CHINA'S 10-YEAR PATH TOWARD CLEANER AIR:

AN ASIAN PERSPECTIVE

十年清洁空气之路

中国与世界同行

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About Clean Air Asia

Clean Air Asia (CAA) is an international non-profit organization which seeks to improve air quality and build livable cities in Asia. Established in 2001, CAA's headquarters is located in Manila, Philippines, with offices in Beijing, China and Delhi, India. CAA's country networks cover six countries including the Philippines, Indonesia, Malaysia, Nepal, Sri Lanka, and Viet Nam.

CAA has been working in China since 2002, focusing on air quality management, green transportation, and energy transition. CAA was issued its "Representative Office of an Overseas Non-Governmental Organization Registration Certificate" by the Beijing Municipal Public Security Bureau on March 12, 2018, and set up the Clean Air Asia (Philippines) Beijing Representative Office. Subject to the supervision and guidance of the Ministry of Public Security and the Ministry of Ecology and Environment (MEE), CAA undertakes capacity building, research, public education initiatives in the field of air pollution prevention and control across China.

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Scope

This special report is part of the "China Air" report series, which presents the key figures detailing China's progress in clean air and climate change mitigation (especially in the past 10 years). It compares data from countries in East Asia, South Asia, and Southeast Asia, as well as some representative countries in Europe and America, to promote mutual learning and identify paths for future improvement. The report team hopes that this series of reports will play a role as a bridge to promote the exchange and application of advanced management experience and best practices among Asian countries and cities, and help countries and cities facing severe challenges find emission reduction and development paths suited to their respective national conditions.

The report covers six key indicators, including air quality, air pollutant emissions, greenhouse gas emissions, energy sector, transport sector and key industrial sectors.

The report team will continue to publish knowledge products such as website, online data platforms, and thematic analyses. The team will keep reports and other outputs as an open source to be continuously developed and updated in collaboration with partners in order to keep improving reports and promote the sharing of results.

Table 1: List of Countries Included in This Report

Region	Country
East Asia	China
	Japan
	Republic of Korea
	Mongolia
South Asia	India
	Pakistan
	Bangladesh
	Sri Lanka
	Nepal
Southeast Asia	Singapore
	Republic of the Philippines
	Malaysia
	Thailand
	Viet Nam
	Indonesia
	Cambodia
	Myanmar
America	United States (US)
Europe	United Kingdom (UK)
	Germany

Comparisons between countries in the report are made only within the above-mentioned countries unless otherwise specified.

Highlights

Asia covers 30% of the world's geographical area and is home to 60% of the world's population. It is also a vital driver of economic growth globally. Many Asian developing countries are still in the midst of rapid urbanization, industrialization, and motorization and face challenges in air pollution control and greenhouse gas emission reduction.

China is the world's most populous country and Asia's largest economy. The continuous improvement of air quality and reduction of greenhouse gas emissions will benefit not only China itself but also the rest of the region and the world. Over the past 10 years, China's economic development model has gradually shifted from intensive development to green development, making progress in air pollution prevention and control and climate change mitigation. In 2020, China announced its goal of achieving carbon peak and carbon neutrality, adding momentum to the continuous improvement of air quality.

However, compared with the development history and current situation of developed countries in America, Asia, and Europe, China and other developing countries in Asia still have a long way to go to achieve clean air and low-carbon development.

Based on the data and information analysis of key indicators, such as air quality, air pollutant emission, greenhouse gas emission, energy, transportation, and key industrial sectors, the report's main findings are as follows:

China has had the fastest progress in air quality improvement in the world. Some South Asian countries still face the dual challenge of achieving economic development and reducing air pollution.

In the past 10 years, China has achieved rapid air quality improvement alongside sustained economic growth. In 2013-2021, China's overall annual average $PM_{2.5}$ concentration dropped by approximately 56%, while the nation's GDP maintained an average growth rate of 6.6%. Based on the air quality variation trend in megacities in each country, 60% of those with an over 10% reduction in the three-year moving average of $PM_{2.5}$ concentration between 2018 and 2021 are Chinese cities.

The relation between per capita GDP and $PM_{2.5}$ exposure in American, Asian, and European countries fits the inverted U-shape theory (also known as the Environmental Kuznets Curve theory). Countries with higher levels of economic development have better air quality, while developing countries with lower incomes have worse air quality. China's GDP per capita has exceeded the $10,000 threshold, crossed the "turning point," and successfully broken the connection between economic development and air quality deterioration. Some South Asian countries, including Bangladesh, India, Nepal, and Pakistan, still face the dual challenge of achieving economic development and reducing air pollution.

China's emission control standards have rapidly reached an advanced level, resulting in a significant decline in major air pollutant emission.

Compared with developed countries and regions in America, Asia, and Europe, China's pollution control for power, transportation, and key industrial sectors started relatively late, but has developed rapidly. At present, China's emission standards rank among the most stringent in the world, with the country transforming from a "follower" to a "leader" in the formulation of emission standards. Meanwhile, developing countries in Asia, in general, have more uneven control standards, and they still need to improve compared to more developed countries.

Taking light-duty vehicle emission standards as an example, while some developing Asian countries are still using Euro 2 and Euro 3 emission standards, China, India, Japan, the Republic of Korea, and Singapore have more stringent limits for light-duty vehicles. Fuel standards are another example. In 2017, China reduced the limits for sulfur content in both diesel and gasoline to 10 ppm, whereas other Asian countries, such as Myanmar and Indonesia, still have them at 500 ppm. The good news is that some Asian countries have already leapfrogged into implementing stricter emission limits, with India upgrading its emission limits from Euro 4 to Euro 6, Indonesia from Euro 2 to Euro 4, and Nepal from Euro 1 to Euro 3.

In 2011-2020, thanks to the introduction and effective implementation of a series of emission control policies, China was able to rapidly reduce major air pollutant emissions while maintaining a steady growth in energy consumption, industrial value added, and automobile ownership. The SO_2 and NO_2 emission per $1000 of GDP of developed American, Asian, and European countries were lower than 0.5kg and 1kg, respectively. China was able to narrow the gap against these developed countries after a decade of continuous emission reduction efforts. However, emissions per unit of GDP are still relatively high for most developing Asian countries, of which Mongolia is experiencing the most unfavorable situation.

China's air quality standards have driven air quality improvement, continuing to upgrade the standard can further protect the health of the general public.

China's current air quality standards have actively driven the improvement of air quality. The annual mean $PM_{2.5}$ concentration of all 339 cities at the prefectural level and above is already within the standard limit. However, China's annual $PM_{2.5}$ concentration standard limit follows WHO's least stringent interim target, which is seven times higher than the WHO guideline value. The annual average concentration weighed by population is still 3-4 times higher than that of developed countries in Europe and America. Upgrading the standards and continuous improvement in air quality can further protect the health of the public (especially vulnerable groups such as the elderly and children), which is crucial for China as it undergoes population aging.

In contrast, current air quality in almost half of the Asian countries still need to meet local standards. Although countries like Bangladesh, Myanmar, and Pakistan have set stricter limits, $PM_{2.5}$ concentrations still exceed standards.

The intensity of China's CO_2 emission has significantly dropped, while developing Asian countries face the arduous task of emission reduction.

As the biggest CO_2 emitter in the world, China has set greenhouse gas emission control as an important goal while seeking economic development. Following rapid economic development and the accompanying increase in its energy consumption, the country started facing continuously increasing CO_2 emissions, reaching tens of billions of tons each year. It reached a third of global CO_2 emissions, exceeding the sum of every other Asian countries' emissions. During the 12th and 13th five-year planning phases, China put forward its goal to reduce CO_2 emission per unit of GDP by 17% and 18%, respectively. Throughout the last 10 years, China has managed to reduce CO_2 emission per unit of GDP by over one-third through various methods, such as adjusting energy and industry structures, as well as improving energy conservation and efficiency.

With the global need for carbon neutrality and net-zero emissions, China and many Asian countries announced their decarbonization goals. However, about one-third of the world's energy consumption and about half of the world's CO_2 emissions come from Asia, making the emission reduction task of developing Asian countries challenging. CO_2 emissions in Germany, Japan, the UK, and the US have peaked, while developing Asian countries are still "climbing the hill." Notably, Viet Nam, a rapidly developing country, is showing a continuous rise in total emissions. China has promised to get from its CO_2 emissions peak to carbon neutrality in about 30 years. To achieve this with its legendary "Chinese speed," China needs to work hard.

Most Asian countries are highly dependent on fossil fuels, with the coal consumption ratio of China, India, and Mongolia reaching over 50% of total energy consumption

China's energy consumption is constantly increasing, but its energy consumption structure is continuously being improved. While being the largest consumer of coal globally, China has started to achieve a downward trend in its coal consumption. In 2019, the ratio was 10% lower than that in 2010. However, coal still dominates China's overall energy structure.

Most Asian countries are highly dependent on fossil fuels. The coal consumption ratio of China, India, and Mongolia is over 50% of total energy consumption. Southeast Asian countries significantly depend on oil, with the ratio ranging from 28%-86%. Countries like Indonesia, Malaysia, the Philippines, and Viet Nam have seen an increase in coal and gas production as oil reserves are decreasing. Indonesia seems to be heading into a production capacity pattern led by coal production, and the country's share of renewable energy production has not increased significantly. Some developed countries in Europe and America are gradually turning toward the production and consumption of renewable and cleaner energy.

China is moving ahead in the development of electric vehicles, and Asia's automotive energy transition has broad prospects.

China has the largest amount of new automobile sales and ownership globally. In 2010-2020, the average annual growth rate of automobile ownership in China reached 13.8%, and the number of automobiles per 1,000 inhabitants reached 199, slightly exceeding the global average. As the demand in the automobile market continues to rise, the task of reducing pollution and CO_2 emissions in China's transportation sector becomes arduous, largely stimulating the development of electric vehicles. In 2011-2021, the average compound annual growth rate of electric passenger cars in China reached 91.3%, significantly higher than the overall global growth rate. Since 2015, China has become the world's largest electric passenger car market, accounting for half of the global market.

In 2021, the global sales of electric passenger cars accounted for 11.7% of overall passenger vehicle sales, with the main market concentrated in China, Europe, and North America. In China, electric passenger car sales accounted for about 15.5% of overall passenger vehicle sales, exceeding the global average. The promotion of electric vehicles in most Asian countries is still in its early stage, but many Asian countries have started proposing medium- and long-term development goals for electric vehicles. The development of automotive energy transformation has broad prospects in Asia.

Air Quality

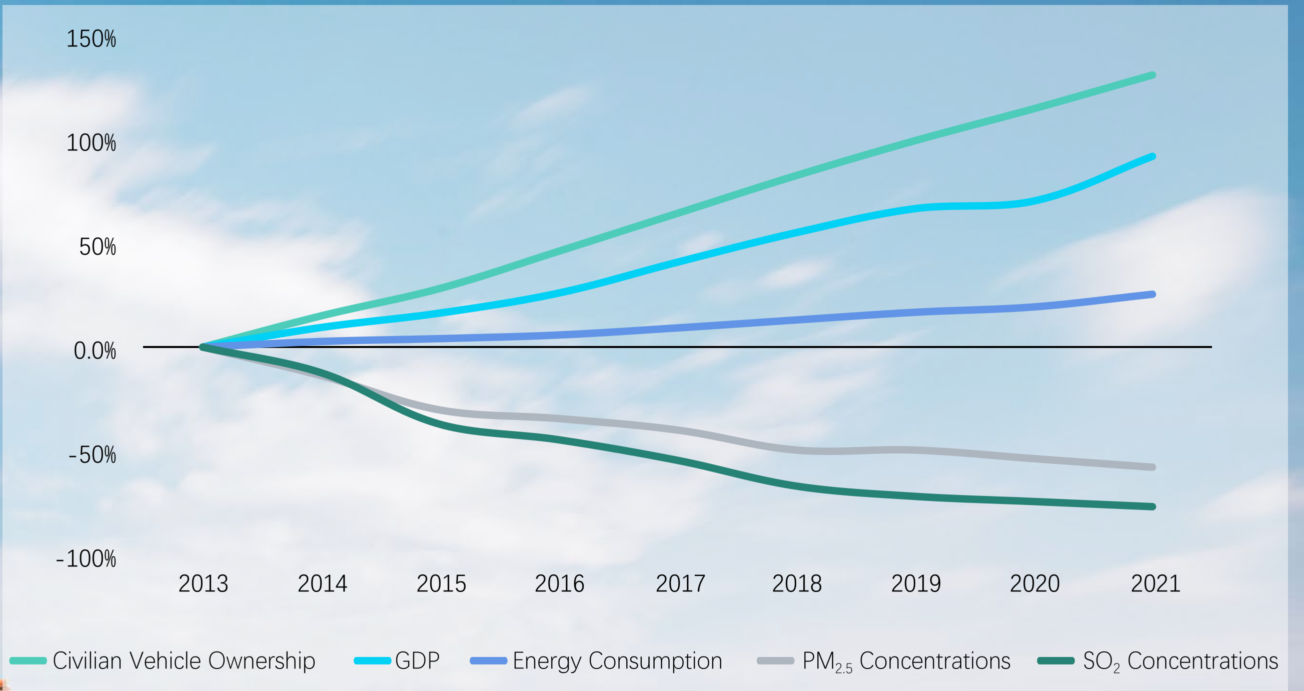


Figure 1.1 Changes in China's GDP, Energy Consumption, Civilian Vehicle Ownership, and Air Pollutant Concentrations, 2013-2021

Source: China Statistical Yearbook, 2014-2022.

To protect the health of the general public, China has declared a war against air pollution in 2013. Since the implementation of the "Action Plan for Air Pollution Prevention and Control" issued in 2013, China has achieved significant improvements in overall air quality while undergoing rapid developments in terms of national economy, industrialization, and urbanization.

In 2013–2021, China' s overall annual average $PM_{2.5}$ and SO_2 concentrations have fallen by approximately 56% and 78%, respectively. During this period, China' s GDP maintained a high average growth rate of 6.6%—nearly twice the average growth rate of developing economies. Energy consumption and the number of civilian vehicles increased by 25.07% and 132.2%, respectively. China has become the country with the fastest progress in air quality improvement in the world while maintaining the economic growth. The Air Quality Life Index (AQLI) study by Energy Policy Institute at the University of Chicago (EPIC) shows that it took several decades and recessions for the United States and Europe to achieve the same pollution reductions that China was able to accomplish in 7 years, even as it continued to grow its economy.

The relationship between GDP per capita and $PM_{2.5}$ exposure in American, Asian, and European countries fits the inverted U-shape theory (also known as the Environmental Kuznets Curve theory). Countries with higher levels of economic development have better air quality, while developing countries with lower incomes have worse air quality.

In the past 10 years, China's GDP per capita has exceeded the $10,000 threshold, crossing the "turning point" and entering a state of decoupling between economic development and air quality deterioration. In contrast, some South Asian countries, including Bangladesh, India, Nepal, and Pakistan, still face the dual challenge of achieving economic development and reducing air pollution.

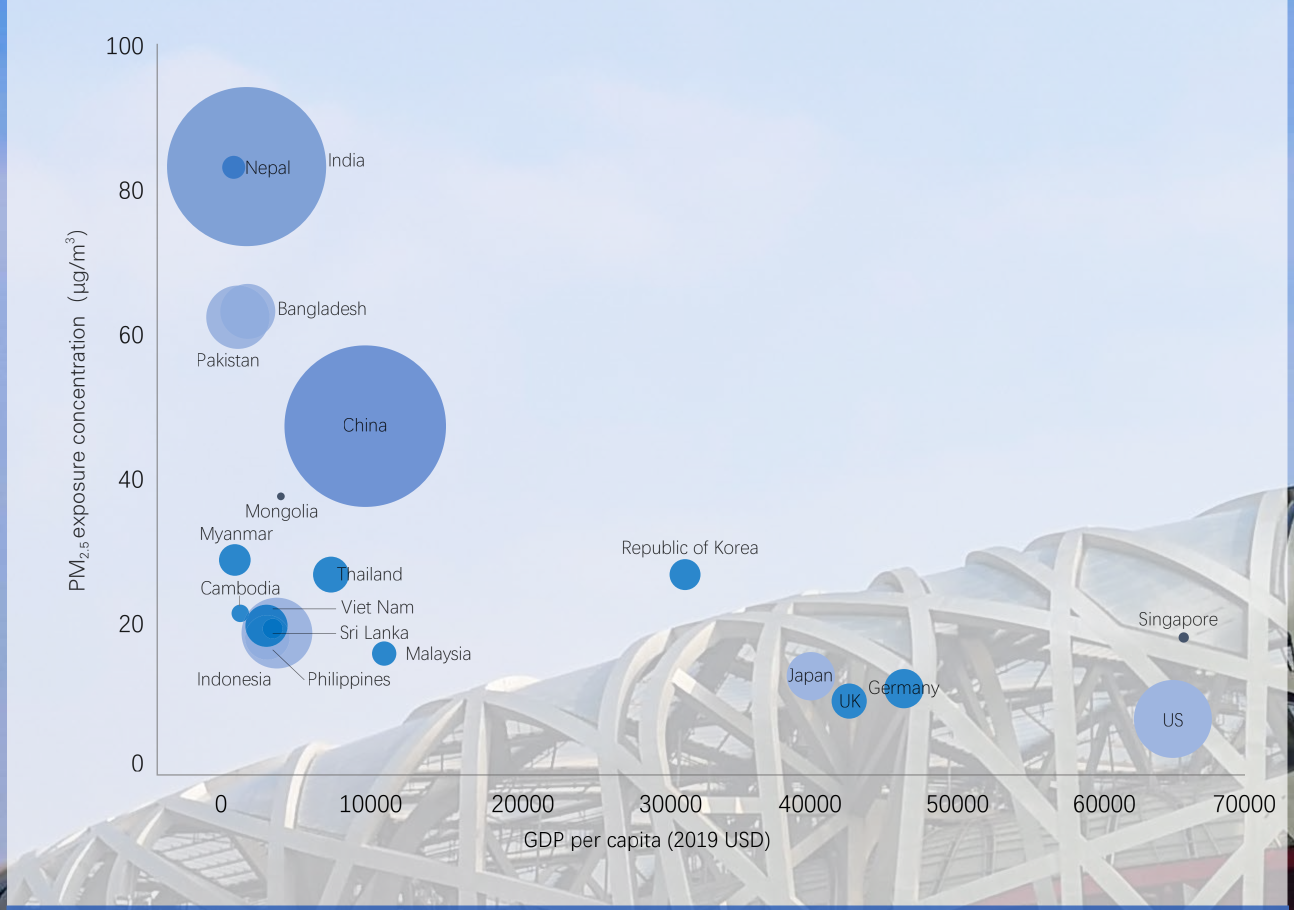


Figure 1.2 $PM_{2.5}$ Exposure Concentration and GDP per Capita of Various Countries

Note: GDP per capita is measured in 2019 US dollars; the size of the bubbles corresponds to the population of each country.
Source: Global Burden of Disease Study 2019, World Development Indicators database

Figure 1.3 $PM_{2.5}$ Concentration in Major Cities in 2021 and Improvement Percentages over 2018-2021

Note: The improvement percentage is for the three-year moving average of $PM_{2.5}$ concentration—that is, comparing the average of $PM_{2.5}$ concentration in 2019-2021 to that in 2018-2020.

At present, the air quality level in megacities across various countries is generally improving. Cities in East Asian countries, especially in China, have had a positive performance. During 2018-2021, eight of the nine cities that had an over 10% reduction in the three-year moving average of $PM_{2.5}$ concentration were in East Asian countries, and six were Chinese cities. The $PM_{2.5}$ concentration in New Delhi and Dacca, the capitals of India and Bangladesh, were higher than that of other megacities. Karachi in Pakistan has had the largest increase in $PM_{2.5}$ concentration (over 10%), and Islamabad, the capital of the country, has experienced a deterioration in air quality.

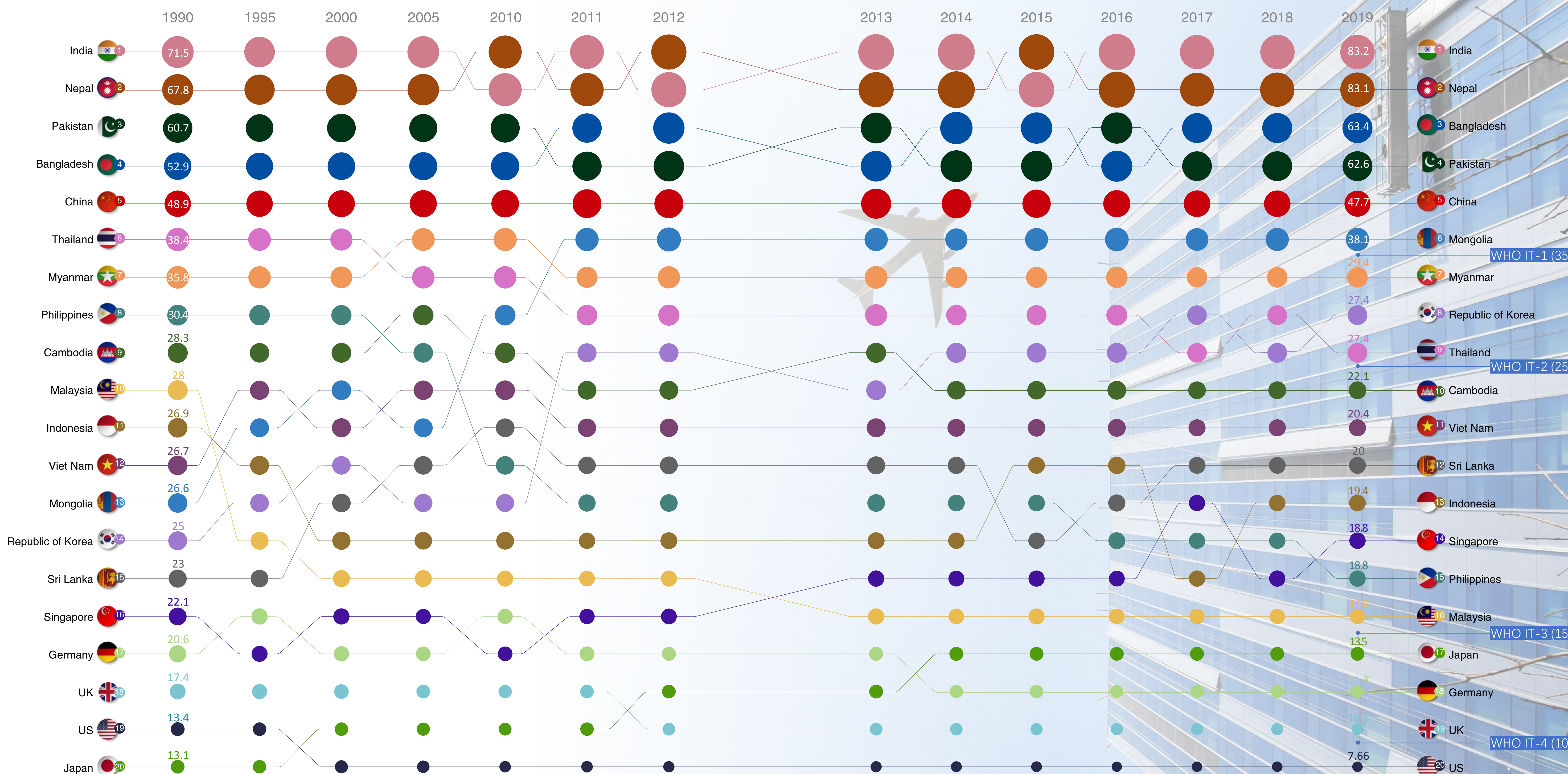


Figure 1.4 $PM_{2.5}$ Exposure Concentration and Ranking by Country, 1990-2019

Note: $PM_{2.5}$ exposure in the figure is the population-weighted annual average $PM_{2.5}$ concentration (μg/m^3).

While the $PM_{2.5}$ concentration in China has been dropping significantly since 2013, the current concentration remains high. The population-weighted annual average $PM_{2.5}$ concentration in China is still 3-4 times that of developed countries in Europe and America, leaving much room for improvement.

In addition to China, Asian countries that have yet to achieve the WHO interim target 1(WHO IT-1, an annual average $PM_{2.5}$ concentration of 35 μg/m^3) include several South Asian countries, such as India, Nepal, Bangladesh, and Pakistan, which have not seen any air quality improvements for several years, and Mongolia, which is experiencing air pollution challenges.

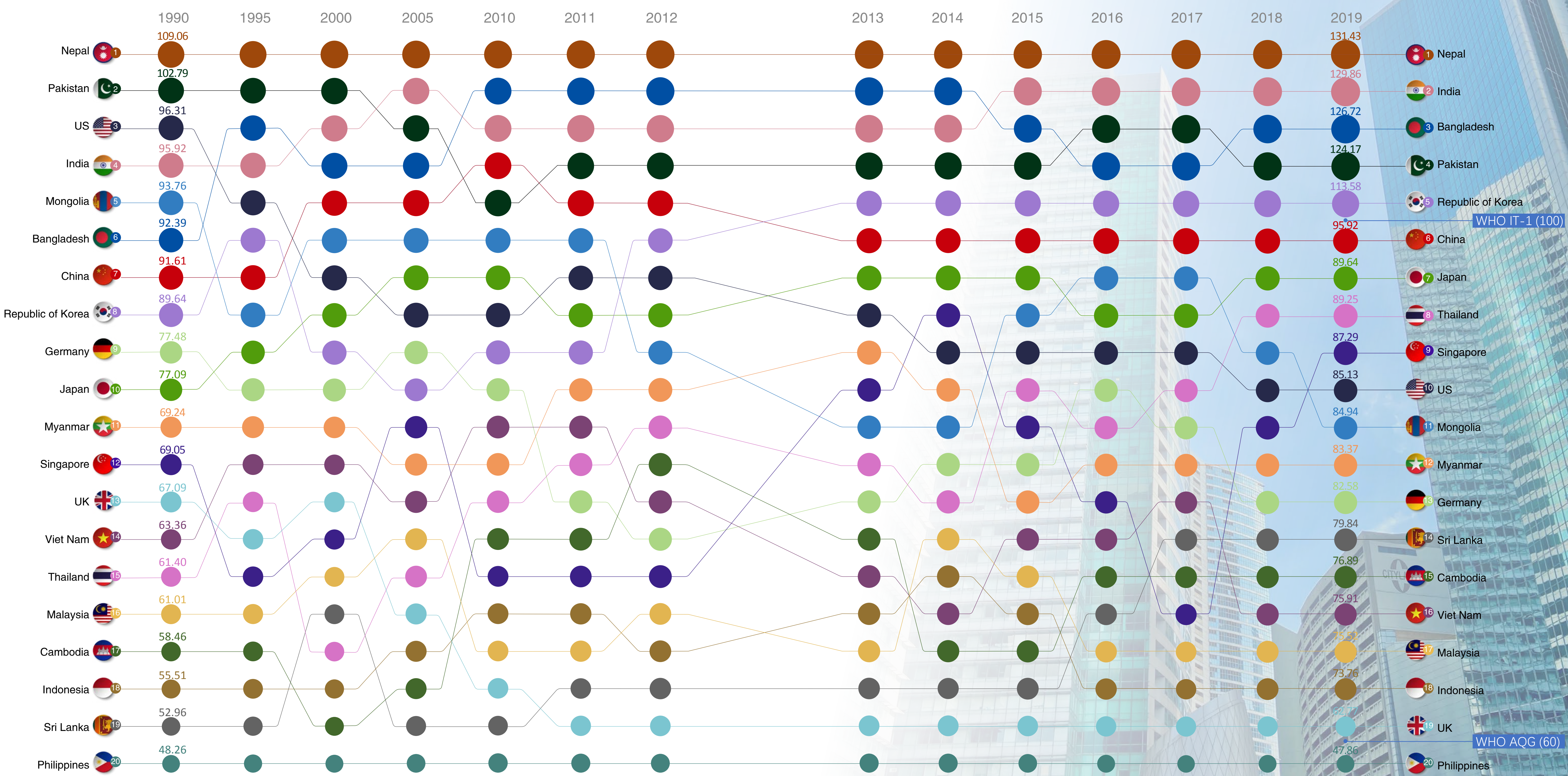
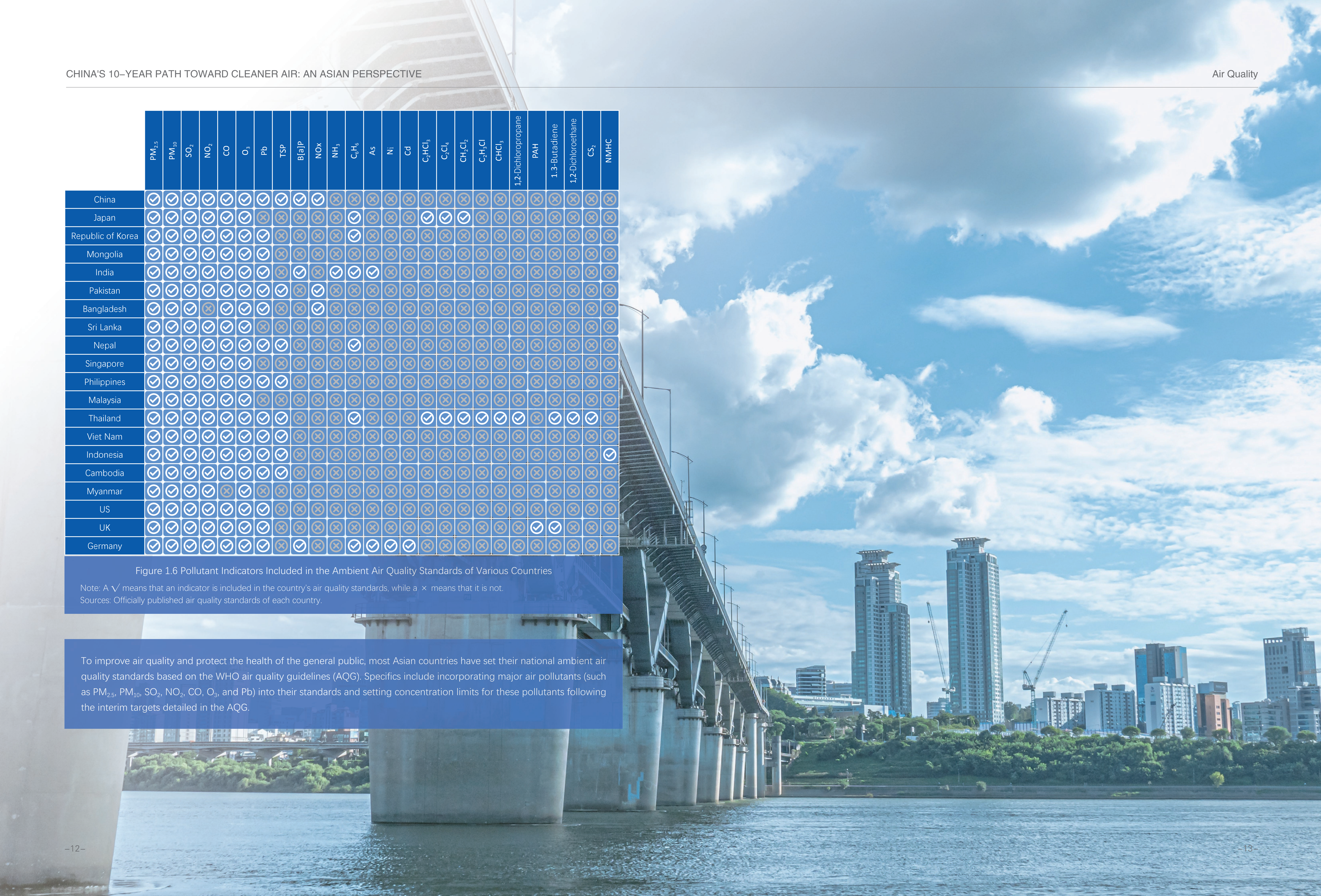


Figure 1.5 O_3 Exposure Concentration in Ozone Season and Ranking by Country, 1990-2019

Note: Ozone season is the six consecutive months with the highest O_3 concentration levels in a year. The figure shows population-weighted annual average O_3 concentrations (μg/m^3).

Countries with relatively high $PM_{2.5}$ concentrations usually face O_3 pollution problems as well, most of which are located in South Asia. China's current O_3 concentration level during ozone season is relatively close to that of Japan and the Republic of Korea, both also in East Asia, and is comparable to the WHO IT-1 of O_3 concentration during ozone season (100 μg/m^3).

There has been a common trend of rising O_3 concentration levels during ozone season in recent years. Over the past 10 years, O_3 concentration levels in India, the Republic of Korea, Singapore, and Sri Lanka have significantly worsened, with the largest increase being over 30%.



	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3	Pb	TSP	B[a]P	NOx	NH_3	C_6H_6	As	Ni	Cd	C_2HCl_3	C_2Cl_4	CH_2Cl_2	C_2H_3Cl	$CHCl_3$	1,2-Dichloropropane	PAH	1,3-Butadiene	1,2-Dichloroethane	CS_2	NMHC
China	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Japan	✓	✓	✓	✓	✓	✓	×	×	×	×	×	✓	×	×	×	✓	✓	✓	×	×	×	×	×	×	×	×
Republic of Korea	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mongolia	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
India	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×
Pakistan	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Bangladesh	✓	✓	✓	×	✓	✓	✓	×	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sri Lanka	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Nepal	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Singapore	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Philippines	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Malaysia	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Thailand	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	✓	×	×	×	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	×
Viet Nam	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Indonesia	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Cambodia	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Myanmar	✓	✓	✓	✓	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
US	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
UK	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	✓	×	×	×
Germany	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×

Figure 1.6 Pollutant Indicators Included in the Ambient Air Quality Standards of Various Countries

Note: A √ means that an indicator is included in the country's air quality standards, while a × means that it is not.
Sources: Officially published air quality standards of each country.

To improve air quality and protect the health of the general public, most Asian countries have set their national ambient air quality standards based on the WHO air quality guidelines (AQG). Specifics include incorporating major air pollutants (such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3, and Pb) into their standards and setting concentration limits for these pollutants following the interim targets detailed in the AQG.

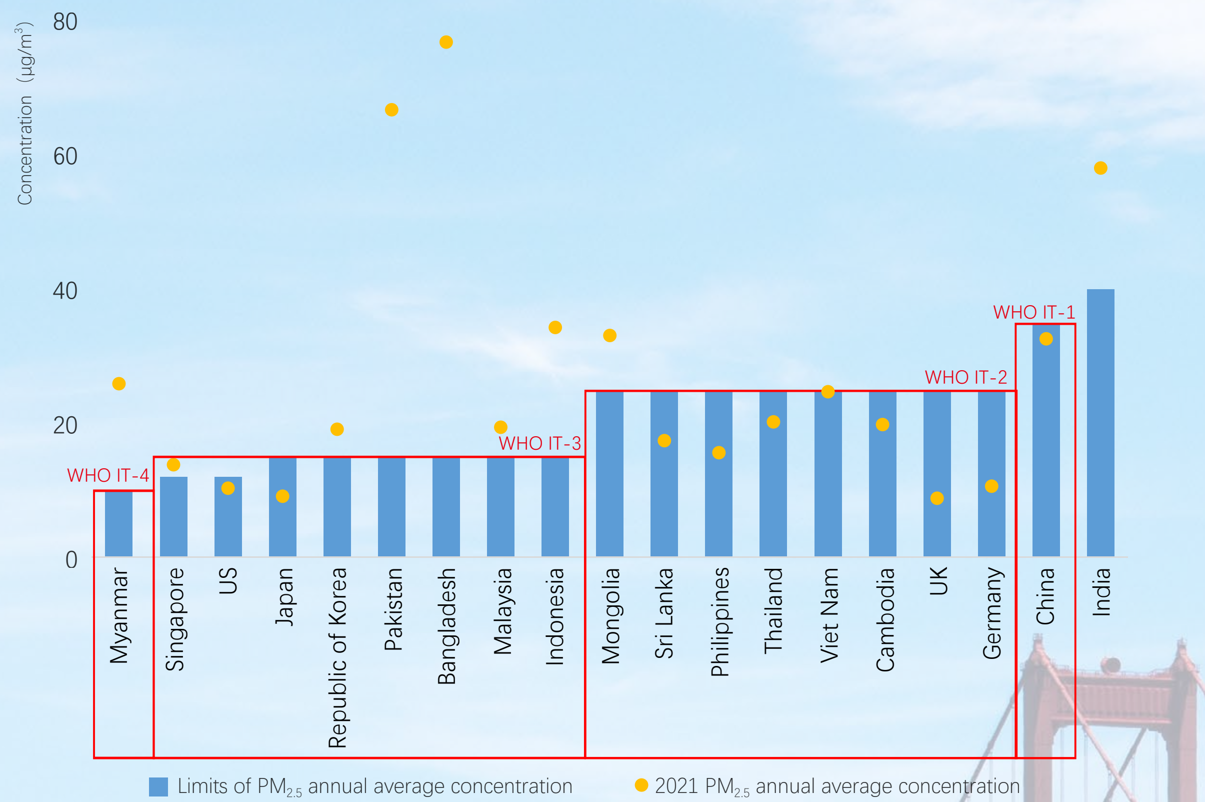


Figure 1.7 Annual Mean Concentration Limits for $PM_{2.5}$ and Monitored $PM_{2.5}$ Concentration in 2021 of Various Countries

Notes: 1. US national ambient air quality standards are divided into primary and secondary levels. The primary standards are set for public health protection, while the secondary standards are set for public welfare protection. Figure uses the former.

2.China has two types of national ambient air quality standards. Class 1 applies to natural reserves, tourist attractions, and other areas needing special protection. These areas usually have good air quality and a sparse population. Class 2 applies to residential, mixed commercial and residential, cultural, industrial, rural, and other areas where public health needs to be protected. Figure uses the latter.

3.India's national ambient air quality standards include limits for eco-sensitive areas, and industrial and residential areas. Figure uses the latter.

4.Nepal's national ambient air quality standards do not include limits for annual average $PM_{2.5}$ concentration.

China's annual $PM_{2.5}$ concentration limit is the same as WHO IT-1, which is the most lenient interim target and more stringent than India's standards only. However, China's standard is the foundation of driving the country's improvement of air quality. At present, the overall annual average $PM_{2.5}$ concentration of all 339 cities at prefectural level and above is about 30μg/m³, meeting the standard requirement.

Current air quality in nearly half of the Asian countries does not meet local standards. Countries like Bangladesh, Myanmar and Pakistan have set relatively strict limits (with reference to WHO IT-3 and IT-4), but their monitored $PM_{2.5}$ concentrations still exceed the standards.

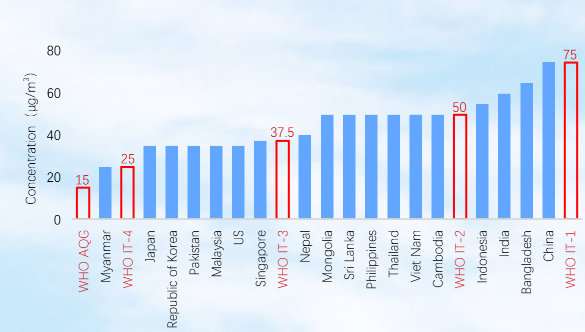


Figure 1.8 $PM_{2.5}$ 24-hour Average Concentration Limits of Various Countries

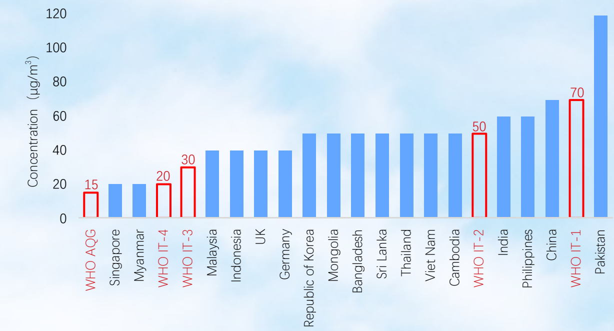


Figure 1.9 PM_{10} Annual Average Concentration Limits of Various Countries

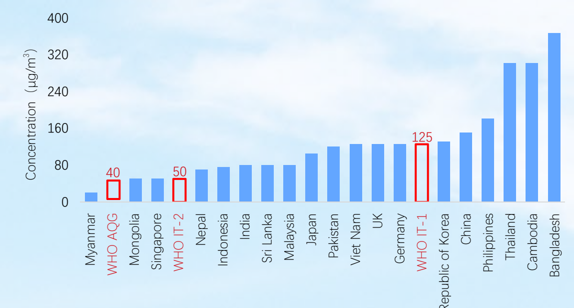


Figure 1.10 SO_2 24-hour Average Concentration Limits of Various Countries

Figure 1.11 PM_{10} 24-hour Average Concentration Limits of Various Countries

Figure 1.12 NO_2 24-hour Average Concentration Limits of Various Countries

Figure 1.13 NO_2 1-hour Average Concentration Limits of Various Countries

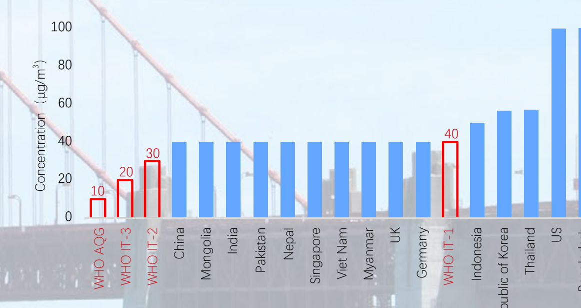


Figure 1.14 NO_2 Annual Average Concentration Limits of Various Countries

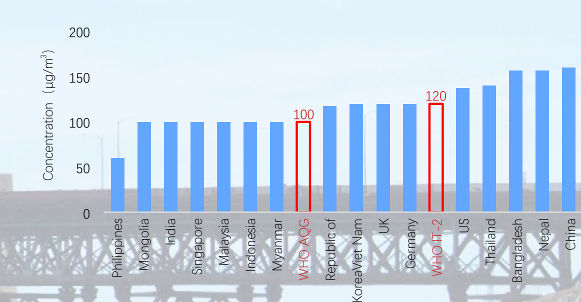


Figure 1.15 O_3 8-hour Average Concentration Limits of Various Countries

Air Pollutant Emissions

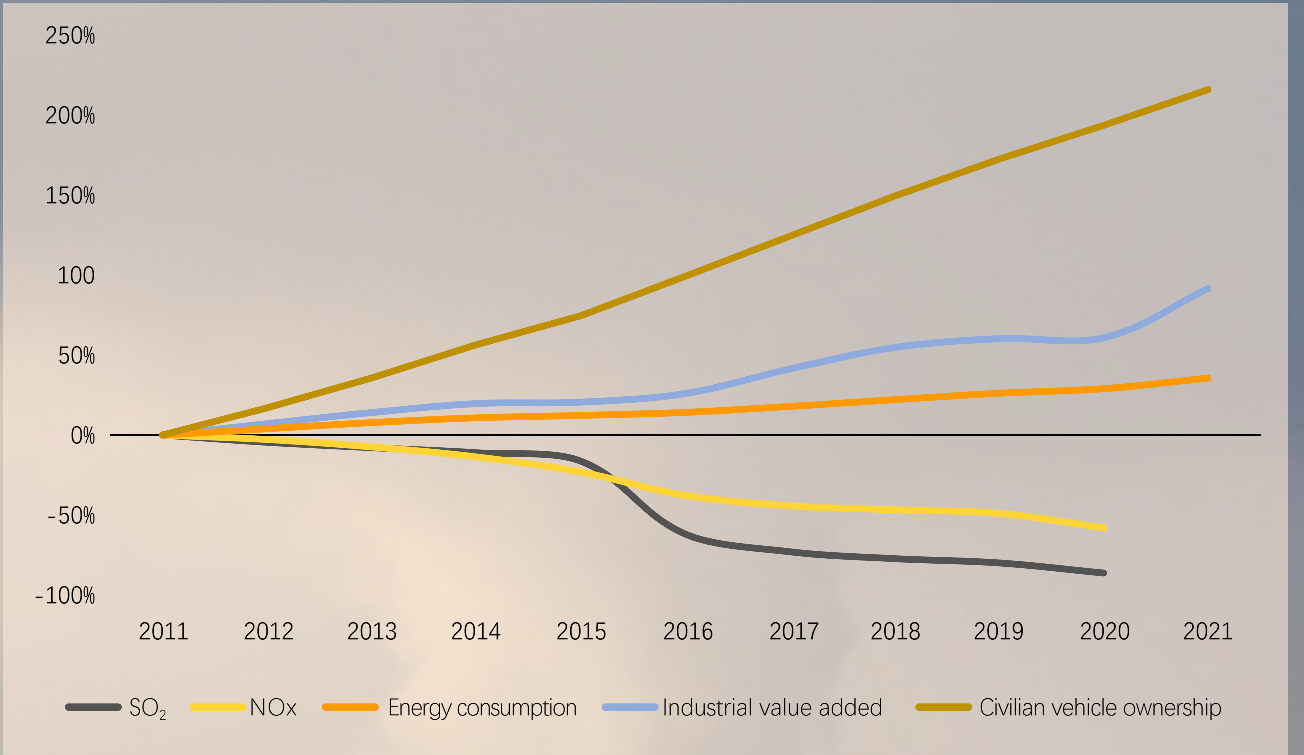


Figure 2.1 Changes in China's Industrial Value Added, Energy Consumption, Civilian Vehicle Ownership, and Air Pollutant Emission, 2011-2021

Source: China Statistical Yearbook, 2012-2022.

In 2011–2020, China's energy consumption, industrial value added, and civilian vehicle ownership had a steady growth of 35%, 91%, and 214%, respectively. Benefiting from the promulgation and execution of a series of emission control policies, China also achieved rapid decrease in the emissions of major air pollutant SO_2 and NOx. In the same period, China's emissions of SO_2 and NOx rapidly declined. SO_2 emission decreased by 86%, from 22.179 million tons to 3.182 million tons, while NOx emission decreased by 58%, from 24.043 million tons to 10.197 million tons.

Figure 2.2 Changes in SO_2 Emission per Unit of GDP of Various Countries, 2011-2019

Unit: kg/1,000 (2015 USD)

Source: Community Emissions Data System (CEDS) , World Development Indicators database

Figure 2.3 Changes in NOx Emission per Unit of GDP of Various Countries, 2011-2019

Unit: kg/1,000 (2015 USD)

Source: Community Emissions Data System (CEDS) , World Development Indicatorsdatabase

There has been a large decrease in major air pollutant emissions intensity in China. In 2011-2019, SO_2 and NO_X emissions per unit of GDP in China dropped by 88% and 70%, respectively, higher than that of other countries.

SO_2 emission per unit of GDP in the US, the UK, Singapore, Thailand, Malaysia, Republic of Korea, Germany decreased by over 40%. The US, Singapore, the UK also maintained an over 40% rapid downward trend of NOx emission per unit of GDP.

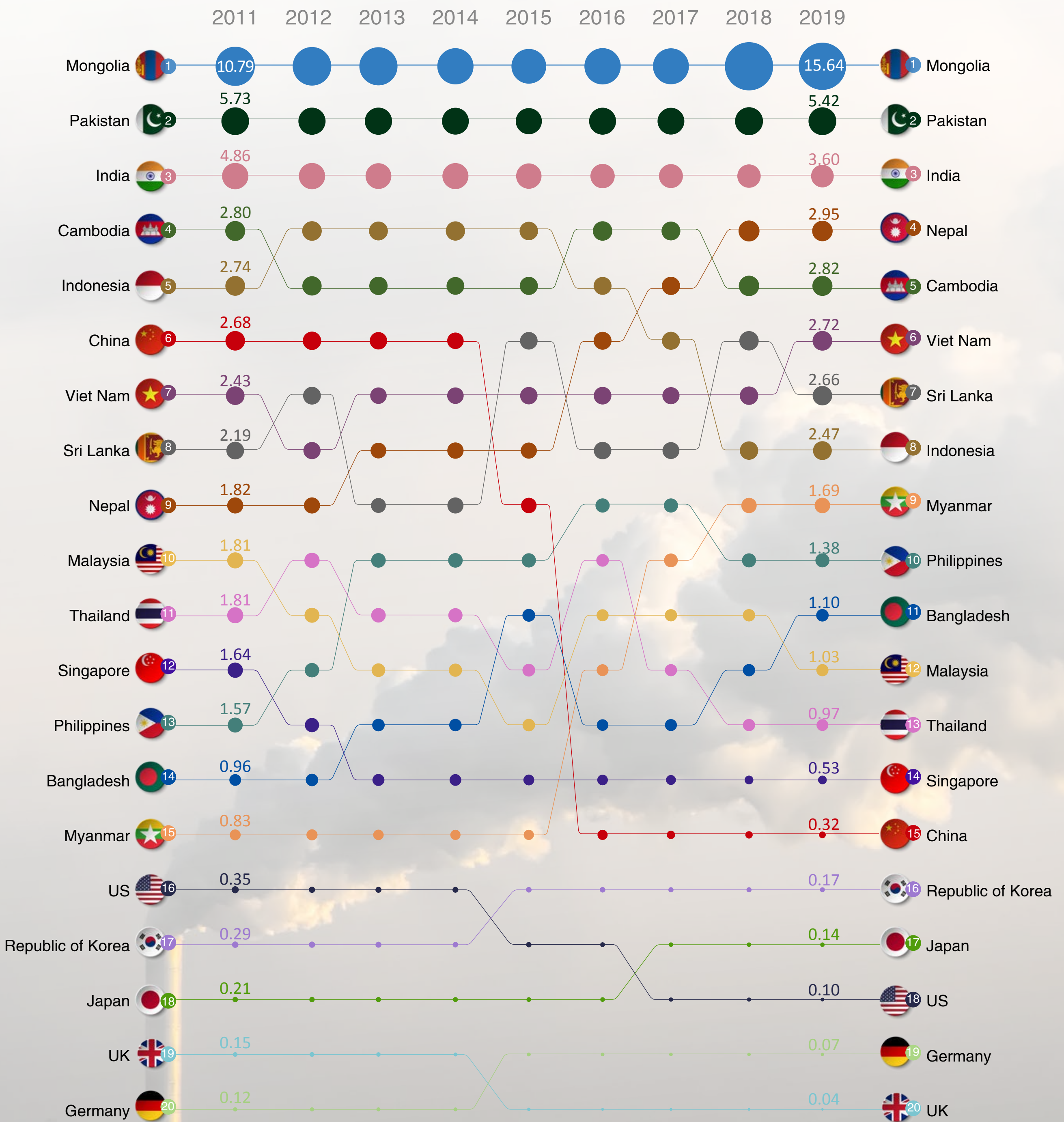


Figure 2.4 SO_2 Emission per Unit of GDP and Ranking by Country, 2011-2019

Unit: kg/1,000 USD(2015)

Source: Community Emissions Data System (CEDS) , World Development Indicators database

Developed countries in Asia, Europe, and the US maintained a downward trend in overall pollutant emission per unit of GDP. SO_2 and NOx emissions per $1,000 of GDP were lower than 0.5 kg and 1 kg, respectively. China was able to narrow the gap against these developed countries after a decade of continuous emission reduction efforts. At present, pollutant emissions per unit of GDP are still relatively high for most developing Asian countries, of which Mongolia is in the most disadvantageous situation.

Figure 2.5 NOx Emission per Unit of GDP and Ranking by Country, 2011-2019

Unit: kg/1,000 USD(2015)

Source: Community Emissions Data System (CEDS) , World Development Indicators database

Greenhouse Gas

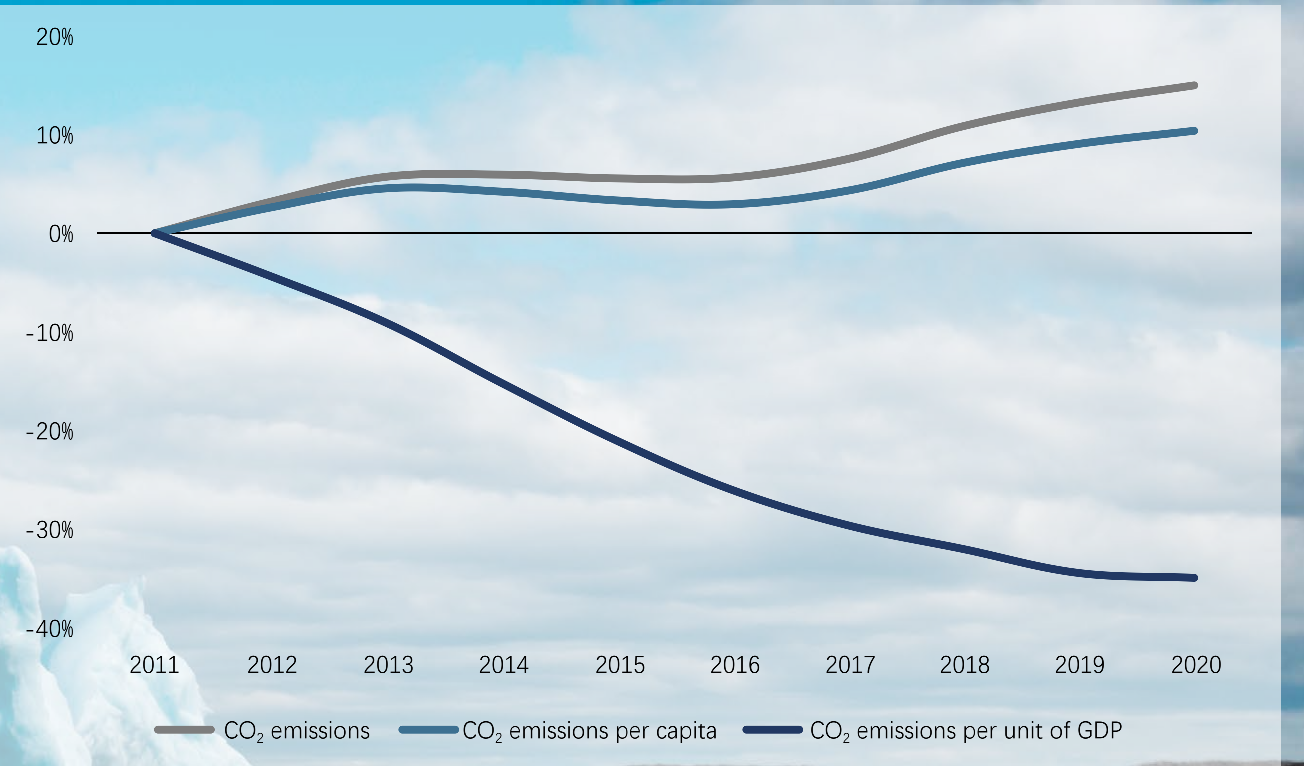


Figure 3.1 Changes in China's CO_2 Emission, Emission per Capita, and Emission per Unit of GDP, 2011-2020

Source: Emissions Database for Global Atmospheric Research

In 2011–2020, following rapid economic development and an increase in energy consumption, China's total CO_2 emission continued to rise. Increased income levels drove up the CO_2 emission per capita in the country, with an increase of 10.4% in the last 10 years. Meanwhile, China is gradually moving from an "intensive" economic development model to a green development model, with CO_2 emission per unit of GDP decreasing by 34.9% in 2020 compared to 2011.

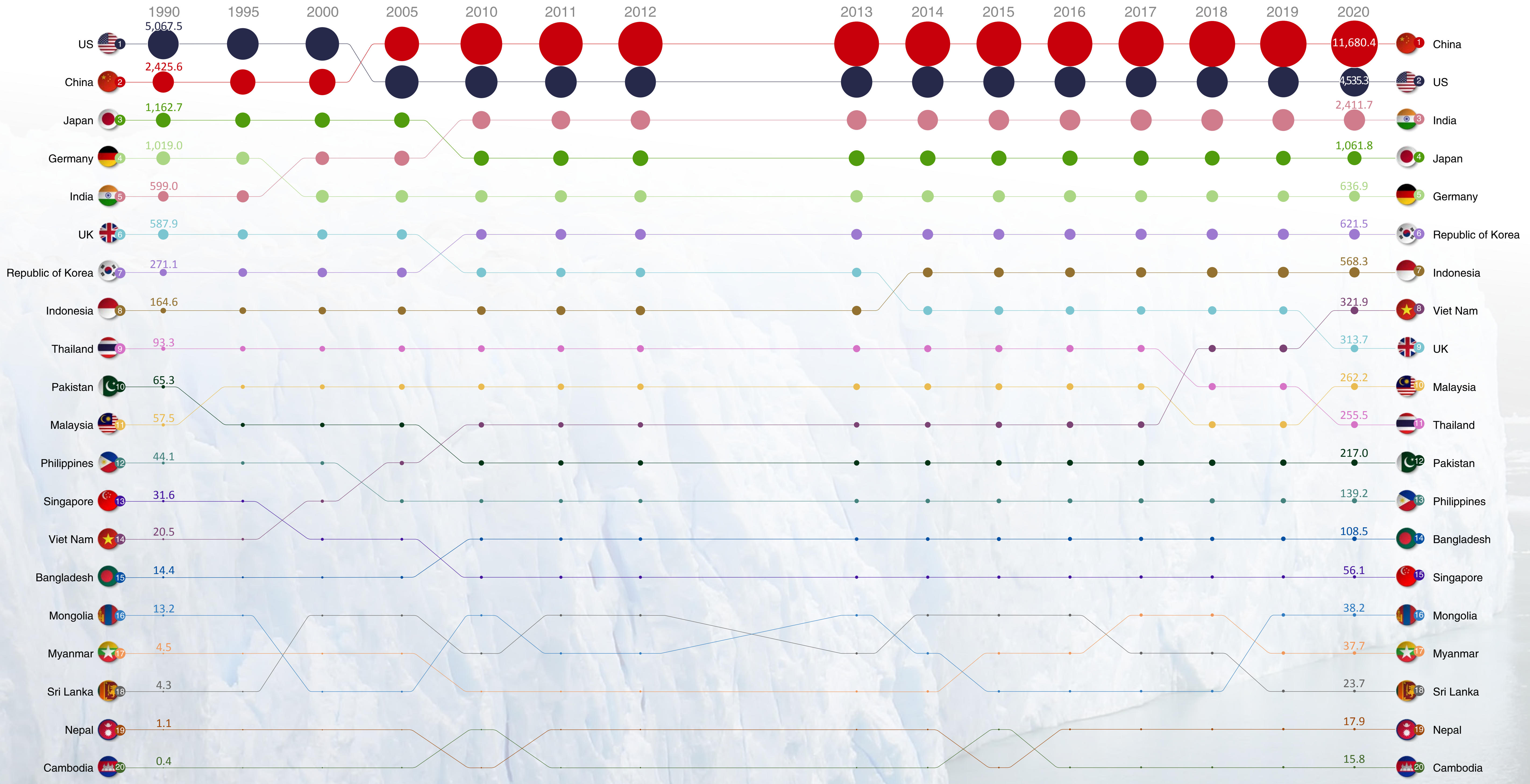


Figure 3.2 CO_2 Emission and Ranking by Country, 1990-2020

Unit: million tons

Source: Emissions Database for Global Atmospheric Research

In 2005, China's annual CO_2 emission exceeded 6 billion tons, surpassing that of the US for the first time and making China rank as the highest emitter globally. Currently, China accounts for one-third of global CO_2 emissions, exceeding the sum of all other Asian countries.

Over the past 30 years, annual global CO_2 emission has continued to rise, with an increase of 13.2 billion tons in 2020 compared to 1990. 70% of the increase came from China.

Japan, Germany, the UK, and the US have achieved peak CO_2 emissions, while Asian developing countries are still "climbing the hill." Notably, the total emissions of Viet Nam, a rapidly developing country, is still increasing.

Over the past 10 years, climate change mitigation has become a global consensus , with countries attempting to lower greenhouse gas emissions and, therefore, CO_2 emissions growth rate has slowed down. In 2020, China's CO_2 emission increased by 15% compared to 2011, accounting for 10% of the increase in the last decade.

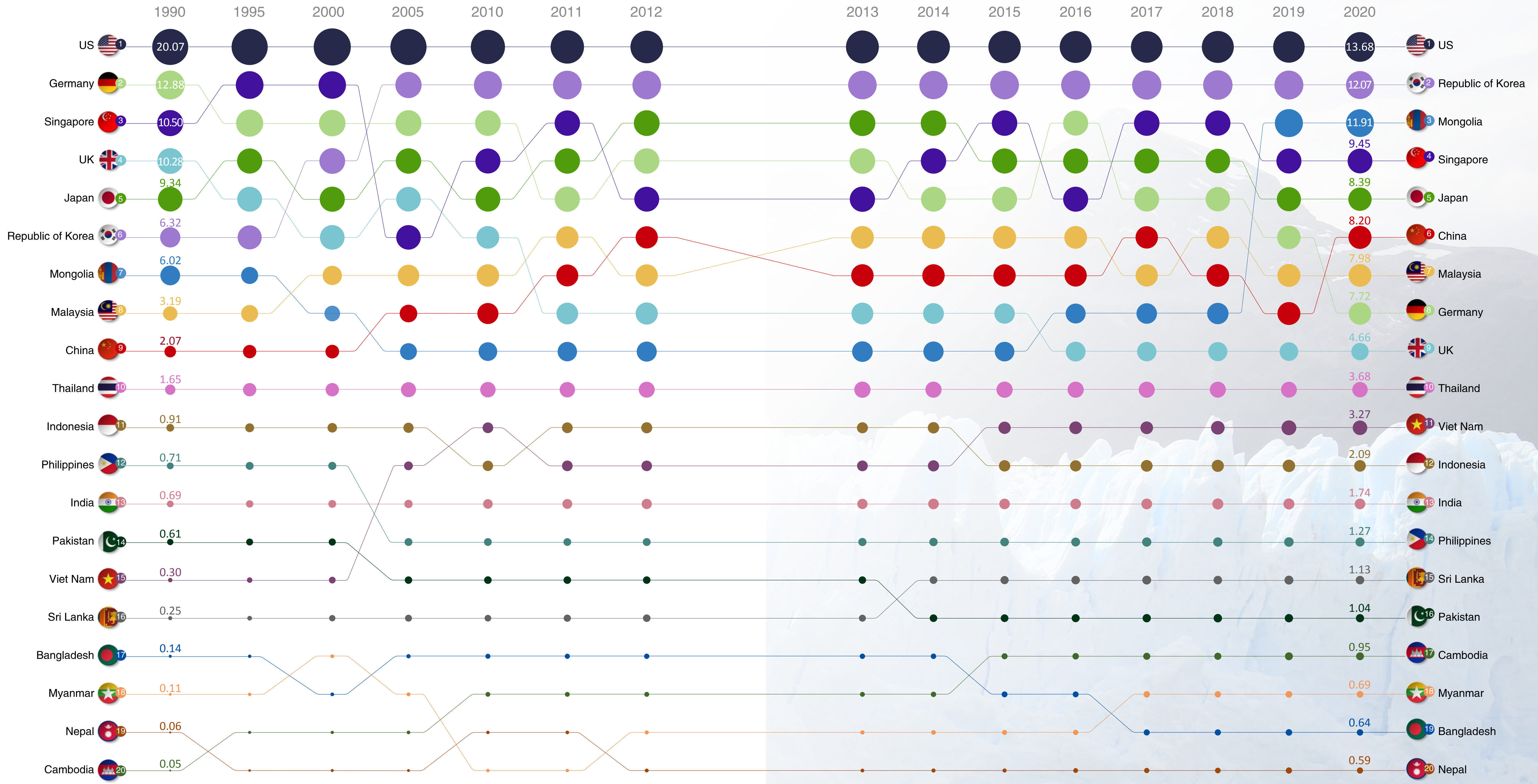


Figure 3.3 CO_2 Emission per Capita and Ranking by Country, 1990-2020

Unit: ton/person

Source: Emissions Database for Global Atmospheric Research

With energy consumption increasing and economic development, the CO_2 emission per capita of developing Asian countries continues to increase, while the high CO_2 emission per capita in developed countries shows a downward trend.

In 2020, China's CO_2 emission per capita was at 8.2 tons, which is 60% of that of the US and lower than that of developed Asian countries like Japan, the Republic of Korea, and Singapore.

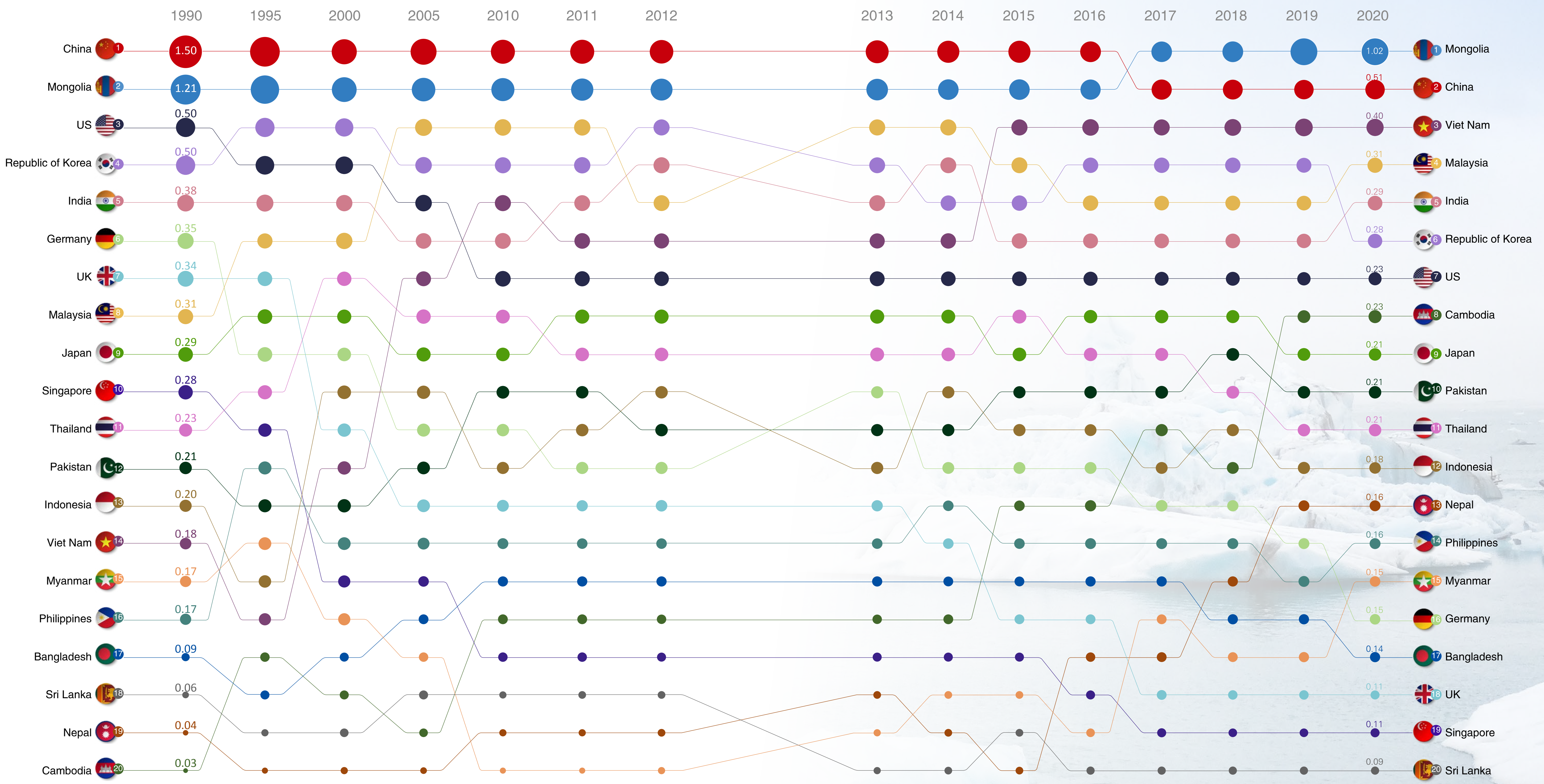


Figure 3.4 CO_2 Emission per Unit of GDP and Ranking by Country, 1990-2020

Unit: ton/1,000 USD

Source: Emissions Database for Global Atmospheric Research

As the largest CO_2 emitter globally, China has set greenhouse gas emission control as an important goal while also seeking further economic development. During the 12th and 13th five-year planning phases, China put forward its goals to reduce CO_2 emission per unit of GDP by 17% and 18%, respectively. From 1990-2020, through various methods like adjusting energy and industry structures, as well as improving energy conservation and efficiency, the country achieved a decline in emission intensity by 66.2%.

In 2010-2020, Germany, the UK, the US and most countries in Asia maintained a downward trend in emissions per unit of GDP, except for Cambodia, Mongolia, Myanmar, Nepal, the Philippines, Sri Lanka, and Viet Nam, where emissions increased, with the largest increase reaching 180%.

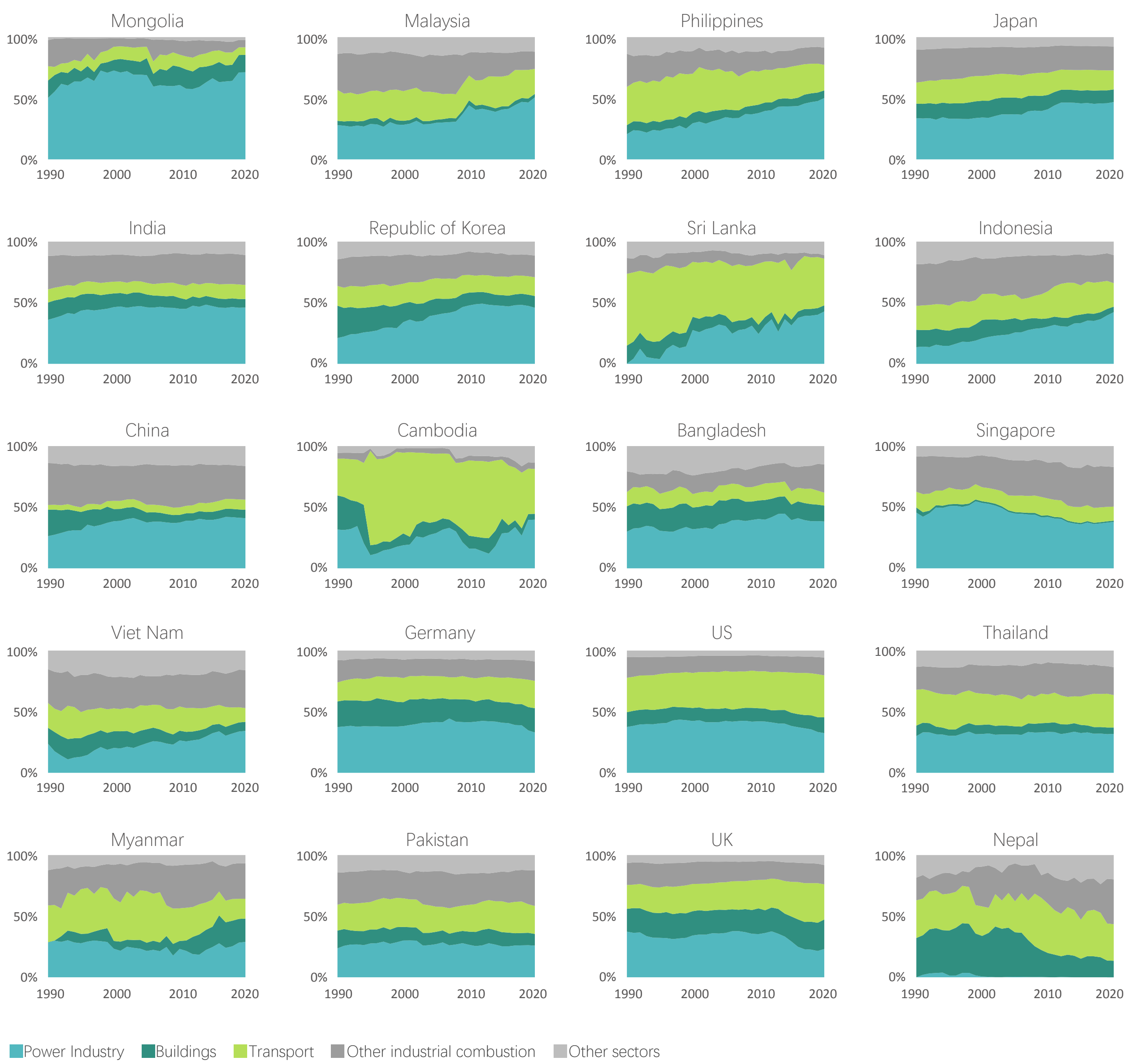


Figure 3.5 Changes in CO_2 Emission Structure by Sector in Various Countries, 1990-2020

Source: Emissions Database for Global Atmospheric Research

Currently, power and industry are the top 2 sectors for CO_2 emissions in China, accounting for nearly 70% of the country's total emissions. Overall, emissions from the power sector are highest, reaching a total of 4.794 billion tons or over 40% of the country's total emissions.

The sectoral emission structure of most Asian countries is similar to China's, with the most emissions coming from the power sector. Emissions from this sector make up between 31.8%-71.3% of the total emissions per country. Exceptions are Myanmar, Nepal, and Pakistan, where the industry sector produces the most emissions. In the US and the UK, the transportation sector produces the highest emissions.

Country	CO_2 emissions in 2020 (million tons)	Year	Goal
1 China	11,680.4	2060	Carbon neutral
2 US	4,535.3	2050	Net zero
3 India	2,411.7	2070	Net zero
4 Japan	1,061.8	2050	Net zero
5 Germany	636.9	2045	GHG neutral
6 Republic of Korea	621.5	2050	Net zero
7 Indonesia	568.3	2060	Net zero
8 Viet Nam	321.9	2050	Net zero
9 UK	313.7	2050	Net zero
10 Malaysia	262.2	2050	Carbon neutral
11 Thailand	255.5	2050	Net zero
12 Pakistan	217.0	2050	Net zero
13 Philippines	139.2		
14 Bangladesh	108.5		
15 Singapore	56.1	2050	Net zero
16 Mongolia	38.2		
17 Myanmar	37.7	2050	Net zero
18 Sri Lanka	23.7	2060	Carbon neutral
19 Nepal	17.9	2045	Net zero
20 Cambodia	15.8	2050	Net zero

Figure 3.6 Decarbonization Goals of Various Countries

Notes: The blanks indicate the country has yet to release the goals related to Carbon Neutrality or Net Zero

Source: Zerotracker

In 2020, China officially announced its goal of reaching carbon peak emissions by 2030 and carbon neutrality by 2060. This strategic decision is crucial for China and the globe. It highlights China's confidence and determination to fight global climate change with other countries and contribute towards fulfilling the "Paris Agreement."

With respect to carbon neutrality and net-zero emission, many Asian countries have announced their decarbonization goals. Currently, one-third of the world's energy consumption and about half of the world's CO_2 emission comes from Asia, making the task of emission reduction for developing Asian countries challenging.

Notably, China has promised to achieve carbon neutrality from peak CO_2 emissions in about 30 years. To achieve this with its legendary "Chinese speed" China needs to work hard.

Energy

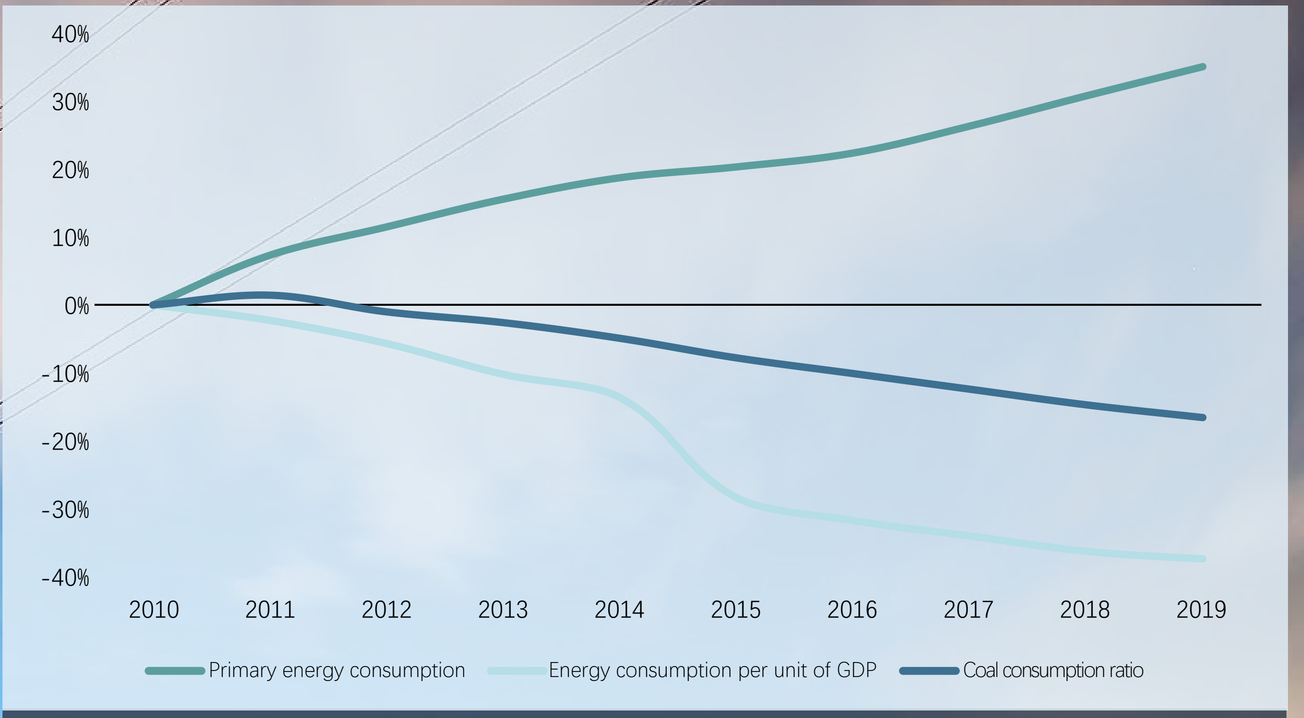


Figure 4.1 Changes in China's Primary Energy Consumption, Energy Consumption per Unit of GDP, and Coal Consumption Ratio, 2010-2019

Source: China Statistical Yearbook, 2011–2020

In 2010–2019, China' s economy grew rapidly, leading to steady growth in energy consumption. Compared to 2010, China' s total energy consumption grew by 35.2% in 2019. While the country' s energy consumption continues to grow, China' s energy consumption structure has been improving.

While China is the largest coal consumer globally, its coal consumption ratio in energy consumption structure has seen a downward trend, decreasing from 62.2% in 2010 to 57.7% in 2019. However, coal consumption still dominates its overall energy structure. With the optimization of China' s energy and industry structures, the country' s energy consumption per unit of GDP steadily decreased, falling by 37.5% in 2019 compared to 2010.

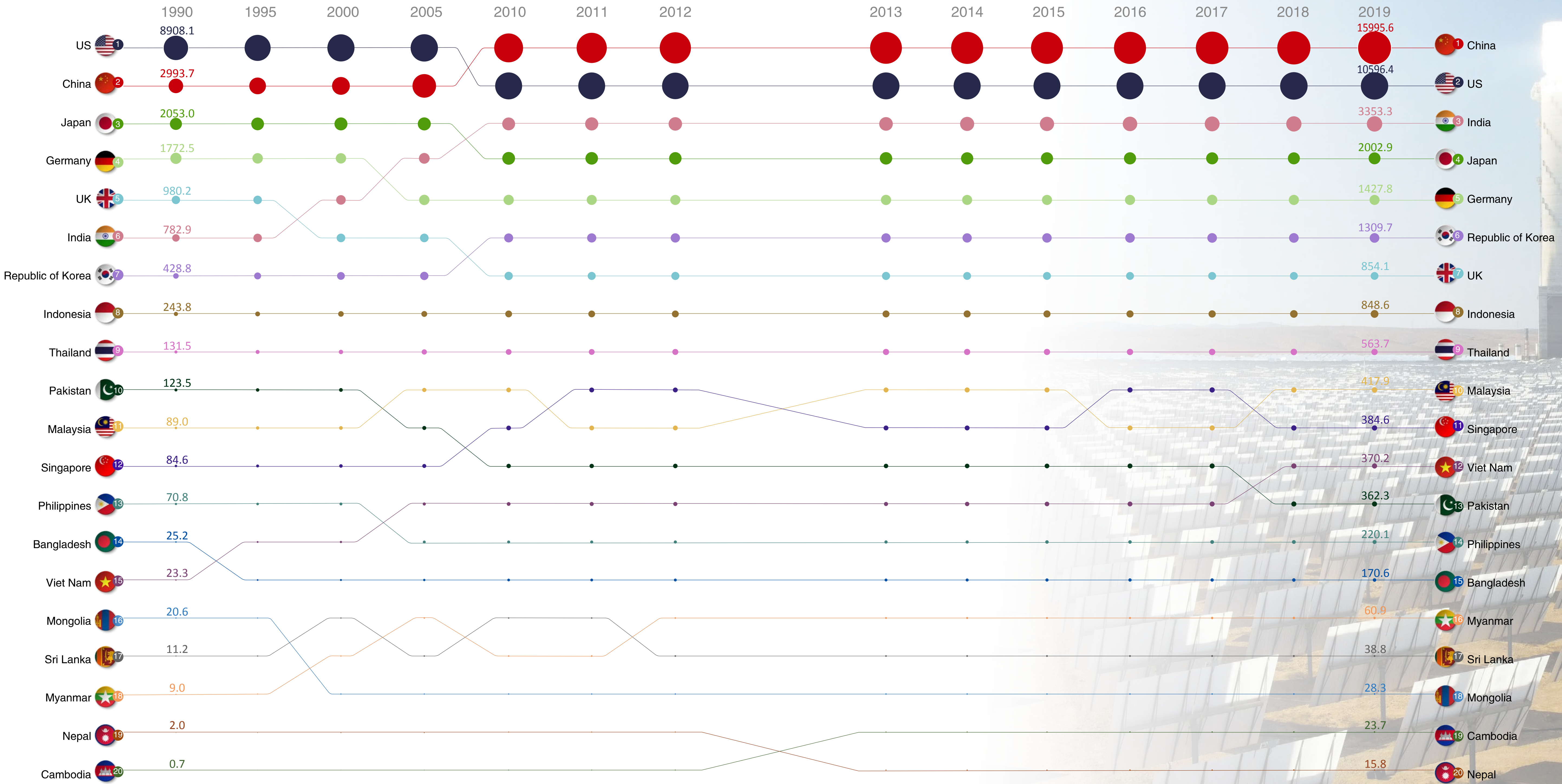


Figure 4.2 Changes in Primary Energy Consumption and Ranking by Country, 1990-2019

Unit: 10 million billion joule

Source: China Statistical Yearbook, 2011-2020.

In the last 30 years, most Asian countries have seen a rapidly increasing trend in energy consumption. China's energy consumption has increased by four times, growing the most in 2000-2010 and surpassing the US to become the country with the highest energy consumption in the world.

Most countries' energy consumption growth slowed down after 2010, and their consumption has been stabilizing. At present, China's total energy consumption is the highest in the world at 159.956 quintillion joules, which amounts to India's, Japan's, and the US' figures combined. The energy consumption of India and the US is still climbing, whereas Japan's is declining.

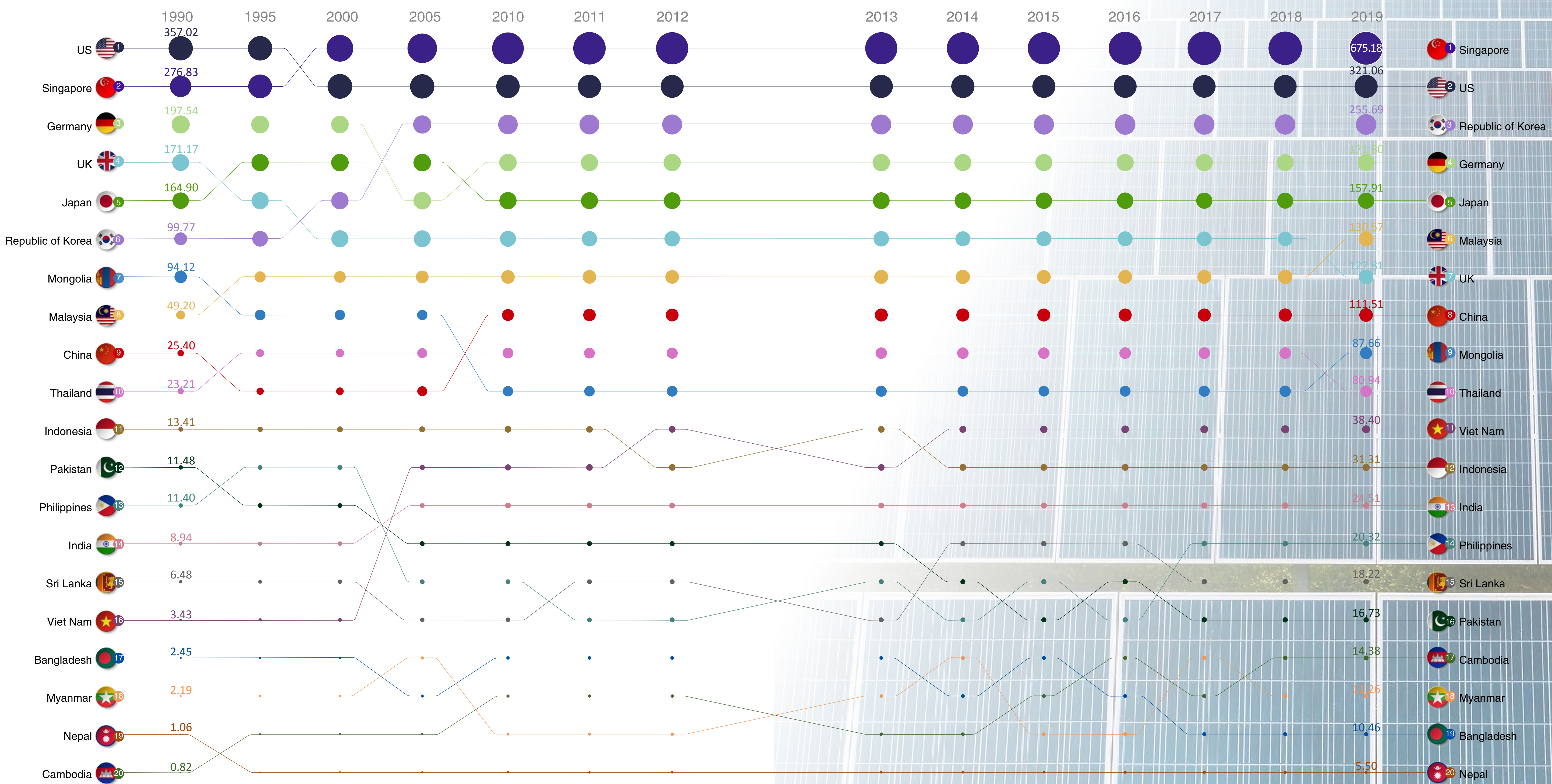


Figure 4.3 Changes in Energy Consumption per Capita and Ranking by Country, 1990-2019

Unit: billion joule/person

Source: U.S. Energy Information Administration database

Energy consumption per capita is highly related to the level of economic development. Most Asian countries have seen an over 100% growth in energy consumption per capita in the past 30 years. China's energy consumption per capita has also seen growth, which is 4.4 times in 2019 as high as that in 1990, although it currently remains lower than that of developed countries in America, Asia, and Europe, and is only about one-third of that of the US.

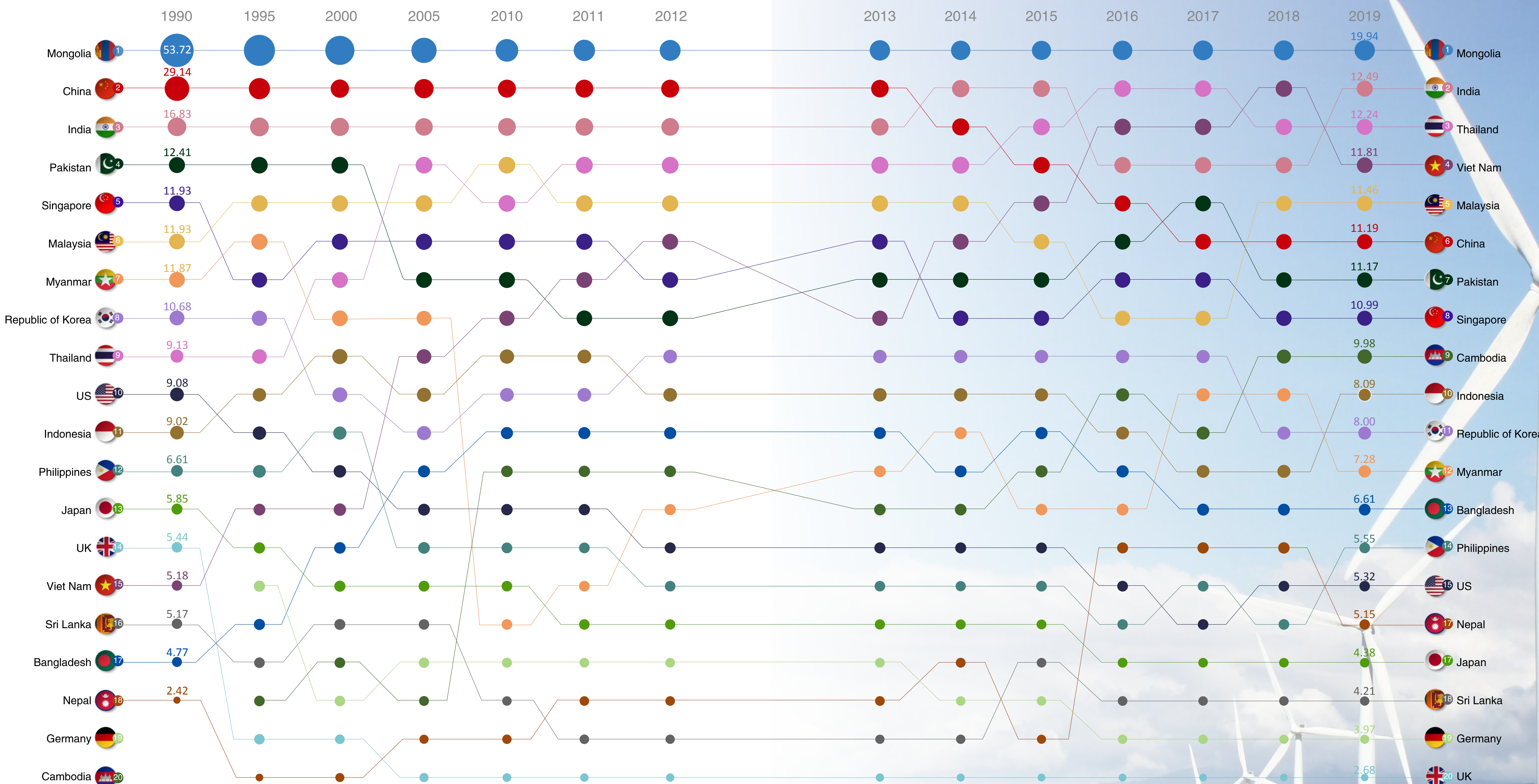


Figure 4.4 Changes in Energy Consumption per Unit of GDP and Ranking by Country, 1990-2019

Unit: million joules/2015 USD

Note: Germany and Cambodia lack data for 1990

Source: U.S. Energy Information Administration database, World Development Indicators database

From 1990-2019, the energy consumption per unit of GDP of most Asian countries followed a downward trend, falling between 4%-63%. China's decreased by 61.6%, from 29.14 million joules/2015 USD to 11.19 million joules/2015 USD. However, the country still needs to focus on heavily optimizing and transforming its energy and industry structures.

Among Asian countries, Bangladesh, Cambodia, Nepal, Thailand, and Viet Nam have shown an increase in energy consumption intensity. In particular, Viet Nam has doubled its consumption intensity in the last 30 years, and Cambodia's has grown by 54.5% since 2010. Even though Mongolia has seen a continuous decline in energy consumption intensity, its intensity level is still comparably high.

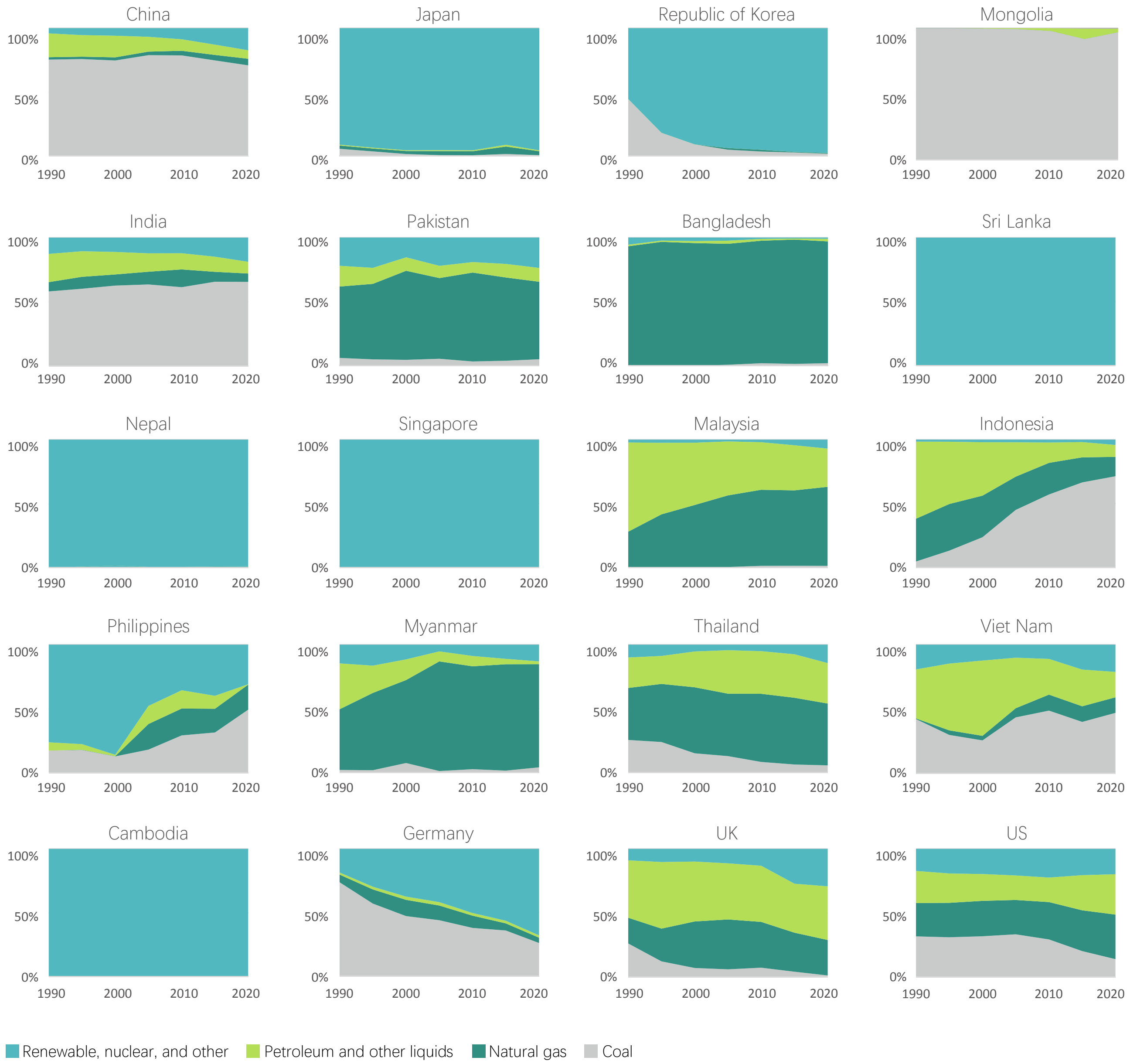


Figure 4.5 Changes in the Energy Production Structure of Various Countries, 1990-2019

Source: U.S. Energy Information Administration database

Because of China's "rich in coal, lacking in oil, and short in gas" characteristics, coal holds an important position in its energy production. Even though the country's coal production ratio in total energy production has been following a downward trend, it still remains high at 68.5%. Mongolia and India have similar energy production structures as China, and Indonesia's energy production structure seems to slowly be heading into one led by coal production.

Indonesia, Malaysia, the Philippines, and Viet Nam have been facing a reduction in oil reserves recently and increasing the proportion of coal and gas production. However, their share of renewable energy production has not increased significantly.

The proportions of coal production in Germany, the UK and the US are declining, and in Germany and the UK, the proportion of renewable energy and nuclear production is significantly growing.

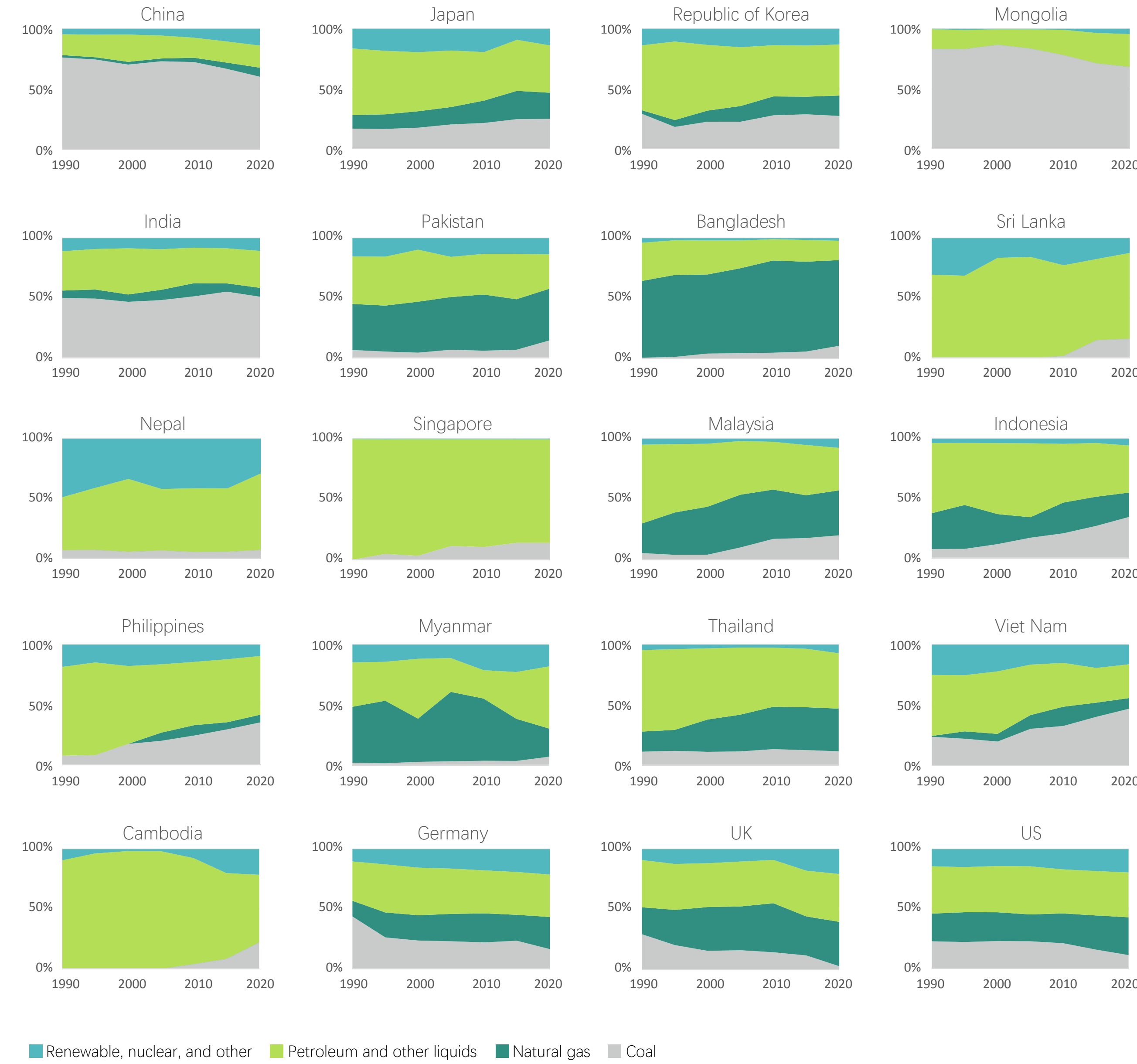


Figure 4.6 Changes in the Energy Consumption Structure of Various Countries, 1990-2019

Source: U.S. Energy Information Administration database

Asian countries generally rely on fossil fuels. China's, India's, and Mongolia's coal consumption ratios in energy consumption structure are at over 50%. Meanwhile, Southeast Asian countries rely more on oil, with their oil consumption ratios ranging between 28%-86%.

Most Asian countries' coal consumption ratios in energy consumption structure have either remained stable or continued to rise. Only a few countries, including China, have seen a decline.

Compared with Asian countries, the energy consumption structures of developed countries such as Germany, the UK, and the US are more balanced. Despite these three countries' reliance on fossil fuels, their coal consumption ratios have seen a decline.

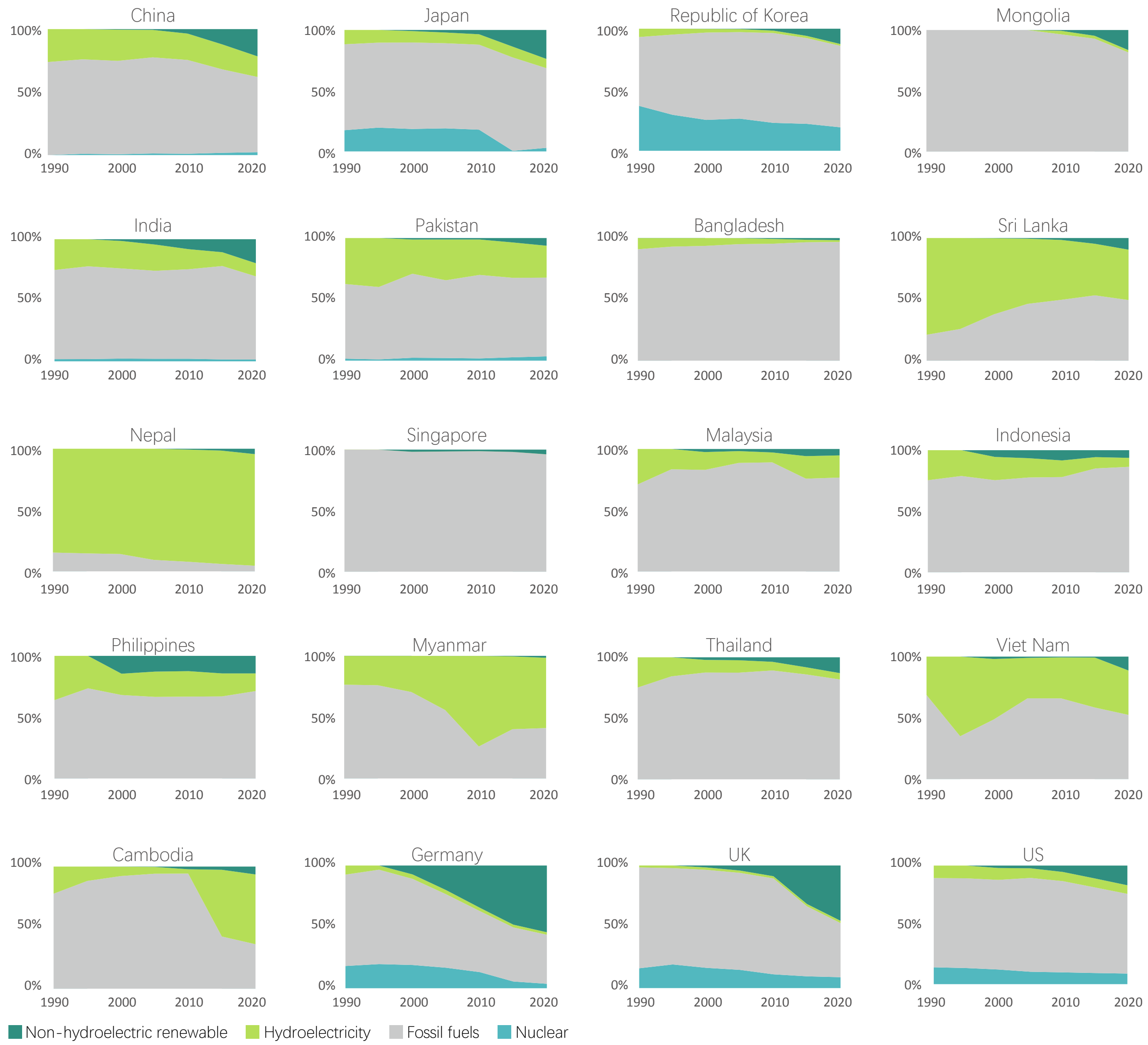


Figure 4.7 Changes in Installed Power Generation Capacity Structure, 1990-2019

Source: U.S. Energy Information Administration database

There has been a rapidly growing trend in the power consumption, production, and installed power capacity of developing Asian countries. In the past 30 years, these three indicators have increased by over 10 times in China while largely remaining stable in developed countries.

Fossil fuel installed capacity take up the highest proportion in the installed capacity structure of most countries. Only Myanmar, Nepal, and Sri Lanka have the most weight for installed hydro power capacity. The proportion of fossil fuel installed capacity in China was about 60% in 2019. The proportion of both fossil fuel and hydropower in the structure of installed capacity in the country has been following a downward trend in the past 10 years, but hydropower is still its second-largest power source, with an installed capacity of 16%. The proportion of installed non-hydro renewable energy has seen an upward trend.

The proportion of fossil fuel installed capacity in Germany, the UK, and the US is following a downward trend. The decline is more obvious in Germany and the UK, which is related to the increasing proportion of installed non-hydro renewable energy and a certain amount of installed nuclear electricity in these countries.

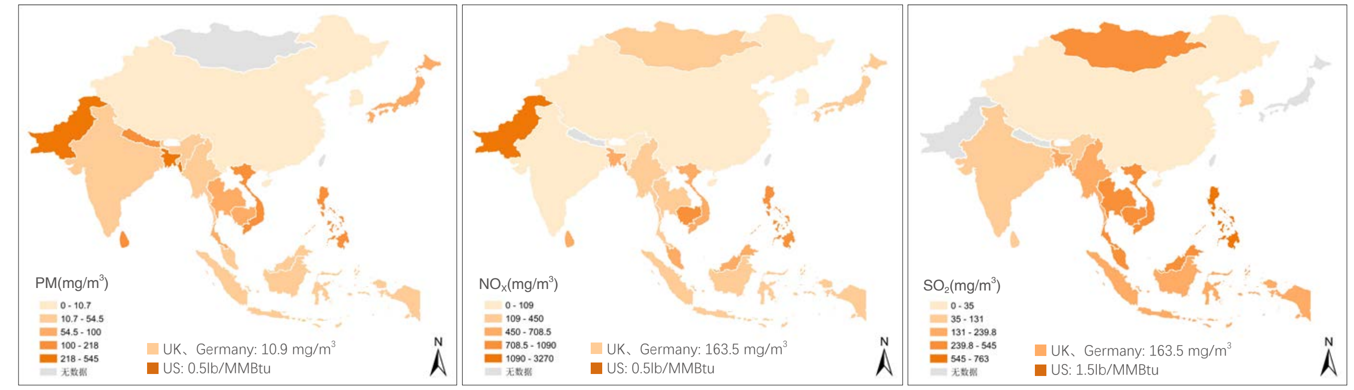


Figure 4.8 Emission Limits of Thermal Power Plants in Various Countries

Notes: 1.EU standards apply to equipment with over 300 MW of power.

2.Myanmar's PM standard specifically pertains to PM_{10} limits.

3.Japan does not have a unified national SO_2 emission standard, which is based on the K value. Japan's SO_2 emission standard is set on the basis of the height of exhaust ports and the K values assigned for different regions. Normal emission standard: K = 3.0-17.5; special emission standard: K = 1.17-2.34.

Sources: Officially published emission standards of various countries

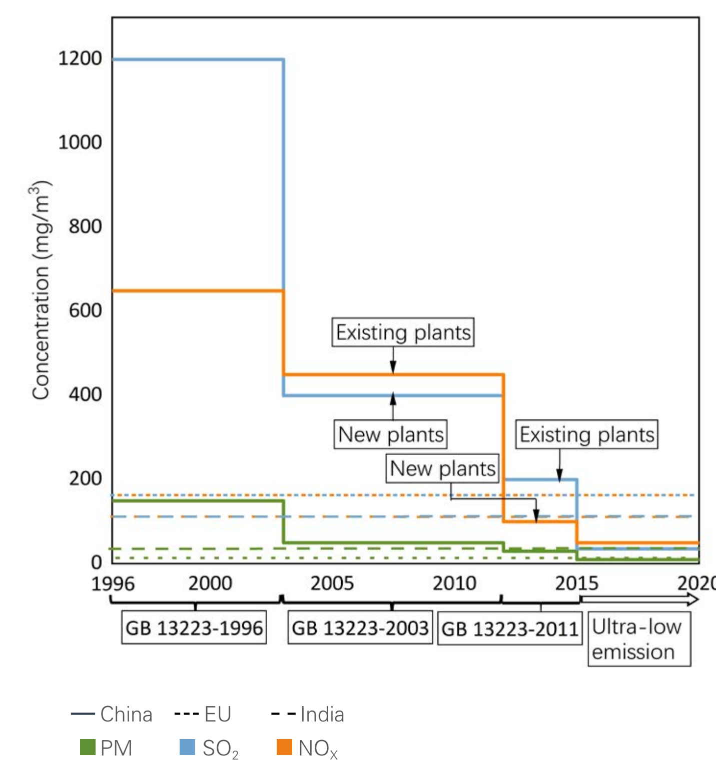


Figure 4.9 Course of Upgrades for the Power Sector's Emission Standards in China

Notes: China ultra-low emission limits apply to the baseline oxygen content equaling to 6%

Sources: See references for details.

Over the past 30 years, the emission control of air pollutants in China's power sector has developed rapidly, with the standards constantly being upgraded and tightened. Under the ultra-low emission policy requirements, the current emission limits of PM, SO_2, and NOx are 10 mg/m^3, 35 mg/m^3, and 50 mg/m^3, respectively, which have been lowered by 93%, 97%, and 92%, respectively compared to the original standard limits in 1996. The emission limits of SO_2 and NOx are 1/5 and 1/3 of the European Union (EU) standard, respectively.

There is a marked difference in the current emission limits for the power sector of Asian countries. China, India, and the Republic of Korea have relatively stricter emission limits, while Cambodia, Pakistan, and Sri Lanka's limits are more lenient at about 10 times higher than the ultra-low emission limits of China for PM, SO_2, and NOx.

Transportation

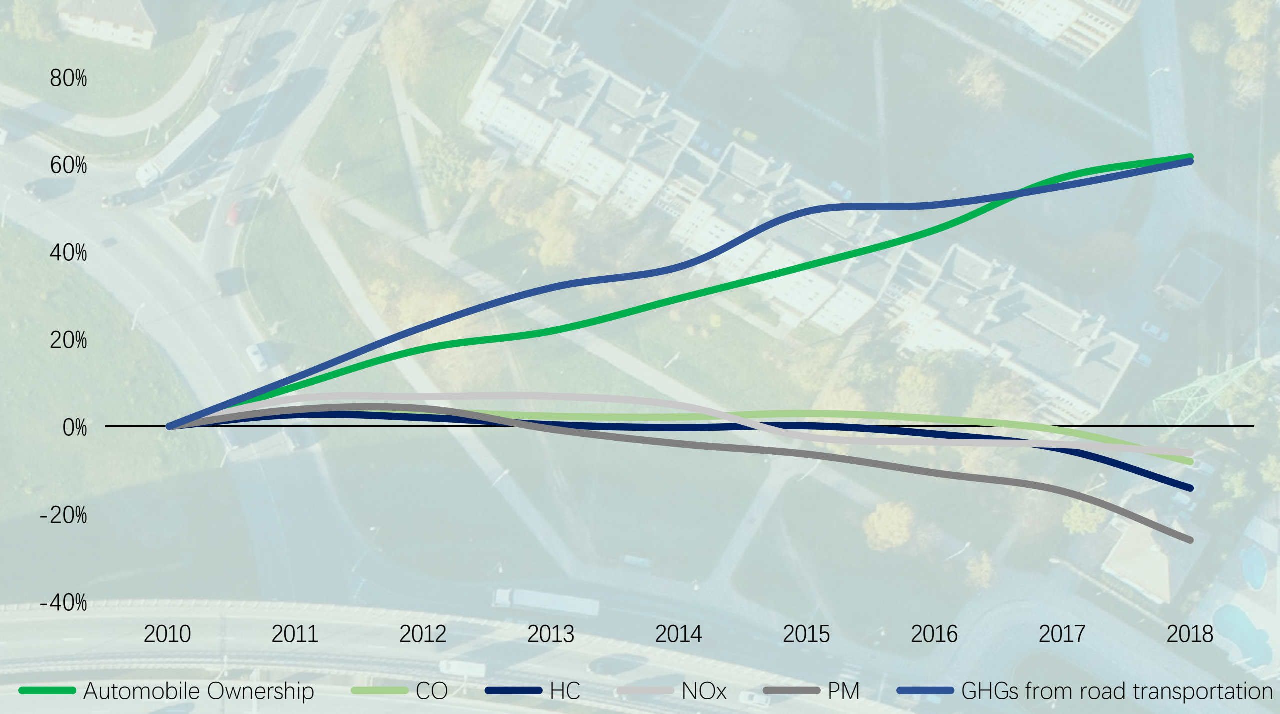


Figure 5.1 Changes in China's Automobile Ownership, Air Pollutants, and GHGs emissions from road transportation, 2010-2018

Note: Greenhouse gases of road transportation include CO_2, CH_4, and N_2O.

Sources: China Vehicle Environmental Management Annual Report; Emissions Database for Global Atmospheric Research.

In the past 10 years, China has enforced various stringent emission reduction measures, achieving positive results for pollutant reduction in the transportation sector. Taking automobiles as an example, the growth of China's automobile ownership has been decoupled from air pollutant emissions. In 2013–2018, China's automobile ownership grew by 32.7%, but major pollutant emissions of CO, NOx, HC, and PM decreased by 10.2%, 12.1%, 14.5%, and 25.6%, respectively.

However, the results of source apportionment show that the transportation sector has become the main contributor of $PM_{2.5}$ for many large and medium–sized cities, accounting for 20%–45%. The transportation sector is also one of the fastest–growing sectors for greenhouse gas emissions. In 2013–2019, the annual average growth rate of CO_2 emissions in the transportation sector has been greater than 5%, and the emissions from transportation account for 10% of China's total CO_2 emissions.

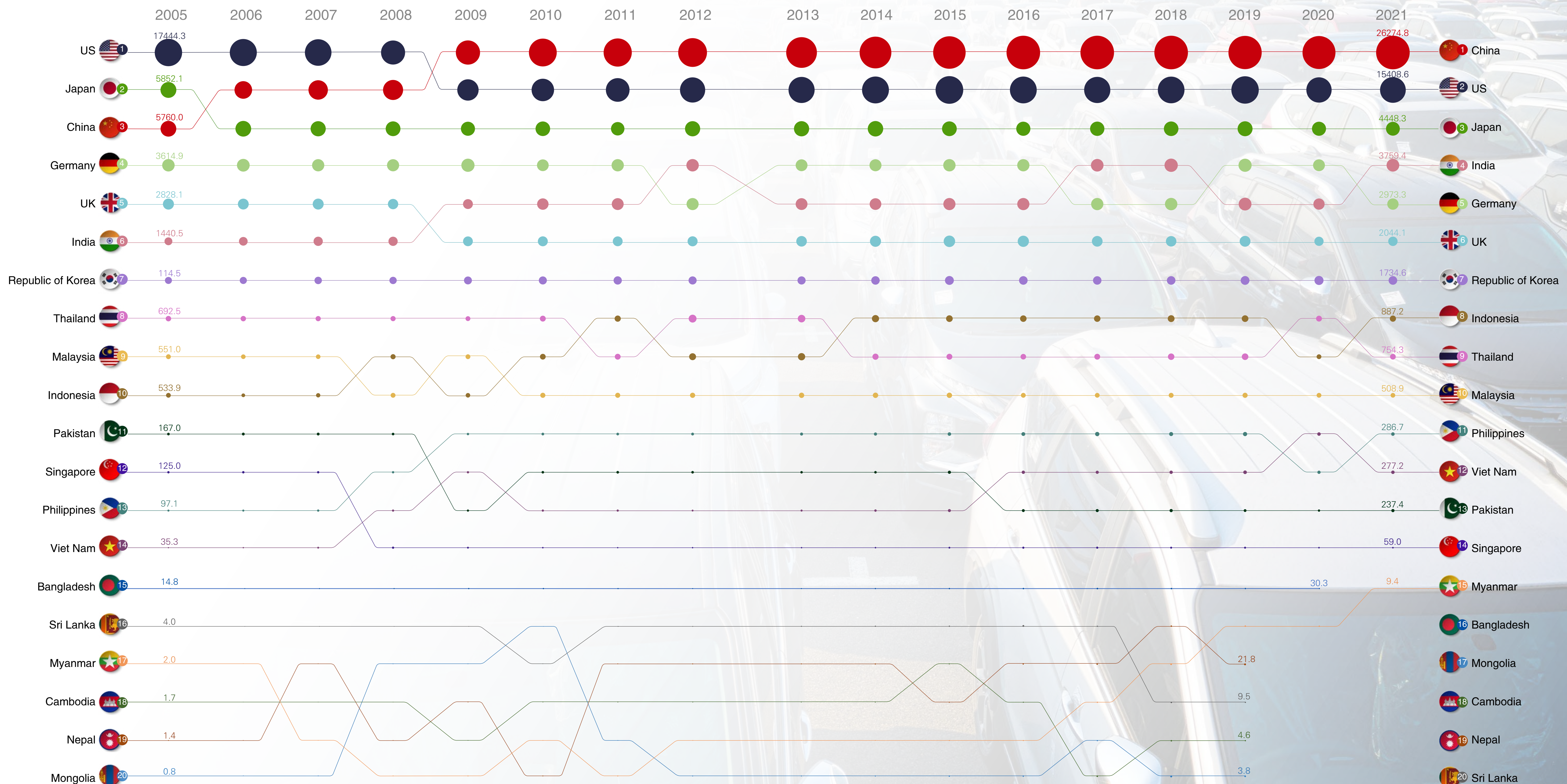


Figure 5.2 Automobile Sales and Ranking by Country, 2005-2021

Unit: 1,000 vehicles

Notes: 1. Some countries lack data for 2020-2021.

2. Unless specified, automobile sales collectively refer to sales of passenger cars and commercial vehicles. Those for Malaysia, Pakistan, and the Philippines only include passenger cars and light-duty trucks. Viet Nam's sales include passenger cars and light-duty trucks in 2005-2012 and passenger cars, commercial vehicles, and special purpose vehicles in 2013-2021.

Sources: International Organization of Motor Vehicle Manufacturers; Chinese Association of Automobile Manufacturers; Japan Automobile Manufacturers Association; Malaysian Automotive Association; ASEAN Automobile Federation; Viet Nam Automobile Manufacturers' Association.

China, the US, Japan, India and Germany have the top five automobile markets globally. In 2020 and 2021, China and the US took up around half of the world's automobile market for new automobile sales.

Since 2009, China has sold more new automobiles than any other country globally. Since 2013, China has become the only country in the world to have sold over 20 million new automobiles annually. As the demand for automobiles grows, the need for the emission control of new and in-use vehicles is also increasing.

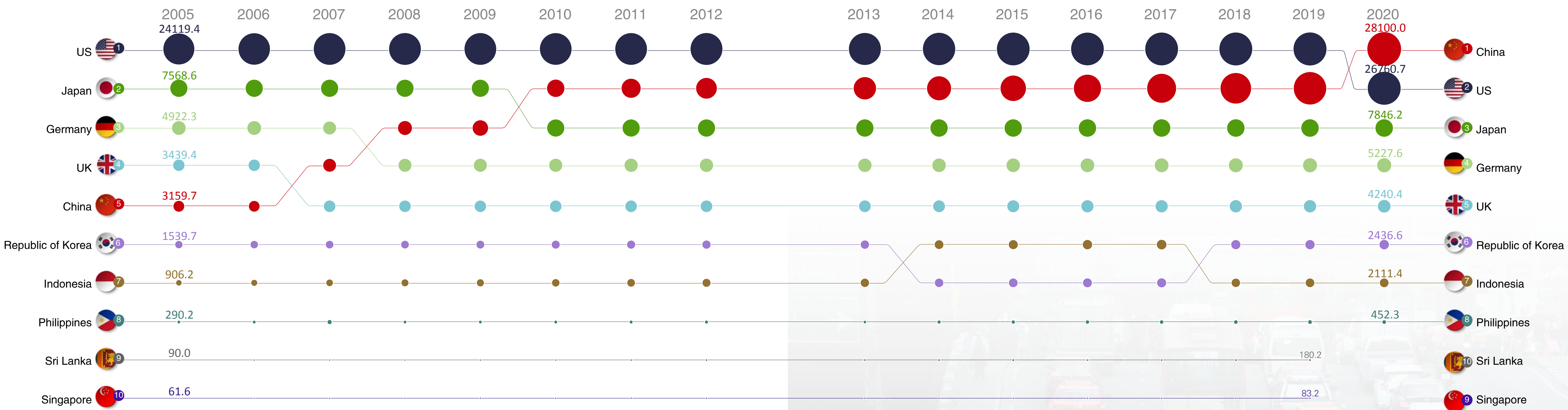


Figure 5.3 Automobile Ownership and Ranking by Country, 2005-2020

Unit: 10,000 vehicles

Note: Sri Lanka and Singapore lack data for 2020.

Sources: International Organization of Motor Vehicle Manufacturers; Chinese Mobile Source Environmental Management Annual Report; Japan Automobile Manufacturers Association; ASEAN Automobile Federation; Ministry of Land, Infrastructure, and Transport of the Republic of Korea; Sri Lankan Department of Motor Traffic; US Bureau of Transportation Statistics.

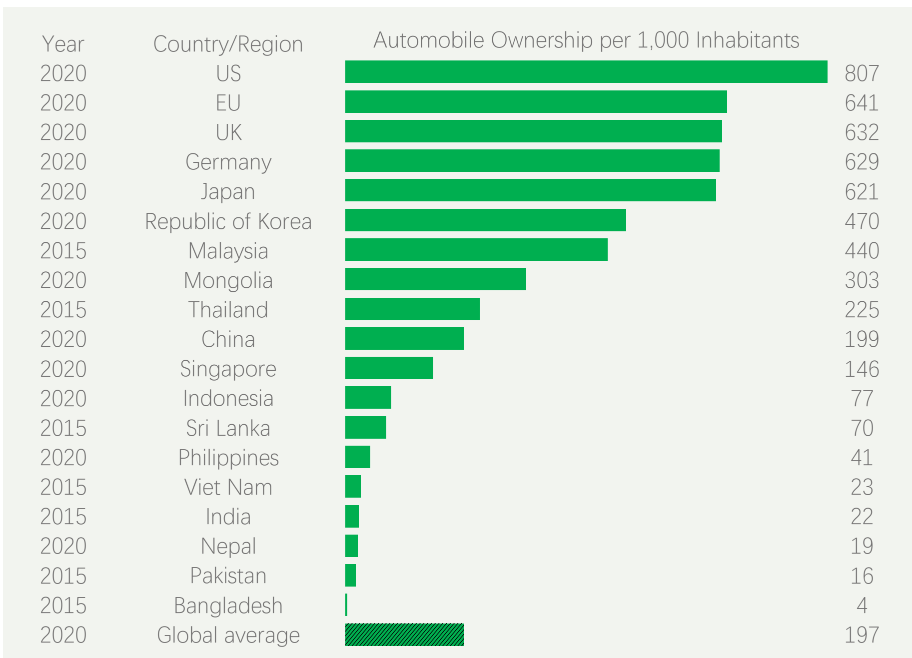


Figure 5.4 Automobile Ownership per 1,000 Inhabitants in Various Countries

Sources: Chinese Association of Automobile Manufacturers; Japan Automobile Manufacturers Association; Malaysian Automotive Association; ASEAN Automobile Federation; Ministry of Land, Infrastructure, and Transport of the Republic of Korea; US Bureau of Transportation Statistics; Mongolian Statistical Information Service; World Development Indicators Database.

China's number of automobiles has been growing rapidly. In 2010-2020, the annual average growth reached 13.8%. In 2020, China's automobile ownership reached 280 million, the largest automobile ownership globally.

In the same period, China's number of automobiles per 1,000 inhabitants continued to rise, from 58 vehicles/1,000 inhabitants in 2010 to 199 vehicles/1,000 inhabitants in 2020, exceeding the global average. In comparison, developed countries in Europe and America, as well as Japan, had over 500 vehicles per 1,000 inhabitants. Of these countries, the US had the highest automobile ownership per 1,000 inhabitants, with over 800 vehicles/1,000 inhabitants. There was a large variation in Asian countries' automobile ownership per 1,000 inhabitants. East Asian countries had exceeded the global average, while South Asian countries had less than 100 vehicles per 1,000 inhabitants.

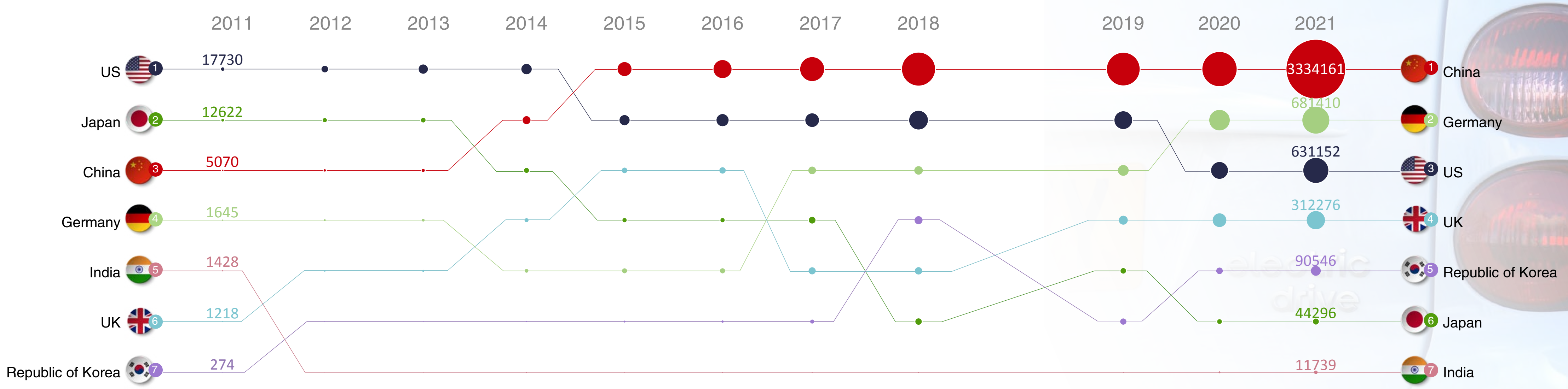


Figure 5.5 Sales and Ranking of Electric Passenger Cars by Country, 2011-2021

Unit: 1 vehicle

Note: Unless specified, "electric vehicles" refers to battery electric vehicles and plug-in hybrid electric vehicles.

Sources: International Energy Agency Database; European Automobile Manufacturers' Association.

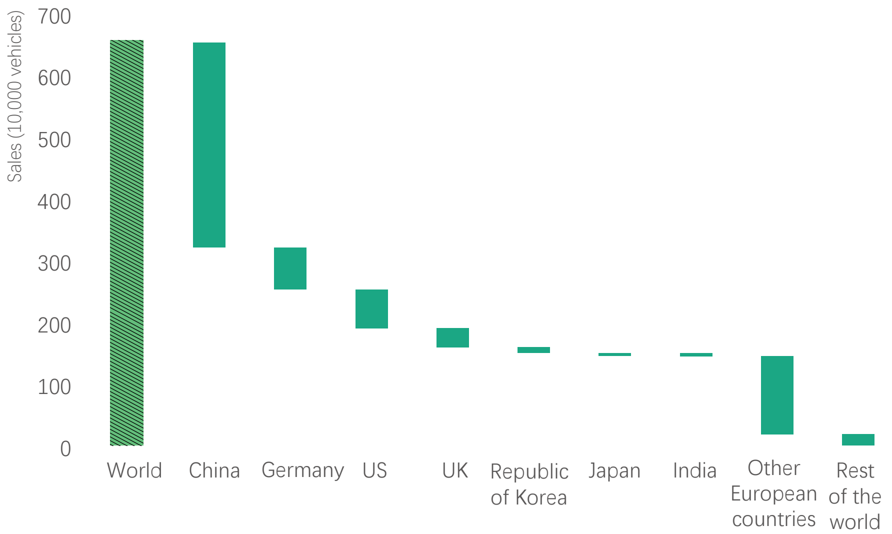


Figure 5.6. Global Electric Passenger Car Sales and Regional Distribution, 2021

Sources: International Energy Agency Database; European Automobile Manufacturers' Association.

In the last 10 years, despite a slowdown in passenger car sales, global electric passenger car sales have increased. In 2011-2021, the annual growth rate for passenger cars globally was -0.3%, but the annual growth rate for electric passenger cars was 63.1%, which continued to grow during the COVID-19 pandemic.

China is taking the lead in the development of electric vehicles. In 2011-2021, the country's annual growth rate for electric passenger cars was 91.3%, higher than the overall global growth rate. Since 2015, China has become the world's biggest market for electric passenger cars, taking up half of the world market share of electric passenger cars.

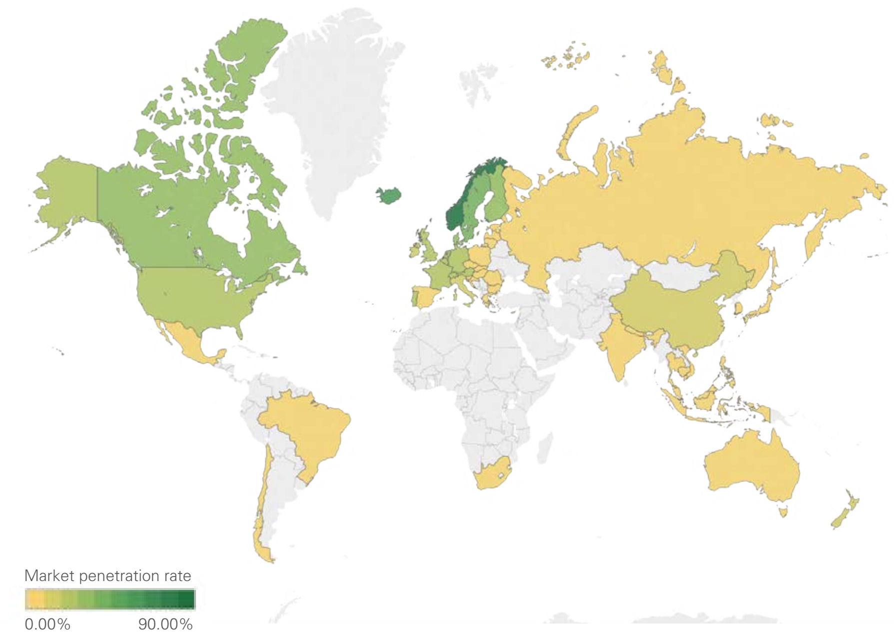


Figure 5.7 Global Market Penetration Rate of Electric Passenger Cars, 2021

Notes: :1. Empty spots in the maps mean there is no relevant data.
2. Unless specified, the data used for various countries is from 2021. Electric passenger cars only include battery electric and plug-in hybrid electric vehicles. Market penetration rate means the rate of electric passenger cars among passenger car sales in 2021.
3. The data for electric vehicles in Cambodia, Malaysia, the Philippines and Viet Nam may include hybrid vehicles, plug-in hybrid electric vehicles, and battery electric vehicles and may also include vehicles other than passenger cars, like jeepneys and motorcycles.
4. The electric vehicle and automobile sales of the Philippines and Viet Nam use the whole year's values from 2020, while Nepal's values were taken from April 2021-January 2022. Automobile sales use estimated values.
5. Indonesia's electric vehicle sales and automobile sales were taken from January-June 2021.
Sources: See references for details.

In 2021, the global promotion of electric passenger cars began to take shape, and market penetration rate reached about 11.7%. Various countries have had large differences in their promotion progress, with the penetration rate varying from 0.1%-86.2% in 2021. Currently, the forefronts of promotion lay in China, Europe, and North America. Although most Asian countries are still in their initial stage of electric vehicle promotion, they have set medium- and long-term targets, and the future of automotive energy transition has broad prospects.

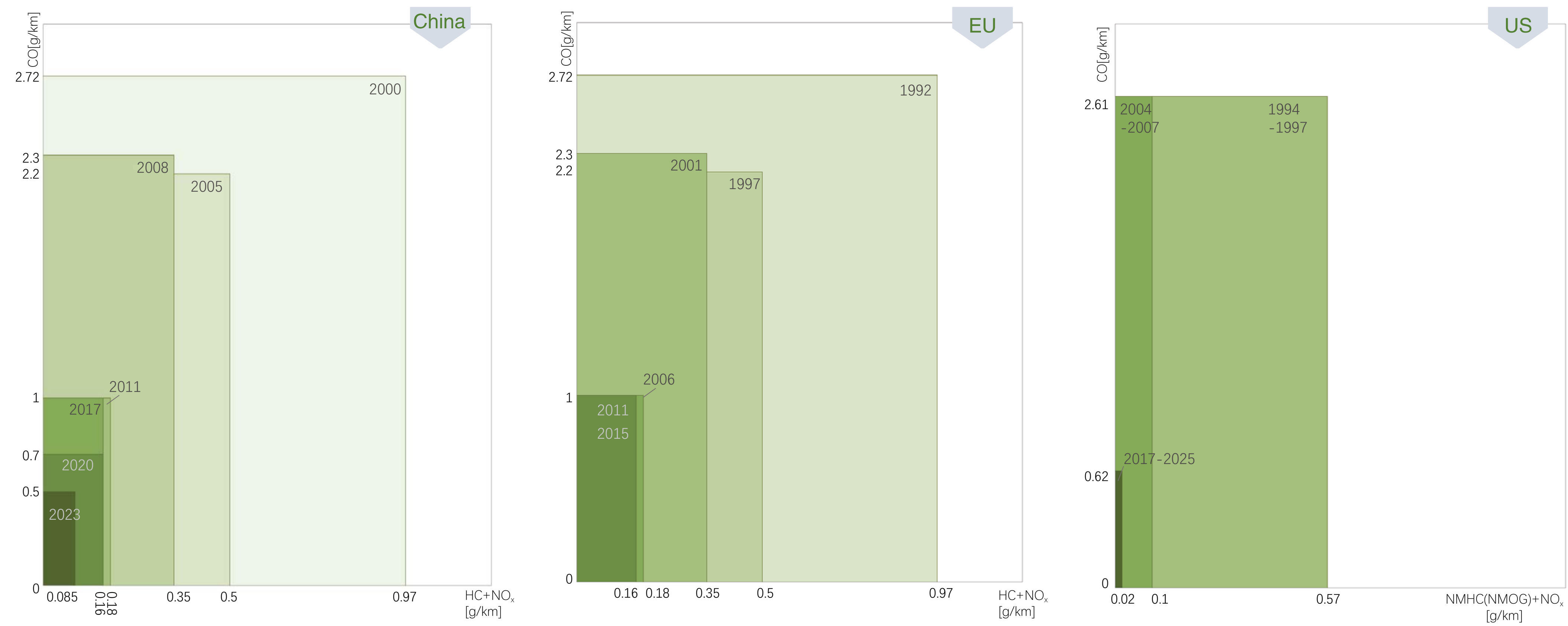


Figure 5.8 Historical Changes in Light-Duty Vehicles' Emission Limits in America, China, and Europe (Using Light-Duty Gasoline Passenger Cars as an Example)

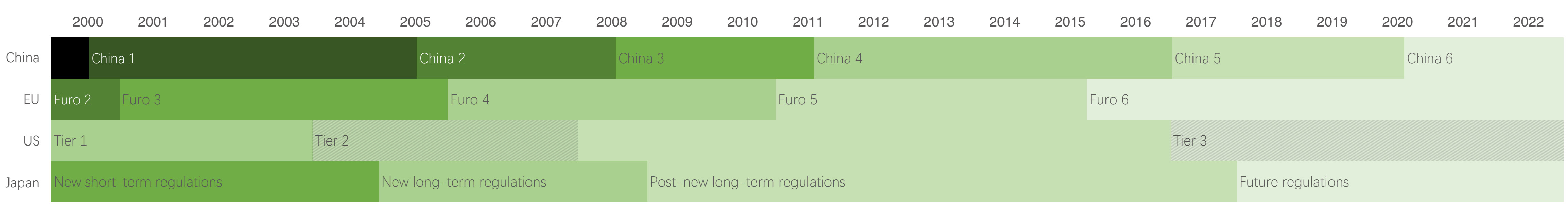


Figure 5.9 Timeline of Upgrades for Light-Duty Vehicles' Emission Standards in American, China, Europe and Japan (Using Light-Duty Gasoline Passenger Cars as an Example)

Notes: 1.The light-duty vehicle emission standards are numbered using Arabic numbers in this report.

2.Due to differences in the test cycles used to determine emissions, it was not appropriate to directly compare emission limits between different regulatory agencies. The Japanese regulatory test cycle varies in different stages, meaning this report does not show the historical change of emission limits in Japan.

3.In terms of implementation date, China's is the effective sales and registration date of vehicles complying with the new standard, while the EU's is the effective registration date of vehicles complying with the new standard. The US has gradually tightened the fleet average emission standards according to model year. The implementation dates in the figure are the starting year and full implementation year of the new tier standards (shaded).

4.For the light-duty vehicle emission standard of the US, regulatory test cycles include FTP-75 cycles and SFTP cycles. This report focuses on the limits of FTP-75 cycles. The US sets emission standards for vehicles during their intermediate and full useful life, and this figure uses the limit values for the full useful life cycle. The US' light-duty vehicles' Tier 2 emission standard includes the fleet average NOx standard, and Tier 3 includes the fleet average NMOG+NOx standard. The figure shows the bin levels that a single vehicle should meet: Tier 2 uses the limit values of Bin5 (equal to the fleet average level that NOx should satisfy), while Tier 3 uses the limit values of Bin30 (equal to the fleet average NMOG+NOx level in 2025). The unit used for the light-duty vehicles' emission standard is g/mi, with the conversion rate of 1 mi = 1.61 km.

5.In Japan' Post-New Long-term Regulation in 2009 and Future Regulation implemented in 2018, the limits for gasoline passenger cars did not change. The Euro 5 and Euro 6 standards for gasoline passenger cars also did not change.

Sources: See references for details.

China has reached an internationally advanced level of light-duty vehicles emission control. Compared to Europe, Japan, and the US, China had a late start in the emission control of motor vehicles, and the implementation time for setting the same level of limits for light-duty vehicles was 5-8 years behind that of the EU. However, in the last 10 years, China has continuously improved its emission standards. Comparing CHINA 6b with CHINA 1, the limits for CO and HC+NOx have become stricter by 82% and 91%, respectively.

Europe and the US are still strengthening their emission limits for light-duty vehicles. The Euro 7 standard proposal released by the European Commission tightens its PN and CO limits, strengthens the control of real-world driving emissions, and improves the durability requirements for the full useful life of vehicles. In line with the requirement to reduce pollution and CO_2 emissions, China also needs to keep tightening its emission standards for motor vehicles, add emission control requirements for greenhouse gases, and tighten the emission limits of conventional pollutants.

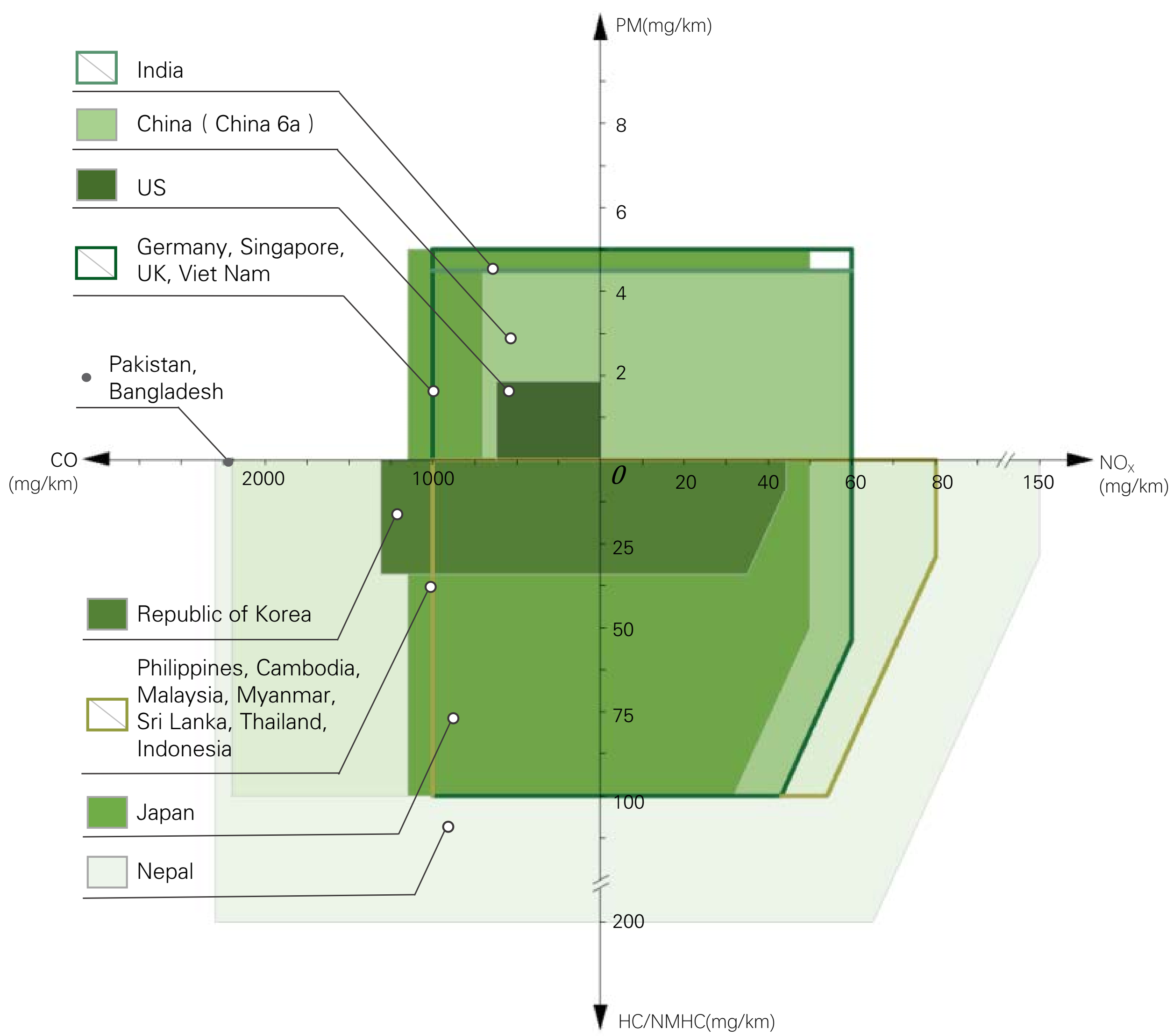


Figure 5.10 Current Emission Limits for Light-Duty Vehicles in Some Countries and Regions (Using Gasoline Passenger Cars as an Example)

Notes: 1. Due to differences in the test cycles used to determine emissions, it was not appropriate to directly compare standards between different regulatory agencies.
2. Regarding the limits currently in effect, countries implementing Euro 4 and earlier standards do not have limits for the PM emission of light-duty gasoline passenger cars. These countries include Bangladesh, Cambodia, Indonesia, Myanmar, Nepal, the Philippines, Sri Lanka, and Thailand. For Bangladesh, the limit for HC+NOx is 500 mg/km.
3. The Tier 3 limits for the US in the figure uses Bin30 limits. The limit for NMOG+NOx is equal to the fleet average level in 2025.
4. There is no PM limit set in current emission standard of the Republic of Korea.
5. Vehicles and engines imported and manufactured or assembled in Singapore and Sri Lanka comply with emission standards from either the EU or Japan.

Sources: See references for details.

In July 2020, China started implementing the CHINA 6a standard, the limits and evaporative emission control requirements of which are stricter than those of Euro 6, making it the world's most stringent regulations for the emission control of light-duty vehicles. Prior to CHINA 6, China's light-duty vehicle emission standards (CHINA 1 to CHINA 5) mainly followed the EU's regulatory system. The CHINA 6 standard currently in effect is more in line with China's actual needs and follows its own autonomous technical standard system.

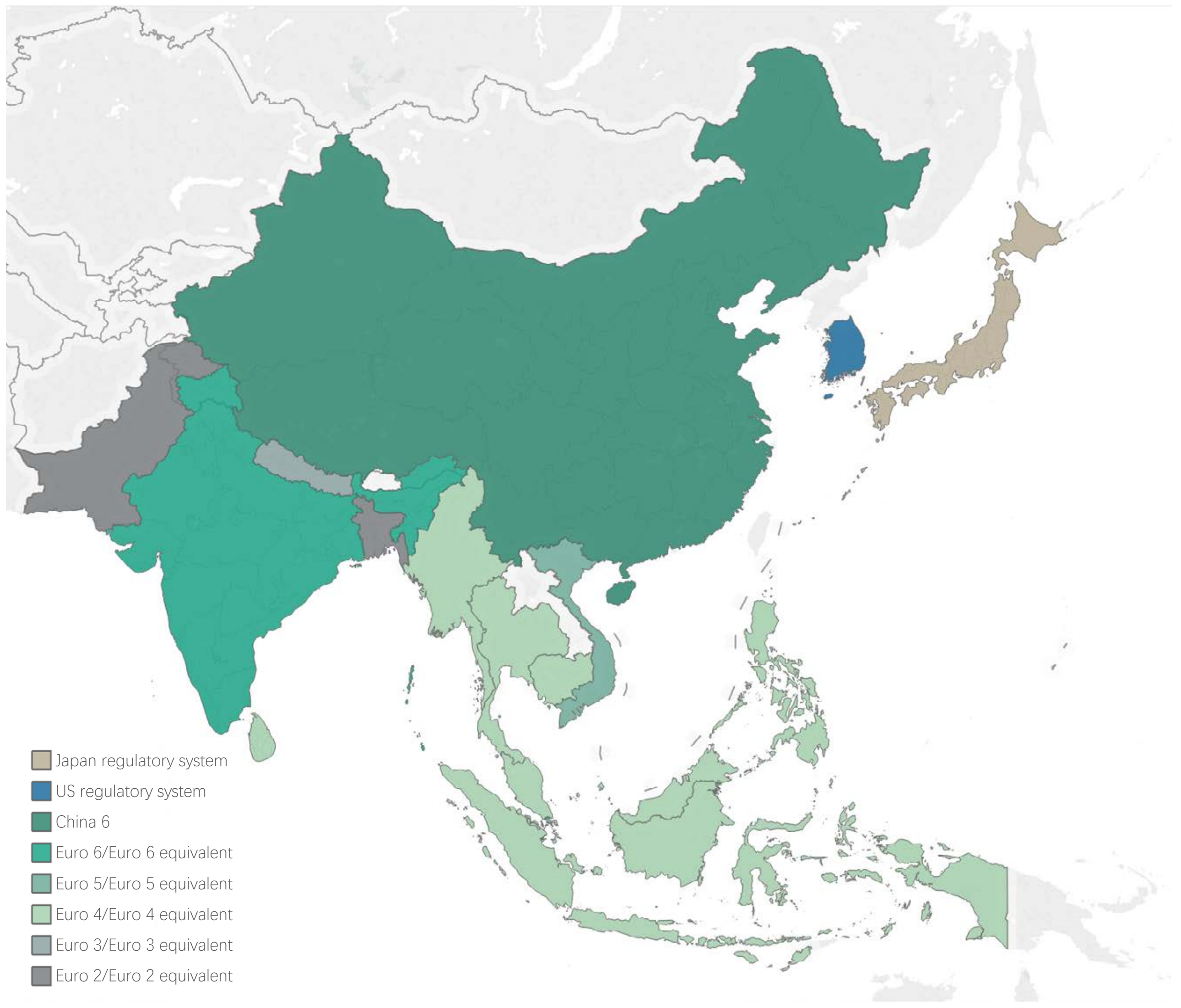


Figure 5.11 Regulatory Systems Adopted by Asian Countries and Their Current Emission Stages (Using Gasoline Passenger Cars as an Example)

Notes: 1.Countries like Singapore and Sri Lanka require automobiles to comply with emission standards from either the EU or Japan. This figure only shows their currently effective EU emission standards.
2.Countries like India and Thailand set their own emission standards based on the EU emission control system, but since the limits are consistent with the EU's in different stages, this figure uses the equivalent EU emission stage for the country's standards.

Sources: See references for details.

The automobile emission laws and regulations of the EU, Japan, and the US are the main regulatory systems worldwide. Most Asian countries follow the EU emission control system, but there are substantial differences between the emission standards of various countries currently in effect. The limits used by China, India, Japan, the Republic of Korea, and Singapore are the most stringent among Asian countries, whereas Bangladesh, Nepal and Pakistan are still using the more lenient Euro 2 and Euro 3 standard. In recent years, some Asian countries have leaped toward using stricter limit values, including India (Euro 4 to Euro 6), Indonesia (Euro 2 to Euro 4), and Nepal (Euro 1 to Euro 3).

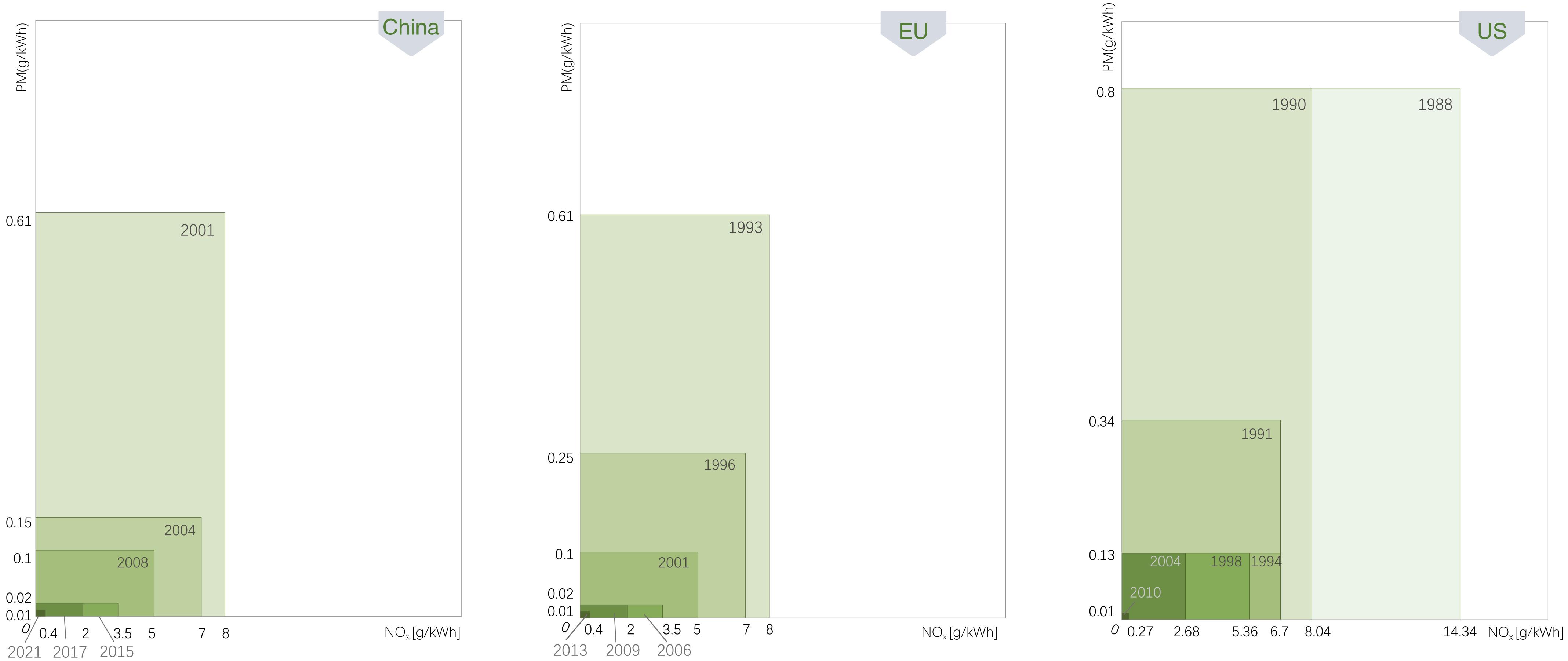


Figure 5.12 Historical Changes in Emission Limits in America, China, and Europe
(Using Heavy-duty Diesel Vehicles as an Example)

Notes: 1. The heavy-duty vehicle emission standards are numbered using Roman numbers in this report.

2. Due to differences in the test cycles used to determine emissions, it was not appropriate to directly compare standards between different regulatory agencies. The Japanese regulatory cycle varies in different stages, meaning this report does not show the historical change of emission limits in Japan.

3. For the test cycles referenced in this figure, the US uses FTP limits, while China and the EU use steady-state limits.

4. The US classifies vehicles with a gross vehicle weight rating (GRVW) of over 8,500 lbs (around 3.85 tons) as heavy-duty vehicles and further categorizes them as either light heavy-duty, medium heavy-duty, or heavy heavy-duty. China, the EU, and Japan classify heavy-duty vehicles as vehicles with a GRVW of over 3.5 tons.

5. In terms of the implementation date, China uses the effective sales and registration date of vehicles complying with the new standard, while the EU uses the effective registration date of vehicles complying with the new standard. Euro VI is divided into 5 phases, VI-A to VI-E, which progress based on additional requirements from a portable emissions measurement system and on-board diagnostics (OBD). Euro VI-E also adds cold start requirement and particle number limit, the progression per stage is marked in the figure. Part of Japan's heavy-duty vehicle emission standard is also based on GRVW and vehicle type; the shaded region in the figure also indicates the progression in years. The US 2010 standard was planned to be progressively implemented in proportion with sales from the 2007-2010 model years. During the actual implementation, the engines between 2007-2009 model years allowed for 1.6 g/kWh of NOx, which is shaded in the figure.

Sources: See references for details.

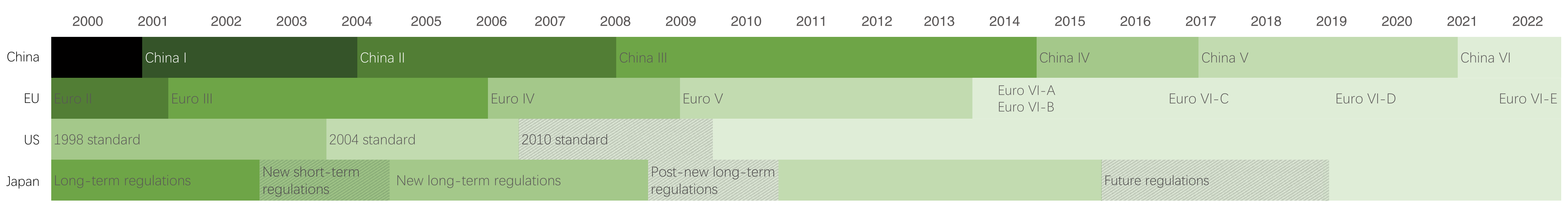


Figure 5.13 Timeline of Upgrades for Heavy-duty Vehicle Emission Standards in America, China, Europe and Japan
(Using Heavy-duty Diesel Vehicles as an Example)

China had a late start in the emission control of heavy-duty vehicles, but the country has progressed quickly. In the past 10 years, China's heavy-duty vehicle emission standard underwent upgrades three times. NOx and PM limits in the currently-in-effect CHINA VI standard are stricter than in CHINA V by 80% and 50%, respectively.

Heavy-duty vehicles are the key source to reduce pollution and CO_2 emissions in China's transportation sector. Both Europe and the US have proposed greenhouse gas emission reduction targets for heavy-duty vehicles in 2025 onward. However, China has not yet proposed any CO_2 emission regulations for heavy-duty vehicles. There is still a certain gap in fuel consumption between China and the internationally advanced levels. In terms of emission limits, California has proposed even stricter emission limits for heavy-duty vehicles, which will be phased in over time. The NOx limit of the vehicle model in 2027 will be 90% lower than that of the 2020 model and the CHINA VI standard as well. China and other Asian countries should improve and strengthen their medium- and long-term emission reduction regulations and strategies for heavy-duty vehicles as soon as possible and promote heavy-duty vehicles achieving ultra-low and net-zero emissions.

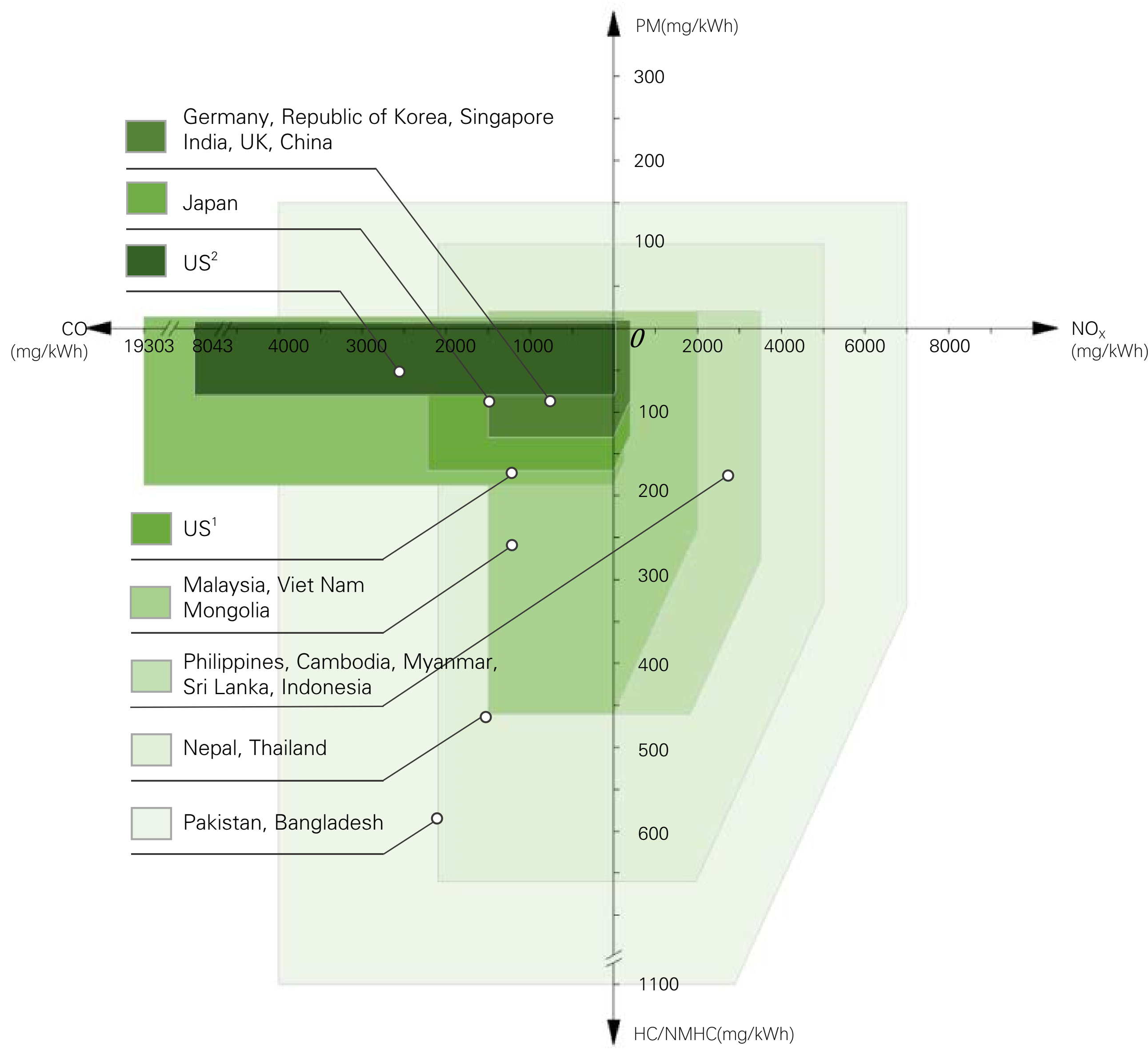


Figure 5.14 Current Limits for Heavy-Duty Vehicles in Countries and Regions
(Using the Limits of Steady-State Cycles for Heavy-Duty Diesel Vehicles as an Example)

Notes: 1.Due to differences in the test cycles used to determine emissions, it was not appropriate to directly compare standards between different regulatory agencies.

2.The unit used in the US limits is g/bhp·h. The report uses a conversion rate of 0.746 g/bhp·h = 1 g/kWh. The US2 marked in this figure pertains to the limits in the country's next phase, to be implemented in 2027.

Source: See references for details.

China started implementing its CHINA VI-a standard in July 2021, reaching the internationally advanced level for the emission control of heavy-duty vehicles. The CHINA VI standard has the combined best practices from the EU and US emission control requirements, features increased strictness in technological standards and compliance supervision, and introduces remote emission monitoring requirements.

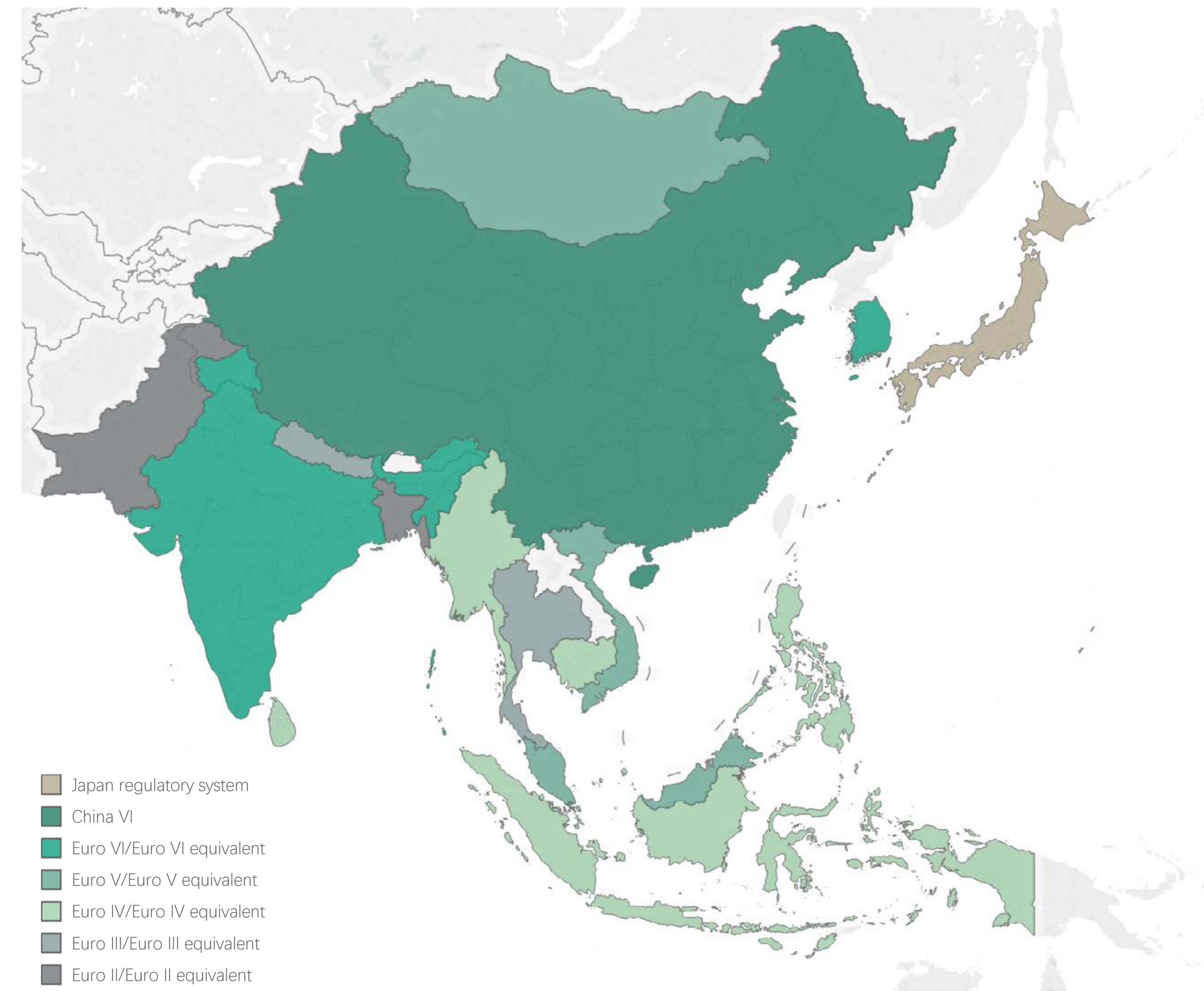


Figure 5.15 Regulatory Systems Adopted by Asian Countries and Their Current Emission Stage
(Using Heavy-Duty Diesel Vehicles as an Example)

Notes: 1. Countries like Singapore and Sri Lanka require automobiles to comply with emission standards from either the EU or Japan. This figure only shows current effective EU emission standards .

2. Countries like India and Thailand set their own emission standards based on the EU emission control system, but since limits are consistent with the values in the different stages of EU standards, this figure uses the equivalent EU standards.

Source: See references for details.

Most Asian countries follow EU regulatory requirements, but there is a marked difference in the current emission standards of various countries. The limits used by China, India, Japan, the Republic of Korea, and Singapore are the strictest among Asian countries, whereas Bangladesh, Nepal, Pakistan, and Thailand are still using the limits from Euro II and Euro III. In recent years, some Asian countries have leaped toward using stricter limiting values. For example, India has leaped directly from Euro IV to Euro VI.

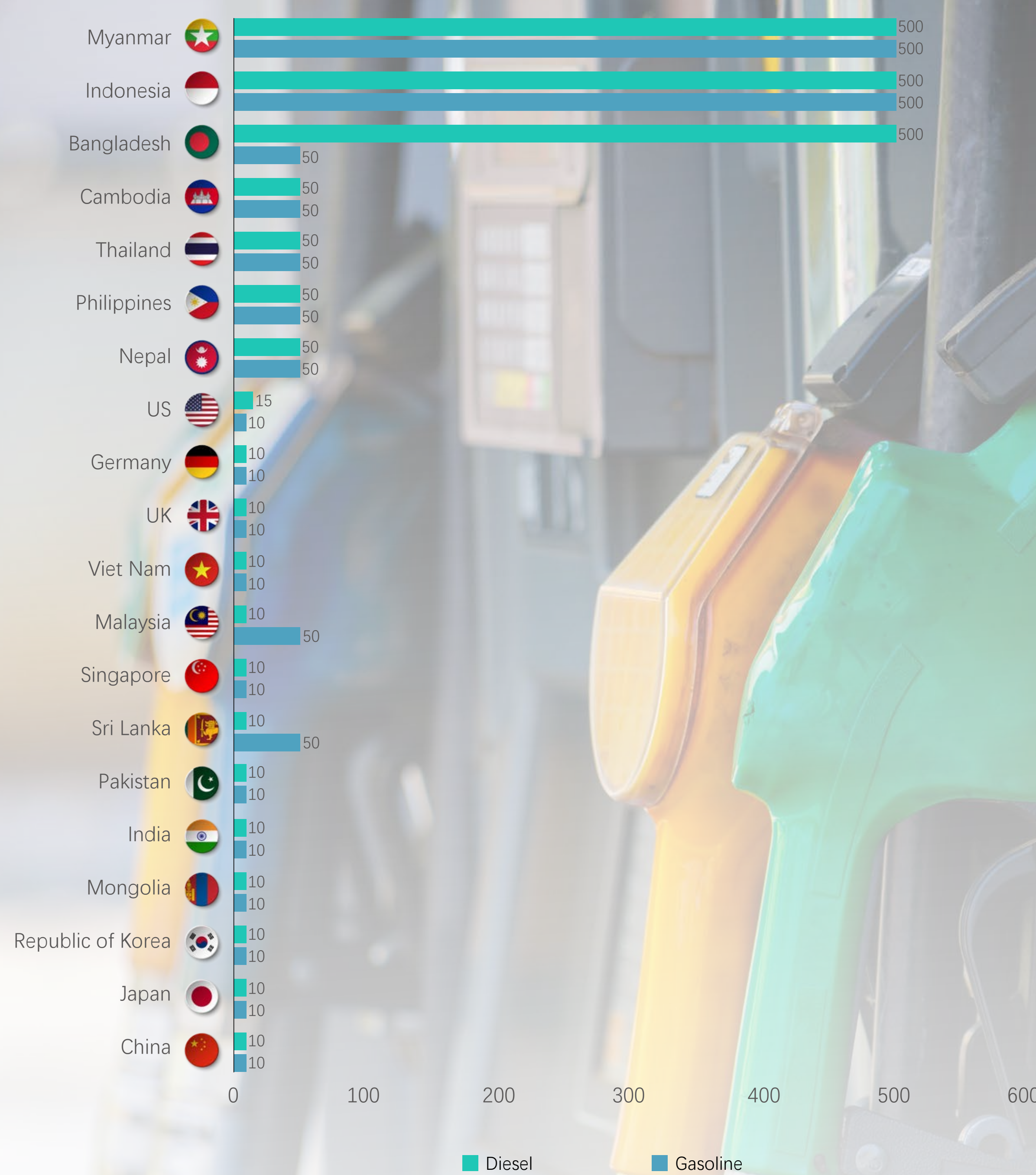


Figure 5.16 Current Gasoline and Diesel Sulfur Content in Various Countries

Unit: ppm

Notes: 1.Gasoline sulfur contents in Bangladesh are divided into regular grade and premium grade; this report uses the premium grade for high-end vehicles and light-duty vehicles. Diesel sulfur contents advance differently in Chittagong, Dhaka, and other regions of the country. This report uses the diesel sulfur content in other regions of the nation. Diesel sulfur content for Chittagong and Dacca is 350 ppm.

2.Sri Lanka's gasoline standards are divided in two types by octane number. The sulfur content of 95-octane gasoline is 50 ppm as updated in July 2018, while the sulfur content of 92-octane gasoline is 300 ppm as updated in March 2015. There are two types of diesel standards: super diesel with sulfur content of 10 ppm as updated in July 2018 and auto diesel with sulfur content of 3,000 ppm as updated in May 2015.

3.Indonesia grades its diesel according to cetane number and its gasoline according to octane number. This report uses the sulfur contents in CN48 and RON90 fuel.

Source: See references for details.

Diesel				Year	Gasoline			
China	Japan	US	EU		China	Japan	US	EU
		500		1993				
		500	2000	1994				1000
		500	2000	1995				500
		500	500	1996		100		500
	500	500	500	1997		100	350	500
	500	500	500	1998		100	350	500
	500	500	500	1999		100	350	500
	500	500	350	2000	1000	100	350	150
	500	500	350	2001	1000	100	350	150
2000	500	500	350	2002	1000	100	350	150
2000	500	500	350	2003	800	100	350	150
2000	500	500	350	2004	800	100	120	150
2000	50	500	50	2005	500	50	30	50
2000	50	15	50	2006	500	50	30	50
2000	50	15	50	2007	500	50	30	50
2000	10	15	50	2008	500	10	30	50
2000	10	15	10	2009	500	10	30	10
2000	10	15	10	2010	150	10	30	10
350	10	15	10	2011	150	10	30	10
350	10	15	10	2012	150	10	30	10
350	10	15	10	2013	150	10	30	10
350	10	15	10	2014	50	10	30	10
50	10	15	10	2015	50	10	30	10
50	10	15	10	2016	50	10	30	10
10	10	15	10	2017	10	10	10	10
10	10	15	10	2018	10	10	10	10
10	10	15	10	2019	10	10	10	10
10	10	15	10	2020	10	10	10	10
10	10	15	10	2021	10	10	10	10

Figure 5.17 Timeline of the Tightening of Sulfur Content in Automobile Fuel in China, the EU, Japan, and the US

Unit: ppm

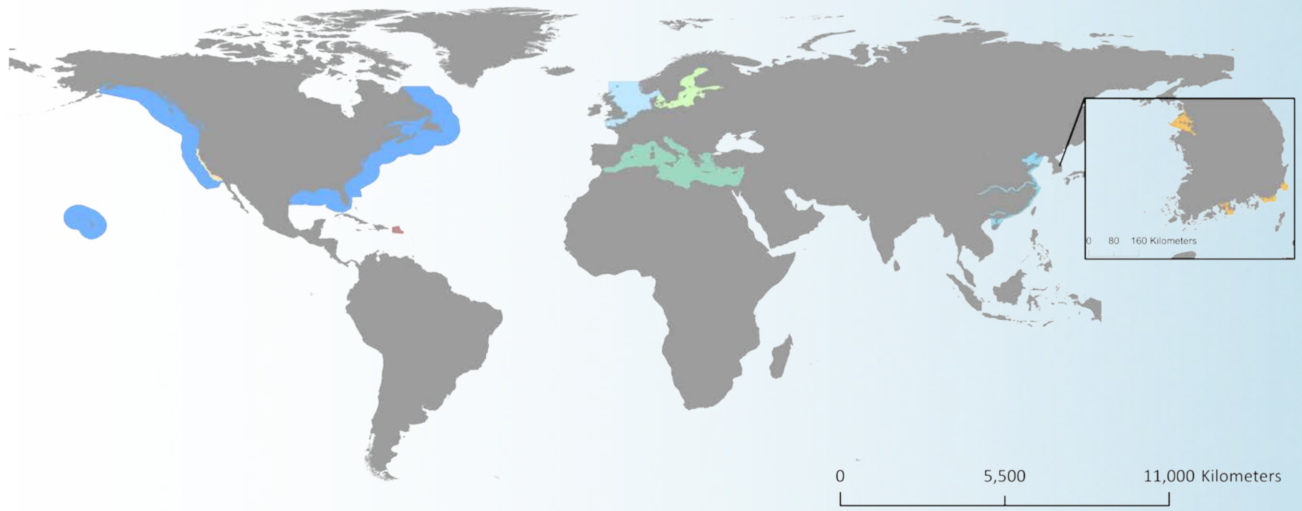
Notes: 1. China proposed a diesel sulfur limit of 500 ppm on "GB/T 19147-2003," which is a recommended standard and not shown in the figure.

2. US gasoline sulfur limits refer to the refinery average. The data for 2004 refers to the corporate average.

Source: See references for details.

In recent years, China has rapidly progressed in tightening its fuel sulfur content. In 2017, both its diesel and gasoline sulfur contents decreased to 10 ppm.

There is a marked difference in fuel sulfur content among Asian countries, ranging from 10-500 ppm. China, India, Japan, the Republic of Korea, and Singapore have implemented stringent motor vehicle emission standards and stringent fuel standards at the same time. Asian countries like Bangladesh, Indonesia and Myanmar still use the same level of fuel sulfur content as Euro 2.



No.		Name	Administration	Effective time of SOx	Effective time of NOx
1		North American Emission Control Area	IMO	2012.8.1	2016.1.1
2		United States Caribbean Emission Control Area	IMO	2014.1.1	2016.1.1
3		Baltic Sea Emission Control Area	IMO	2006.5.19	2021.1.1
4		North Sea Emission Control Area	IMO	2007.11.22	2021.1.1
5		Mediterranean Emission Control Area	IMO	Expected 2024 or 2025	——
6		California's Maritime Vessel Regulatory Zone	California Air Resources Board	2009.7.1	——
7		Domestic Emission Control Area (DECA) for Air Pollution from Maritime Vessels in China	Ministry of Transport, China	2016.1.1/2019.1.1	2022.1.1
8		SOx Emission Control Area (SECA) in the Republic of Korea	Ministry of Oceans and Fisheries, Republic of Korea	2020.9.1/2022.1.1	——

Figure 5.18 Emission Control Areas for Ships

Notes: 1. Marine diesel engines constructed or modified on or after the effective date and operating in emission control areas approved by the International Maritime Organization (IMO) follow the IMO Tier III NOx standard.

2. California's Maritime Vessel Regulatory Zone covers waters within 24 nautical miles of the baseline of its territory.

3. Since 1 January 2016, China has established DECAs for ships in the Bohai-Rim Area, the Pearl River Delta, and the Yangtze River Delta. On 1 January 2019, the country expanded the DECAs, including coastal control areas, which include waters within 12 nautical miles of the baseline of its territory. The inland river control area includes navigable waters along the main lines of Yangtze River and West River.

4. The IMO-Tier III NOx emission control requirements for emission control areas in China apply to Chinese ships with a single-cylinder displacement at or above 30 L, constructed or modified on or after 1 January 2022, entering coastal emission control areas in the waters surrounding Hainan and inland river emission control areas.

5. Since 1 September 2020, the Republic of Korea has established SECAs for ships, which include the ports of Busan, Incheon, Pyeongtaek-Dangjin, Ulsan, and Yeosu-Gwangyang and their nearby waters. The requirement for SOx control applies to ships berthing at ports in the emission control areas since 1 September 2020 and those operating within the emission control areas since 1 January 2022.

Source: See references for details.

Air pollution control for oceangoing ships uniformly follows IMO requirements. IMO member states can apply for the establishment of international emission control areas from the IMO and impose stricter requirements than general global standards. At present, IMO has approved five international emission control areas, of which four have already taken effect, with a stricter implementation of fuel sulfur content limits and emission standards for engines.

The IMO has yet to establish an international emission control area in Asia. China and the Republic of Korea have set their own emission control areas according to local laws and regulations, further limiting sulfur content values for ships entering the emission control areas to manage their SOx and PM emissions.

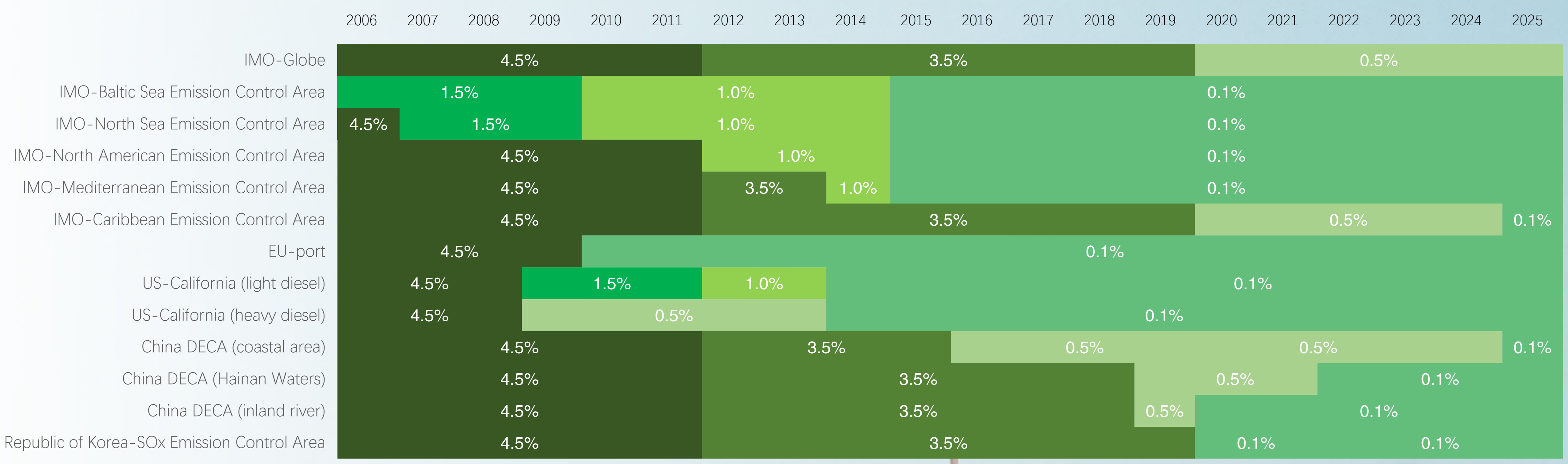


Figure 5.19 Timeline of Fuel Sulfur Content Upgrades for Oceangoing Ships

Notes: 1.The MEPC78 conference saw the approval of establishing SOx and PM emission control areas in the Mediterranean Sea, estimated to occur in 2025.

2.The EU requires ships berthing at their ports to use marine fuel with a sulfur content equal to or less than 0.1% m/m, but this requirement does not apply to ships berthing for less than two hours or that switch off all engines or use on-shore power while at berth in ports. In addition, the EU required regular passenger ships operating to or from any EU ports to use fuel with sulfur content equal to or less than 1.5% within EU's territorial waters and exclusive economic zones (except emission control areas in the North Sea and Baltic Sea) before January 2020.

3.Since 1 January 2016, China has established DECAs for ships in the Bohai-Rim Area, the Pearl River Delta, and the Yangtze River Delta. Ships are required to use fuel with sulfur content less than or equal to 0.5% m/m in stages when berthed. In 2019, DECAs were upgraded and expanded to waters within 12 nautical miles off the coast and along the main lines of Yangtze River and West River, with the full implementation of a fuel sulfur content limit of less than or equal to 0.5% m/m.

4.The limit requirement of less than or equal to 0.1% m/m sulfur content for fuel oil used on board was/will be implemented for maritime ships entering the DECAs for air pollution from ships: on 1 January 2020 in the inland river emission control areas, on 1 January 2022 in coastal emission control areas in the waters surrounding Hainan, and on 1 January 2025 in coastal emission control areas (feasibility needs to be evaluated).

5.Ships entering the SECAs in the Republic of Korea are required to burn fuel with sulfur content lower than 0.1% m/m: on 1 September 2020 for all ships at berth in their ports and on 1 January 2022 for ships operating in the SECAs.

Source: See references for details.

In 2020, the IMO 2020 Global Sulfur Cap for oceangoing ships was implemented globally. The maximum limit of fuel sulfur content decreased from 3.5% m/m-0.5% m/m.

By establishing and upgrading the DECAs, China has progressively promoted the use of fuel with sulfur content 0.5%m/m for oceangoing and coastal ships during berthing and while operating in emission control areas. In addition, China started to require inland ships to use diesel fuel with sulfur content lower than 0.001% m/m in 2018, making it one of the countries with the strictest inland water sulfur content requirements.

Compared with Europe and the US, the sulfur content requirement for oceangoing and coastal ships entering China's exclusive economic areas is not the strictest. Europe and North America have set four international emission control areas approved by the IMO. Ships entering within 200 nautical miles of these areas must comply with the strictest fuel sulfur content requirements in the world (0.1% m/m). California and the EU have also established regional emission control areas, requiring all ships within 24 nautical miles (for California) or at berth in ports (for the EU) to use fuel with sulfur content lower than 0.1%m/m.

Figure 5.20 Historical Changes in NOx Emission Control for Oceangoing Ships

Notes: 1.IMO's NOx emission limits apply to marine diesel engines with a power output of more than 130 kW.

2.Marine diesel engines constructed or modified on or after the effective date of the IMO NOx requirement shall meet the corresponding emission control standard.

Source: IMO, Special Areas under MARPOL

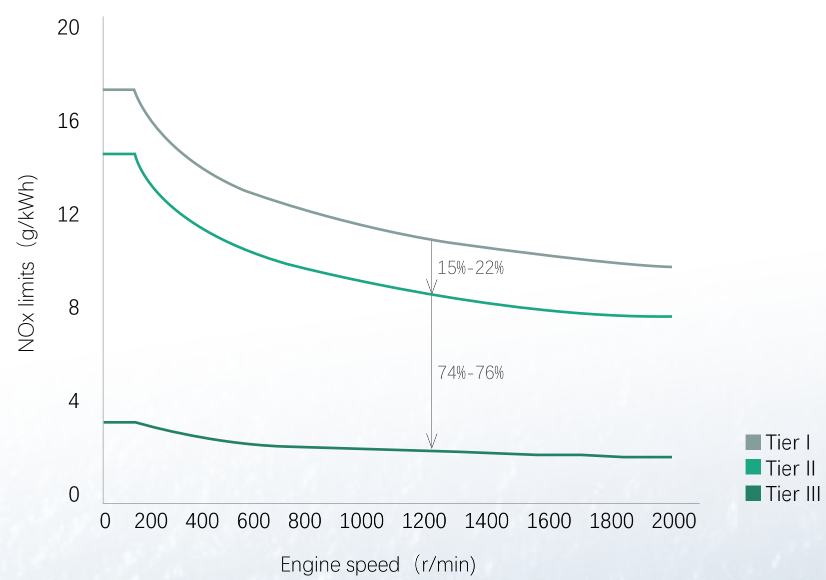


Figure 5.21 IMO's Limits for the NOx Emission of Oceangoing Ships

Source: MARPOL Annex VI: Prevention of air pollution by ships—Regulation 13

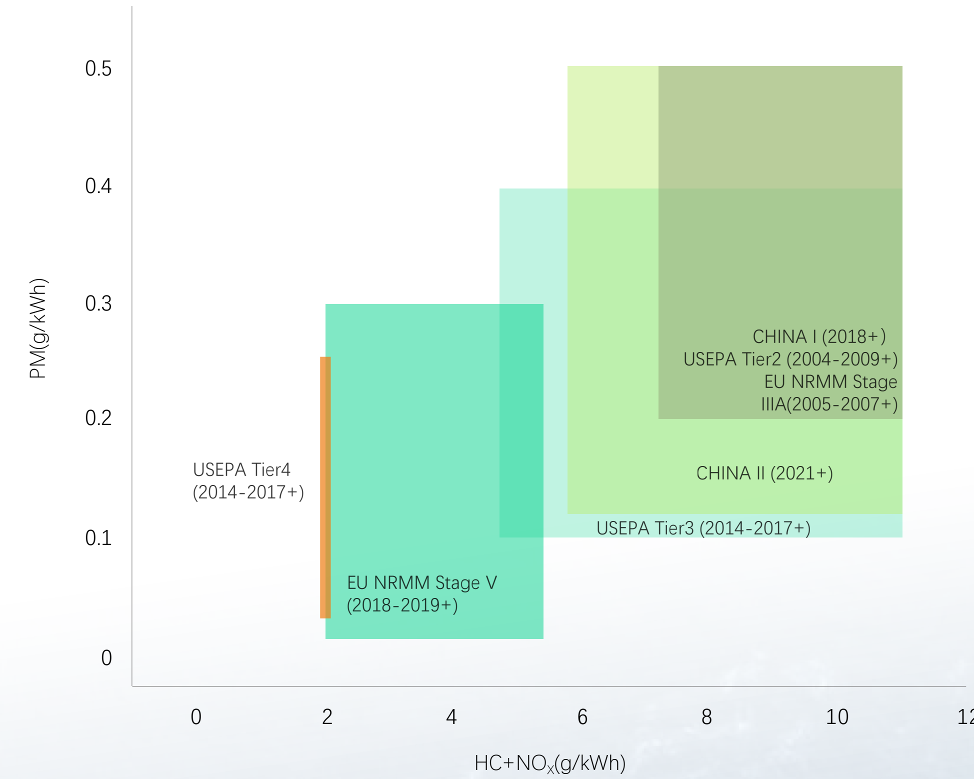


Figure 5.22 Limits of Air Pollutants for Domestic Ship Engines in China, Europe, and the US

Notes: 1.The color block boundaries in the figure represent the minimum and maximum values for each category limits. The emission limits of various countries and regions for domestic ship engines are set and categorized based on engine use, single-cylinder displacement, power, and other factors.

2.The labeled implementation time is the effective date for engine type approval.

3.The two stages of the emission limits applied to engines of inland waterway ships in the EU are Stage III-A and Stage V. Stage III-A mainly applies to engines with a power of 37 kW or higher, while Stage V applies to engines with a power of 19 kW or higher.

4.China's standard shown in this figure applies to the category 1 and 2 engines specified in GB15097. The first pertains to engines with rated net power higher than or equal to 37 kW and single-cylinder displacement lower than 5 L, while the second pertains to engines with rated net power higher than or equal to 37 kW and single-cylinder displacement equal to or higher than 5 L but lower than 30 L.

5.The US standard shown in this figure applies to the category 1 and 2 engines specified in the 40 CFR 1042 standard, which are mainly engines with single-cylinder displacement lower than 30 L. The Tier 2 standard is not applicable to engines with 37 kW of power or below.

Source: See references for details.

International oceangoing ships must comply with the engine emission control requirements of the IMO. Member states can apply to IMO for the establishment of international NOx emission control areas, which impose stricter requirements for the engine emission control of ships entering emission control areas.

China has not applied for the establishment of an international NOx emission control area. According to the "United Nations Convention on the Law of the Sea," stricter engine emission control requirements cannot be imposed on foreign ships operating within China's DECAs. Foreign ships entering 200 nautical miles within China's territorial waters only need to meet IMO's Tier II standard.

There are four international NOx emission control areas approved by the IMO implementing the Tier III standard, which sets a NOx limit 74%-76% stricter than that of Tier Ⅱ . These four emission control areas are located in Europe and America.

Air pollutant emission standards for domestic ships are developed autonomously by each country. China started working on these standards 10 years later than Europe and the US.

In 2016, China published air pollutant emission standards for marine engines for the first time, but there remained a certain gap with Europe and the US. The CHINA I marine engine limits implemented in July 2018 were equivalent to those of EU Stage III-A and US Tier 2, as well as the CHINA II heavy-duty vehicle emission limits. The CHINA II marine engine limits upgraded and implemented in July 2021 were equivalent to those of US Tier 3, but gaps remain compared to the current limits in the EU and US.

In terms of pollutant control, the standards of China, the EU, and the US all cover CO, NOx, PM, and HC. In EU's Stage Ⅴ marine diesel engine emission limits, the EU added standards for the particles number, making the control of PM emissions more precise.

Key Industrial Sectors

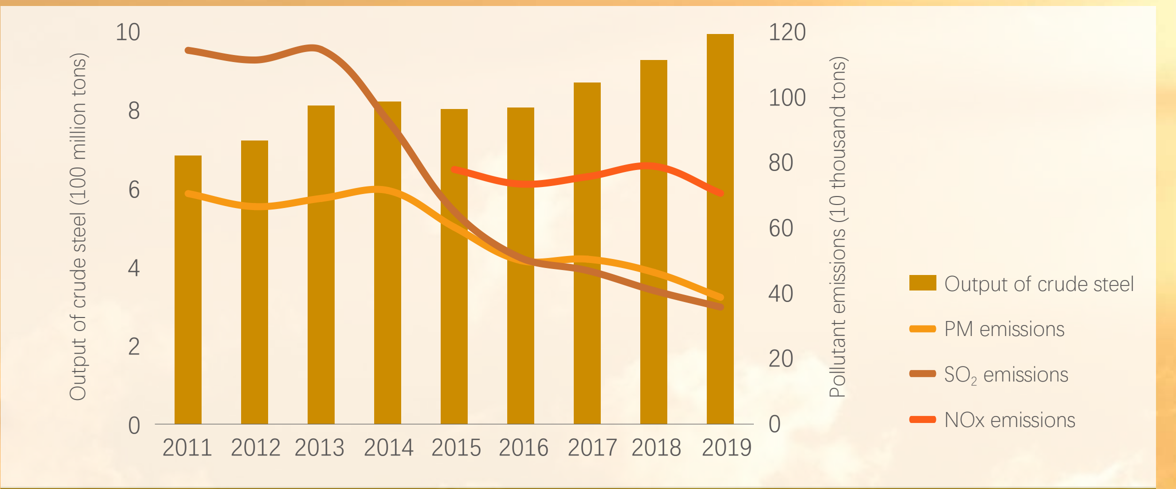


Figure 6.1 China's Crude Steel Production and Air Pollutant Emissions from the Iron and Steel Industry, 2011-2019

Sources: China's Statistics for the Environmental Protection of the Iron and Steel Industry (2019); China Statistical Yearbook, 2012-2020.

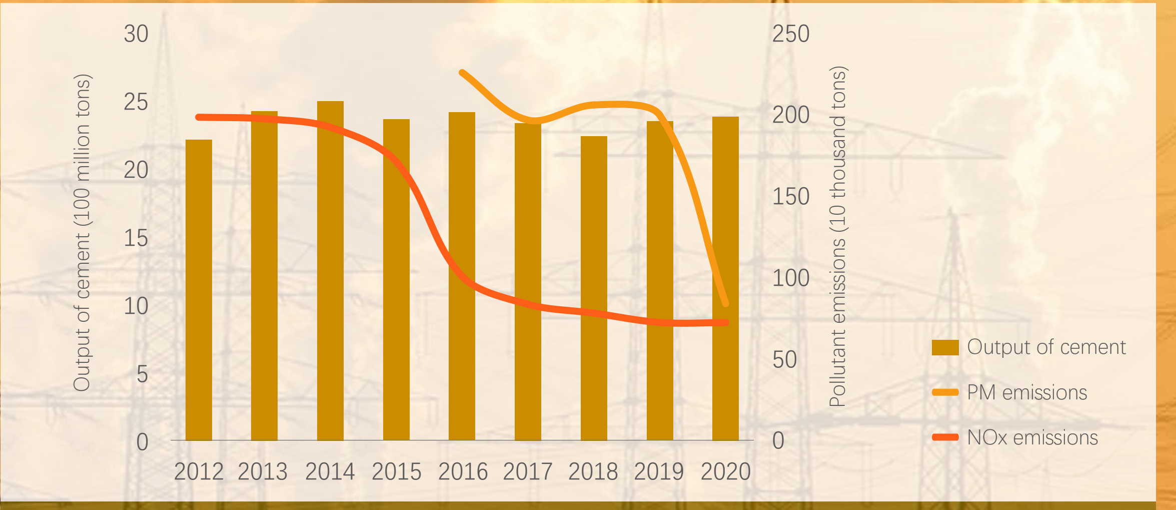


Figure 6.2 China's Cement Production and Air Pollutant Emissions from the Cement Industry, 2012-2020

Sources: China's Annual Statistical Reports for the Ecological Environment, 2012-2020; China Statistical Yearbook 2013-2021.

After 2010, China' s crude steel production increased, driven by global and domestic market demands. China has contributed over half of the world's raw steel production, which is 10 times that of the United States. During the same period, emissions of PM and SO_2, the main pollutants from the iron and steel industry, significantly decreased by 45.0% and 68.7%, respectively. NOx emission dropped by 9.4%.

China is also a major cement producer. The country' s cement production reached 2.38 billion tons in 2020, accounting for 60% of the world's cement output. In recent years, emissions of NOx and PM, the main air pollutants from the cement industry, significantly decreased by 63.5% and 62.8%, respectively.

The successful reduction of emissions from major industrial sectors have mainly been the result of strengthening industrial emission standards for the iron and steel, cement and other industries. Following the power sector, the two industrial sectors have reached an ultra–low emission phase.

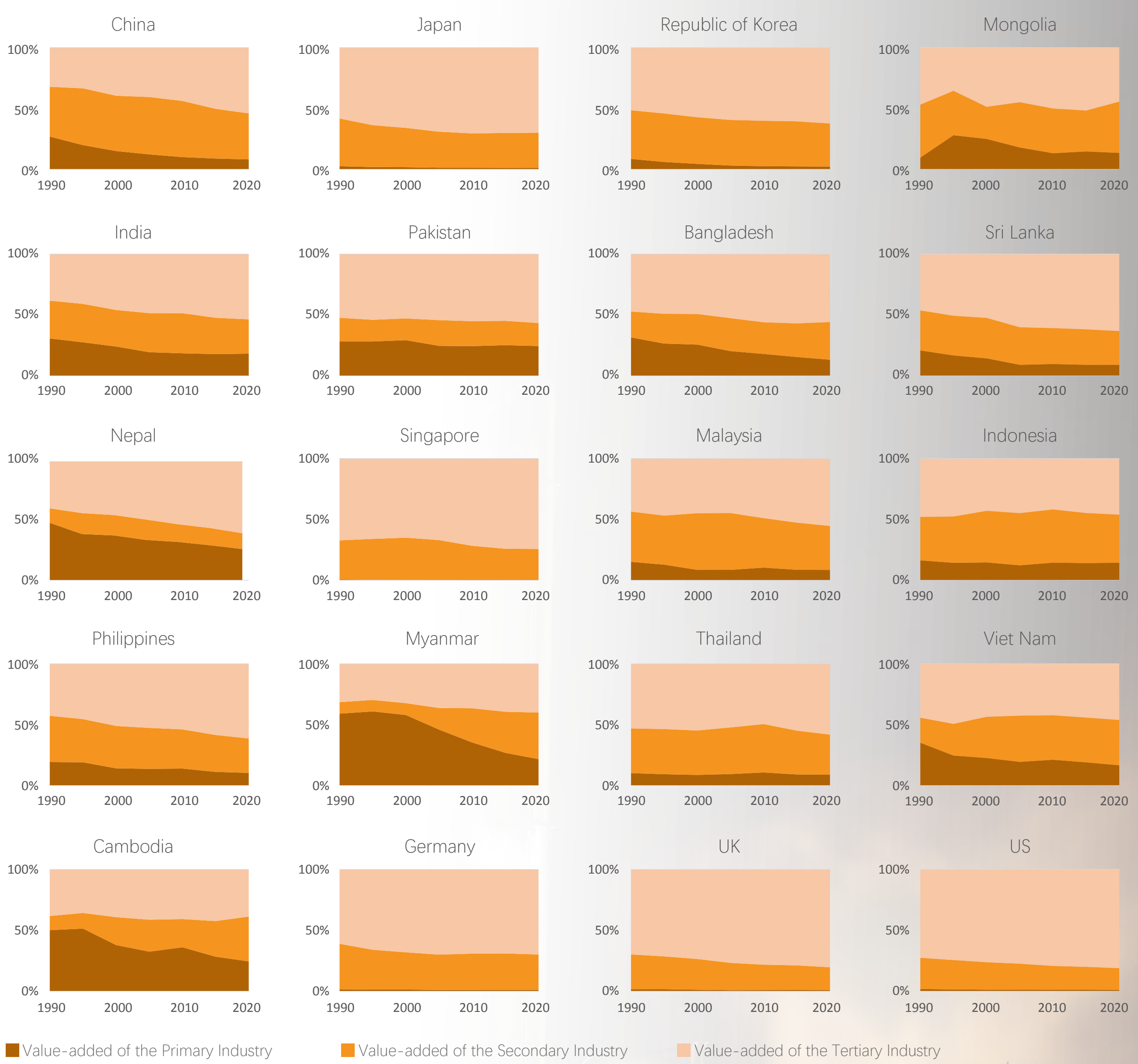


Figure 6.3 Changes in the Industry Structure of Various Countries, 1990-2020

Source: UN National Accounts database

The secondary industry is the pillar of China's economic development, having maintained a 40% weight for a long time. Through active promotion of industrial transition and upgrades, China's industry structure has significantly changed. The value added of the tertiary industry has steadily increased, while the proportion of the value added for the secondary and primary industries has slowly declined compared to previous years. In 2010-2020, the proportion of value added for the secondary industry decreased from 46%-38%.

India, Indonesia, Malaysia, the Philippines, and Thailand have also experienced a small decrease in their secondary industry's value added in the last 10 years, but those of Myanmar and Cambodia have continued to rise steadily.

In comparison, developed countries like Germany, Japan, the Republic of Korea, Singapore, the UK, and the US have already experienced a period of rapid industrial development and entered a post-industrial era dominated by tertiary industries. The value added of the secondary industry for these countries has generally been maintained at around 30% or below.

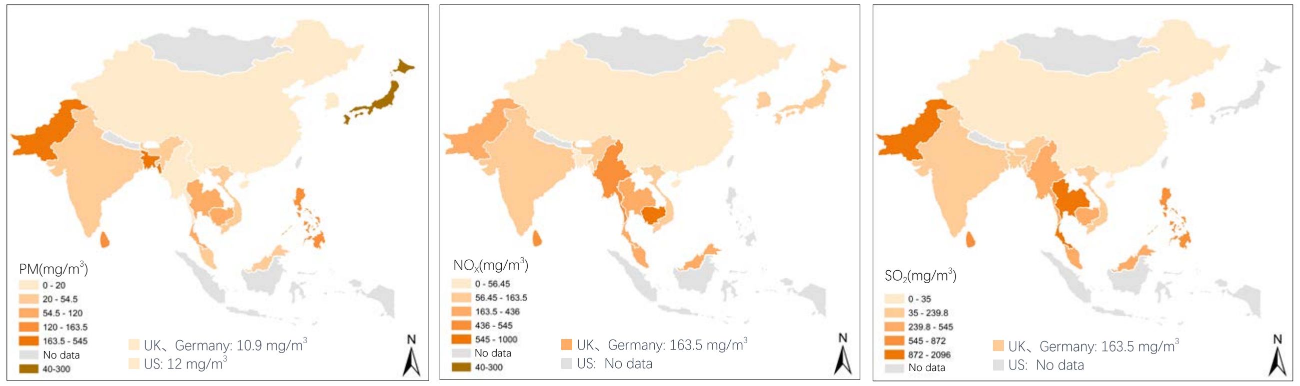


Figure 6.4 Emission Limits of the Iron and Steel Industry in Various Countries

Notes: 1.EU standards apply to equipment with over 300 MW of power.

2.China's limits are the ultra-low emission limits as per the policy requirement.

3.Myanmar's PM standard specifically pertains to PM_{10} limits.

4.Japan does not have a unified national SO_2 emission standard, which is based on the K value. Japan's SO_2 emission standard is set on the basis of the height of exhaust ports and the K value assigned for different regions.

5.Japan's PM emission standard is within the range of 30 mg/m^3-400 mg/m^3.

6.India's standard is a more comprehensive standard specified for blast furnaces.

7.Malaysia's standard mainly applies to its sintering machines. Pakistan's standard mainly applies to its blast furnaces. The Philippines' standard mainly applies to its smelting furnaces. The US' standard mainly applies to its electric arc furnaces. The other countries do not indicate specific equipment for their emission standards, which apply to all processes.

8.Sources: Officially published emission standards of various countries.

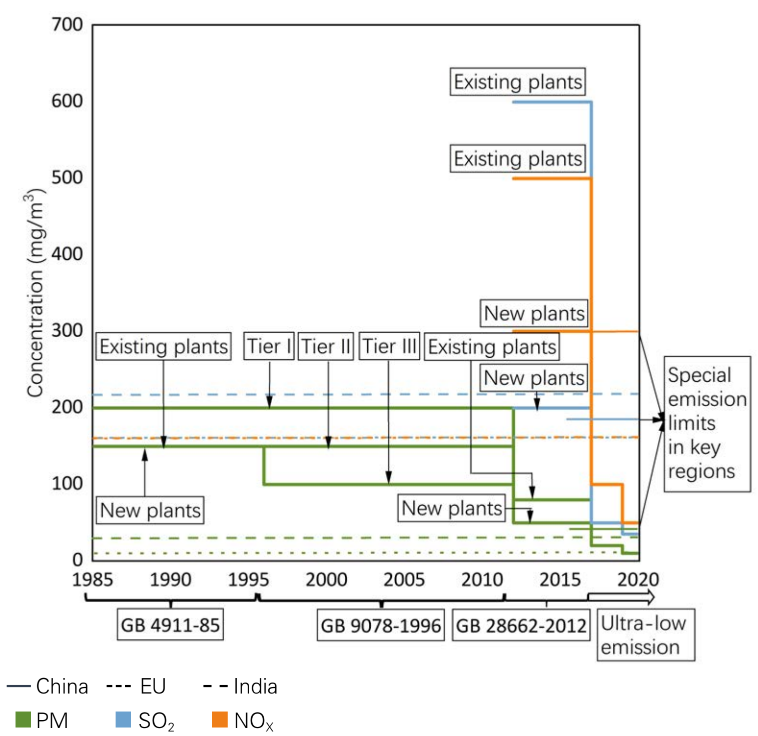


Figure 6.5 Course of Upgrades for the Iron and Steel Industry's Emission Limits in China

Notes: Tiers I, II, and III apply to Types 1, 2, and 3 functional areas of China's GB3095-1996 "Ambient Air Quality Standards."

Sources: See references for details.

China had a late start in the iron and steel industry's air pollutant emission control, but in the last 10 years, the country has improved the standards quickly. The current limits of PM, SO_2, and NOx required by the ultra-low emission policy are 10 mg/m^3, 35 mg/m^3, and 50 mg/m^3, respectively, which are more stringent than the original 1985 standards by 95%, 94%, and 90%, respectively. SO_2 and NOx emission limits are 1/5 and 1/3 of the EU standards, respectively.

There is a marked difference in the current emission limits of the iron and steel industry in Asian countries. China, India, the Republic of Korea, and Viet Nam have relatively stricter emission limits. Cambodia, Pakistan, and Thailand have more lenient limits at 10 times that of China's ultra-low emission standards for the three pollutants.

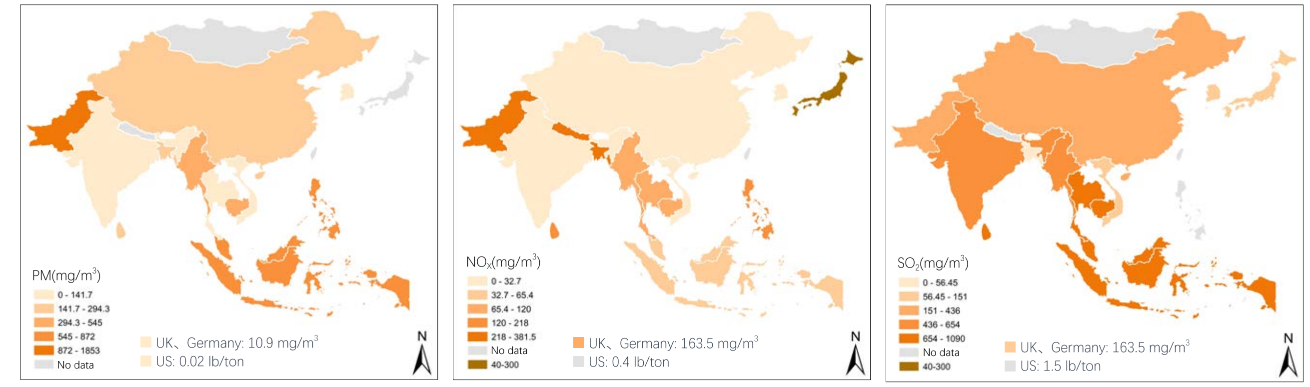


Figure 6.6 Emission Limits of the Cement Industry in Various Countries

Notes: 1.EU standards apply to equipment with over 300 MW of power.

2.Myanmar's PM standard specifically pertains to PM_{10} limits.

3.Japan does not have a unified national SO_2 emission standard, which is based on the K value. Japan's SO_2 emission standard is set on the basis of the height of exhaust ports and the K values assigned for different regions. Normal emission standard: K = 3.0-17.5; special emission standard: K = 1.17-2.34.

4. Japan's PM emission standard has a range of 30 mg/m^3-400 mg/m^3.

Sources: Officially published emission standards of various countries.

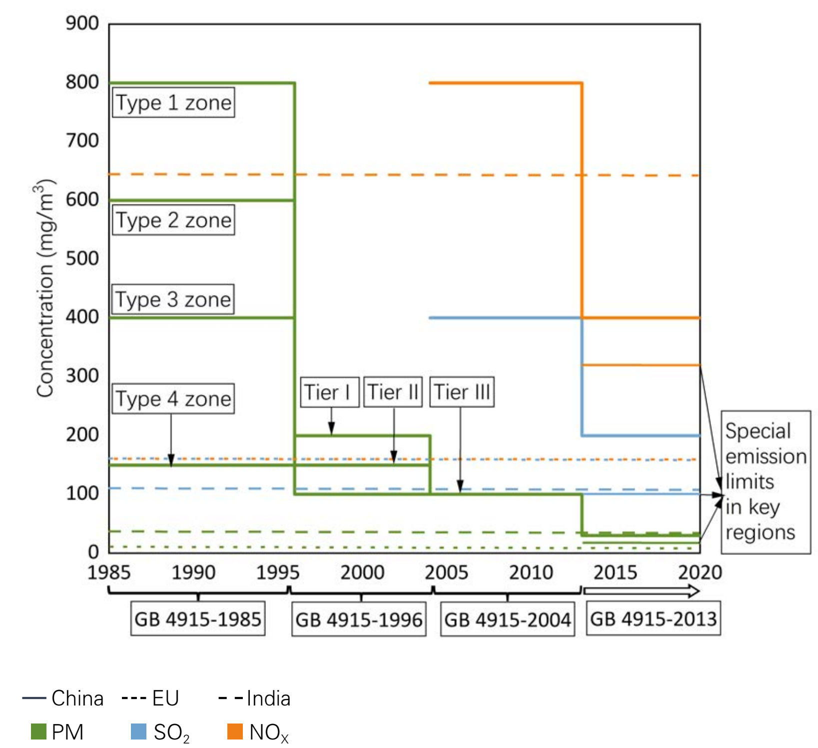


Figure 6.7 Course of Upgrades for the Cement Industry's Emission Limits in China

Notes: The Types 1, 2, 3, and 4 zones in this figure are divided according to the cement industry's production characteristics and respective regions. Type 1 refers to the state-specified zone with special requirements; Type 2 refers to urban, county residential, and mixed commercial traffic and residential zones in major coastal and inland cities; Type 3 refers to rural, county urban, and independent industrial zones; and Type 4 refers to towns and rural villages with a low level of pollution.

Sources: See references for details.

The emission standards for air pollutants in China's cement industry have been revised three times. The current emission limits of PM, SO_2, and NOx are at 30 mg/m^3, 200 mg/m^3, and 400 mg/m^3, respectively, which are stricter than the 1985 original standards by 95%, 94% and 90%, respectively. These standards are also stricter than those of most Asian countries but are still behind those of the EU, the Republic of Korea, and Viet Nam. China starts promoting the ultra-low emission retrofitting of the cement industry in 2022 and will significantly tighten its emission standards.

There is a marked difference in the emission limits of the cement industry in Asian countries. China, India, the Republic of Korea, and Viet Nam have relatively stricter emission limits, while those of Cambodia, Pakistan, and Sri Lanka are lagging behind at about 3 times higher than China's limits for the three pollutants.

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