing out coal, improving energy efficiency, and developing the hydrogen industry. Currently, the energy sector in the Republic of Korea is heavily reliant on fossil fuels, with substantial imports of oil, natural gas, and coal being crucial for the country's energy supply. To support this transition, the ROK government set up the 10^{th} Basic Plan for Long-term Electricity Supply and Demand (BPLE)[27]. The country anticipates reducing fine dust by 53% by 2030 and 68% by 2036, while SO_2, NOx, and total dust are anticipated to be reduced by approximately 50%. Greenhouse gases are projected to decline by 44.4%.

An important element of the strategy to achieve the GHG reduction goals is an increase in renewable energy capacity. Hydropower has had a very steady and small (only about 0.1% – IEA[28] and Figure 26) share of energy supply, but solar, wind, and biomass share has grown from about 2% in 2015 to over 7% by 2022 (Figure 26), while nuclear contribution remains rather constant at about 15% ±2%. Compared to some of the countries in the region, the renewable share and its development is rather small in Korea, while fossil fuel-based electricity generation continues to dominate representing still nearly 80% of the capacity with coal taking about a third of it. Exploring the potential for renewables and accelerating the transition would offer several environmental, human health, and economic co-benefits.

27 The full report in Korean is available at https://www.motie.go.kr/kor/article/ATCLc01b2801b/68162/view#
28 https://www.iea.org/countries/korea

Figure 26: **Development of renewable energy capacity in Republic of Korea.**

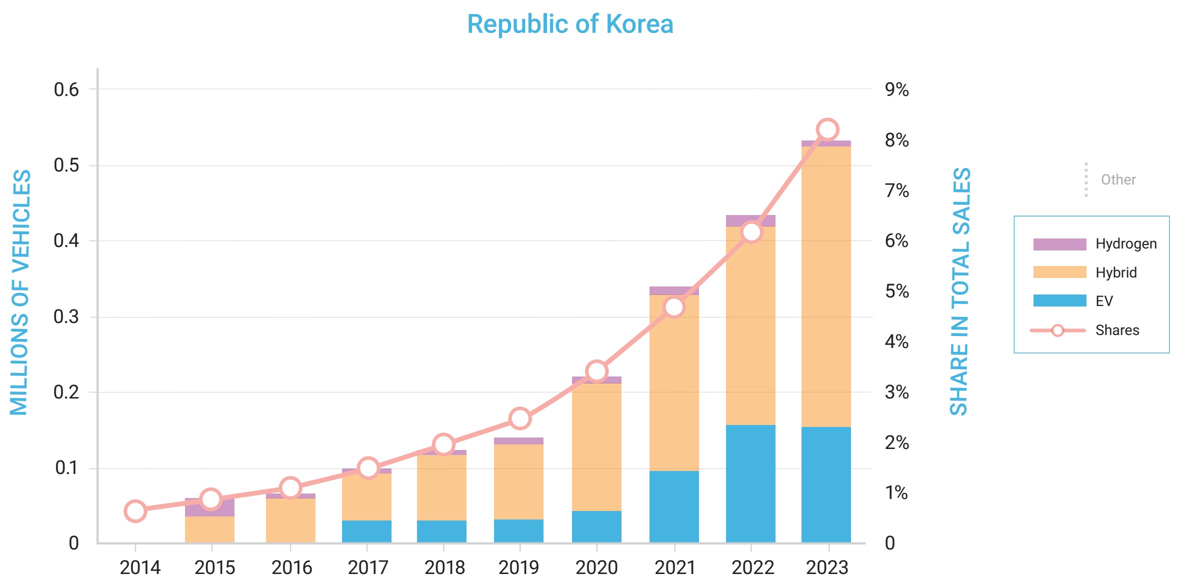


Source: IEA Electricity Information https://www.iea.org/data-and-statistics/data-product/electricity-information

Another important aspect of energy transformation and urban air quality improvement involves policies related to city planning, including enhancements to public transport within and outside of the city, as well as the reduction of fossil fuel vehicles. According to data from the Korea Automobile Manufacturers Association and the Ministry of Land, Infrastructure and Transport (MOLIT), the number of registered EVs in the country exceeded half a million by the end of 2023, with the total number of NEVs surpassing two million vehicles (Figure 27). This development is driven by active policies and the expansion of charging infrastructure, which currently includes over 300,000 units and is rapidly growing. Interestingly, the structure of NEVs in Korea is more similar to that of Japan rather than China, where EVs dominate. In Japan and Korea, hybrid vehicles, including plug-in hybrids, represent the largest share.

According to the Third Energy Master Plan released in 2019 by the ROK government, the number of green vehicles will grow dramatically with the plan to distribute 8.3 million EVs and 2.9 million vehicles by 2040, which in total will account for the half of the vehicles registered in Korea.

Figure 27: **New registrations of NEV in Korea.**



Source: Ministry of Land, Infrastructure and Transport (MOLIT).

4.4 Emerging Environmental Challenges

In the last decade, significant progress has been made in several North-East Asian countries addressing acute air pollution problems, especially particulate matter pollution. However, despite this progress and strong improvements in air quality, large parts of population are exposed to $PM_{2.5}$ levels above the national standard values, except Japan. While efforts continue to reduce emission of precursor gases, new challenges arise which will require further strengthening and accelerating of implementation of some policies as well as development of new approaches to address these emerging issues. This section highlights a few prominent examples of such challenges, their origin, and offers initial solutions to tackle them.

4.4.1 Ozone pollution in cities

China, Japan, and the Republic of Korea face increasing challenges in controlling O_3 pollution, which requires integrated control strategies for O_3 and $PM_{2.5}$ owing to their complex photochemical interactions. With $PM_{2.5}$ concentrations decreasing significantly, the relative contribution of ozone to air pollution became progressively greater, particularly in terms of its contribution to the air quality non-attainment rate, especially in urban areas. As has been shown in Chapter 2, all four countries struggle with managing emissions of Volatile Organic Compounds (VOCs) and nitrogen oxides (NOx), crucial precursors to O_3 formation.

With the continuing economic growth over the next 10-15 years, **China** will face increasing challenges related to energy consumption, electricity generation, and vehicle population, leading to increase in multiple pollutant emissions. Controlling regional air pollution, particularly fine particles and ozone, and reducing carbon emissions from fossil fuels will be significant challenges (Wang, 2021). The observations from 106 sites in the North China Plain from 2013 to 2018 showed suppression of ozone pollution at high $PM_{2.5}$ concentrations, consistent with a model simulation in which $PM_{2.5}$ scavenging of HO_2 and NO_X depresses ozone concentrations by 25 ppb relative to $PM_{2.5}$-free conditions. The effect of $PM_{2.5}$ chemistry on ozone production has important implications for a coordinated emission control strategy to decrease both $PM_{2.5}$ and ozone. Decreasing VOC and NO_X emissions would have benefits for ozone to offset the ozone penalty from decreasing $PM_{2.5}$. In addition, NOx and VOC emission controls reduce not only ozone but also $PM_{2.5}$ pollution, a 9% decrease in NO_X emissions by 2020 would decrease $PM_{2.5}$ on average by about 1.8%. Aggressive reduction of NO_X and aromatic VOC emissions would be particularly effective for decreasing both $PM_{2.5}$ and ozone (Li et al., 2019a, 2019b).

Insufficient reduction of VOC emissions in **Japan** has also likely been behind challenges managing ozone; the attainment rate of the domestic air quality standard for photochemical oxidants is below 1%. (Botta & Yamasaki, 2020; Ito et al., 2021). Photochemical Oxidants Study Group (2017) called for the promotion of photochemical oxidant countermeasures rather than pursuing the common approach emphasizing reduction of VOCs and NOx. Some of those calls focused on improving modelling cooperation between 'atmospheric observation, atmospheric simulation, and emission inventory' (Morikawa, 2018). Others suggested alignment between air pollution and climate change policies—for instance integrating controls on NOx/VOC with efforts to mitigate methane (Akimoto, 2019). Owing to the role methane plays in the increase of background ozone and the change in atmospheric regime towards NOx-limited, especially for cities, means a combined strategy is needed across East Asia (Lee et al., 2021).

In **ROK**, ozone levels have consistently failed to meet targets across all criteria, indicating a nationwide increase in concentrations of O_3 and calling for strengthening of the VOCs and NOx management. In 2017, the MOE reported a lack of background data on precursors and management tools for ozone sources near residential areas. Consequently, initiatives linked to ozone strategies were introduced, aiming to reduce emissions of precursors such as nitrogen oxides (NOx) and volatile organic compounds (VOCs). However, smaller businesses and local governments have encountered technical and financial difficulties in managing these pollutants pointing to the necessity to develop appropriate mechanisms and incentives to achieve emission reductions. For example, development and training to establish and regularly provide emission inventories, incentivize programmes to reduce emissions and exposure at workplace, e.g., through an emissions allowance system.

4.4.2 Urban-rural pollution interactions

Air pollution in Asia is mainly perceived as an urban issue, because the largest pollution levels are typically measured within cities. For decades monitoring efforts have been focusing on urban pollution often providing long time-series datasets with good spatial and pollutant coverage and naturally this has received more attention from both policymakers as well as the scientific community (Dong et al., 2022; Enkhbat et al., 2020; Ganbat et al., 2020; Kim and Lee, 2018; Le et al., 2020; Li et al., 2019a; Maji et al., 2019; Minoura et al., 2006; Tessum et al., 2022; Tomorrow City, 2024; Wu et al., 2016; Zhang et al., 2019).

The efforts to counteract increasing pollution levels have been focusing on search for solutions within the cities' jurisdictions, addressing key local pollution sources which included typically; transport, residential cooking and heating and industrial sources if such were still of priority, i.e., not moved outside of the city already (Chen and Chen, 2019; Enkhbat et al., 2020; Liu et al., 2019a, 2020; Michael and Patrick, 2018; UNEP, 2023; Xu et al., 2021; Zhao et al., 2017). However, such policies have often not delivered the desired effects and the pollution levels did not decline as expected. Scientific analysis (e.g., Amann et al., 2017; Shu et al., 2022, 2023; World Bank, 2023) has shown that a significant part of the observed pollution in the cities originates from sources outside of the city, including industry, agricultural burning and many others. This necessitates collaborative efforts involving several stakeholders from various sectors and policy makers from the city and neighbouring jurisdictions. Consideration of the above in development of policies addressing urban air quality would provide markable improvement in air quality and deliver on several SDGs, including SDG11 on sustainable cities, which has been improving but the progress has not been satisfactory across some of the regions (Table 6).

4.4.3 Attaining WHO air quality guidelines and SDGs

Over the past ten years, China, Japan, Mongolia, and the Republic of Korea have made significant strides in reducing air pollution through strong legal and policy frameworks. However, they all face challenges in meeting the new World Health Organization (WHO) air quality guidelines (WHO, 2021). The subregion's socioeconomic development has come at an environmental cost, contributing to one third of global greenhouse gas emissions and over 2 million premature deaths from air pollution per year, even as it improves resource efficiency and progresses towards decarbonizing energy systems and economies.

As has been shown in Chapter 2 and section 4.4.1-2, the air pollution levels at the national and regional level, and in particular in cities, have been exceeding the WHO air quality guideline values. At the same time, significant improvements have been made in the last decade, which resulted in exposure levels consistent with the WHO Interim Target 4 (for $PM_{2.5}$: 35 µg/m^3 or less) for most of the population. Except for ozone, concentrations of all key air pollutants, including $PM_{2.5}$ continue declining, which is also evident from the monitoring of progress towards SDG goals. However, major challenges remain to attain the SDG goals and the WHO guideline values. For the latter, the challenges and 'distance to target' vary across the countries necessitating diversified approaches at local level while pursuing development of national policies that integrate across domains (air quality, climate, energy security, equity, etc.) exploring the co-benefits of such approach and improving the cost-efficiency of respective policies.

The analysis at the global and regional level (e.g., Amann et al., 2020; UNEP, 2019, 2023; Vandyck et al., 2018) highlighted the challenges of attaining ambitious air quality goals but also the opportunities associated with the policies that would integrate across different domains, i.e., air-quality, climate, and the sustainable development goals. Additionally, assuring enforcement of current policies is an important step towards demonstrating success of current commitments and feasibility of bringing about change (Amann et al., 2020). Last but not least, international collaboration will be essential to secure attainment of the long-term targets to efficiently reduce the health, ecosystem, social and economic burdens across the region.

Clean air policies in China have substantially reduced particulate matter air pollution in recent years, primarily by curbing end-of-pipe emissions. Despite China's progress in reducing pollution, there's still room for improvement. To achieve this may require and depend upon the air quality co-benefits of ambitious climate action, since the benefits of end-of-pipe measures are likely 'exhausted' within the next decade. Recent analysis (Cheng et al., 2021; Shi et al., 2021) indicates that implementing China's carbon neutrality roadmap and clean air policies, could contribute to more than an 80% reduction in $PM_{2.5}$ and O_3-8h 90th percentile concentrations relative to the 2020 levels. The national annual mean $PM_{2.5}$ concentrations could drop to about 11µg/m^3 by 2060, with approximately only half of the 337 cities meeting the 2005 WHO air quality guidelines of 10 µg/m^3. At the regional level within China, heavy polluted regions in northern and North-East China have been receiving a lot of attention. For example, in Beijing-Tianjin-Hebei (BTH) and surrounding region ('2 + 26'), action plans have been implemented since 2016 to promote the substitution of solid fuel use in rural households. Significant reduction of health impacts induced by the outdoor and indoor air pollution from burning solid fuel use were avoided (Liu, 2020) – such targeted policies remain a one element of the longer-term strategy to align with the WHO recommendations.

Continuous improvement of air quality indicators – except for ozone – in Japan (Figure 1) has led to the attainment of the 2005 WHO guidelines for $PM_{2.5}$ in recent years. However, achieving further reductions will be more challenging and will require a decrease in a fall in sources of secondary PM, including ammonia (NH_3) from agriculture. Furthermore, while the nationwide average has fallen, the $PM_{2.5}$ environmental quality standards (EQS) are not 100% satisfied, especially in several urban areas. Overall, enacted policies have resulted in continuous air quality improvements and Japan is on track to achieve several of the SDGs.

The annual mean concentration of $PM_{2.5}$ in the air in **Ulaanbaatar (Mongolia)** remains higher, although it has decreased from about 80 µg/m^3 to 40 µg/m^3 since 2017[29] (see also Figure 1 in Chapter 2), a level considered safe by WHO. Moreover, during the winter months (from November to March) the mean concentration of particulate matter typically exceeds 60 µg/m^3, reaching 100-200 µg/m^3 during the coldest months. Policies addressing key sources of $PM_{2.5}$ precursors (coal stoves and boilers, transport, and power plants) have been contributing to a measured reduction in air pollution exposure but they come short of what is needed to approach the WHO guideline and meet SDG objectives, although they assure compliance with the current national standard for $PM_{2.5}$ of 50 µg/m^3. Lack of $PM_{2.5}$ measurements for other cities in Mongolia, does not permit robust conclusions, given that coal is the primary fuel source for residential heating, it is likely that urban populations are generally exposed to levels exceeding WHO recommended values and approaching them will bring challenges similar to those faced in Ulaanbaatar.

The national air quality standards in **ROK** have been gradually tightened and required implementation of measures that brought in steady improvement of air quality and reduction of emissions (Figure 1, Figure 2). The current standard for $PM_{2.5}$ of 15 µg/m^3 is not yet achieved (annual mean for 2022 was reported as 17.5 µg/m^3) but is intended to stimulate further policies and measures enabling its achievement and further approaching the WHO AQG and can be partly seen as a response to WHO recommendations at large indicating that there is no safe level of PM concentrations. An important part of the policy in ROK is a law (introduced in 2019) that requires evaluation of the adequacy of environmental standards every five years. This in turn has stimulated research work to understand the progress and implications of further advancement of air quality standards. The national air environment improvement comprehensive plan, established in 2022, aims to achieve 13 µg/m^3 by 2027 and 12 µg/m^3 by 2032. While these goals are ambitious, they still fall short of the WHO recommendations, illustrating the daunting challenges linked to attainment of thereof. International collaboration that could be further developed and stimulated by work under NEACAP, could be an important factor in attainment, or approaching, of the WHO recommendations in the long-term.

To achieve balanced development in economic growth, social inclusion, and environmental sustainability, countries in the region have been adopting a holistic approach. They have established comprehensive concepts to address all aspects and engage various sectors and stakeholders, contributing to the 2030 Agenda for Sustainable Development.

China's vision of ecological civilization promotes balanced and sustainable development, aiming for harmony between humans and nature. This approach aligns with the Chinese government's commitment to 'Putting People First', aiming to improve quality of life within ecological limits (Hanson, 2019). The Chinese government places high importance on implementing the 2030 Agenda for Sustainable Development, adhering to a people-centered development philosophy, and fully, accurately, and comprehensively applying the new development concept of innovation, coordination, green development, openness, and sharing. China actively fosters a new development paradigm, continuously drives economic and social progress, and contributes valuable wisdom to advancing global sustainable development goals. In April 2016, China released the *Position Paper on Implementing the 2030 Agenda for Sustainable Development,* followed by the China's *National Plan on Implementing the 2030 Agenda for Sustainable Development* in September of the same year. Over the past decade, China has closely aligned the implementation of the 2030 Agenda with its medium- and long-term development strategies, including the 13th and 14th Five-Year Plans and the Long-Term Objectives Through 2035.

29 http://agaar.mn/index?lang=en

A cross-departmental coordination mechanism involving 45 government agencies was established to promote progress across multiple SDGs.[30] The adopted approach is illustrated in Figure 28. Beyond the national plan, the SDG goals have been also pursued at a local level.

Figure 28: **The relationship between the six principles of Ecological Civilization and UN Sustainable Development Goals (SDGs).**

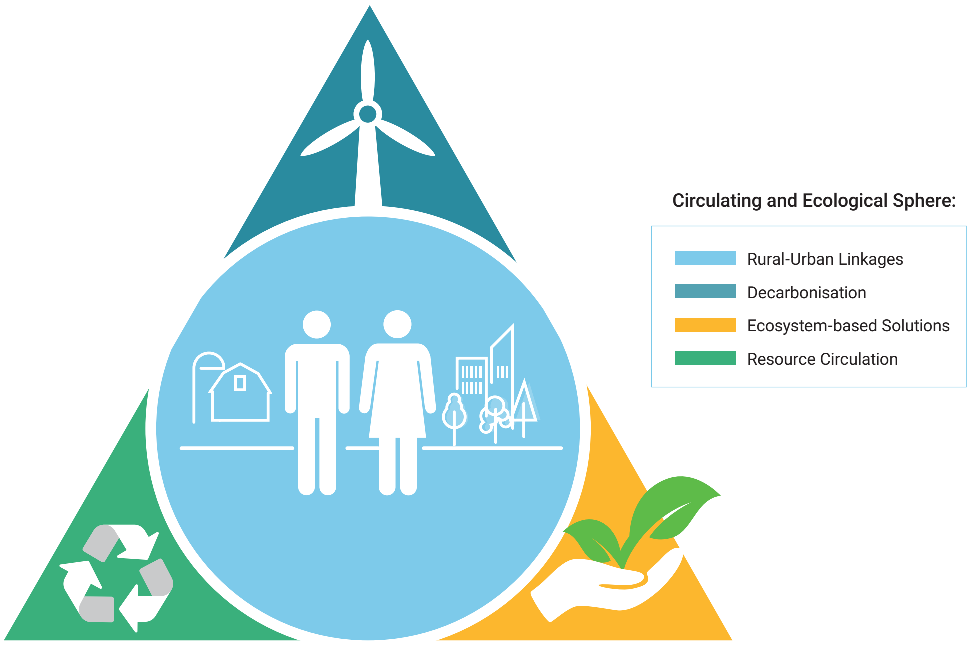
Source: Wei et al. (2021).

The Government of **Japan** in its Fifth Basic Environment Plan of 2018 proposed the concept of the Circulating and Ecological Sphere (CES) to guide sustainable transitions in light of the sustainable development goals (SDGs) (MOEJ, 2018). The CES provides a framework for a new paradigm in sustainable development bringing together existing approaches, namely, rural–urban linkages, ecosystem-based solutions, decarbonization, and resource circulation. The CES advances a spatio-environmental system

30 Progress Report on China's Implementation of the 2030 Agenda for Sustainable Development, 2023.https://www.cikd.org/detail?docId=1701419996870234114#:~:text=%E4%B8%AD%E5%9B%BD%E5%9B%BD%E9%99%85%E5%8F%91%E5%B1%95%E7%9F%A5%E8%AF%86,%E5%B9%B4%E8%AE%AE%E7%A8%8B%E5%87%9D%E8%81%9A%E5%8A%9B%E9%87%8F%E3%80%82

in which 'each region demonstrates its strengths by utilizing its unique characteristics, thereby building a self-reliant and decentralized society where different resources are circulated within each region, leading to symbiosis and exchange with neighboring regions according to the unique characteristics of each region' (MOEJ, 2018; Ortiz-Moya et al., 2021). The CES integrates responses to climate change, biodiversity loss, and the advancement of the SDGs by combining recurrent 'niches' in sustainability science—such as rural–urban linkages, the circular economy, transitions to low or zero-carbon living, or ecosystem-based solutions to disaster risk reduction and climate change adaptation and mitigation (Figure 29).

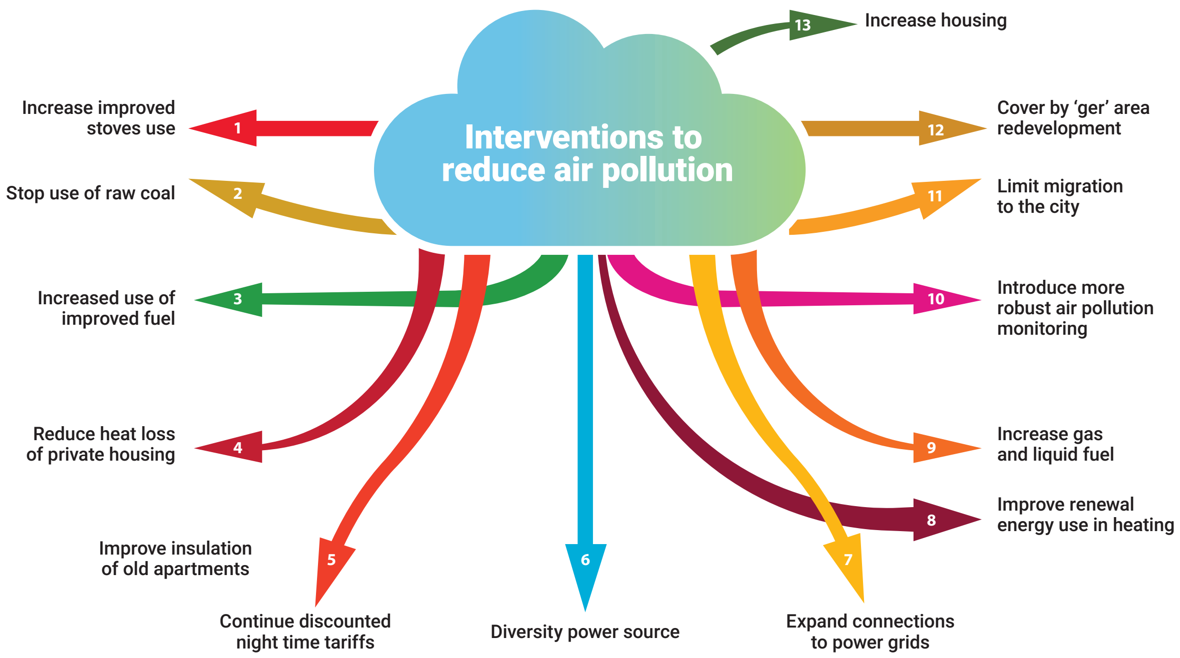
Figure 29: **The Government of Japan proposed Circulating and Ecological Sphere (CES) concept.**



Source: Ortiz-Moya et al (2021)

In **Mongolia**, the 2019 Voluntary National Report (VNR) highlights the need to enhance cooperation between air pollution control and the SDGs framework. The VNR report documents efforts to achieve the 17 Sustainable Development Goals (SDGs) that sit at the center of the 2030 Agenda on Sustainable Development (Government of Mongolia, 2019). It examines the impact of air pollution on health, education, income and the environment, describing air pollution as a complex global issue that requires cross-sectoral coordination and multi-stakeholder partnerships for sustainable development. Recognizing that air pollution poses an urgent challenge in Mongolia, affecting public health and productivity and imposing significant economic costs, the report also outlines a series of specific measures that can help improve air quality while delivering climate co-benefits (Figure 30). This illustration provides a well-defined set of interventions, reflecting country-specific circumstances, which reduce air pollution while providing climate and development co-benefits — note that the colours and numbers in the arrows refer to the respective SDGs that would be improved by the specific measure. Further, and more detailed, characterization of links between air pollution, climate and social impacts vs specific measures and policies envisaged by the Government of Mongolia is discussed in the VNR report and illustrated in Figure 38, included in the Annex to this report.

Figure 30: The frameworks to tackle air pollution and achieve sustainable development together.



Source: Mongolia Voluntary National Report 2019

The Republic of Korea introduced its 'National Sustainable Development Goals (K-SDGs)' in 2018, comprising 17 policy goals and 122 targets. The government then launched its fourth basic plan for sustainable development (2021-2040), which includes a situational analysis, vision and strategy, detailed policy tasks for each goal and priorities for 2021 to 2025. This plan includes key strategic targets and overarching goals such as an inclusive society where people enjoy their lives under the vision of realizing a sustainable nation through inclusion and innovation, improvement in the quality of life for people benefitting from innovative development, a clean air environment to enjoy for future generations, and global harmonization and cooperation development.

Figure 31: K-SDGs: Vision and Strategies under the Fourth Basic Plan for Sustainable Development (2021-2040) (2021).

4.4.4 Climate change and air quality

There is growing literature on the impacts of climate change on human health (e.g., heat stress) and ecosystems (e.g., migration of species, increasing frequency of fires, etc.) and the effects of climate change on O_3 but fewer studies on the impact of climate change on the formation of PM. The 5th and 6th IPCC Assessment Reports highlighted that background O_3 could decrease under most scenarios due to higher water vapour concentrations in a warmer climate. However, under the pathways where methane (CH_4) emissions will continue to grow, its abundance will lead to increases in background O_3 that offset the O_3 and decrease due to climate change, especially in the long term (Doherty et al., 2017; IPCC, 2021). Regionally, in polluted areas with high levels of nitrogen oxides (NOx), elevated surface temperatures and humidity yield increases in surface O_3, termed the 'O_3 climate penalty'.

Future changes in regional and local concentrations of $PM_{2.5}$ driven by climate change are much less certain. Since components of particulate matter, either warm the atmosphere by absorbing sunlight (e.g., black carbon) or cool it by scattering sunlight (e.g., sulfates), interact with clouds, these radiative and microphysical interactions can induce changes in precipitation and regional circulation patterns (Fiore et al., 2015). Consequently, climate change is expected to degrade air quality in many polluted regions by changing air pollution meteorology (ventilation and dilution), precipitation and other removal processes, and by triggering some amplifying responses in atmospheric chemistry and in anthropogenic and natural sources (Fiore et al., 2015). Increased magnitude and frequency of forest fires combined with stagnation episodes will also lead to increased PM concentrations and consequently short- and long-term health impacts (IPCC, 2021; Xie et al., 2020). Several studies examined the range of RCP and SSP scenarios and assuming continued air pollution reduction efforts, under these pathways the impact of emission changes on air quality by 2050s will be larger than that due to climate change (Doherty et al., 2017; IPCC, 2021; Vandyck et al., 2018). At the same time, removal of aerosols might result in additional warming, or unmasking warming from greenhouse gases, since some species such as sulfate and nitrate have cooling effects. Consideration of such interactions in both modelling as well as in policy design requires cooperation among air quality and climate change communities.

Pollution episodes are associated with stagnation events and sometimes, extreme heat. Since climate change will affect climate extreme weather events such as heatwaves (Adelekan et al., 2022; IPCC, 2021), it is likely that the impact on air quality would increase too, especially in the cities (Revi et al., 2022).

Northern China is often hit by sandstorms, causing pollution levels to rise. The increasing frequency of of these events is inextricably linked to desertification in Mongolia, which is driven by climate change. Pollution by particulate matter is not the only concern. Comparing the same 2006 to 2010 and 2046 to 2050 periods, Hong et al. (2019) estimated that climate change will increase heatwave days in 74 cities from 2.7 to 8.8 per year. This will make urban ozone pollution more frequent: the number of summer days when maximum one-hour ozone concentrations exceed national standards will increase by 3.8 days per year (Hong et al., 2019).

Addressing all the above issues will require development and implementation of integrated synergistic policies focusing on decarbonization of energy systems while also dealing with acute air quality and development challenges. Such analysis and even strategies addressing air pollution and global climate change simultaneously already exist but need to be upscaled and introduced into the policy agenda (e.g., Lu et al., 2020; UNEP, 2019, 2023). Collaboration within scientific and policy networks would stimulate exchange of experience and allow for taking advantage of existing synergies.

CHAPTER 5
RECOMMENDATIONS

This chapter provides an overview of how countries tackle air quality and climate and highlights the role of established collaborative networks in fostering technical, scientific, and policy collaboration. It concludes with a set of recommendations based on the entire report, not just this section.

5.1 Linkages Between Air Quality, Development, and Climate Policies

Improving air quality, fostering socio-economic development, and mitigating climate change are crucial for future decision-making. In general, there exist three-dimensional synergies among air quality, socio-economic development and climate policies that collectively enhance ambient air quality. In recent years, stringent clean air policies with clear air quality target have significantly improved air quality in **China** and led to considerable CO_2 emission reductions by transforming the energy system. For example, phasing out outdated, polluting combustion facilities during clean air actions have successfully promoted the transformation of the country's energy system, resulting in a net accumulative reduction of 2.43 Gt CO_2 from 2013 to 2020, exceeding the accumulated CO_2 emission increase in China (2.03 Gt CO_2) during the same period (Shi et al., 2022).

Besides air pollution control policies, climate policies aiming at reducing fossil fuel consumption also yield substantial air quality benefits. In September 2020, China announced its ambitious climate commitment to achieve carbon neutrality by 2060, which may be the means by which long-term air quality improvement is brought about in China. It is well known that pollutants control measures driven by 'Beautiful China' would play a critical role on air quality improvement before 2035, however, after 2035, with the wide application of the advanced, end-of-pipe control technologies in major pollutant sources like power and industrial sectors, the air quality improvement benefits brought by end-of-pipe controls will gradually decrease (Shi et al., 2021).

In **Japan**, a multi-faceted policy instrument of law and measures is being implemented to ensure the coordination of policies and regulations aimed at reducing air pollution and greenhouse gas emission. The Law of Air is grouped into the issues of climate change and reducing its negative effects, protecting the ozone layer, and reducing air pollution and its goals are set to protect air, prevent pollution, reduce, and control the release of air pollutants. The Government sets a long-range goal until 2050, where more focus is on climate change issues rather than air pollution. Goals were set on the development of a low-carbon, productive and inclusive green economy and contribute to international efforts to mitigate climate change. Key actions included in the Net-Zero strategy by 2050 include shutdown of most coal power generation capacity and a strong increase in solar and wind capacity, creating markets, strong growth for electric vehicles and heat pumps, work on (R&D) carbon capture, sequestration and carbon neutral fuels as well as development of hydrogen infrastructure.

It appears that the co-benefits of greenhouse gas reduction policies and air quality management policies began to be discussed in **ROK** in earnest around the mid-2000s. Considering these international discussions, studies such as Chae Y. (2010) and Chae and Park (2011) suggested that it is essential to implement integrated measures that consider the co-benefits of reducing air pollutants and greenhouse gases in the Republic of Korea, where economic resources are limited and air pollution is serious. In particular, these studies suggested that an optimal emission reduction scenario should be developed to achieve both air quality improvement and greenhouse gas reduction goals, minimizing costs through co-benefit and cost-effective analysis.

More recently, a consensus was formed on the need for integrated management of climate and air quality (Lee et al., 2021; Sim et al., 2020; UNEP, 2023). However, it is still limited to a conceptual approach and has not been attempted in terms of actual policy development and implementation. The problems in the relevant legal system and national plans were analyzed by Chae et al. (2018) to develop an empirical approach and attempt a pilot public benefit analysis of policies in the power generation and transportation sectors. Sim et al. (2020) showed a high correlation between CO_2 and the increase in air pollutants through mobile campaigns and building monitoring conducted in downtown Seoul. This may support the fact that CO_2 and air pollutants in the air in urban areas are emitted from the same source and suggests that monitoring urban CO_2 concentrations could be a potentially effective approach to diagnosing urban air quality. More quantitative research using national integrated assessment models (IAMs) was conducted by Woo et al. (2024) and Kim et al. (2024), which identified a significant co-control effect of energy-climate policies and highlighted the irreplaceable effect of fugitive air pollution control policies. Since Korea declared that it would achieve carbon neutrality by 2050, research and discussions on the co-benefits and integrated management of carbon neutrality and air management policies have been ongoing through research such as Choi et al. (2022) *and* Jang et al., (2024).

5.2 Learning From Successful Regional Collaboration

As highlighted in previous chapters, China, Japan, Mongolia, and the Republic of Korea face similar but distinct challenges regarding the levels, trends and sources of air pollution, necessitating varied policy interventions. Acknowledging the importance and benefits of collaborative efforts to reduce air pollution, China, Japan, and the Republic of Korea, have established bilateral and trilateral cooperation channels and have deepened their policy cooperation (Table 9).

Since 2014, **China and Japan** have implemented 'Japan-China Inter-city Cooperation Project.' This project leverages the knowledge and experience of Japanese local governments to address air pollution and initially focused on exchanges between 13 Chinese cities and 11 Japanese cities. The project aimed at human resources development and capacity building in major cities across China by facilitating activities such as expert dispatches, joint seminars, training, monitoring reports, and initiatives in areas like VOC control and $PM_{2.5}$ emission analysis. This cooperation continued with the 'Cooperation on Research and Model Projects to Improve Air Quality in China', under the 'Agreement on Cooperation to Conduct Research and Implement Model Projects to Improve Air Quality' signed by the Ministry of Environment of Japan and the Ministry of Ecology and Environment of China in 2018. The model projects cover various topics, including reducing air pollutant emissions through new technologies, integrated use of residual stems from crops to reduce particulate matter, measures for air pollution in the restaurant and textile dyeing industries, VOC emissions reduction from manufacturers, and wide-area ozone pollution in priority[31]

In 2019, **China and the Republic of Korea** signed the 'Blue Sky Plan', a new cooperation framework encompassing policy and technology exchange on air pollution prevention, joint research on forecasting information, and technology industrialization with a focus on sharing environmental industry information and demonstrating air pollution prevention technology. The two countries have also begun organizing various industry and technology exhibitions or exchange meetings at national and provincial levels.

Since 2015, **Japan and the ROK** have held policy dialogues and engaged in joint research focusing on $PM_{2.5}$ relevant modelling, emission inventories, ambient air monitoring (including sharing real-time monitoring data of $PM_{2.5}$), forecasting accuracy, transboundary pollution, and countermeasures toward achieving environmental standards of $PM_{2.5}$. In Phase II (2020-2022), collaboration focused on improving the accuracy of the forecasting models, sharing the latest scientific information related to emission inventories, and understanding vehicle and VOCs emissions from point sources. From the policy perspective, exchange will concentrate on the $PM_{2.5}$ management, countermeasure technologies, and the application of Best Available Techniques (BATs) for emissions management, particularly in response to high concentration episodes.[32]

The Tripartite Environment Ministers Meeting (**TEMM**) of China, Japan and the Republic of Korea has conducted the Tripartite Policy Dialogue on Air Pollution (TPDAP) since 2014, holding annual meetings of two working groups during Phase I (2015-2019). Phase II (2021-2025) focuses on sharing information about $PM_{2.5}$ and O_3 episodes and exchanging policies and technologies for controlling $PM_{2.5}$ and O_3.

Table 9: Trilateral cooperation in North-East Asia.

Name (*establishment year*)	Participating countries	Operating entity	Cooperation areas	Remarks
The Tripartite Environment Ministers Meeting among China, Japan and Korea: **TEMM** (1999)	China, Japan, ROK	Ministry of Environment of each country	All environmental areas with policy focus	Minister level
Tripartite Policy Dialogue on Air Pollution: **TPDAP** (2014)	China, Japan, ROK	Ministry of Environment of each country	Policy exchange related to air pollution	Policy dialogue at director level

Several regional collaboration initiatives address air pollution challenges in Asia and globally (Table 10). China, Japan, Mongolia, and the Republic of Korea have joined regional cooperation efforts led by ESCAP, UNEP and the Asian Development Bank (ADB). These initiatives aim to foster collaboration in sharing knowledge and experiences across broader regions beyond North-East Asia. In connection with the launch of NEACAP in 2018, member countries of ESCAP in 2019 adopted resolution 75/4 on strengthening regional cooperation to tackle air pollution challenges in Asia and the Pacific. The resolution led to the negotiation and adoption of the Asia-Pacific Regional Action Programme on Air Pollution (RAPAP) in 2022, which is the first of its kind in Asia and the Pacific. Further to this, progress in regional cooperation, the 6th session of the United Nations Environment Assembly (UNEA-6) adopted the resolution 6/10, promoting regional cooperation on air pollution to improve air quality globally.

32 MOE, Japan and MOE, ROK, 2019. 2016-2018 Bilateral Cooperation on $PM_{2.5}$ Between Japan and the Republic of Korea

Table 10: **Regional cooperation in North-East Asia and beyond.**

Name	Participating countries	Operating entity	Cooperation areas	Institutional status
North-East Asia Clean Air Partnership: **NEACAP** (2018) under the North-East Asian Sub-regional Programme for Environ-mental Cooperation (NEASPEC)	China, DPRK, Japan, Mongolia, ROK, and the Russian Federation	ESCAP Subregional Office for East and North-East Asia	Information and knowledge sharing, joint research and capacity building	Intergovernmental programme
Asia Pacific Clean Air Partnership: **APCAP** (2015)	16 countries (including Japan, Mongolia and ROK). In 2019, Gyeonggi Provincial Government from ROK joined	UNEP Asia Pacific Office	Sharing scientific knowledge and information, supporting implementation of mitigation policy, preparing science-based policy evaluation reports and supporting national capacity building	UNEP's programme for assessment and knowledge sharing
Asia Clean Blue Skies Programme: **ACBSP** (2022)	68 countries (including China, Japan, Mongolia and ROK)	ADB	Leveraging technical and financial resources to build the capacity of the developing countries on the design and implementation of investment projects with air quality and low carbon benefits.	Technical assistance supporting the imple-mentation of ACBSP
Asia-Pacific Regional Action Programme on Air Pollution: **RAPAP** (2022)	53 members and 9 associate members (China, Japan, Mongolia, ROK, and the Russian Federation)	ESCAP	Air quality management, Air quality monitoring and data sharing, Best practices exchange, Capacity building	Regional and intergovernmental action plan
Forum for International Cooperation on Air Pollution: **FICAP** (2021)	UNECE members and beyond	UNECE	Outreach and capacity building	International collaboration framework under CLRTAP

There are numerous scientific collaborations occurring in North-East Asia and beyond (Table 11). A significant recent initiative involves EANET's project on the assessment of emissions inventories and source apportionment of air pollution in Southeast Asia. Establishing a common information base on air pollution emissions and related factors is essential to support scientific assessments, policy discussions and technical cooperation. This project could serve as a valuable learning opportunity for North-East Asia in this context.

Table 11: Scientific collaboration in North-East Asia.

Name	Participation	Operating Entity	Cooperation Areas	Remarks
Joint Research Project on Long-range, Transboundary Air Pollutants in Northeast Asia: **LTP** (1996-2019)	China, Japan, ROK	National Institute of Environmental research	Monitoring, model-ling and inventory building for joint scientific research	Discontinued after the release of the first joint study in November 2019 and replaced by the Collaborative Research Programme: For Better Air Quality Over North-East Asia (CRP/ BAQONE)
Acid Deposition Monitoring Network in East Asia: **EANET** (2001)	13 countries including China, Japan, Mongolia, ROK, and the Russian Federation	UNEP Asia Pacific Office and Asia Center for Air Pollution Research (ACAP)	Monitoring, data collection system, capacity building, etc	Scope was amended in 2021 to cover air pollution. In 2024, it initiated a project on 'Stocktaking and Methodological Assess-ment of Emissions Inventories and Source Apportionment of Air Pollution in Southeast Asia'
Regional Emission inventory in ASia (**REAS**)	Japanese experts	ACAP, NIES, Japan	Emission inventory in Asia	Latest data sets: REASv3.21
The Model Inter-Comparison Study for Asia (**MICS-Asia**)	Experts from North-East Asia		Improvement of air quality and climate models as well as developing emission inventories in Asia	
Air Quality in North-East Asia (**AQNEA**)	Tsinghua University (China), Beihang University (China). Kyoto University (Japan), National Institute for Environmental Studies (Japan) Seoul National Seoul National University (ROK), Sookmyung Women's University (ROK), and Inter-national Institute for Applied Systems Analysis (IIASA, Austria)	–	Conducting integrat-ed assessments by developiing a regional air quality modeling framework in support of NE Asia Future Air Quality Forecasting	Emission pathways and cost-effective control measures specific to respective country

In the context of regional air quality challenges and international policy, the UNECE Convention on the Long-Range Transboundary Air Pollution (LRTAP) stands as a notable example. Originating in 1979 amidst significant political and economic disparities in Europe, the Convention was catalyzed by scientific findings highlighting the transboundary nature of air pollution's impact on ecosystems. This led to the establishment of revised protocols aimed initially at reducing emissions of specific pollutants causing acidification, culminating in the comprehensive Gothenburg Protocol of 1999. Although not directly replicable for North-East Asia, the institutional framework and collaborative approach of the LRTAP experience could offer valuable insights.

Early in the Convention's history, a network of experts was formed, including working groups and Task Forces, to consolidate knowledge and support policy negotiations. A pivotal decision was the adoption of a common methodology for emission calculation and reporting, ensuring transparency and compatibility across participating countries. The collaborative effort facilitated the establishment of independent knowledge platforms and expert groups, continuously evaluating scientific advancements and progress towards emission reduction goals. Given the existing collaboration among North-East Asian countries, developing a similar common format for collection of emissions could prove instrumental. This step would enhance harmonized platform for information exchange and foster deeper regional collaboration in addressing air quality issues effectively. Recently, LRTAP Executive Body approved the establishment of the Forum for International Cooperation on Air Pollution (FICAP)[33] in 2021 to act as a forum for international exchange and mutual learning, to facilitate the sharing of science, technical and policy expertise internationally.

5.3 Scope and Role for International Assistance and Science

Technical assistance and capacity building projects have been crucial in establishing and maintaining monitoring networks, emission inventories, application of modelling tools, and eventually supporting the policy making process. Such projects will continue to play a significant role in the future, illustrating how to leverage and strengthen future collaboration at both the policy and science levels. This is particularly important for Mongolia. Table 12 lists key projects in Mongolia supported by organizations like the World Bank, ADB, and JICA. These initiatives, along with those mentioned in section 5.2, will help build on existing efforts and develop new approaches in collaboration with donors and the scientific community.

33 https://www.naturvardsverket.se/en/international/cooperation/multilateral/international-cooperation-on-air-pollution/

Table 12: **Key national-scale projects in Mongolia supported by international organizations.**

Organization	Project	Fields
Millennium Challenge Corporation	Funded the Energy and Environment Project (EEP) which included the $33.8 million Energy Efficient Innovation Facility Activity under which the energy efficient stove subsidy was implemented.	Energy efficiency
World Bank	'Ulaanbaatar Sustainable Roads and Transport' project https://projects.worldbank.org/en/projects-operations/project-detail/P174007 (February 2022-2026). Comprehensively solve the problem of road congestion and improve road safety by renewing the traffic light management system of UB city and create sustainable development.	Traffic
World Bank	'Ulaanbaatar Clean Air Project' /2012-2017/ – improving energy productivity, reducing heat loss, and introducing energy saving technologies.	Energy efficiency, energy saving
JICA	Measures to reduce emissions caused by automobiles, including vehicle emissions regulations, EURO IV and V fuel consumption, traffic light regulation systems, remote exhaust gas detectors (RSD), and particulate filters (DPF).	Traffic
ADB	'Ulaanbaatar Air Quality Improvement Programme' loan	Technical assistance
UNICEF, SDC	Measures were taken to improve the indoor air quality of the kindergarten, environmental monitoring, creation of an electronic system, determination of health exposure by measuring the indoor environment, improvement of the insulation of the kindergarten in the neighborhood dominated by low-income families, and installation of double windows.	Indoor air quality, health

The scientific community will play a vital role in developing further air quality policies in the region, similar to its support for policy processes within the LRTAP Convention and the European Commission. With scientific input, it is possible to establish a common understanding of the environmental state across the region and develop methods for exchanging harmonized information or creating comparable datasets for various indicators, such as emissions or impact indicators. For effective discussion on achieving air quality and climate mitigation goals, a shared understanding of objectives and a common approach to joint discussions are necessary. The scientific community within North-East Asia is already involved in these discussions, as countries rely on emission inventories, monitoring data, remote sensing information, etc. However, much of this information is independently generated by national teams and only partially processed and stored in a harmonized manner, such as through GEMS-PAN and EANET.

Building further capacity to establish common formats for collecting and processing scientific information, like emissions of key precursors of $PM_{2.5}$ and ozone, would provide significant benefits. It would ensure the comparability of national emission estimates and their trends, allowing the community to develop consistent and comparable time series data for the entire region. One challenge would be to develop an agreeable methodology for emission estimation, ensure full transparency of emission data, and maintain a continuous process of updating the science behind emission estimates and potentially validating them. Another important element to be considered is collaboration with the climate community and administration reporting greenhouse gas emissions owing to common air pollutants (including SLCF) and GHG sources and often joint reporting needs to international bodies.

5.4 Key Messages and Next Steps

Based on the recommendations provided in each chapter, actionable options at national and regional levels are identified. Here's a detailed breakdown, followed by a diagram to illustrate the relationships and responsibilities across these levels.

At the national level, countries are encouraged to:

1. Enhance Air Quality Monitoring

- Expand monitoring networks in rural and urban areas.
- Invest in advanced monitoring technologies to track pollutants like $PM_{2.5}$ and Ozone and inform policy decision.

2. Develop and Enforce Robust Legal Frameworks

- Keep updating ambient air quality standards to align with WHO guidelines.
- Strengthen and monitor enforcement of existing legislation and where necessary, update emission limit values with state-of-the art technologies.
- Develop policies and regulations addressing ammonia from the agriculture sector.
- Strengthen policies addressing NMVOC emissions from fugitive sources.

3. Urban Planning for Air Quality

- Integrate air quality considerations into urban planning processes.
- Implement green spaces and other urban designs to promote active mobility, potentially reduce pollution and eventually improve citizen wellbeing.
- Promote regional and stakeholder cooperation to address both local and regional sources of pollution affecting the city.

4. Integrate Air Quality and Climate Change Policies

- Develop integrated national policies addressing air quality, climate change and sustainable development goals.
- Promote policies leveraging the co-benefits from implementation of air quality and climate change measures.

5. Support Technological Advancements

- Promote research and development of advanced emissions control technologies.
- Provide incentives for industries to adopt cleaner technologies.

At the (sub) regional level, countries, through NECAP, can:

1. Strengthen Policy Collaboration

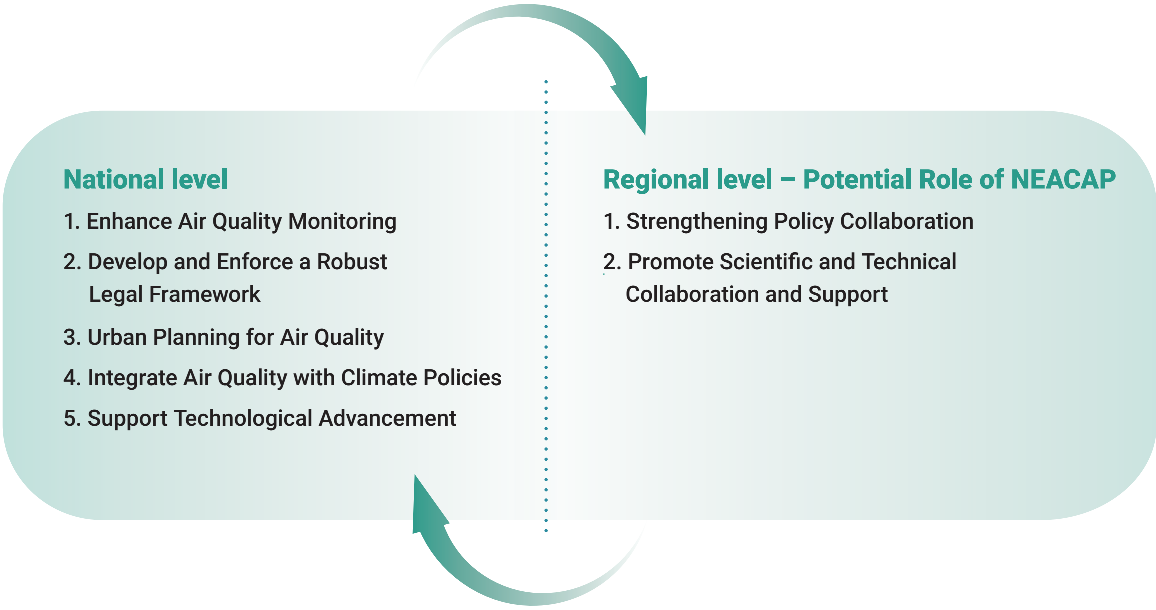
- Implement coordinated initiatives to enhance the sharing of best policy and implementation practices through regional and global cooperation mechanisms; such exchanges could support development of approaches to overcome existing implementation barriers.

2. Promote Scientific and Technical Collaboration and Support

- Facilitate the exchange of expertise and technology supporting development of more effective policies.

The following conceptual diagram shown below represents the relationships and responsibilities across national and regional levels based on the policy options. It shows how policies at different levels complement and support each other, creating a comprehensive framework for addressing air quality issues.

Figure 32: **Relationships and responsibilities across national and regional levels based on the policy options.**



CHAPTER 6
SUMMARY AND CONCLUSIONS

This report has reviewed the policy progress, identified key challenges, and highlighted achievements of four countries—China, Japan, Mongolia, and the Republic of Korea—in their efforts to tackle air pollution. Over the past decade, these countries have successfully reduced air pollution through robust legal and policy measures, supplemented by scientific assessments for managing air quality. Since the 1960s, they have been establishing institutions and air quality related standards though the pace has varied across the region. These established standards and respective laws, along with enhanced monitoring capacity, have enabled governments to analyze and tackle air pollution, develop targeted strategies, and implement further regulations that address their unique economic, environmental, and social contexts.

Despite these achievements, the four countries face both common and unique challenges in managing air quality. While China, Japan, Mongolia, and the Republic of Korea share challenges such as addressing O_3 pollution, balancing economic growth with environmental protection, and integrating air quality with climate change policies, they also encounter specific issues related to institutional frameworks, financial constraints, local governance, and urban planning. Effective air quality management in these countries requires a combination of regional (within the same country) strategies and tailored national approaches to address their distinct challenges.

Improving air quality and mitigating climate change are critical priorities for future policymaking in these countries. There are synergies between air quality and climate policies that jointly promote the continuous improvement of ambient air quality. This report also emphasizes the value of regional collaboration by showcasing examples from EANET and LRTAP and highlights the role of scientific cooperation in these initiatives.

In a nutshell:

- ✓ Integrating policies on air quality, socioeconomic development, and climate change yields considerable co-benefits and reduces societal costs.
- ✓ Implementing policies that address both air quality and climate change can improve long-term acceptance of necessary greenhouse gas reductions by showing tangible improvements in air quality.
- ✓ As climate change might adversely affect air quality, further reductions in precursor emissions are required through transformative measures such as reducing demand and changing behaviour.
- ✓ Collaboration in North-East Asia can facilitate further knowledge and technology sharing, leading to more efficient policies, securing support of the public and other stakeholders, while robust monitoring is crucial for tracking progress.
- ✓ Strengthened collaboration between (and within) the climate and air quality modeling communities would lead to improved understanding of regional, national, and local air quality changes and links to climate change
- ✓ Achieving WHO Air Quality Guidelines necessitates simultaneous climate and air quality measures, supported by scientific research and collaborative programmes.

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ANNEX

Table 13: **Annual average concentrations of ozone for the period 2010-2022 in China, Japan, Mongolia, and ROK [μg/m³].**

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
China				139	140	134	138	149	151	148	138	137	145
Japan	64	58	63	64	65	66	65	67	65	65	65		
Mongolia*		35	22	21	27	29	35	40	33	25	22	37	32
Republic of Korea		48	50	52	54	54	54	58	54	60	60	64	

Sources: China: Ministry of Ecology and Environment, Japan: National Institute for Environmental Studies (NIES), Mongolia: Meteorological and Environmental Analysis Department of Mongolia,[34] and Republic of Korea: Air Korea.[35]

Notes: (1) The reported values are not directly comparable across all countries. China reports maximum daily one-hour means while for other countries the annual average is calculated from eight-hour daily means. Additionally, the time over which the averaging is done might differ. (2) For Mongolia (*), the concentrations are for the capital city of Ulaanbaatar.

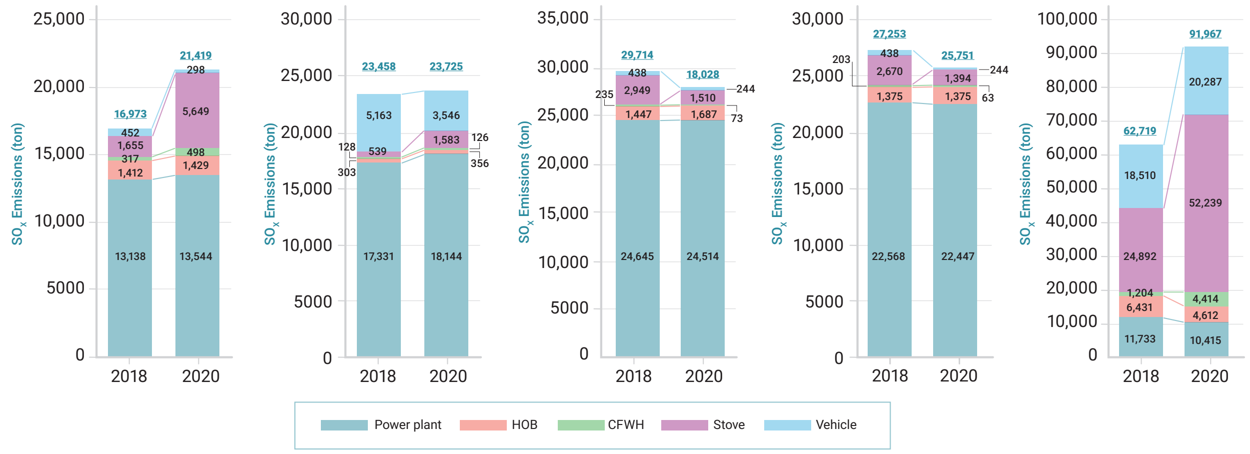
The following table and figure show emissions for air pollutants and their change over time in Ulaanbaatar. As indicated earlier in the main text, there are some significant discrepancies compared to other regional inventories–both in absolute values and relative changes. At the same time the relative importance of the emission sector is generally well represented. For example, in 2018 and 2020, the power plants were estimated to emit less than 15 kt of SO_2, while the national total for this sector in the HTAP inventory exceeds 100 kt in 2018 (see Figure 10, Figure 33, and Table 17 in the Annex). Considering that some of the country' key coal-fired power plants are located in Ulaanbaatar, the emissions reported the in JICA inventory seem low – or alternatively, the HTAP inventory (Crippa et al., 2023) may be overestimating emissions from this source. Similarly, for the transport sector, the estimate of NO_X emissions in Ulaanbaatar is in the order of 3.5 kt (Figure 31, Table 17) while the national figures indicate 40-60 kt in the same period (Figure 10), which is puzzling, given that nearly 60% of the country's vehicles are registered in Ulaanbaatar. Emission trends from stoves in Ulaanbaatar show a sharp increase in SO_2 and NO_X emissions, along with a doubling of CO emissions, while $PM_{2.5}$ emissions declined by half between 2018-2020. This raised important questions: was there a significant improvement in stove efficiency or coal quality during this period? If so, why did CO emissions increase so substantially?

Table 14: **Emission inventory for Ulaanbaatar by air pollution sources, tons/year.**

	SO_X	NO_X	TSP	PM_{10}	CO
Power plants	13,544	18,114	24,514	22,447	10,415
HOB	1,429	356	1,687	1,603	4,612
SFWH	498	126	73	63	4,414
Stove	5,649	1,583	1,510	1,394	52,239
Vehicles	298	3,546	244	244	20,287
Total	**21,419**	**23,725**	**28,028**	**25,751**	**91,967**

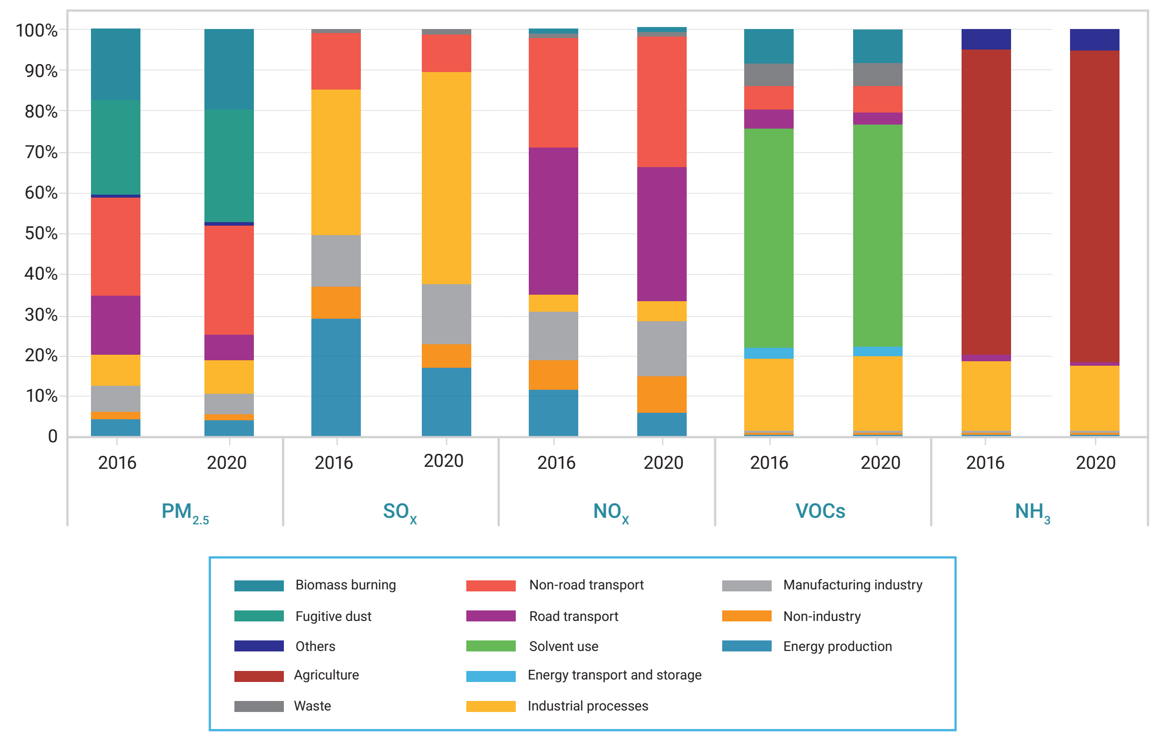
34 *Report on the State of the Ecology and Environment in China*. Available at: https://english.mee.gov.cn/Resources/Reports/soe/index.shtml
35 https://tenbou.nies.go.jp/download/

Figure 33: Comparison of 2018 and 2020 emissions in Ulaanbaatar.



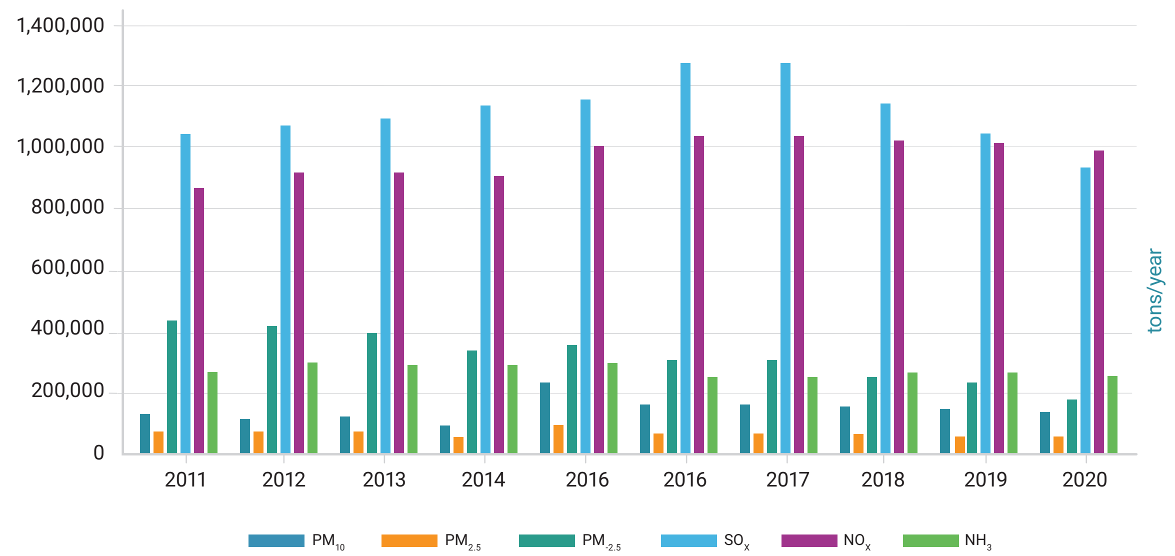
Source: JICA inventory

Figure 34: Structural change in emissions for key pollutants and precursors of $PM_{2.5}$ and ozone in Korea.



Source: National Air Emission Inventory and Research Center (2023), National air pollutants emission in 2020 and recalculations of national air pollutant emissions for the past years 2016 to 2019.

Figure 35: Trends in anthropogenic emissions in Korea (tons/year [*official national statistics-revised version since 2016*]).



Source: National Air Emission Inventory and Research Center, National Air Pollutants Emission (2011-2020).

Note: *Emission statistics estimation methodology was significantly revised in 2020, and this table includes results from 2016~2019 using the revised methodology.

Table 15: State ambient air quality monitoring network (MEE, China Air Quality Improvement Report. (MEE, 2019b).

Function	Urban air	Background air	Regional air	Acid deposition	Sand and dust weather	Greenhouse gases	Particulate matter composition	Photochemistry	Laser radar
Layout	339 cities 1,734 stations	16 stations	92 stations	440 stations	78 stations	11 stations	42 cities 49 stations	78 cities 78 stations	35 cities 42 stations
Methods	Automatic	Automatic	Automatic	Manual + Lab	Automatic	Automatic	Automatic + Manual	Automatic + Manual	Automatic
Items	SO_2, NO_2, PM_{10}, CO, O_3, $PM_{2.5}$, five meteorological parameters, visibility, etc	SO_2, NO_2, PM_{10}, CO, O_3, $PM_{2.5}$, black carbon, acid deposition, five meteorological parameters, visibility, etc	SO_2, NO_2, PM_{10}, CO, O3, $PM_{2.5}$, five meteorological parameters, visibility, etc	Rainfall, pH, EC, and 9 water soluble ions	TSP, PM_{10}, visibility, wind speed, and wind direction	CO_2, CH_4, and N_2O	$PM_{2.5}$, water-soluble ions, inorganic component, OC/EC, online single particle mass spectrometry, etc	Alkanes, olefins, alkynes, aromatics, oxygen-containing volatile organic compounds, and halogenated hydrocarbons	Vertical distribution of aerosols
Target	Quality monitoring			Important special monitoring			Pollution causes monitoring		

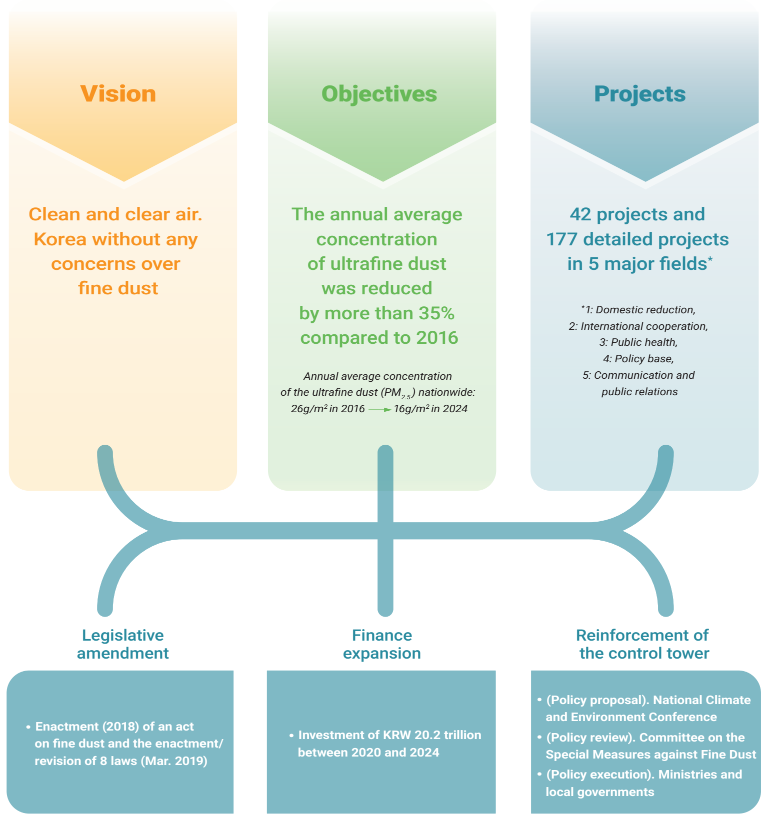
Source: China National Environmental Monitoring Centre

Table 16: List of air quality monitoring sites with measured parameters in Mongolia.

Site name (ID)	Measuring parameters						
	Weather parameters	SO_2	NO_x	CO	O_3	$PM_{2.5}$	PM_{10}
Ulaanbaatar City							
Misheel (UB1)	0	0	0	0	0	–	0
Baruun 4 zam (UB2)	0	0	0	0	–	0	0
1-r horoolol (UB3)	0	0	0	0	0	0	0
Zuun 4 zam (UB4)	0	0	0	0	0	0	0
Zuun ail (UB5)	0	0	0	0	0	–	0
Officer (UB6)	–	0	0	–	–	–	–
Mongol gazar (UB7)	0	0	0	0	–	–	0
Urgakh naran (UB8)	0	0	0	0	0	–	0
Selbe (UB12)	–	0	0	–	–	0	0
Hailaast (UB11)	–	0	0	–	–	–	0
Tolgoit (APRD1)	0	0	0	0	0	0	–
Zuragt (APRD2)	0	0	0	0	0	0	–
Amgalan (APRD3)	0	0	0	0	0	0	–
Nisekh (APRD4)	0	0	0	0	0	0	0
Bayankhoshuu (APRD6)	0	0	–	–	–	0	0
Other cities (province centres)							
1-Altai	Δ	0	0	–	–	–	–
2-Arvaikheer	Δ	0	0	–	–	–	–
3-Baganuur	Δ	0	0	–	–	–	–
4-Baruun-Urt	Δ	0	0	–	–	-	–
5-Bayankhongor	Δ	0	0	–	–	–	0
6-Bulgan	Δ	0	0	–	–	–	–
7-Darkhan-1	Δ	0	0	–	–	–	0
8-Dalanzadgad	Δ	0	0	–	–	–	-
9-Zuunmod	Δ	0	0	–	–	–	-
10-Zuunkharaa	Δ	0	0	–	–	-	-
11-Mandalgobi	Δ	0	0	–	–	-	-
12-Murun	Δ	0	0	–	–	-	0
13-Ulgii	Δ	0	0	–	–	-	-
14-Undurkhaan	Δ	0	0	–	–	–	-
15-Sainshand	Δ	0	0	–	–	–	-
16-Ulaangom	Δ	0	0	–	–	–	-
17-Uliastai	Δ	0	0	–	–	–	-
18-Khovd	Δ	0	0	–	–	–	-
19-Tsetserleg	Δ	0	0	–	–	–	–
20-Choibalsan	Δ	0	0	–	–	–	–
21-Choir	Δ	0	0	–	–	–	–
22-Shariin gol	Δ	0	0	–	–	–	–
23-Erdenet-1	Δ	0	0	–	–	–	0
24-Erdenet-2	Δ	0	0	–	–	–	
25-Sukhbaatar	Δ	0	0	–	–	–	–

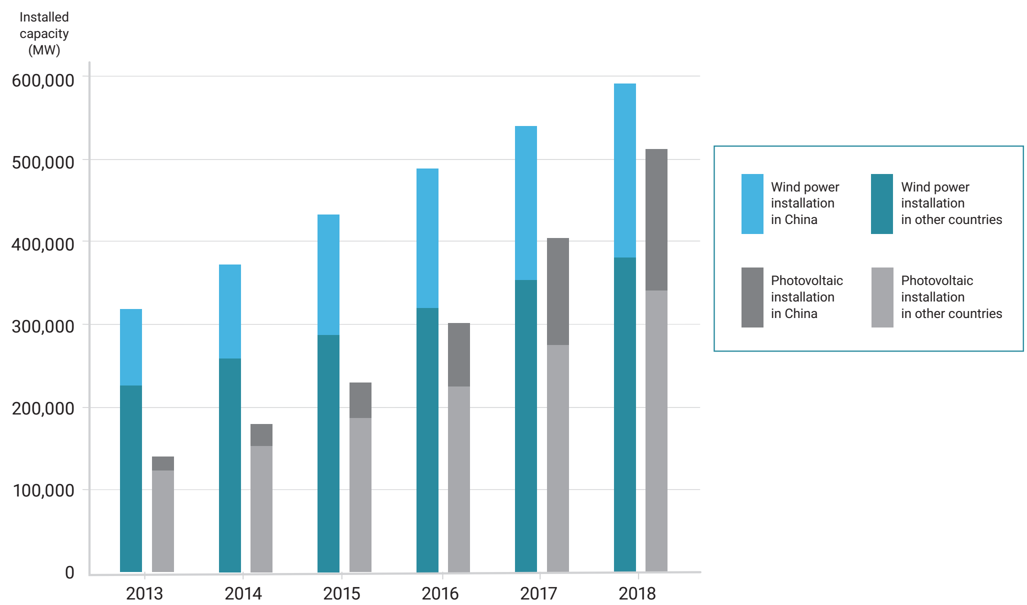
Note: **0** Measured; – Not measured; **Δ** Measured at local weather station.

Figure 36: Outline of the comprehensive plan for the management of fine dust.



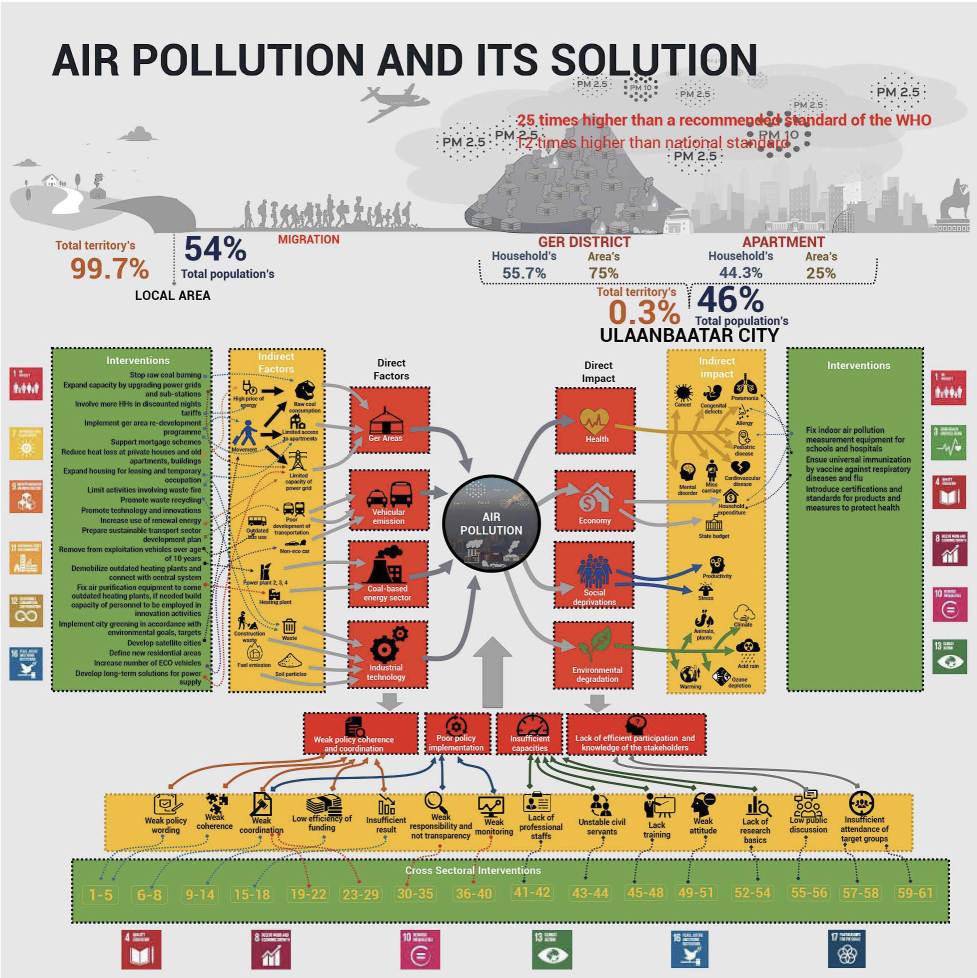
Source: The Government of the Republic of Korea

Figure 37: The installed capacity of wind and photovoltaic power generation in China and other countries since 2013.



Source: Chinese Academy of Environmental Planning

Figure 38: Illustration from Mongolia's VNR demonstrating links between air pollution and other development priorities.



Source: (Government of Mongolia, 2019)

Table 17: **Emission limit values for power plants, industrial boilers, and waste incinerators (unit: mg/m³).**

Sector	Country	Code of Standard	Types	SO_2	NO_2	PM
Power Plants	China	Emission standard of air pollutants for thermal power plants (GB13223-2011)	Ultra-low emission standard	35	50	10
			National standards (key areas)	50	100	20
			National standards (general area/new build)	100	100	30
			National standards (general area/ existing)	200	100	30
	Japan	Emission Limits for existing coal-fired power plants	Emissions limits are set on the plant level, so limit values are based on compilation of actual emissions values – 90th percentile shown.	200	376	46
	Mongolia	MNS 6298:2011	Maximum permissible level and measuring method of air pollutants in flue gas of new Thermal Power Plant and Thermal plant.	400 mg/m³ (population density between 10-1000 per km²)	1100 mg/m³ (V_{daf}<10%)	50 mg/m³ (population density between 10-1000 per km²)
				600 mg/m³ (population density <10 per km²)	650 mg/m³ (10%<V_{daf}<20%)	200 mg/m³ (population density <10 per km²)
					450 mg/m³ (V_{daf}>0%)	
	Republic of Korea	Clean air conservation act and act on the integrated control of pollutants	liquid fuel	20~140 ppm	50~250 ppm	TSP 10~20 (mg/m³)
			solid fuel	25~140 ppm	15~90 ppm	TSP 5~20 (mg/m³) (mg/m³)
			gaseous fuel	10~200 ppm	10~180 ppm	TSP 10~20 (mg/m³)

Table 17: Emission limit values for power plants, industrial boilers, and waste incinerators (unit: mg/m^3).

Sector	Country	Code of Standard	Types	SO_2	NO_2	PM
Waste Incinerator	China	GB 18485-2014	Limiting value of flue gas from domestic waste incinerator	100 mg/m^3 (1h)	NO_x 300 mg/m^3 (1h)	30 mg/m^3 (1h)
				80 mg/m^3 (24h)	NO_x 250 mg/m^3 (24h)	20 mg/m^3 (24h)
	Japan	Regulatory schemes for air pollutants emitted from factories and workplaces	Combustion of fuels and minerals in boilers, waste incinerators, etc.	Regulation value (amount) according to the height of the outlet (He) and the value of the constant K determined for each region. Allowable emission (Nm^3/h)=K×10-3×He2 General emission standards: K = 3.0 to 17.5 Special emission standard: K = 1.17 to 2.34	Emission standards by facility and scale 60 to 950 ppm	–
				Seasonal fuel use standards Sulfur content in fuel by region Sulfur content: 0.5 to 1.2% or less	Total emission limits set by region and plant based on total emission reduction plan	
				Total volume control set by region and plant based on total volume reduction plan		
	Mongolia	MNS 6342:2012	Maximum permissible level of some air pollutants in flue gas from the hazardous waste incinerator	200 (30 min)	300 mg/m^3 (30 min)	80 mg/m^3 (30 min)
				100 (24 h)	200 mg/m^3 (24 h)	20 mg/m^3 (24 h)
	Republic of Korea	Clean air conservation act and act on the integrated control of pollutants		20~35 ppm	50~70 ppm	10~25(mg/m^3)

Table 17: Emission limit values for power plants, industrial boilers, and waste incinerators (unit: mg/m³).

Sector	Country	Code of Standard	Types	SO_2	NO_2	PM
Boilers	China	GB 13271-2014 for newly constructed boilers	Coal-fired boiler	300 mg/m³	NOx 300 mg/m³	50 mg/m³
			Oil-fired boiler	200 mg/m³	NOx 250 mg/m³	30 mg/m³
			Gas-fired boiled	50 mg/m³	200 mg/m³	20 mg/m³
	Japan		Combustion of fuels and minerals in boilers, waste incinerators, etc	Regulation value (amount) according to the height of the outlet (He) and the value of the constant K determined for each region. Allowable emission: (Nm³/h)=K×10-3×He2 General emission standards: K = 3.0 to 17.5 Special emission standard: K = 1.17 to 2.34	Emission standards by facility and scale 60 to 950 ppm	
				Seasonal fuel use standards Sulfur content in fuel by region Sulfur content: 0.5 to 1.2% or less	Total emission limits set by region and plant based on total emission reduction plan	
				Total volume control set by region and plant based on total volume reduction plan		
	Mongolia	MNS 6298:2011		400 mg/m³ urban 600 mg/m³ remote	450-1,100 mg/m³ based on volatile	50-200 mg/m³
	Republic of Korea	Clean air conservation act and act on the integrated control of pollutants	liquid fuel	50~210 ppm	50~140 ppm	10~30 mg/m³
			solid fuel	20~120 ppm	50~70 ppm	10~30 mg/m³
			gaseous fuel	10~70 ppm	20~60 ppm	–

Source: MEE China (available at: https://english.mee.gov.cn/standards_reports/standards/Air_Environment/Emission_standard1/201201/W020110923324406748154.pdf; https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/gthw/gtfwwrkzbz/201405/W020140530531389708182.pdf; and https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqgdwrywrwpfbz/201405/W020140530580815383678.pdf,). MOE of Japan (available at: https://www.env.go.jp/air/osen/law/t-kisei1.html) and https://energyandcleanair.org/comparison-of-coal-power-plant-emissions-standards/. MOE of Mongolia (available at: https://www.jcm-mongolia.com/wp-content/uploads/2015/11/Session-1_20130122_Air-pollution-emission-standards-MGL.pdf and Mongolian National Standard and Enforcement Rules of the Act on the Integrated Management of Environmental Pollution Facilities, Republic of Korea.

Table 18: Existing legislation addressing open burning of waste, including open burning of agricultural residues.

Country	Legislation	Related details
China	Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Waste (Article 20)	Open-air burning of stalks in densely populated areas, in the neighbouring areas of airports, on the peripheries of the main lines of communications and in the areas delimited by local people's governments is prohibited.
	Law of the People 's Republic of China on the Prevention and Control of Atmospheric Pollution (Article 76, 77, and 119)	Any individual or unit that burns outdoors substances like straw bubble and leaves, substances including rubber, plastic, feather, and rubbish shall be fined and ordered to rectify their acts.
Japan	Waste Management and Public Cleansing Law (Article 16-2)	No one shall incinerate waste except the following methods: 1) conducted in accordance with the municipal solid waste disposal standards, industrial waste disposal standards 2) where incineration in unavoidable for the public good or in accordance with social customs.
	Regulations of Waste Management and Public Cleansing Law (Article 1-7)	Municipal solid waste shall be incinerated inside equipment from which the outer air shall be shut out except the air intake and the tip of the chimney.
Mongolia	Law of Mongolia on Waste (Article 10.3)	Citizens, business entities and organizations shall be prohibited to conduct the following activities associated with waste: burning/ combustion of waste in nature (open air)
	Law of Mongolia on Air (Article 20.6)	Discarding, disposing or burning waste in a non-designated area or any waste disposing activities that do not meet requirements of waste disposal standards shall be prohibited.
Republic of Korea	Waste Control Act (Article 8)	No one shall bury or incinerate waste in any area other than the landfill sites permitted, approved, or reported under this Act: provided, that the foregoing shall not apply to incineration at places specified.

Source: For China, available at: http://www.npc.gov.cn/zgrdw/englishnpc/Law/2007-12/12/content_1383723.htm and https://www.fao.org/faolex/results/details/en/c/LEX-FAOC144719/, accessed on April 2nd, 2024. For Japan, https://www.env.go.jp/en/recycle/basel_conv/files/Waste_Management_and_Public_Cleansing.pdf and, https://www.env.go.jp/content/000043856.pdf, accessed on April 2nd, 2024. For Mongolia, https://legalinfo.mn/en/edtl/16760167759581 and https://legalinfo.mn/en/edtl/16532497622381, accessed on April 2nd, 2024. For Republic of Korea, available at: https://elaw.klri.re.kr/eng_service/lawView.do?hseq=63699&lang=ENG, accessed on April 2nd, 2024.

Table 19: Gasoline light commercial vehicle emission standards by countries.

Country	Stage	Category	Class	CO	HC	NMHC	HC+NO_x	NO_x	N_2O	H_2CO	PM	HC		PN	Measurement Method
												Blow by Gas	Boil of Gas		
				g/km								(g/drive)	(g/test)	#/km	
China	China 6b	Type 1	–	0.500	0.050	0.035	–	0.035	0.020	–	0.0030	–	–	$6x10^{11}$	–
		Type 2	I	0.630	0.065	0.045	–	0.045	0.025	–	0.0030	–	–	$6x10^{11}$	–
			II	0.630	0.065	0.045	–	0.045	0.025	–	0.0030	–	–	$6x10^{11}$	–
			III	0.740	0.080	0.055	–	0.050	0.030	–	0.0030	–	–	$6x10^{11}$	WLTP
Japan	–	Passenger cars		1.15	–	0.10	–	0.05	–	–	0.005	–	–	–	WLTP
		Light commercial vehicles (GVW ≤ 3500 kg)	Mini	4.02	–	0.10	–	0.05	–	–	0.005	–	–	–	WLTP
			≤ 1700 kg	1.15	–	0.10	–	0.05	–	–	0.005	–	–	–	WLTP
			> 1700 kg	2.55	–	0.15	–	0.07	–	–	0.007	–	–	–	WLTP
Republic of Korea	–	Automobiles, small passenger/ freight vehicles, medium-sized passenger/ freight vehicles	Criteria 1	2.61	–	–	0.100	–	–	0.0025	-	0	0.35	–	CVS-75
				5.97	–	–	0.087	–	–	–	–	–	–	–	US06
				2.0	–	–	0.062	–	–	–	–	–	–	–	SC03
			Criteria 2	1.31	–	–	0.078	–	–	0.0025	–	0	0.35	–	CVS-75
				5.97	–	–	0.075	–	–	–	–	–	–	–	US06
				2.0	–	–	0.044	–	–	–	–	–	–	–	SC03
			Criteria 3	1.06	–	–	0.044	–	–	0.0025	–	0	0.35	–	CVS-75
				5.97	–	–	0.075	–	–	–	–	–	–	–	US06
				2.0	–	–	0.044	–	–	–	–	–	–	–	SC03
			Criteria 4	1.06	–	–	0.031	–	–	0.0025	–	0	0.35	–	CVS-75
				5.97	–	–	0.075	–	–	–	–	–	–	–	US06
				2.0	–	–	0.044	–	–	–	–	–	–	–	SC03
			Criteria 5	0.625	–	–	0.019	–	–	0.0025	–	0	0.35	–	CVS-75
				5.97	–	–	0.031	–	–	–	–	–	–	–	US06
				2.0	–	–	0.012	–	–	–	–	–	–	–	SC03
			Criteria 6	0.625	–	–	0.00125	–	–	0.0025	-	0	-	–	CVS-75
				5.97	–	–	0.031	–	–	–	–	–	–	–	US06
				2.0	–	–	0.012	–	–	–	–	–	–	–	SC03
			Criteria 7	0	–	–	0	–	–	0	–	–	–	–	CVS-75

Source: Emission Standards for China and Japan available at: https://dieselnet.com/standards/cn/hd.php, accessed on 3 April 2024. Emission Standard Korea available at: Enforcement Regulations of the Clean Air Conservation Act [Attachment 17] https://www.law.go.kr/%EB%B2%95%EB%A0%B9/%EB%8C%80%EA%B8%B0%ED%99%98%EA%B2%BD%EB%B3%B4%EC%A0%84%EB%B2%95%EC%8B%9C%ED%96%89%EA%B7%9C%EC%B9%99, accessed on 3 April 2024.

Notes: NMHC refers to non-methane hydrocarbons. China has recently introduced China 6b standard in July 2023, which has the same emission limits with China 6a but more stringent testing requirements. Chinese emission standards for new passenger cars and light-duty commercial vehicles up to China 6b are based on European regulations. Light-duty vehicle categories are based on the EU classification with some changes. Type 1 vehicles are designed and constructed for the carriage of no more than 6 passengers including driver, and GVW≤2.5ton. Type 2 are further divided into three weight classes: Class I (RW≤1305kg), Class II (1305kg<RW≤1760kg), and Class III (1760kg>RW). This classification is based on the Reference Weight (RW), defined as the mass of the vehicle in running order minus the uniform mass of the driver of 75 kg, and increased by a uniform mass of 100 kg.

For light commercial vehicles, Japan has introduced Gross Vehicle Weight (GVW), defined as the weight of the empty vehicle plus the weight of the maximum payload that the vehicle is designed to carry. The Worldwide Harmonized Light-duty vehicle Test Procedure (WLTP) is a global standard for determining the levels of pollutants, CO_2 emissions and fuel consumption of vehicles. From 2009, PM values apply only to vehicles with lean-burn direct injection (DI) gasoline engines equipped with NO_x, adsorber catalysts. From 2020, PM values apply to all vehicles with DI gasoline engines, including stoichiometric DI vehicles.

ROK adopted California's Non-Methane Organic Gases (NMOG) Fleet Average System (FAS) for gasoline-fueled vehicles. This system enables car manufacturers to have a range of models with varying emissions levels. The measurement methods are as follows: (1) CVS-75 tests certified fuel efficiency and emissions under standard driving conditions; (2), US06 represents aggressive, high speed and/or high acceleration driving behaviour, rapid speed fluctuations, and driving immediately after startup; and (3) SC03 stimulates the engine load and emissions associated with the use of air conditioning (A/C).

Table 20: Diesel light commercial vehicles emission standards by countries.

Country	Stage	Type		CO	NMHC+NO_x	HC	NMHC	NO_x	N_2O	PM	PN	test
				g/km							#/km	
China	China 6b	Type 1		0.500	–	0.050	0.035	0.035	0.020	0.0030	6×10^{11}	
		Type 2	I (RW≤1305kg)	0.500	–	0.050	0.035	0.035	0.020	0.0030	6×10^{11}	
			II (1305<RW≤1760kg)	0.630	–	0.065	0.045	0.045	0.025	0.0030	6×10^{11}	
			III (RW>1760kg)	0.740	–	0.080	0.055	0.050	0.030	0.0030	6×10^{11}	WLTP
Japan	–	passenger cars	EIW<1250kg	0.63	–	–	0.024	0.15	–	0.005	-	WLTP
			EIW>1250kg	0.63	–	–	0.024	0.15	–	0.005	-	WLTP
		light commercial vehicles (GVW<3500 kg)	GVW≤1700 kg	0.63	–	–	0.024	0.15	–	0.005	-	WLTP
			GVW>1700 kg	0.63	–	–	0.024	0.24	–	0.007	-	WLTP
Republic of Korea	–	light-medium passenger cars		0.5	0.17	–	–	0.08	–	0.0045	6x1011	WLTP
		light-medium freight vehicles	RW≤ 1,305 kg	0.5	0.17	–	–	0.08	–	0.0045	6x1011	WLTP
			1,305 <RW≤ 1,760 kg	0.63	0.195	–	–	0.105	–	0.0045	6x1011	WLTP
			RW> 1,760 kg	0.74	0.215	–	–	0.125	–	0.0045	6x1011	WLTP

Sources: Emission Standards for China and Japan available at: https://dieselnet.com/standards/cn/hd.php, accessed on 3 April 2024. Emission Standard Korea available at Enforcement Regulations of the Clean Air Conservation Act [Attachment 17], Emission Standard Korea available at Enforcement Regulations of the Clean Air Conservation Act [Attachment 17] https://www.law.go.kr/%EB%B2%95%EB%A0%B9/%EB%8C%80%EA%B8%B0%ED%99%98%EA%B2%BD%EB%B3%B4%EC%A0%84%EB%B2%95%EC%8B%9C%ED%96%89%EA%B7%9C%EC%B9%99, accessed on 3 April 2024.

Notes: In 2016, China released the Stage 6 Limits and Measurement Methods for Emissions from Light-Duty Vehicles (GB18352.6—2016), which applies to light-duty vehicles (M1, M2, and N1 categories up to 3,500 kg of maximum mass) powered primarily by gasoline or diesel. The Stage 6 standard includes two sets of fuel-neutral emission limits — China 6a (set to be effective from July 2020, with implementation delayed to January 2021) and 6b (effective from July 2023) — covering both air and climate pollutants such as carbon monoxide (CO), total hydrocarbons (THC), nitrogen oxides (NO_x), particulate matter (PM), particle number (PN), and nitrous oxide (N_2O). Additionally, the Stage 6 standard shifts from the New European Driving Cycle (NEDC) to the World Harmonized Light Vehicle Test Cycle (WLTC) and World Harmonized Light Vehicle Test Procedures (WLTP).

NMHC refers to non-methane hydrocarbons. China has recently introduced the China 6b standard (July 2023), which has the same emission limits with China 6a, but more stringent testing requirements. Chinese emission standards for new passenger cars and light-duty commercial vehicles up to China 6b are based on European regulations. Light-duty vehicle categories are based on the EU classification with some modifications. Type 1 vehicles are designed and constructed for the carriage of no more than 6 passengers including driver and have a gross weight (GVW) of 2.5tons or less. Type 2 vehicles are further divided into three weight classes: Class I (RW≤1305kg), Class II (1305kg<RW≤1760kg), and Class III (1760kg>RW). This classification is based on the Reference Weight (RW), defined as the mass of the vehicle in running order minus the uniform mass of the driver of 75 kg, and increased by a uniform mass of 100 kg. Japan classifies passenger cars by Equivalent Inertial Weight (EIW), which represents the assumed driving condition of the vehicle for exhaust gas testing, incorporating the effect of inertial weight. For light commercial vehicles, Japan has introduced Gross Vehicle Weight (GVW), defined as the weight of the empty vehicle plus the weight of the maximum payload that the vehicle is designed to carry. ROK classifies light-and medium-duty freight vehicles into three types based on reference weight.

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