China Council for International Cooperation on Environment and Development

# Special Policy Study (SPS) on the Collaborative Mechanism for Carbon Reduction, Pollution Reduction, Green Expansion and Growth

CCICED Special Policy Study Report

CCICED

Aug, 2023

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# Executive Summary

The report of the 20th National Congress of the Communist Party of China made a major strategic deployment to promote green development and harmonious coexistence between human beings and nature. The report emphasized the need to promote the construction of a beautiful China, reduce carbon dioxide ($CO_2$) emissions and other air pollution, and low-carbon economic expansion and growth while prioritizing ecological conservation alongside green development. Promoting the synergy of pollution and carbon reduction is a powerful tool to implement this new development concept and promote the comprehensive green transformation of economic and social development. It is also an inevitable choice to achieve the construction of beautiful China and the goal of "dual carbon," which is based on the concept that air pollutants and carbon emissions are both highly homogeneous and largely consistent in terms of control ideas, management tools, tasks, and measures. Promoting the synergistic control of air pollution prevention and greenhouse gas (GHG) control is a key way to achieve synergy in $CO_2$ emissions and air pollution reduction.

This study first analyzes the relationship between the "dual carbon" target and economic growth, then proposes policy recommendations on how to promote sustainable economic growth and high-quality development. Second, it focuses on synergistic management preventing air pollution and reducing $CO_2$, constructs a monitoring index system for both, and analyzes the effectiveness and obstacles of the synergistic management of both in China by tracking the progress of each index and proposing solutions. This study selects two key sectors for $CO_2$ and air pollutant emissions-power and transportation-to analyze the progress of synergistic control, identify key issues, and assess the current situation and challenges faced in pollution reduction and $CO_2$ reduction. This study further analyzes the synergistic benefits and path planning for key initiatives, such as coal power reduction and heavy-duty vehicle electrification, referencing international best practices and experiences. The report presents policy recommendations to promote a low-carbon transition and achieve the synergistic effect of pollution reduction and $CO_2$ reduction. Moreover, the report analyzes regulatory and enforcement mechanisms for synergistic control of pollution reduction and $CO_2$ reduction, refines the basic principles for effective formulation and implementation of multipollutant synergistic control measures and action plans based on the combing and summarizing of international experiences, and proposes relevant policy recommendations for improving environmental governance and environmental public interest

litigation. The report also analyses possible challenges and makes policy recommendations from a gender quality perspective for the synergistic management of carbon reduction, pollution reduction, green expansion, and growth.

The main findings and conclusions of the research on this study are as follows:

## Expanding Green Growth: How Emissions Reductions Enhance Economic Growth

The essence of promoting $CO_2$ reduction, preventing air pollution, and stimulating green expansion and growth is to take "carbon reduction" as a strategic grasp in the process of complete, accurate, and comprehensive implementation of the new development concept. This can form a mutually reinforcing relationship between environment and development and achieve a win-win situation between environmental protection and economic development by promoting a comprehensive green transformation of the economy and society. With green, low-carbon industries such as new energy vehicles and the renewable energy sector, the "dual carbon" target is providing new momentum and sustainable growth for China's economic development.

The "1 +N" framework provides an excellent basis for this work. It must be followed by detailed plans, organized around a healthy race to the top, and supported with detail at the provincial and municipal level. Controlling both conventional pollution (NOx, $PM_{25}$, SOx, and other particulates) while reducing the GHG emissions of $CO_2$, $CH_4$, and $N_2O$ can improve public health, save vast sums of money, and steer investments to better choices. Beyond advances in the economy and standards of living, co-control of conventional and traditional pollutants will spur better health and livability. China has benefited from world-leading renewable energy investment and new energy vehicle (NEV) development, and these efforts benefit the world by providing ample supply and lowering technology costs. Pushing important technologies down the learning curve offers broad and rapid returns. China should identify more realms where it can reduce costs for key technologies and practices, including industrial heat pumps, zero-carbon steel, zero-carbon concrete, petrochemicals, electric vehicles (EVs), and so forth. Almost all of this can be wrapped up in a carefully designed mix of performance standards, sector-specific goals, and economic signals that drive rapid environmental improvements while making new markets for advanced goods and services.

## A Carbon-Neutral and Clean Air Synergy Path

We analyze the process and challenges of the synergistic management of air pollution and $CO_2$

reduction in China based on five indicator categories: structural transformation, carbon pollution synergy, air quality, health benefits, and local practices. The assessment results show several lessons.

- First, at the social management level, China has begun building a management and policy system for the synergistic governance of pollution reduction and $CO_2$ reduction. Synergistic strategic planning has gradually taken shape, and the synergistic governance system in the fields of environmental assessment, monitoring, regulation, and environmental unification has gradually been improved. Meanwhile, economic policies, such as the carbon trading market, carbon finance, and climate investment, have made breakthrough progress.

- Second, at the level of technology application, structural transformation and applying new clean-energy generation and emission reduction technologies are fundamental to realizing the synergistic benefits of air quality improvement and $CO_2$ emissions reductions. Technologies that can help achieve the low-carbon transition for energy, industry, transportation, and other sectors are being applied at an accelerated pace.

- Third, at the level of synergistic management effectiveness, pollution reduction and $CO_2$ reduction promote continuous air quality improvement and create significant health benefits, with $PM_{2-5}$, $0_3$, and $NO_2$ exposure levels decreasing continuously in recent years; for example, consider that the number of premature adult deaths associated with long- and short-term $PM_{2-5}$ exposure decreased by 23.9% and 26.2%, respectively, between 2017 and 2021.

- Fourth, there is still much room for improving the synergy between air pollution and $CO_2$ reduction in China. At the city scale, only 31.3% of cities achieved a synergistic reduction in $PM_{2-5}$ concentration and $CO_2$ emissions during 2015-2020, and most cities have not yet achieved synergy between air quality improvement and $CO_2$ reduction. In terms of key areas, the industrial sector has achieved positive synergy between $CO_2$ emission reduction and $PM_{2-5}$ pollution improvement, while the electricity, heat supply, transportation, and civil sectors still show negative effects, and the synergistic emission reduction potential of their structural adjustment has yet to be significantly released.

The synergistic future path of carbon neutrality and clean air in China should fundamentally implement structural adjustments and green upgrades, accelerate the shift from end-of-pipe control to source management, and promote the transition of energy structure and technology with the goal of carbon neutrality, all to help achieve the goals of carbon peaking and carbon neutrality alongside clean air. This path has four steps.

- First, promote the green and low-carbon development of energy, control the total consumption of fossil energy, and build a new power system with a steadily increasing proportion of non-fossil energy.
- Second, deepen the adjustment of industrial structure, curb the "two high and one low" project blind development, eliminate backward production capacity, resolve excess capacity, focus on source management, and vigorously develop green low-carbon industries.
- Third, optimize the transport structure, accelerate the deployment of clean motor vehicles, promote clean energy alternatives, build an efficient and intensive logistics system, accelerate a shift in the transport of bulk goods and long-haul goods "from highway to railway" and "from highway to waterway," and vigorously develop multimodal transport.
- Fourth, steadily adjust the land-use structure, continue to promote the optimized layout of key industries, implement key enterprises to relocate to the city, promote the prevention of agricultural dispersed source pollution, and strengthen dust control.

## Coal Power Reduction: The Pathway to Synergistically and Efficiently Reducing Air Pollution and Carbon Emissions

Coal power is the primary contributor to GHG and air pollutant emissions in China, accounting for 35% of national anthropogenic $CO_2$ emissions, as well as 15% each of $SO_2$ and NO, emissions. Promoting the transition from coal-based power systems to low-carbon energy sources is an imperative choice to achieve China's carbon peaking and carbon neutrality goals, sustainably improve air quality, and safeguard human health. But coal power currently represents over 60% of China's total power generation, and phasing it out poses several challenges. First, the variability of renewable energy sources poses significant challenges and opportunities to the energy system when transitioning away from coal-fired power generation. Second, with the rapid development of coal power infrastructure, the average service life of China's coal power units is relatively low at 11 years, meaning large-scale coal power retirement would entail substantial risks of stranded assets. But, as renewables are now cheaper than coal, there are symmetrical opportunities

International experience demonstrates that establishing GHG emission standards for coal-fired power plants or the power industry, along with accelerating the transition to a new power system dominated by renewable energy sources, are key to achieving a low-carbon power sector transition. It is crucial to ensure the reliability and affordability of the power system throughout this transition. We propose several policy recommendations for China's coal power decommissioning strategy to achieve deep emission reduction and a smooth transition:

- First, systematically design coal power decommissioning policies that consider emission levels, technical attributes, cost-effectiveness, asset stranding risks, health benefits, and social equity for coal power plants. This approach aims to achieve optimal comprehensive benefits from coal power decommissioning.
- Second, accelerate the flexibility retrofit of remaining coal plants to enhance their balancing value to a high penetration of variable wind and solar energy, while meeting peak regulation requirements. Think of coal as a peaker, rather than a base-load asset to the grid.
- Third, implement the nationwide economic dispatch of the power system, with a focus on the competitive risks posed by inefficient coal-fired power plants. This strategy aims to improve plant efficiency, reduce renewable energy curtailment, and promote the construction of renewable energy and energy storage projects.
- Fourth, expand power system reliability responsibilities from the provincial scale to the regional scale, aiming to reduce the dominance of coal power and create more opportunities for accelerated deployment of renewable energy.
- Fifth, set new, more ambitious targets for clean energy and energy storage deployment.
- Sixth, modify the market structure to maintain reliable services for most existing coal-fired units based on non-demanding power dispatch, and consider developing reliable storage products where necessary.
- Seventh, strengthen research on the reliability of high-percentage renewable energy systems and collaborate with major grid operators in other countries to implement best-practice models for better assessing the reliable contributions of various resource types.

## Key Issues and Challenges in Reducing Transportation Pollution and Carbon Emissions

Heavy-duty vehicles pose a significant challenge to reducing transportation sector air pollution and $CO_2$ emissions, with their emissions of particulate matter, NOx, and $CO_2$ accounting for 52%, 76%, and 30% of total motor vehicle emissions, respectively. Transforming heavy-duty fleets into NEVs is an essential measure for reducing transportation sector air pollution and $CO_2$. Based on the results of life-cycle assessments, EVs in different regions of China can achieve $CO_2$ reduction benefits ranging from 30% to 60% compared to traditional fuel vehicles. As the proportion of renewable electricity increases in China, it is expected that the life-cycle $CO_2$ emissions of EVs in China will be reduced by more than 50% in 2030.

However, the electrification of heavy-duty vehicles in China faces two major practical challenges. First, the utilization rate of electric heavy-duty vehicles is currently lower compared to their diesel counterparts, limiting the potential for emission reduction throughout the fuel cycle. Consequently, electric trucks have a higher total cost of ownership and reduced economic competitiveness when compared to diesel trucks. Second, inadequate charging infrastructure poses a hurdle to the widespread adoption of long-distance, heavy-duty trucks.

We propose several policy recommendations to accelerate the transition to NEVs for heavy-duty trucks in China:

- First, a clear and more ambitious long-term development target for NEV heavy-duty trucks should be established. Based on commercial availability and cost of ownership projections, we recommend that the sales ratio of NEV heavy-duty trucks be set to reach 45% by 2030, 75% by 2035, and 100% by 2040.
- Second, in alignment with the "dual credit" policy for light-duty passenger vehicles, it is necessary to establish an industrial sales standard for NEV heavy-duty trucks to effectively meet the sales targets.
- Third, China's existing portfolio of policy tools for the promotion of NEVs should continue to be improved and expanded. This includes measures such as developing NEV industry sales standards; expanding NEV infrastructure construction; continued implementation of fiscal incentives, such as preferential exemption from vehicle purchase tax for NEV trucks, and non-fiscal incentives, such as allowing a right-of-way priority for NEV heavy-duty trucks; and clear procurement requirements for NEVs in commercial fleets.
- Fourth, maximize the use of renewable energy power through coordinated charging and other means to improve the synergistic benefits between the power and transportation systems and achieve higher grid stability, lower fuel costs, and deeper emissions reductions.
- Fifth, accelerate technological innovation in battery storage, as well as the construction of NEV infrastructure, such as charging stations and battery-swap stations, to improve the utilization rate of electric trucks and enhance their cost competitiveness.
- Furthermore, creating sustainable and livable urban areas in China requires supporting fast and reliable public transit, establishing physically protected bikeways, providing ample space

for pedestrians on shaded walkways, realizing the concept of a "15-minute city" for residents, and ensuring new urban development aligns with the 'Emerald Cities" principles for a safe, pleasant, and efficient lifestyle.

## Establishing a regulatory and enforcement mechanism for collaborative control

Based on California's experience with synergistic air pollution and climate change management, we propose several basic principles and necessary elements for the effective identification, development, and implementation of multipollutant synergistic management measures and action plans:

- First, establish clear, traceable, and measurable targets.
- Second, set a strong technical basis for data and analysis.
- Third, develop broad partnerships and an open and transparent public participation mechanism.
- Fourth, prioritize guidance measure development.
- Fifth, establish a comprehensive plan to prioritize and guide measure development.
- Sixth, support capacity and expertise to develop and implement these measures.
- Seventh, maintain continuous monitoring and strong enforcement and regulatory mechanisms.
- Eighth, measure effectiveness evaluation and adjustment optimization.

California's building code policies provide an excellent example of enhancing building efficiency requirements and encouraging the adoption of high-efficiency appliances and building materials. On this basis, the common barriers to collaborative governance are summarized. First, the subjects of collaborative governance mostly involve multiple stakeholders, such as different departments, groups, or administrative regions. This makes it necessary to maximize the benefits by reshaping the organizational structure, cooperative relationships, and interest mechanisms to drive multistakeholder collaboration. Second, the laws and regulations for both air pollution prevention and control and climate change response are relatively isolated, and the constraints and safeguards for collaborative governance are relatively weak.

Since its implementation in China in 2015, environmental public interest litigation (EPIL) as a new environmental enforcement tool has become an important driving force for companies to achieve better compliance with environmental laws. Challenges to the implementation of EPIL in China include the narrow scope of environmental law application and the lack of a bill authorizing EPIL to target GHG emission reductions; the lack of a legal mechanism to compensate for damages for potential environmental problems, which is limited by the current "damage-based" provisions; and the weakness of environmental governance and EPIL infrastructure capacity. In addition, the basic capacity of environmental governance and EPIL are weak, and the relevant personnel do not have enough legal or environmental expertise.

Improving environmental governance and EPIL will require several steps. First, expand the scope of EPIL from environmental damage to GHG control, then guide and facilitate EPIL cases against GHG emissions and climate damage by issuing legal documents and providing national guidelines. Second, provide further political support for EPIL mechanisms and implementation. Third, establish a preventive EPIL mechanism to avoid potential environmental and climate damage. Fourth, promote the development of provincial EPIL regulations and allow and encourage drafting and promulgation of provincial EPIL implementation rules. Fifth, strengthen capacity building for EPIL operations.

# Foreword

The report of the 20th National Congress of the Communist Party of China has made a significant strategic deployment to promote green development and harmonious coexistence between human beings and nature. The report emphasizes the construction of a beautiful China, reducing carbon dioxide ($CO_2$) emissions, curbing air pollution, and fostering low-carbon economic growth, all while giving priority to ecological conservation alongside green development.

Promoting the synergy of pollution and carbon reduction is a powerful tool to implement this new development concept and drive the comprehensive green transformation of economic and social development. It is also an inevitable choice to achieve the construction of a beautiful China and the goal of "dual carbon." The concept is based on the fact that air pollutants and carbon emissions are highly interconnected and largely consistent in terms of control approaches, management strategies, tasks, and measures.

Conventional air pollutants ($NO_x$, $PM_{2.5}$, $SO_x$ and other particulate matter) and greenhouse gases ($CO_2$, $CH_4$, $N_2O$, etc.) have a high degree of homology, and synergistic control can effectively integrate resources, improve efficiency, reduce costs, improve public health, and at the same time promote the application of new technologies, direct investment to better choices, and provide new impetus for economic growth.

This SPS focuses on the analysis of collaborative management of Greenhouse Gases and criteria air pollutants and at the same time keep a healthy economic growth and an effective enforcement system, specifically looking into the potentials in the electricity sector and transportation sector. This research reviewed international experiences and domestic challenges. This year, the project team has identified and prioritized the power and transportation sectors as the two key areas to focus on. Specifically, the power sector investigates international accelerated coal power retirement experience and China's progress and challenges in decarbonizing the grid while aiming for secure, reliable, and flexible electricity supply. For the transportation sector, the team investigates policy options to enhance the transition of heavy-duty trucks to zero-emission vehicles, assessing technical and economic feasibility as well as emission reduction benefits. Additionally, the team explores options to improve management mechanisms and implement policies more efficiently, drawing on lessons learned from California's experiences.

In Chapter One, this study first analyzes the relationship between the "dual carbon" target and economic growth. It then proposes policy recommendations on how to promote sustainable economic growth and high-quality development.

Chapter Two focuses on synergistic management to prevent air pollution and reduce $CO_2$ emissions. It constructs a monitoring index system for both aspects and analyzes the effectiveness and obstacles of this synergistic management in China. The study tracks the progress of each index and proposes solutions.

This study selects two key sectors for $CO_2$ and air pollutant emissions-power and transportation-to analyze the progress of synergistic control. It identifies key issues, assesses the current situation, and highlights challenges faced in pollution reduction and $CO_2$ reduction. Chapter Three and Chapter Four elaborate on the analysis, challenges, and suggestions. The research team analyzed the synergistic benefits and path planning for key initiatives such as coal power reduction and heavy-duty vehicle electrification, referencing international best practices and experiences.

Furthermore, the report analyzes regulatory and enforcement mechanisms for synergistic control of pollution reduction and $CO_2$ reduction. It refines the basic principles for effective formulation and implementation of multi-pollutant synergistic control measures and action plans based on the combination and summarization of international experiences. The report also proposes relevant policy recommendations for improving environmental governance and environmental public interest litigation.

In each chapter, the report presents policy recommendations to promote a low-carbon transition and achieve the synergistic effect of pollution reduction and $CO_2$ reduction. These recommendations are summarized in Chapter Seven.

# Chapter 1. Promoting Economic Growth Through Emissions Reductions

The report to the 20th CPC National Congress stresses the need to promote concerted efforts to cut carbon emissions, reduce pollution, expand greening, and pursue economic growth. This, by its nature, requires creating synergy between the carbon peak and carbon neutrality goals (the "dual-carbon" goals) and economic growth through the carbon reduction strategy under the new development philosophy.

The relationship between the "dual-carbon" goals and economic growth is, in essence, the relationship between the environment and development. However, emissions reductions have long and wrongly been considered a burden on economic growth. Today, the debate about the relationship between the "dual-carbon" goals and economic growth places more emphasis on how to strike a balance between the two. But increasingly, evidence shows that decarbonizing the economy is a major domestic opportunity and a driving force for promoting the high-quality development of China's economy.

The key to recognizing and seizing the opportunity lies in whether we can completely, accurately and comprehensively understand and put into practice a new development philosophy. A simple criterion to distinguish between old and new development philosophies is whether the environment and development are deemed to be mutually reinforcing or contradictory. In advancing both the "dual-carbon" goals and the need to cut conventional pollutants, it is essential to abandon the traditional outdated and disproven idea that decarbonization is a net cost to the economy. This chapter argues, with careful evidence and clear, successful examples, that economic development, reducing conventional pollution, and achieving the "dual-carbon" goals can go hand-in-hand-if they are supported with the right policies.

## 1.1 Why Carbon Neutrality Is a Major Opportunity for China

### 1.1.1 Carbon Neutrality is an Opportunity for China to Create a Sustainable Development Paradigm.

The "dual-carbon" goals involve not only energy but also a shift in development paradigm; carbon neutrality is not only China's action, but also reflects worldwide consensus and action. So far, more than 150 countries have committed to carbon neutrality in various forms. These countries account for around 90% of the world's carbon emissions and economy. [1] Why have so many countries committed to carbon neutrality? First, of course, because the climate crisis is getting worse and, if unabated, the humanitarian burdens on China and the planet will be staggering. Second, experts and policymakers increasingly see the huge opportunities behind emissions reduction. The past decade has witnessed a sharp decline in the cost of new energy and electric vehicle (EVs). In the last 10 to 15 years, the price of solar photovoltaics (PV) has dropped more than 90%. Likewise, onshore wind, and now offshore wind, have had huge reductions-roughly half-in price. Batteries, lighting, heat pumps, and other key technologies are becoming less expensive than their inefficient predecessors.

This is creating an international trend. About 70% of the 150 countries that are committed to carbon neutrality are developing countries. In the past, it would have been difficult to imagine developing countries committing to carbon neutrality, since the conventional wisdom holds that the development path of the developed world features an inverted U-shaped curve of carbon emissions, which peaks before falling. But the fact that so many developing countries have committed to becoming carbon neutral and achieving economic prosperity through a low-carbon development model is a disruptive change to the traditional development model. The global consensus and action on carbon neutrality signifies that the traditional development paradigm is becoming a thing of the past, and a new green development paradigm is on the horizon.

China possesses unique advantages in green development. The first advantage is its new development philosophy. Having experienced the drawbacks of the traditional development model and owing to its 5,000-year-old culture of "man-nature harmony," China has a deeply rooted history of green development and ecological conservation. The second advantage is its strong government commitments. The green transition saves money and speeds development, but it requires a steady and smart suite of policies to break free from old ways. This systematic shift in the development

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paradigm requires government push and coordination, which China's government leadership can master. The third advantage lies in its market. With a population exceeding that of Europe and the United States combined, China has the world's largest future single market for its modernization. This provides fertile soil for the incubation and growth of green technologies. The fourth advantage lies in technology. China has already developed R&D and manufacturing capabilities in all sectors, such as clean energy and new energy vehicles (NEVs), enhancing a strong independent innovation capacity, and strong economic resilience. In sum, the industrial revolution-built prosperity at the expense of the environment. The green development paradigm turns the trade-off between environment and development into synergy and will determine the future.

### 1.1.2 Carbon Neutrality Is a Major Opportunity for China's Industries to "Change Lanes."

Carbon neutrality is the most comprehensive and profound shift in development paradigms since the Industrial Revolution, and this means that many of the industries established in the traditional industrial era will be modified or even rebuilt. This transition process is a major challenge, but it will also bring a wealth of new opportunities. For example, if China continues the path of traditional fuel-powered vehicles and conventional energy, it will be very difficult for the country to catch up with its developed counterparts that have more than a century of technological excellence, but carbon neutrality offers a rare historical opportunity for China to drive progress in green development.

China has already developed a competitive edge in many realms that can help it shift its development paradigm. China's solar PV industry supplies more than 60% of the world's silicon, more than 90% of silicon wafers, about 89% of cells, and more than 70% of modules. Meanwhile, China is also the world's largest manufacturer of wind turbines, accounting for half of the global production. Ten out of the global top 15 wind turbine manufacturers by market share come from China. In 2021, China contributed 35% to global renewable energy investment, accounting for about half of the combined investment of the world's top 10 investors.

In 2020 and 2021, China's NEVs accounted for 41% and 53%, respectively, of global sales. Of the world's top 20 NEV manufacturers, 12 of them are China-based, three are Germany-based, and two are U.S.-based. In 2021, China's NEV exports reached 310,000 vehicles, marking a remarkable increase of 304.6% year on year.

According to *Global Electric Vehicle Outlook 2023*, more than 10 million electric cars were sold worldwide in 2022, and sales are expected to grow by another 35% in 2023 to reach 14 million.

This explosive growth means electric cars' share of the overall car market has risen from around 4% in 2020 to 14% in 2022 and is set to increase further to 18% this year. Sixty percent of global electric car sales took place in China in 2022. Today, more than half of all electric cars on the road worldwide are in China. According to the China Association of Automobile Manufacturers, in the first quarter of 2023, China exported 1.069 million vehicles and overtook Japan's 1.047 million. China will likely export 4 million vehicles in the entire year, overtaking Japan to become the biggest car exporter.

## 1.2. How the "Dual-Carbon" Goals Are Promoting Economic Growth

### 1.2.1. Are the "Dual-Carbon" Goals Dragging or Driving Economic Growth?

The "dual-carbon" goals can be either a drag on or a driver of economic growth: the difference depends on the *pattern* of economic growth. If the traditional pattern of high emissions and high resource consumption, namely "digging coal, opening mines and running factories," established after the Industrial Revolution was adopted, then the "dual-carbon" goals would impede economic growth; if a green transition pattern was adopted, which features a modem concept and content of development, then the "dual-carbon" goals and prosperity would reinforce each other.

In fact, China has an increasingly sophisticated view of the relationship between environmental protection and growth. In the early days of its industrialization, China considered emissions reduction to be a burden on economic growth because production requires energy inputs, and for China especially, that has meant huge amounts of fossil energy. This pathway offered two possible outcomes from carbon reduction: less production, which impacts economic growth, or higher production costs. In both cases, the "dual-carbon" goals would become a burden on economic growth. Logically, then, under this obsolete model, each country perceived carbon emissions as a so-called right to development, with the hope that other countries would reduce more while it could reduce less.

After the 18th CPC National Congress, China made a fundamental shift in its understanding of the relationship between the environment and development and related action, from "being told to reduce emissions" to "reducing emissions."

The "dual-carbon" goals are "what we want to do ourselves" rather than "what others want us to do." The core reason behind this is that the traditional development model is no longer sustainable, and China's economy must undergo a green transition. This opened a new era of economic opportunity through green development, including a clean energy transition. The fundamental purpose of development is to improve the well-being of the people. The traditional development model has not only brought on an unsustainable environmental crisis but also often left behind this core purpose of development. The new development philosophy has the core goals of a better life and people-centred benefits. It is the essence of the fundamental purpose of development.

Once such a green transition takes place, the environment and development reinforce each other. For example, under the traditional economic structure of coal-fired power plants, cutting emissions entailed cutting electricity use. Under the new structure of wind, solar, and other renewables, cutting emissions is accelerating clean energy technology, and bringing about numerous new economic opportunities. In this way, cutting emissions can become a process of "creative destruction," which will enable the economy to leap from an old structure to a more competitive new one.

With traditional development theories and thinking, one can scarcely perceive the profound shift in the development paradigm behind the "dual-carbon" goals and the huge opportunities for growth brought about by such a shift. Just as it is impossible to understand the economic phenomena in the industrial age with a traditional agricultural age mindset, the economic phenomena and opportunities that are happening in the green development era cannot be understood with the thinking of the traditional industrial age.

### 1.2.2. Shifting Away From the Old Sources of Growth in the Old Development Paradigm

The first old source of growth in the old development pathway is, based on consumerism and excessive consumption, to encourage people to wastefully consume more physical goods. For example, the proportion of overweight adults resulting from over-consumption, which is closely related to chronic diseases, rocketed from 9.9% in 1975 to 32.3% in 2016 in China.[2] This has led to "diseases of affluence." Disease treatment becomes a huge, but tragic, source of economic growth. This distortion of "getting ill first and get treated later" in the medical industries is astonishingly consistent with the traditional economic development logic of "polluting first and cleaning up later."

The second old source of growth is to create new market demand by stimulating people's desires through marketing and "innovation." Most of these desires do improve people's well-being, but many are useless and may even have negative side effects. As Smith[IJ stated, the high productivity in a market economy is driven by the illusion that material wealth would bring happiness. A survey conducted by the CASS research team at the Research Institute for Eco-civilization[2l shows that about 75% of the respondents believe that an appropriate reduction in material consumption

2 https:/ /ourworldindata.org/grapher/share-of-adults-who-are-overweight?tab=chart&country=~IND

does not affect the quality of their life. Significant literature has been published on the dubious relationship between materialism and happiness[3-61. This means that the source of growth should not be limited to and/or relies on mass production and consumption of material goods.

**1.2.3. New Development Paradigm: A return to the original purpose of economic development**

Unfortunately, the so-called modem economic growth is, to a great extent, moving toward the first or second pathway above. A significant portion of the so-called modem economic activities are essentially "ditching and filling" in the Keynesian sense. Green transition is the third pathway. Such transition is a comprehensive campaign under a new development philosophy, not just the one that has been around since the 1980s, which focuses on the "smiling curve"-technological progress or industrial upgrading. Indeed, the "smiling curve" could be a pathway for an individual firm or country to foster economic growth, but what we need now is a green transition for the whole world economy. Hence, a green transition is more fundamental.

The new development pathway is to satisfy people's demand for well-rounded development-that is, translating the demand for cultural and other services beyond materials into a driver of economic growth after core material needs are met. This means a change in what is produced and consumed. Economic growth is increasingly built upon intangible resources, such as knowledge, technology, environment, culture, and experience, rather than the input of material resources, as in the past. This pathway requires a systematic shift in the concept and content of development, the business model, and institutions. It is the most comprehensive and profound shift in the development paradigm after the industrial revolution.

To drive a shift in the development paradigm, we need to answer a fundamental question: what is the purpose of growth? GDP only measures direct financial transactions. This traditional development model does not sufficiently measure the quality of people's lives, as it leaves out both the costs and benefits of various external costs, hidden costs, long-term costs, and opportunity costs. GDP-oriented growth just instrumentalizes people. Today, China's development strategy is changing dramatically, from GDP-oriented development to well-being-oriented development or people-centered development. This could be seen from the progress in the Human Development Index and life satisfaction in China.

### 1.2.4. Analysis of the Impact of Emission Reduction on Economic Growth[3]

***1.2.4.1*** *Promote economic growth and emission reduction at the same time by improving the economic efficiency of traditional sectors, including by reducing carbon intensity through technological innovation, organizational innovation, and management innovation.*

Figures 1-1 and 1-2 show the potential for efficiency improvement in China. Figure 1-1 1s the carbon intensity of electricity. As it shows, compared to the U.S., the European Union and the world average levels, there is still a big gap for China to improve, including to decrease its share of electricity generation from fossil fuels. Figure 1-2 is about output per hour worked -China, at this stage, is much lower than the international level in the absolute level but is catching up quickly.

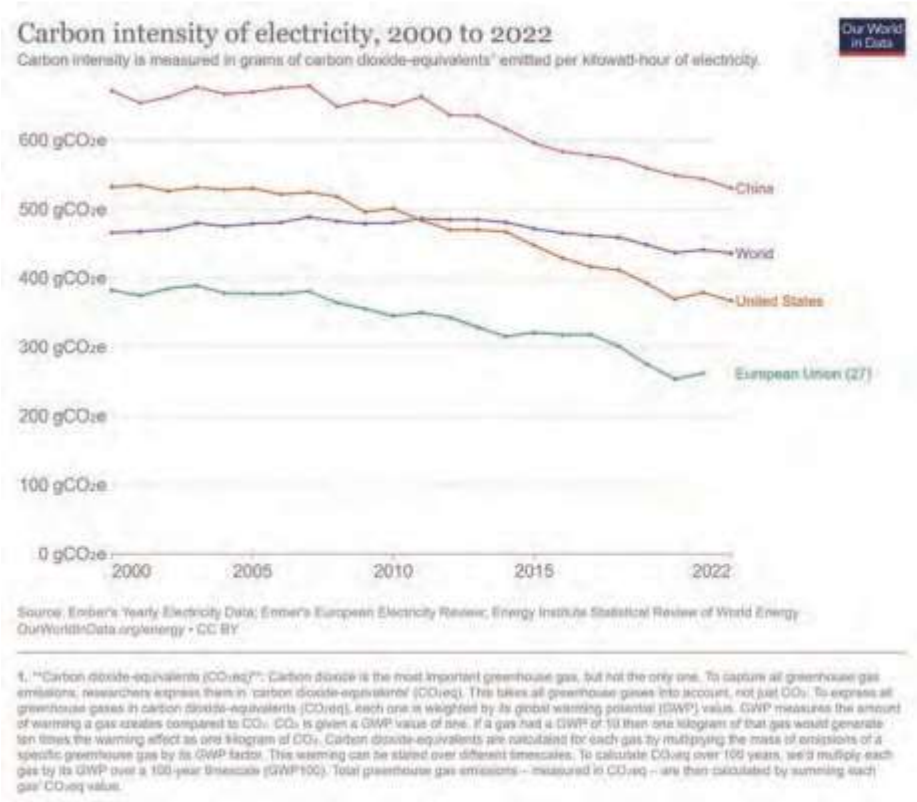



**Figure 1-1. Carbon intensity of electricity**[4]

3 Further Quantitative Research Yet To Be Conducted

4 https://ourworldindata.org/grapher/carbon-intensity-electricity?tab=chart&country=OWID_WRL-CHN-USA-OWID_EU27

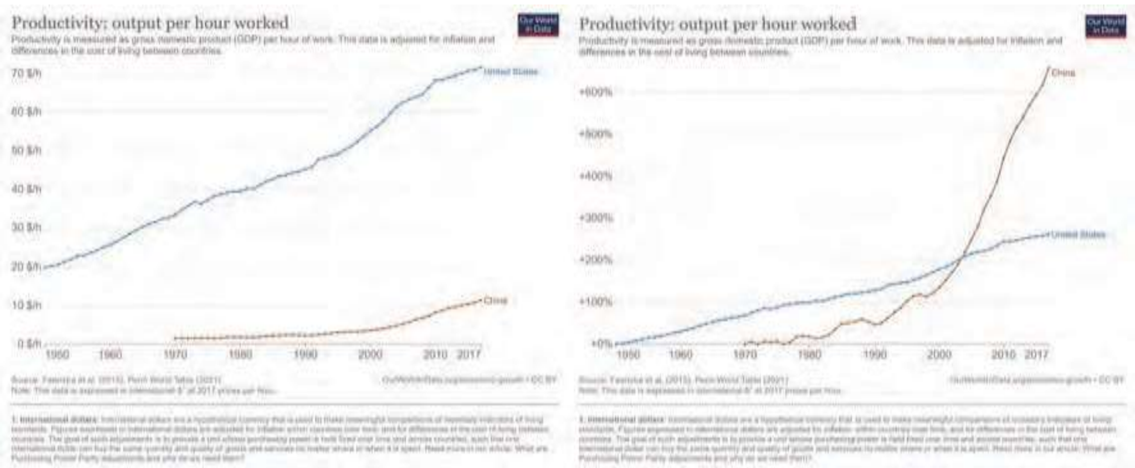



**Figure 1-2. Productivity: Absolute level and growth rate5**

*1.2.4.2. Internalizing external costs as much as possible to make green development more cost-effective.* If the external and social costs are taken into account, the seemingly efficient traditional development model is actually more costly. Instead, green development might be more cost-effective.

We use air pollution as an example to show the potential for China to decrease the external cost of its traditional growth model. Figure 1-3 shows that, though the share of deaths attributed to air pollution from 1990 to 2019 keeps dropping, it is still much higher than the world average level.

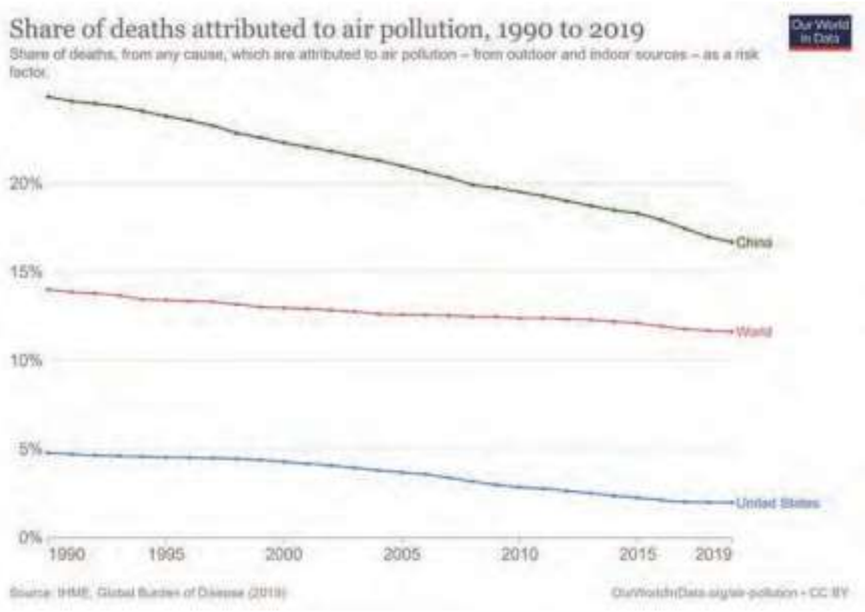



**Figure 1-3. Social cost of the old growth model[6]**

5 https:// ourworldindata.org/working-hours

6 https://ourworldindata.org/air-pollution

*1.2.4.3. How emission reduction contributes to the economy's leap to a new, more sustainable structure, which is called creative destruction-for example, a leap from the 'fossil fuel-powered vehicles" structure to the "NEVs" one.* As we can see from the dramatic decline in new energy prices and increase in new energy generation in Figures 1-4 and 1-5, the economy is experiencing a leap to a new, more competitive structure.

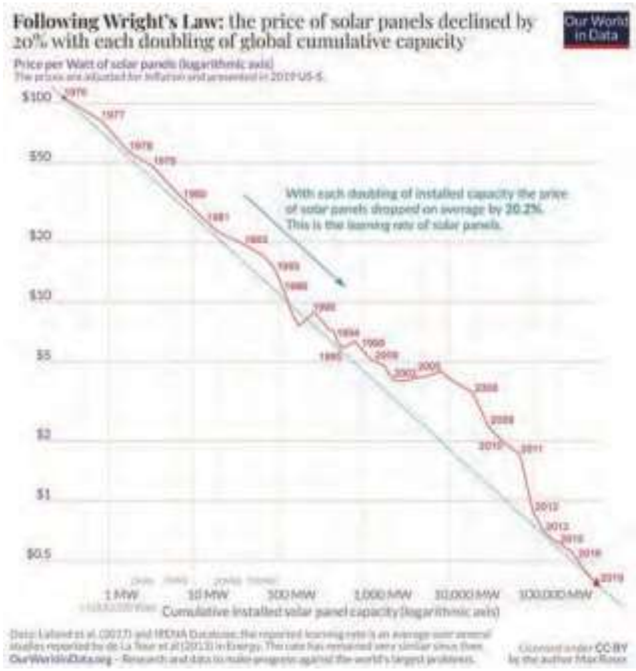



**Figure 1-4. Creative destruction driven by rapid technological progress**[7]

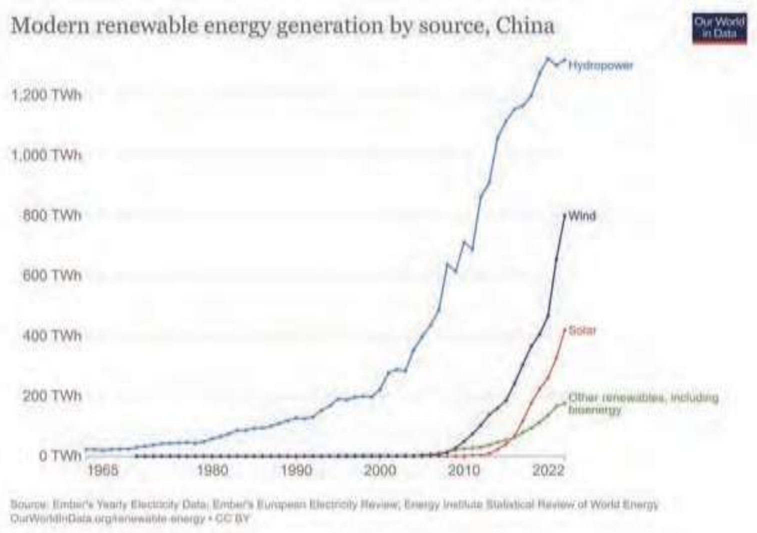



**Figure 1-5. The leap to new energy**[8]

7 https://ourworldindata.org/learning-curve

8 https:// ourworldindata.org/learning-curve

*1.2.4.4 The economy can be more dematerialized, and growth can be more dependent on the input of non-material resources-for example, technology, knowledge, culture, ecological environment, creativity...to achieve higher productivity, greater sustainability, and better well-being.*

We use "the number of people using the Internet" as a proxy to show China's potential to achieve a green economy in the digital era. The number in China is almost equal to the number in Europe and North America combined. As Smith[7] pointed out, the division of labor is the source of economic growth, and the division of labor is limited by the extent of the market. The large number of people using the Internet is a unique opportunity for China in developing its green economy in the digital era.

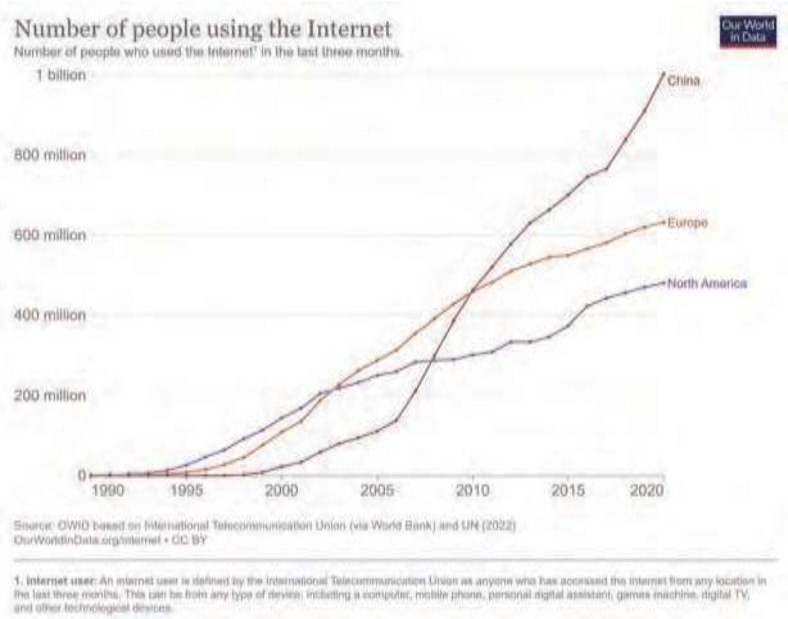



**Figure 1-6. The number of people using the internet indicates significant market potential[9]**

## 1.3. The "Dual-Carbon" Goals Are Becoming a New Driver of China's Economic Growth

The "dual-carbon" goals create new drivers of growth. In fact, the "dual-carbon" goals have not affected China's economic growth. After the 18th CPC National Congress, China made a fundamental shift in its understanding of the relationship between the environment and development and has taken unprecedented actions to protect the environment without sacrificing economic growth. Over the decade from 2012 to 2022, two thirds of the increased energy consumption in China came from clean energy; carbon dioxide emissions per unit of the national GDP fell by

9 https:// ourworldindata.org/internet

34.4%; and the share of coal in primary energy consumption dropped from 68.5% to 56%[81]. During that period, China witnessed a historic leap in its economic strength, with GDP growing from RMB 54 trillion to RMB 114 trillion.

From the perspective of new energy and NEV industries, which are most relevant to the "dual-carbon" goals, these goals are promoting-rather than hindering-economic growth. These industries have seen a growth spurt since the "dual-carbon" goals were announced.

In 2021, China's new energy growth rate was two to three times that of installed power generation capacity nationwide. Specifically, the installed capacity of on-grid solar PV power was 306 million kW, an increase of 20.9% year on year; solar PV power generation was 325.9 billion kWh, up 24.8% year on year. The installed capacity of on-grid wind power was 328 million kW, an increase of 16.6% year on year; wind power generation was 652.6 billion kWh, up 39.9% year on year. The installed capacity of on-grid biomass power was 37.98 million kW, an increase of 28.7% year on year; biomass power generation was 163.7 billion kWh, up 23.5% year on year.

It should be particularly noted that NEVs provide a vivid example for understanding the relationship between the "dual-carbon" goals and economic growth. It is because of the explosive growth of NEVs that China's vehicle production and sales both exceeded 27 million vehicles in 2022, ending 3 consecutive years of decline in production and sales since 2018. If the traditional path is followed, the growth potential of the oil auto industry has already run out, while the path of green transition will revive these industries. Such growth in the auto industry is also happening in emerging sectors such as 5G, robotics, artificial intelligence (AI), and the Internet economy.

**Meanwhile, phasing out fossil fuels has a controllable impact on the economy.** The impact of the "dual-carbon" goals on economic growth is most directly felt by traditional fossil fuels and related sectors. According to China's national planning, the share of fossil fuels in the country's energy consumption will drop to 75% and 20% by 2030 and 2060, respectively. Some worry that fossil fuels would henceforth become a sunset industry, causing a huge impact on financing, employment, local finance, social security, and financial security, and thus triggering a series of economic and social risks. However, the fossil fuel phaseout does not necessarily mean that the fossil fuel industry will immediately fall into a slump. Under the "3060" roadmap, fossil fuel prices might continue to stay at a relatively high level since, on the one hand, the energy demand in China will keep increasing and, on the other hand, a relatively high price of fossil fuel is a condition for fostering new energy and reducing the demand for fossil fuels.

# Chapter 2. Synergistic Mechanism and Pathway for Carbon Neutrality and Clean Air

Climate change has become a major issue concerning the survival and sustainable development of mankind, and risks such as high temperatures and heat waves, extreme precipitation and natural hazards are growing, presenting an urgent need for collaboration among countries to achieve $CO_2$ reduction worldwide. China has announced the major strategic decision of peaking its carbon emissions by 2030 and achieving carbon neutrality before 2060. In addition, the task of improving air quality remains daunting in China since air pollution is still at a relatively high level. and short- and long-term exposure to pollution has many adverse effects on human health. The air pollutants from fossil fuel combustion and greenhouse gases (GHGs) are "of the same origin and from the same process," for which carbon neutrality and clean air goals are intrinsically consistent. The "dual-carbon" goals not only point out the direction for high-quality social and economic development but also provide a basic guideline for coordinating air pollution control and GHG emissions reduction.

## 2.1. Research Background

Since the beginning of the 14th Five-Year Plan (FYP) period, China has entered a critical period of ecological conservation, during which the country will, with the reduction in carbon emissions as a major strategic goal, advance the synergistic reduction of pollution and carbon emissions, promote a comprehensive transition to green economic and social development, and bring a fundamental change to its eco-environment by accumulating small changes. Promoting concerted efforts to cut carbon emissions, reduce pollution, expand green development, and pursue economic growth is the key to the implementation of the new development philosophy in China. However, existing studies on the collaborative mechanism for pollution reduction, carbon reduction, green expansion, and growth often focus on a single area-for instance, energy mix, air quality, changes in emissions, etc.-and lack systematic, across-the-board or comprehensive assessment.

Against this backdrop, the SPS worked out 20 indicators in five areas, including Air Pollution and Climate Change, Governance Systems and Practices, Structural Transformation and Governance

Technology, Atmospheric Component Source Sinks and Emission Reduction Pathways, and Health Impacts and Synergistic Benefits. It established an air pollution and climate change synergistic management monitoring index system (Figure 2-1). By tracking the progress in each indicator, the SPS analyzed the achievements and obstacles in the process of China's co-governance of carbon neutrality and clean air.


**Figure 2-1. Air pollution and climate change synergistic management monitoring index system**

The report selected five key indicators-structural transformation, synergistic reduction of pollution and carbon emissions, air quality, health benefits, and local practice-from the index system. By backtracking changes in these indicators, the report identified key points for policy improvement and put forward corresponding policy recommendations.

## 2.2. Process Evaluation of China's Co-Governance of Carbon Neutrality and Clean Air

### 2.2.1. Structural Transformation

The low-carbon transformation of the energy mix, the industrial and transportation structures, and the application of next-generation energy and emission reduction technologies are fundamental to a continuous reduction in $CO_2$ and air pollutant emissions and to synergy between air quality improvement and $CO_2$ reduction (Figure 2-2).

From an energy mix perspective, promoting green and low-carbon energy development and building a new electricity system with an increasing share of new energy provide important support for coordinating high-quality eco-environmental protection and high-quality economic development. From an industrial structure perspective, measures such as resolutely curbing the haphazard development of energy-intensive and high-emission projects and developing green and low-carbon industries have effectively promoted the synergistic reduction of pollution and carbon emissions. From a transportation structure perspective, it is of great significance to continuously improve the energy efficiency in the transportation sector, promote the substitution of clean energy, and gradually optimize the transportation structure, in order to propel the reduction of pollution and carbon emissions across China's society and economy.

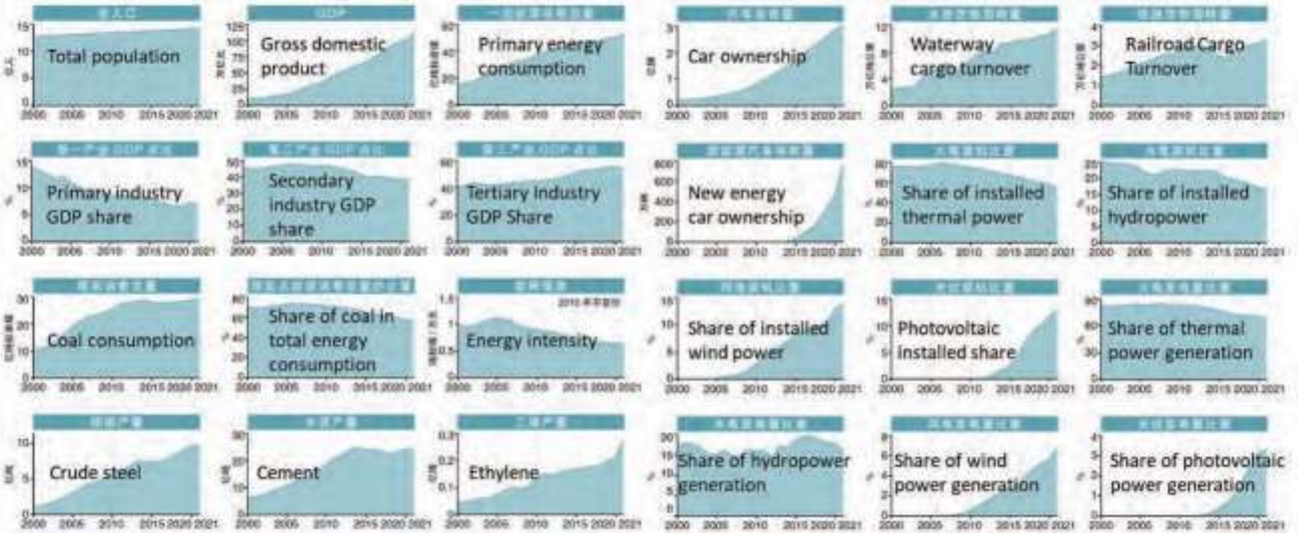



**Figure 2-2. Progress in China's structural transformation, 2000-2021**

### 2.2.2. Synergistic Reduction of Pollution and Carbon Emissions

Amid the overarching goals of achieving carbon peak and carbon neutrality, China is persistently intensifying the coordinated control of GHG emissions and atmospheric pollutants, as well as enhancing the synergistic control of fine particulate matter and ozone. In terms of pollution control, the potential for emissions reductions from end-of-line treatments in conventional industrial sectors and emissions-intensive sectors has been almost fully tapped. However, it is expected that deep pollution control in non-power sectors, management of volatile organic compounds, control of mobile source emissions, and promotion of clean heating in rural areas will continue to play a significant role. This is particularly pertinent for pollutants such as volatile organic compounds and ammonia, the emissions of which have yet to demonstrate a significant decline. To further the synergistic benefits of "pollution and carbon reduction" in these areas, effective emissions reduction strategies should be further implemented.

Air pollution control policies have led to the synergistic reduction of pollution and carbon emissions. On a national scale (Figure 2-3), there was a positive synergy between $CO_2$ emission reduction and $PM_{2-5}$ pollution improvement in China's industrial sectors between 2015 and 2020, indicating effective measures for the adjustment of the energy mix and the industrial structure during the 13th FYP period. On the contrary, the synergy between $CO_2$ reduction and $PM_{2.5}$ improvement in the power and heat sector was negative because the continuous growth of coal power during the 13th FYP period drove an increase in carbon emissions from the power sector while the ultra-low pollutant emission upgrades in the power sector resulted in a reduction in $PM_{2.5}$ concentrations. With the further implementation of end-of-pipe control in the power sector, the potential for the synergistic reduction of carbon and pollutant emissions is relatively limited, while there is still a large space for pollution control in the heating sector. The potential of structural adjustment for synergistic reduction of emissions is yet to be substantially unleashed.

For transportation and residential sectors, although structural adjustment, bulk coal control, and other transformation measures taken during the 13th FYP period have begun to deliver results, $CO_2$ emissions were still growing on the whole, with a slight increase of 8%. In addition to structural adjustment, the implementation of end-of-pipe control measures-such as upgrading automobile emission standards and integrating the control of vehicles, fuels, and road transportation-brought $PM_{2.5}$ concentrations down by 22%-23% during that period. Further structural transformation in transportation and residential sectors still enjoys great potential for the synergistic reduction of pollution and carbon emissions.

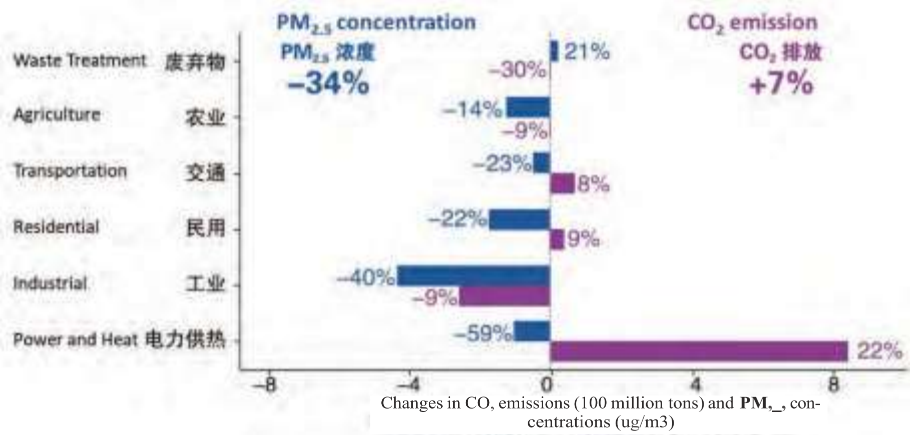



**Figure 2-3. The coordinated control of $CO_2$ emissions and $PM_{2.5}$ pollution in China, 2015-2020**

### 2.2.3. Air Quality

China's achievements in the reduction of pollution and carbon emissions are fully embodied in the process of air-quality improvement (Figure 2-4). In 2021, pollutant concentrations in China's 339 prefecture-level cities and five key regions-including Beijing-Tianjin-Hebei (BTH), Fenwei Plain (FW), Yangtze River Delta (YRD), Chengdu-Chongqing (CC), and Pearl River Delta (PRD)-dropped compared to 2020 levels, with the regional annual average $SO_2$ and $NO_2$ concentrations reaching the national Grade I standards (annual average concentrations: $SO_2$:S20μg/$m^3$; $NO_2$:S40μg/

m3). Except for FW, the regional annual average $0_3$ concentration also reached the national Grade II standards (the 90th percentile of daily maximum 8-hour moving $0_3$ concentration: $0_3$-8H90Per:S160μg/m3).Nevertheless, many regions have not reached $PM_{2–5}$ standards (annual average concentration: $PM_{2\ 5}$ >35μg/$m^3$).

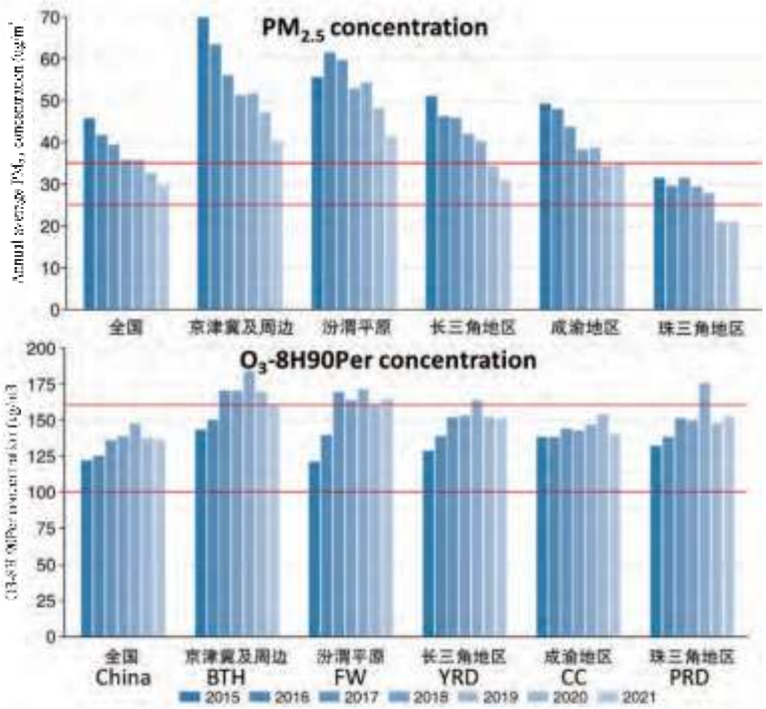



**Figure 2-4. Changes in $PM_{2\cdot5}$ and$0_3$ concentrations in China and its key regions, 2015-2021**

### 2.2.4. Health Benefits

The goal of carbon neutrality will drive profound transformations in energy structures and technology iterations, thereby significantly improving air quality and enhancing health standards. Thanks to air-quality improvement, the levels of long- and short-term exposure to $PM_{2–5}$ in China continue to fall, and associated premature adult deaths have significantly decreased (Figure 2-5). In 2021, China witnessed 1.21 million and 60,000 premature adult deaths associated with long- and short-term exposure to **$PM_{2–5}$**, respectively, a decrease of 23.9% and 26.2% over the 5 years from 2017 to 2021. These numbers are both higher than the decreases between 2013-2017 (long-term: 9.1%; short-term: 25.2%), with a particularly noticeable growth rate in the decrease in premature deaths associated with long-term $PM_{2–5}$ exposure. Apart from continuous improvements in exposure, other possible causes include (1) the long-term $PM_{2–5}$ exposure-response relationship is steeper at low concentrations, indicating greater marginal benefits of exposure improvement based on low and medium concentrations than on high concentrations; (2) population aging has increased the overall population susceptibility to $PM_{2–5}$, partly amplifying the health benefits associated with $PM_{2–5}$

improvement.

Some studies showed that the health hazards of $0_3$ exposure were independent of those of $PM_{2\text{-}5}$ exposure and that the increase in $0_3$ exposure made it one of the major air pollutants threatening China's public health. In 2021, the numbers of premature adult deaths associated with long- and short-term exposure to $0_3$ were 130,000 and 80,000, respectively, both down from the levels over the 3-year period between 2019 and 2021. A comparison suggested that the number of premature deaths associated with short-term $0_3$ exposure was higher than or on par with (if the uncertainty is taken into account) that of $PM_{2\text{-}5}$.

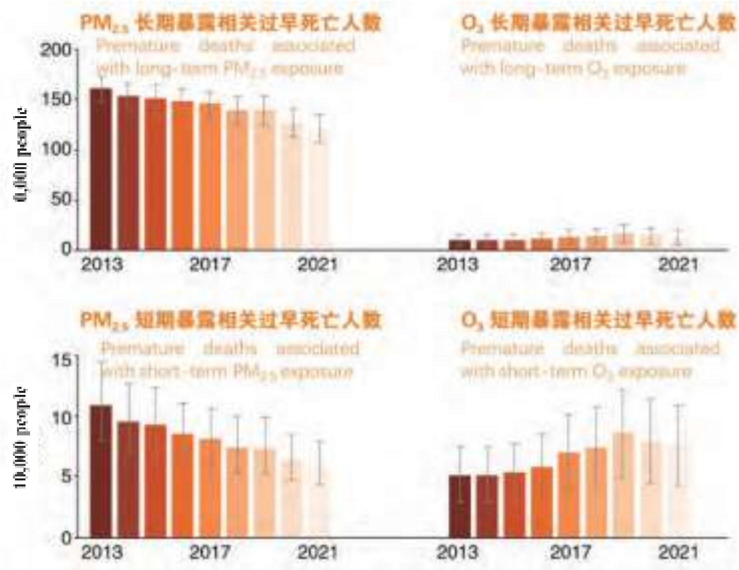



**Figure 2-5. Premature adult deaths attributed to $PM_{2\text{-}5}$ and $0_3$ exposure in China, 2013-2021[10]**

### 2.2.5. Local Practice

Despite some successes in China's reduction of pollution and carbon emissions, there is still much room for improvement. Based on ambient air-quality monitoring data and inventories of $CO_2$ emissions, the report analyzed the trend in coordinated variation of $PM_{2\text{-}5}$ concentrations and $CO_2$ emissions in China's 335 prefecture-level cities and above between 2015 and 2020 (Figure 2-6). The results showed that from 2015 to 2020, only 105 cities, or 31.3% of all the cities, witnessed a reduction in both annual average $PM_{2\text{-}5}$ concentrations and $CO_2$ emissions. On average, the annual average $PM_{2\text{-}5}$ concentrations in these cities decreased by 29%, and $CO_2$ emissions by 23%, both higher than the decreases between 2015 and 2019. On the contrary, the annual average $PM_{2\text{-}5}$ concentrations and $CO_2$ emissions both increased in 17 cities, accounting for 5.1%. A study found

10 https://pubs.acs.org/doi/10.1021/acs.est. 1 c04548

that most cities failed to achieve a synergistic decline in $PM_{2.5}$ concentrations and $CO_2$ emissions between 2015 and 2020, indicating that synergies to reduce pollution and carbon emissions need to be further promoted at the city level.

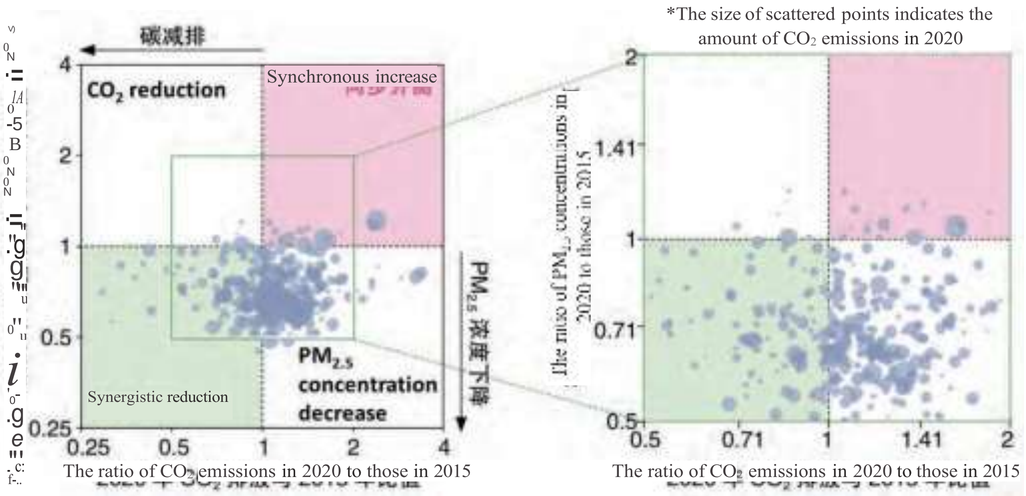



**Figure 2-6. Comparison between changes in annual average $PM_{2.5}$ concentrations and those in $CO_2$ emissions on a city scale**

## 2.3. Policy Recommendations

Achieving synergy between pollution and carbon reduction is increasingly seen as the driving force behind the green transformation of economic and social development. Entering the 14th FYP period and under the guidance of new development concepts, strategic planning and specific policies in the field of ecological and environmental protection have gradually begun to harmonize atmospheric pollution prevention and GHG reduction efforts.

At the national level, the 14th FYP introduced in 2021, the central government's proposals on carbon peaking and carbon neutrality, and prevailing in the battle against pollution all reflect new expectations of a mutual and collaborative focus on pollution and carbon reduction. This provides guidance on how to drive a comprehensive green transformation of socio-economic development with carbon reduction at the helm, strengthen the collaborative control of multiple pollutants and GHGs, and use pollution reduction as a key measure to achieve carbon reduction goals. Building on this, the Ministry of Ecology and Environment of the PRC is acting in areas such as environmental impact assessments, monitoring and supervision around the collaboration of pollution, and carbon reduction. These efforts aim to improve existing management systems and integrate carbon emission management requirements into ecological and environmental management systems, gradually perfecting a coordinated governance structure.

In terms of market mechanisms, the carbon emissions trading system has made significant progress. In 2021, the first compliance cycle of the national carbon emissions trading market concluded successfully. Voluntary GHG reduction trading has been further promoted. In addition, areas such as Shanghai, Beijing, Shenzhen, Hubei, and Guangdong, combined with local carbon market pilots, have been actively exploring innovative carbon financial products, and pilot projects for climate investment and financing have also officially been initiated. Cities like Qingdao and Chengdu, aligning with national goals and leveraging their own foundations, have introduced and implemented innovative action plans for GHG reduction and air pollution control. They have also made innovative efforts to promote the integration of atmospheric pollutant emission inventories and GHG emission inventories.

In summary, at the societal management level, China has begun proactively establishing a management system and policy framework that promotes mutual enhancement and synergistic efficiency between pollution and carbon reduction. At the technological application level, technologies conducive to transitioning the structure of energy, industry, and transportation toward low-carbon and green models are being increasingly adopted. However, the continued increase in energy consumption due to rapid economic growth and urbanization is still the main driver of China's rising $CO_2$ emissions, posing the greatest challenge to achieving synergistic efficiency in reducing pollution and carbon emissions.

Overall, China has yet to fully achieve the synergistic reduction of pollutants and $CO_2$, and there is an urgent need for the implementation of more targeted policies. The report from the 20th National Congress of the Communist Party pointed out that "we need to synergistically promote carbon reduction, pollution reduction, green expansion and growth, and promote ecological prioritization, resource conservation, and green low-carbon development." However, as a new concept in the field of ecological civilization construction, the coordinated management of pollution reduction and carbon reduction lacks a mature theoretical framework and technical methods. It urgently requires scientific and technical research around coordinated management and speeding up the exploration of synergistic efficiency mechanisms, implementation paths, governance technologies and policy innovation. To build a future mechanism for coordinating carbon neutrality and clean air, China should continue to adjust its energy mix and industrial, transportation and land-use structures, accelerate the transition from end-of-pipe control to source control of pollution, and reduce carbon emissions by addressing climate change, thus fundamentally solving the problem of environmental pollution. Specifically, China should pay attention to the following four areas.

(1) China should continue to adjust its energy mix by controlling the total consumption of fossil fuels, encourage the clean and efficient use of coal, advance the upgrading and retrofitting of coal-fired power units, and promote cogeneration (or combined heat and power, CHP) transformation projects in large coal-fired power plants. China should actively develop non-fossil energy, and vigorously promote power generation from renewable energy such as wind and solar energy. China should continue to implement projects replacing bulk coal with natural gas and electricity to strictly control bulk coal burning in rural areas.

(2) China should further adjust its industrial structure by curbing the haphazard expansion of energy-intensive and high-emission projects, shutting down outdated production facilities, scaling down overcapacity, and dynamically eliminating small, poorly managed and heavily polluting enterprises. China should speed up energy-saving upgrades and further pollutant control in key sectors such as electric power, steel, and cement. China should carry out comprehensive management of Volatile organic compounds (VOCs) and implement projects using raw and auxiliary materials and products containing zero or low levels ofVOCs.

(3) China should actively adjust its transportation structure by updating the composition of the motor vehicle fleet, removing high-emission old vehicles from roads, and promoting new energy or clean energy vehicles. China should build an efficient and intensive logistics system, facilitate a shift in bulk cargo transportation and mid-long distance freight transportation from highways to railways and waterways, and make great efforts to develop multimodal transportation. China should strengthen the control over non-road mobile sources and eliminate outdated construction machinery.

(4) China should steadily adjust its land-use structure by optimizing the use of fertilizers and feed, promoting reduced yet more efficient use of fertilizers and pesticides, and stepping up pollution control and recycling of resources from livestock and poultry waste on large-scale livestock farms. China should improve the comprehensive utilization of crop straw and strengthen crop straw burning regulations. China should guide key sectors to relocate to areas with ample environmental capacity and good diffusion conditions and implement the relocation of key enterprises from cities.

# Chapter 3. Coal Power Reduction: Pathways to synergistically and efficiently reduce air pollution and carbon emissions

Coal-fired power stations are the leading sources of air pollution and GHG emissions in the power sector globally, including in China. There are mature technology options for reducing air pollution, many of which are in place for newer coal-fired plants today: flue gas desulfurization for $SO_2$, selective catalytic reduction (SCR) for NOx, baghouses for particulates, and mercury controls. Less mature technologies are in development to capture and permanently sequester fossil fuel plant carbon emissions. As of 2021, there are approximately 21 large-scale carbon capture and storage (CCS) facilities in operation around the world[9], according to the Global CCS Institute, including four projects in China.

Pollution standards requiring advanced pollution reduction technologies and efficiency standards for new power plants is a best practice that has resulted in remarkable pollution reduction in China, the U.S., and Europe. Overall, China's pollution control standards for new and existing coal-fired power plants have decreased power sector NOx by 81%, $SO_2$ by 77%, and $PM_{2.5}$ by 80% since 2005, even as coal generation increased 117% over the same period[10]. The U.S. made similar progress between 1990 and 2021, where annual emissions of $SO_2$ from power plants fell by 94%, and annual emissions of NOx from power plants fell by 88%[11].

Both countries have shown the effectiveness of power plant pollution controls in improving public health and air quality, but the U.S. has made larger gains in GHG emissions reductions due to three factors: economic competition from clean resources, state GHG and clean energy standards, and coal pollution standards. These have combined to dramatically reduce coal's role in the U.S. power sector, with significant pollution co-benefits. Since 2011, U.S. coal power has declined more than 50%.

Today, for China and the U.S., the first and most cost-effective pathway to limiting both conventional and GHG pollution more quickly is replacing coal with carbon-free renewable energy and storage. With coal generating less than 20% of U.S. electricity today, and falling fast, coal use for electricity will likely be close to zero by the end of this decade. China has an opportunity to learn from the U.S. and other countries' experiences while continuing to focus on power sector reforms that promote dispatching the most efficient, cleanest resources and enhancing system energy security.

## 3.1. Overview of Current Coal Power and its Phasedown Risks in China

### 3.1.1. Status of Coal Power in China

The power system in China still strongly relies on coal. During the 13th and 14th FYPs, total coal consumption in China gradually transitioned from a phase of rapid growth to a stable stage[121]. Through the early retirement of outdated generating units and the implementation of ultra-low emission standards for power plants, coal power has made promising progress in energy conservation and emission reduction. Although the share of coal-fired power generation slightly declined to 60% in 2021, China still possesses the world's largest coal-fired power infrastructure, with total installed capacity exceeding that of all other countries combined (1,110 GW in 2021[31]. As of 2020, the power sector in China consumed 2.1 billion tonnes of coal, accounting for 50% of total coal consumption in the country. Against this backdrop, China's coal-fired power sector has not halted its pace of new construction. The country retired 8.6 GW of coal power in 2020, leading to a net 29.8 GW increase in China's coal fleet in 2020[141]. The rapid development of coal power infrastructure leads to a short average lifetime of existing coal plants in China, of which more than 75% had operated for less than 15 years by 2020[151]. The expansion of coal power is creating higher risks of asset stranding and hindering China's progress toward building a modem power system to achieve carbon neutrality goals.

As one of the major anthropogenic emitters in China, the emissions of pollutants from coal power have been effectively controlled since clean air action begin in the country. By 2015, the ratio of coal plants equipped with FGD and de-NOx devices reached 95.6% and 84.2%, respectively. China's Ultra Low Emissions (ULE) Standard attempts to improve coal plant efficiency while further reducing $PM_{2-5}$, $SO_2$, and NOx emissions from coal plants, which will dramatically reduce air pollution and improve public health. In 2020, coal power in China contributed 1.2 Mt of $SO_2$, 3.0 Mt ofNOx, and 0.2 Mt of $PM_{2-5}$, which is much lower than the emissions levels in 2015[161]. Figure 3-1 shows how different kinds of power plant regulations have vastly reduced power plant emissions even as coal use increased from 2005 to 2020.

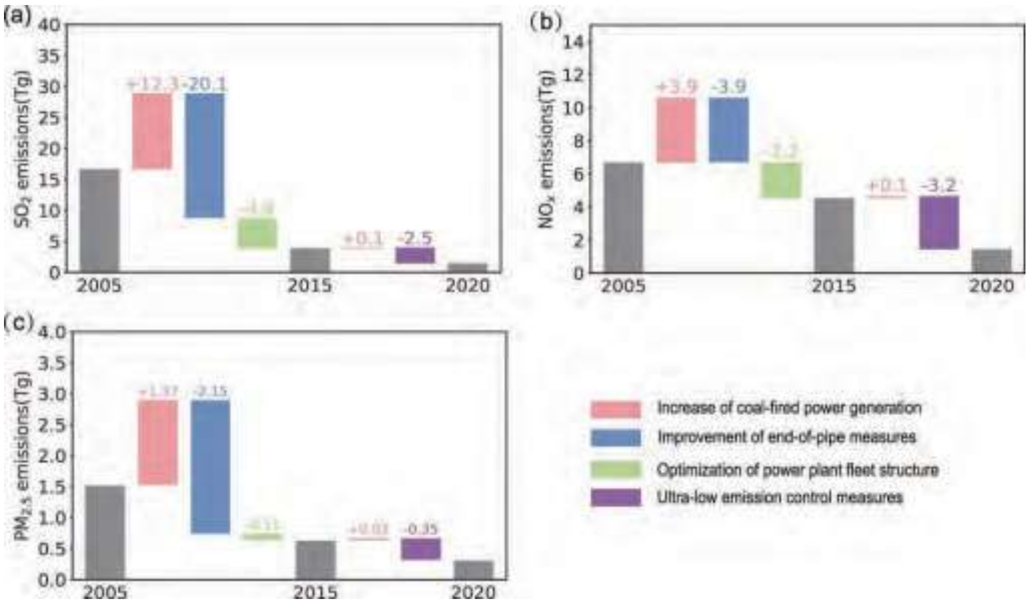



**Figure 3-1. Power Plant Regulations have Vastly Reduced Power Plant Emissions[10]**

Despite this tremendous progress in reducing pollution from coal, the clean development of coal power cannot cover up the threat of coal-fired power toward climate goals. Coal-fired power in China still emitted 3514 Mt of $CO_2$, accounting for 35% of the national carbon emissions from human activities[17]. Coal plants have become more efficient, emitting 80% less GHG per kWh in 2020 than in 2005, but this progress plateaued from 2015 to 2020, reflecting the limits of thermal efficiency in modern coal plants. With the deepening of end-of-pipe control, the potential for emissions reductions in China's power sector is gradually narrowing. New paths must be sought to promote a synergistic reduction in carbon and pollutant emissions. Therefore, shifting the power system from relying on coal to low-carbon electricity sources is a necessary part of China's strategy to mitigate GHG emissions and further improve local air quality, due to potential challenges for climate targets and public health.

### 3.1.2. Necessity and Risks of the Coal Power Phasedown

One serious challenge posed by the existing coal-fired power plants is that the substantial committed emissions of GHGs hinder China's 2030 carbon peak and 2060 carbon neutrality targets[18,19]. It is estimated that global committed $CO_2$ emission from the existing and proposed power plants (including coal power plants) reaches up to 846 Gt, exceeding the limit of the Paris Agreement 1.5°C budget (420-580 Gt $CO_2$), accounting for approximately 70% of the lower limit of the 2°C target (1,170-1,500 Gt $CO_2$)[20]. Yet promising carbon dioxide removal technologies (such as CCS, direct air capture, afforestation, enhanced weathering, and direct ocean capture with carbon storage) have shown great potential for facilitating carbon emissions reductions[21] the extent to which these technologies that offset carbon emissions from coal-fired power plants remain largely uncertain due to their highly unpredictable cost in the long term[22,231. It is projected that global negative emission technology potentials in 2050 would be 0.5-5 Gt $CO_2$ yr-[1] for BECCS, 0.5-5 Gt $CO_2$ yr-[1] for DACCS, 0.5-3.6 Gt $CO_2$ yr-[1] for reforestation, and 0.5-2 Gt $CO_2$ yr-[1] for biochar-and some of them span across nearly one order of magnitude[221. These negative emission technologies are not expected to satisfy the requirement of future climate targets unless most coal-fired power plants and other fossil fuel power plants are substituted by clean, renewable energies, such as wind and solar power[221.

Another serious threat is that current coal-fired power plants are expected to result in a large amount of premature death related to the emission of air contaminants, undermining the UN Sustainable Development Goal of good health and well-being, despite the widespread deployment of strong and stringent pollution controls in coming future[24,251. For example, there were roughly 7.30 million premature deaths in the world related to $PM_{2-5}$ exposure in 2010, 12% (861,300) of which is contributed by emissions from fire power plants using coal, natural gas, oil, and biomass[251. If power plants phase down as they have historically done, taking weak end-of-pipeline controls, annual premature deaths related to $PM_{2-5}$ exposures will remain at a rate of about 1 million, regardless of climate mitigation scenarios in Representative Concentration Pathways 1.9 and 6.0[201. China's coal power-related premature deaths reached 159,200 in 2018, which constitutes over 10% of premature deaths related to fire powered $PM_{2-5}$ pollution around the world[251. Therefore, the most feasible and cost-competitive strategy for addressing such challenges is to rapidly phase down current coal-fired power plants and to raise the penetration of clean renewables, notwithstanding the potential risks in unemployment, energy security, and stranded assets[26,271.

The most severe risk is that a coal-fired phasedown undermines the security of energy systems. China's total electricity consumption was as high as 7779.1 TWh in 2020, 63.2% of which is contributed by coal-fired power (4917.7 TWh)[281. Although China's total power generation is expected to be 12,500 TWh and 14,500 TWh by 2050 under the context of 2 °C and 1.5 °C climate targets, respectively, the proportion of coal-fired power will decrease gradually by less than 800 TWh[261. That suggests that a coal-fired power phasedown will pose great risks to the security of energy systems due to the weak stability and reliability of variable renewables regardless of their daily and seasonal cycles[291. Moreover, a coal-fired phasedown would result in substantial stranding asset losses in China due to relatively short operation duration (the average operation duration is less than 15 years). A prior study[301 estimated that the accumulative stranding assets of fossil fuels over the world are projected to be a USD 1 trillion-4 trillion (amounting to about 10 % of global

GDP in 2016) of discounted wealth loss by 2035 to achieve the 2°C climate target. Compared to developed countries whose coal-fired power plants have usually operated for more than 30 years[191], the standing assets and macroeconomic impacts of a coal power phasedown in China would be much larger owing to its young power plant units.

## 3.2. U.S. Experiences: Rapid reductions in coal-fired generation go hand-in-hand with an affordable, reliable grid

### 3.2.1. US Experience Regulating Air Pollution From Coal-Fired Power Plants

In 2005, coal generation provided half of U.S. power generation. In 2022, that fell to 19%, replaced by natural gas, renewables, and greater energy productivity. This singular trend has been responsible for the majority of U.S. GHG emissions reductions since 2005, and is the result of three primary factors: stringent pollution standards for coal-fired power plants, state clean energy policies, and fuel switching to cheaper gas, wind, and solar.

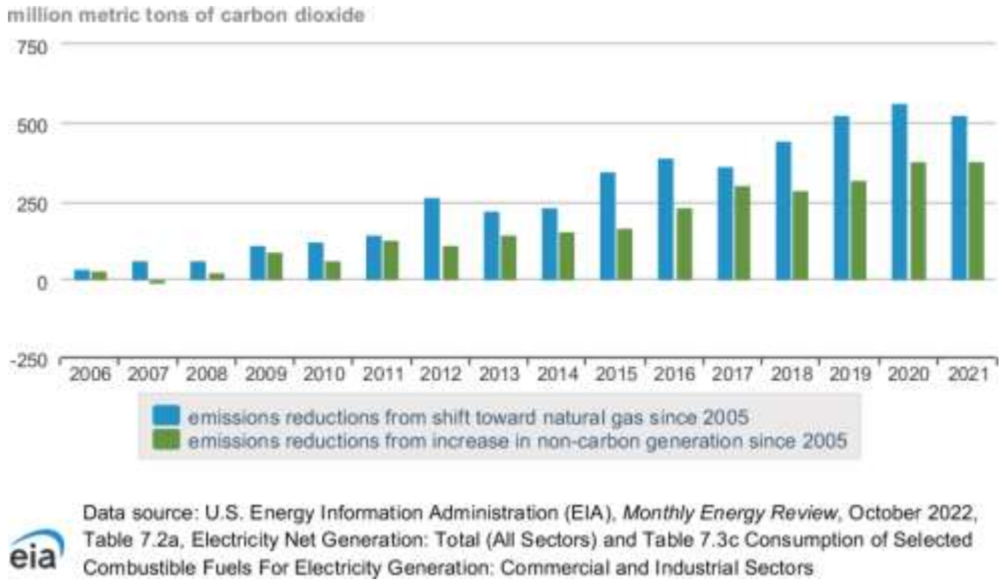



**Figure 3-2. $CO_2$ emissions reductions caused by changes in the fuel mix of electricity generation relative to 2005**

The U.S. Environmental Protection Agency (EPA) is the primary regulator of coal plant pollution and GHG emissions in the United States. EPA sets health-based air-quality standards and then required technology-mandate standards to help meet these air-quality standards. The EPA also promulgates standards to reduce water pollution from coal plants, including pollution associated with the disposal of coal ash and scrubber waste. In addition to the EPA setting national standards for power plants, states have also delegated the authority to ensure air and water quality standards are met within their state boundaries. The EPA is required to conduct a cost-benefit analysis before requiring power plants to meet specific performance standards.

Over the past two decades, the EPA has been increasing the stringency of pollution standards for new and existing coal-fired power plants. These standards have internalized the pollution costs and led to hundreds of coal plants retiring or announcing their retirement this decade. Ever since the EPA implemented a GHG standard in 2015 for new coal plants, mandating CCS, very few new coal plants have commenced construction, with utility investments primarily directed towards wind, solar, storage, and natural gas. $CO_2$ pollution standards for existing coal plants announced in May 2023 would require any existing coal plant operating past 2035 to install CCS with a 90% capture rate. Similar standards for baseload gas plants would require 90% CCS or blending 96% hydrogen.

In the past decade, some coal plants have installed major new pollution controls, while others have opted instead to retire the plant and replace it with cleaner generation. The chart below shows how pollution controls for SO" NO" PM, and mercury were installed on existing coal plants at a high rate from 2005 to 2019. As a result, the average book value of regulated coal plants has doubled since 2005, meaning there is more capital asset value to pay down now compared to 15 years ago. These controls can be amortized over shorter periods than in the past, keeping the door open for retiring the plant within the next decade. Given the U.S. policy to get off of unabated coal by 2035, the better outcome for consumers would almost uniformly have been to retire rather than retrofit these plants.

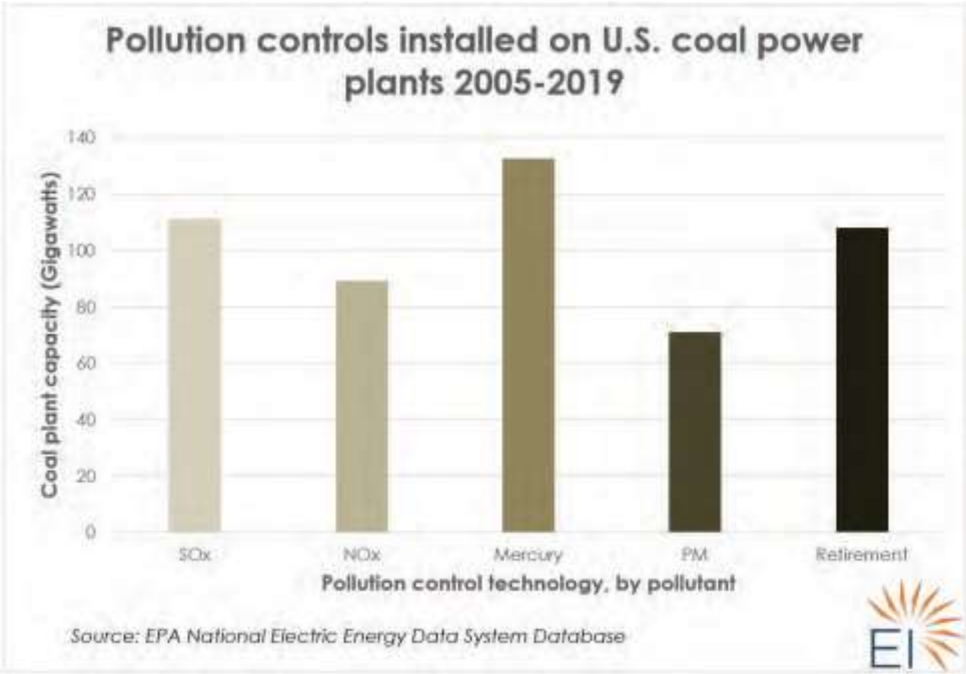



**Figure 3-3. Pollution controls installed on U.S. coal power plants, 2005-2019**

Ultimately, what matters for GHG emissions and pollution is both the rate of pollution per unit of power and the total amount of fossil fuels burned. Modelling studies by U.S. academic institutions and Energy Innovation agree that eliminating coal by 2030 is a cost-effective pathway to achieving the U.S. nationally determined contribution for 2030. To achieve this goal, the U.S. is relying on three primary actions: 1) the EPA's new round of additional pollution standards, including a carbon standard for existing gas and coal, 2) new federal incentives for clean energy and storage to make clean energy cheaper than coal and gas in most instances, and 3) state clean energy policies.

In summary, we offer four takeaways from the U.S. experience:

1. Regulating pollution from existing coal-fired power plants can have large GHG co-benefits when markets are putting economic pressure on reducing generation, switching to cleaner fuels, or retiring the plant. Regulating GHG emissions could also come with large pollution co-benefits, but the U.S. has limited experience doing so.
2. The least-cost solution to reduce fossil power plant pollution is overwhelmingly switching to a mix of zero-carbon power plants, battery storage, demand-side management, and transmission investment.
3. The U.S. has reduced coal's share of electricity generation from 50% to less than 20% in the space of a decade while maintaining a reliable, affordable power system.
4. Utilities can manage stranded asset risks by setting long-term power sector carbon goals and ensuring all new investments in existing power plants-for pollution controls or otherwise-are amortized over a period consistent with carbon reduction targets, including President Biden's commitment to 100% clean electricity by 2035.

### 3.3.2. Challenges and Policy Options

Power plant cost dynamics between zero carbon and coal power are similar in China and the U.S.- recent wind, solar, and storage cost declines in China mean that new wind and solar power is cheaper than the average existing coal-fired power plant, according to IRENA. However, the Chinese market system is quite different from the U.S.'s. Economic dispatch is still evolving, so the regulation of pollution will not necessarily have the same co-benefit of GHG reduction in the U.S., where higher costs made it harder for less efficient coal plants to compete and forced some older coal plants to retire. Improving economic dispatch in China can be a GHG reduction policy because more efficient, cleaner plants will run more, and more polluting coal plants will run less. The same can be said for increasing the geographic scope of economic dispatch from provincial to regional, which can reduce costs and reduce renewable curtailment. Addressing still-growing power sector emissions will help peak and begin to meaningfully reduce Chinese emissions before 2030.

With stringent pollution standards already in place alongside robust efficiency requirements, future GHG reductions from the Chinese power sector must likely come from fuel switching, CCS retrofits, or both. Learning from the U.S.'s disjointed approach to pollutant-specific regulation, China has an opportunity to promulgate sector-wide GHG emission standards that allow subnational governments the :flexibility to choose between technologies that best optimize other public policy and reliability objectives. For example, the U.S.-proposed $CO_2$ standards for existing coal plants allow states to choose between retirement, CCS, or gas co-firing. Similar requirements for existing gas plants will allow owners of large baseload gas plants to choose between CCS retrofits, hydrogen blending, or lower capacity factors to comply. Similar standards for Chinese fossil power plants can coexist alongside provincial and national clean energy capacity targets.

Setting standards now that are aligned with China's carbon goals also helps draw some boundaries around continued coal plant expansion in China that can help avoid stranded assets or higher costs in the future. Adding a coal plant likely means increasing generation-once an asset is built, it lasts for at least 20 to 30 years. China would be wise to avoid the looming stranded asset problem facing the uneconomic coal fleet and gas-generation infrastructure. GHG emissions standards for the power sector could help promote fuel switching now and promote the examination of clean energy resources that provide reliability value similar to new coal plants. When absolutely necessary, coal plant capacity could increase, but a GHG standard would place de facto limitations on the utilization of unabated coal and prompt inefficient plants to run less.

Reliability is key. Coal still has high reliability and energy security value. But with the advent of affordable grid-scale battery storage, clean energy resources are now able to provide significant reliability services. A recent Lawrence Berkeley National Lab study shows that no new coal is needed to maintain a reliable electricity system, even as China reaches 80% clean electricity and the load grows 60% in the study's main scenarios[[3,1]. The existing 1,100 GW of coal can provide balancing alongside hundreds of GW of battery and pumped hydro storage, while renewables and nuclear start providing the vast majority of energy.

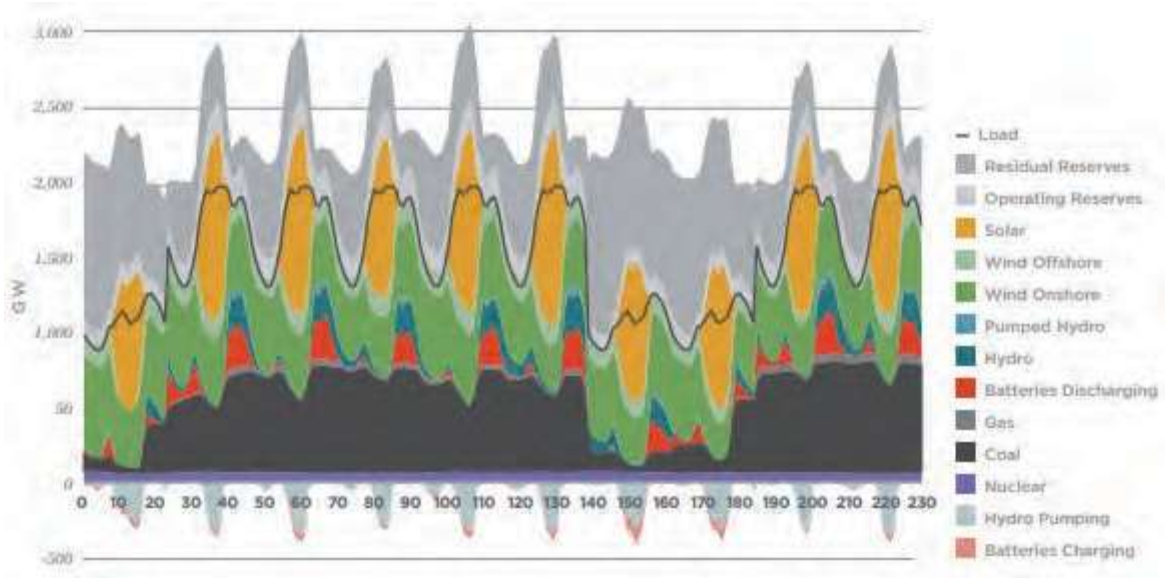



**Figure 3-4. National system dispatch in the highest net load week in summer, with 10% demand shock in an 80% clean electricity system in 203[51311]**

China can learn from the U.S. experience by focusing on fuel switching to carbon-free sources instead of delaying the transition through more fossil investment or switching to an intermediate fossil fuel like gas. GHG emission standards that address the power system as a whole maximize flexibility and cost-effectiveness. Because competitive markets are still maturing and limiting the impact of efficiency on coal and renewable dispatch, an additional focus on GHG standards is crucial to achieving pollution and GHG reduction co-benefits.

In summary, policy will be key to reducing GHG and pollution in the power sector together. A key policy will be to create coal plant or sector-wide GHG emissions standards, allowing flexibility in which technologies plant operators and subnational governments can use to reduce emissions. Because the economics of renewables in China are so favourable, and with new cleaner options to improve reliability, it is possible to rapidly reduce coal-fired generation, grow investment in renewable energy, and more quickly achieve GHG and pollution reduction goals.

Some complementary policies will also be key to achieving these goals while maintaining reliability and enhancing affordable power, including:

- Implement economic dispatch country-wide to reward greater power plant efficiency, reduce renewable energy curtailment, and promote economic renewable and storage projects that outcompete existing coal generation.
- Further expand electric system reliability obligations from the provincial scale to the regional

scale, building pilot program experience. This will improve the reliability value of renewables, improve transmission planning, and create even more opportunities for efficiency and faster renewable energy deployment.

- Set newer, more ambitious clean energy deployment standards, including battery storage deployment targets, to help continue China's leadership in growing the clean energy share.
- Change market structures to pay coal plants for reliability services without also requiring them to dispatch uneconomically. Consider developing reliability reserve products as a reliability measure supporting variable renewables until confidence in reliable system operations grows.
- Continue to gain sophistication on the reliability of renewable energy systems. Collaborate with leading grid operators in other countries and implement best-practice modelling to better compare the reliability contributions of all types of resources.
- Invest in research on dispatchable clean energy resources such as advanced geothermal, advanced nuclear, hydrogen, long-duration storage, and demand management to replace the capacity value of the coal fleet.

## 3.3. Co-benefits and Pathways for the Targeted Coal Power Phasedown

### 3.3.1. Incorporating Health Co-Benefits in Decision-Making for the Coal Power Exit

The early retirement pathway for coal power in China is highly uncertain and requires careful design. Due to the overwhelming magnitude and the short operational lifetime of existing coal power infrastructure, the early retirement of coal power generating units would face significant risks. Current policies for a coal-fired power phasedown mainly target small-capacity, substandard generating units and auto-producers. However, a phasedown strategy with simple criteria is unlikely to seize the opportunity to maximize the benefits of decarburization policies. Policy-makers should take more factors into consideration when designing a strategy.

The coal power exit, which is designed for climate mitigation, would also reduce emissions of air pollutants, resulting in air-quality improvements and health co-benefits. The health co-benefit assessments of coal power early retirement should be integrated into decision making about climate policies. The optimization of the coal power plant fleet structure in China was proved to lower the population-weighted $PM_{2.5}$ concentrations by 2.1 μg/$m^3$ from 2005 to 2015[IoJ_ Future aging populations will further exacerbate the health burdens of coal power pollutant emissions in China[32,33]_Protecting public health should be prioritized as a starting point for the early retirement of coal power to the synergistic governance of climate change and air pollution. Focusing on the decarbonization pathway of the power system in China, air-quality improvements due to climate measures, especially the regional health co-benefits, may offset or even exceed the mitigation costs[32,33]. $CO_2$ mitigation measures in the power sector aiming to realize the nationally determined contributions could avoid more than 0.36 million premature deaths in 2050, and the overall health benefits would substantially increase to 3-9 times the implementation costs[34].

Notably, health co-benefits due to $CO_2$ emission reductions from the coal exit vary drastically from facility to facility[35]. When designing the coal exit pathway, the heterogeneity of co-benefits at the facility level should be considered. Early retirement strategies targeting super-polluting units could substantially reduce the health burden[25]. Therefore, incorporating a facility-level health co-benefits assessment into the policy design of the coal power exit is necessary for protecting China's public health, mitigating the risks of early retirement, and maximizing the benefits.

In addition to health, the early retirement of coal power also has positive impacts on water scarcity mitigation, ecological conservation, and other aspects[36,37]. Under the 1.5°C target and stricter carbon emission reduction constraints, the water stress will have been greatly eased in most catchments in China, except in certain areas in Xinjiang[38]. Except for pollutant emission removal, a coal power phasedown will reduce heat emissions contained in cooling effluents, which can lead to extended stretches of thermally polluted rivers and lakes, compromising the habitats of aquatic orgam•sms[39].

### 3.3.2. Targeted Coal-Fired Power Plant Phaseout Pathway Design

A facility-level assessment of the coal power exit is in line with the current principles ofrefined governance in China. To explore the optimal pathway for the coal power exit, it is necessary to quantify the facility-level benefit potential and targeted phaseout of the super-polluting power plant. This can provide scientific support for minimizing the costs and maximizing the benefits of China's coal power exit. Previous studies have explored the future pathway based on various assessment models, such as multicriteria optimization, chemical transport model, and the cost-benefit analysis[38,26,29].

Evaluated by unit-level technical, economic, and environmental criteria, nearly 20% of operating coal-fired power units are identified as low-hanging fruits[26]. Those prioritized retirement units are mainly concentrated in high-pollution areas with dense populations in central and eastern China, especially in Hebei, Heilongjiang, and Shandong provinces. Those coal-fired power units shared common characteristics, such as small size, long lifetime, and out-of-date equipment. To achieve the 1.5°C target, it is urgent to stop coal power infrastructure construction and rapidly retire those low-hanging plants. For other existing coal-fired power plants, the average lifetime should be further shortened to 20 years or the average operating hours should be reduced from 2020's 4,350 h to 3,750h in 2030.

Health co-benefits of power decarbonization depend on tailored coal power retirement strategies. Pollutant emissions abatement and deaths avoided resulting from the same amount of carbon reduction vary drastically by the location and technical attributes of power plant units[9]. For example, 0.8% (333 units) of coal-fired capacity in China produced 16% of $PM_{2.5}$ emissions from all coal-fired units in 2010. Similarly, coal-fired generating units with 5% of $CO_2$ emissions could disproportionately contribute to more than 40% of the health burden[35]. Under the same climate-energy and clean air pathway, early retirement strategies targeting super-polluting units could substantially reduce the health burden by avoiding millions of deaths in China[25]. More than 50% of $PM_{2.5}$-related deaths linked to emissions from power plants emission (~78,000 deaths) can be avoided in 2030 in China under the ambitious climate target of successfully avoiding 1.5 °C of warming if strategic power plant retirements and pollution controls are implemented.

To alleviate side effects caused by the coal power exit and to deepen the decarbonization process, another alternative pathway to retrofit coal-fired power units as biomass and coal co-firing power units with CCS (BCP-CCS) was evaluated based on unit-level heterogeneity information and resource spatial matching results[40]. With abundant biomass resources, significant breakthroughs in technology and rapidly declining costs, retrofitting to BCP-CCS is expected to help China's power sector achieve the goal of net-zero or even negative emissions in a short time. In this scenario, the cumulative negative $CO_2$ emission could reach 10.32 Gt by 2060.

Despite uncertainties in the above coal power retirement pathway analyses, they serve as innovative ideas and valuable references for a transformation away from a coal-based power system in China. However, designing a coal power phasedown pathway is still a complex undertaking, and current pathway analysis on coal power phaseout is still relatively weak. It is necessary to resolve the current and future drivers of coal power infrastructure construction and explore possibilities for reversing the growing trend of coal power capacity. A more comprehensive assessment framework for coal power retirement from multiple perspectives, including asset stranding, resource endowment, environmental impact, social equity, and energy demand, is urgently needed. This will provide new insights for policy-makers through a multi-dimensional quantitative analysis approach.

In addition, the early retirement of thermal power plants is not the only means to synergistically reduce pollution and carbon emissions in the power sector. The coordination of the coal phaseout with other measures, such as source control, process control and end-of-pipe control, would have substantial benefits. Zero/low-carbon generating technologies such as wind, solar, biomass, and green ammonia would help to shape a clean and secure new power system. The power sector in China should complete the ultra-low emission transformations and promote energy-saving transformations, heating transformations, and flexibility transformations for existing coal-fired power plants. Those measures would lead the power sector to a new stage of "reducing air pollution through decarbonization."

## 3.4. Policy Recommendations for a Coal Power Phasedown

To deepen decarbonization and realize a stable transformation for China's energy systems, systematic design that integrates energy security, stranded asset, and social equity into coal power phasedown policies is urgently needed. The top priority is to maintain energy security when coal-fired power plants gradually phase down. Safeguarding the security of the energy system requires a well-designed coal power plant phasedown so that the remaining plants are capable of meeting peak load demand and preventing accidental load loss. An overly aggressive coal-fired power phasedown would likely lead to potential electricity supply shortfalls, particularly during a period of extreme weather when wind and solar power outputs drop dramatically[41]. If dispatchable energy generators and energy storage are not capable of providing enough flexible electricity, it will trigger electricity outage events and cause enormous economic losses and societal problems[41].

Moreover, coal power phasedown should combine with stranded assets, social equity, and economic development. Most of China's coal-fired power plants are no more than 15 years old, which is much younger than those in developed countries such as European Union, Australia, and the U.S.[20]. Thus, a rapid retirement policy that does not consider stranded assets will cause enormous capital losses[42]. Moreover, potential economic and social losses of coal-fired power plants may not be equally distributed across varied stakeholders, groups, and regions, particularly for areas where economic development and employment depend heavily on coal-fired power-associated industries[30,43]. Therefore, the future strategy of the coal power plant phaseout needs to consider social equity, especially for the livelihood of stakeholders, despite the global impacts of coal-fired power plant retirement on climate mitigation[44].

Another recommendation is to accelerate the flexibility modification of remaining coal power plants, thereby realizing the safe and clean utilization of coal power and improving the ability to accommodate the high penetration of intermittent wind and solar energies in the coming future.

It is projected that variable renewable energies such as solar and wind powers will dominate electricity generation after 2035, when over half of electricity demand is satisfied by solar-, wind-, and hydro-generated power, enhancing the decarbonization of the electricity system[26]. With the decarbonization of China's energy systems, the role of coal-fired power will transform from the main power source to a regulative backup that is designed to accommodate a high penetration of intermittent electricity supplies from wind and solar under the context of changing climate[45]. However, coal power plants that serve as peak load regulators for a fluctuating renewable electricity supply will result in increased operation costs and enhanced emissions of GHGs and air contaminants[46]. For example, the integration potential increment of 20% of rated power is inferior to that of 30% of rated power for coal-fired power plants that serve as peak load regulators. Therefore, conventional coal-fired power units that are not modified to provide flexible supply usually fail to meet the flexibility requirement of integrating a high share of solar and wind powers[47]. This is partly because operating low-load coal power plant units allows growth in heat losses and a decline in power generation efficiency, thus raising coal consumption and operation costs[47,48,46]. Therefore, the future flexibility modification of remaining coal power plants is required to satisfy the requirements of peak load regulation and reduce the emission of air contaminants.

Moreover, coal-fired power plants should be combined with renewable thermal power, such as biomass. It is urgent to promote the use of biomass liquid fuels in thermal power, which will allow enhanced agricultural and forestry waste industrialization. This effort is expected to give rise to some potential benefits. For one thing, it would reduce retired thermal power plants, thereby lowering the risk of stranded assets and the associated societal problems, such as unemployment and economic stagnation[49]. For another thing, biomass power plants are capable of clear and renewable electricity supply, which will boost the net-zero electricity system and enhance the achievement of future climate targets[22,23]. Besides, biomass power plants are expected to provide flexible electricity generation, which will accommodate increasing peak regulation demand for variable wind and solar outputs and facilitate energy security. Moreover, bioenergy with CCS technology has been considered one of the most promising negative emission technologies to remove GHGs, despite expensive costs and potential emissions of air contaminants[22].

# Chapter 4. The Transportation Sector: Key issues and challenges in reducing pollution and carbon emissions

## 4.1. Introduction

As a major source of both local and global air pollutants, heavy-duty freight trucks (HDTs) should be a priority for emissions co-management. HDTs typically consume diesel fuel and are used for high-intensity operations, covering an annual driving distance of more than 75,000 km and weighing more than 12 tonnes. Diesel combustion in conventional HDTs produces higher levels of local and global air pollutants compared to passenger cars, which are mainly fuelled by gasoline. HDTs accounted for 3.08% of motor vehicles (excluding motorcycles) in China in 2021, yet they emit a large share of pollutants responsible for serious public health damage: they are responsible for 51.5% of PM and 76.1% of $NO_x$from motor vehicles. Peer-reviewed studies(so,siJshow clean air improvements from the accelerated deployment ofNEVs[11] in China, saving thousands of lives[521.

Turning to GHG emissions, HDTs are responsible for about 30% of $CO_2$ emissions from China's transportation sector[531. When paired with zero-emission electricity, EVs create a pathway to achieving net-zero emissions vehicles. Electricity is getting cleaner in China, as it is globally, a trend set to continue due to dropping costs and the rapid adoption of solar and wind technologies. Since 2020, renewable technologies have captured more than half of global investment in new electricity generation capacity, with more deployment of renewable energy in China than anywhere else[531.

In addition to pollution reductions, accelerated NEV deployment would deliver two economic co-benefits: first, by increasing incentives for innovation, recommendations will boost domestic technological progress; second, by hastening technological progress and giving Chinese enterprises early advantages in scale and experience, they will improve the competitiveness of China's new energy heavy-duty truck manufacturers. In 2010, the 12th FYP identified NEV production as a national strategic industry. As a result of this and other actions, China has emerged as a global leader

11 NEVs include battery-electric, hydrogen fuel cell, and plug-in hybrid electric vehicles.

in new energy passenger vehicles and new energy bus exports[541].

Sales of all types ofNEVs are taking off globally, supported by increasingly positive economics due to an 89% decline in battery cost from 2010 to 2021, largely driven by Chinese policies and enterprises. This trend of improving performance and lowering costs will continue due to future learning curve effects. Innovation will come from advances across an increasingly diverse set of commercialized battery chemistries and continued learning by doing as production ramps up. There is also high confidence in future cost reductions due to economies of scale benefits. By 2030, global battery production capacity will expand at least fivefold, by at least 500%, according to current plans[551].

Improved energy security is another reason for China to accelerate the transition to NEV HDTs, which offer three advantages. First, NEVs build on China's strong position in the battery manufacturing industry. By contrast, conventional vehicles have caused China to become the world's largest oil importer. By contrast, China has a position in processing raw minerals necessary for battery production[561]. Since mineral input refinement is the most technically complicated aspect of the critical mineral supply chain, it is also the most important, and because most minerals are well distributed globally, a faster NEV transition will enhance China's energy security[571]. Second, imported petroleum fuel dependency is inherently riskier than reliance on important battery minerals. Petroleum price spikes immediately affect all petroleum vehicles, no matter how new or old. The need for refuelling is continuous. In contrast, mineral price fluctuations are likely to have no impact on most consumers because they are embedded in very infrequent capital purchases. Third, whereas the use of petroleum fuel involves its complete conversion to waste-unused heat and unwanted air pollutants-there exists the potential to recover and recycle battery minerals at the end of a battery's lifetime.

## 4.2. China's Experience and Challenges in the Electrification of Heavy-Duty Vehicles

### 4.2.1. The Status of Electric Heavy-Duty Vehicle Promotion in China

China currently has the largest number of electric heavy-duty vehicles in the world, with its ownership of such vehicles accounting for more than 90% of the global total in 2021. The last few years of HDT NEV sales in China bear similarity to the early liftoff in the NEV passenger market, which, in 2018, became the first national market to exceed 1 million EVs sold and has remained the largest market since. NEV HDT sales briefly peaked at 1.7% in 2018[561], driven by commercial vehicle purchase incentives. In the last 2 years, NEV sales have begun taking off anew, growing to 3.5% of HDT sales in 2022. China EV 100 Vice Chairman Minggao Ouyang recently predicted NEV HDV sales would grow by at least 90% in 2023, an outlook serving as the basis for our 6.6% 2023 sales estimate in Figure 4-1. So far, battery-electric trucks have captured more than 90% of HDT NEV sales, though hydrogen fuel cell vehicles also qualify, and their share of NEVs has been increasing[ssi.

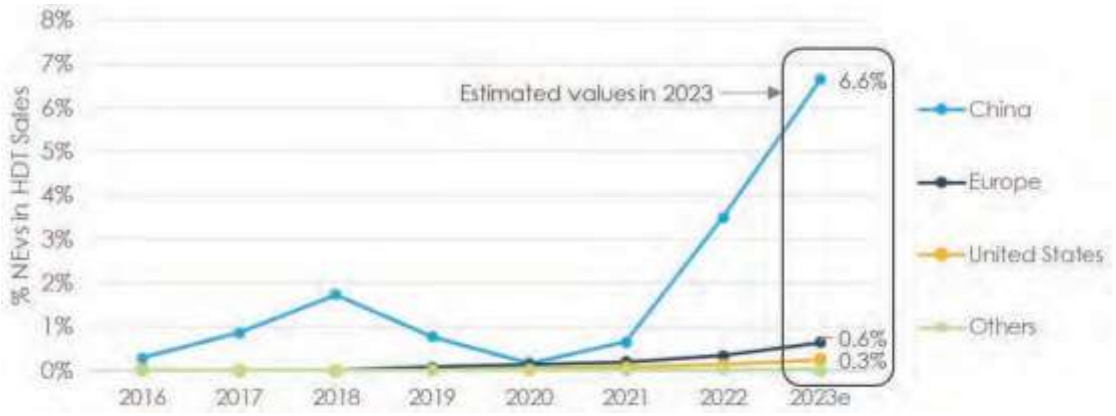



**Figure 4-1. Share ofNEVs in HDT sales globally[159–6][11]**

In the process of promoting electric heavy-duty trucks, China has been attaching great importance to the role of public fleets and has vigorously promoted the electrification of taxies, buses, sanitation vehicles, and urban freight vehicles, increasing the share of electric buses nationwide from 20% in 2015 to 60% in 2020. Beijing, Shenzhen, and many other cities have set the requirements for the share of NEVs in the public sector and the deadline for full electrification. For example, Shenzhen electrified all taxi and bus fleets as early as 2018; Beijing set the requirement of no less than a 50% share of new electric sanitation vehicles and vocational vehicles for railway works, in addition to the requirements for new energy buses and taxis. Shanghai and Tianjin proposed updating all urban buses to NEVs by 2020. As shown in Figure 4-2, China's new heavy-duty passenger vehicles and trucks fueled by new energy added up to 470,000 vehicles between 2018 and 2020, which were mainly buses and light trucks (gross vehicle weight below 4.5 tonnes mainly for sanitation, postal service, and urban logistics), accounting for more than 90% share of NEV HDVs. Based on the pilot city program, China issued the *Development Plan for the New Energy Vehicles Industry* in 2020, which clearly states no less than an 80% share of new or updated public sector vehicles, such as buses, taxis, and logistics distribution vehicles in key areas, be NEVs, starting in 2021.

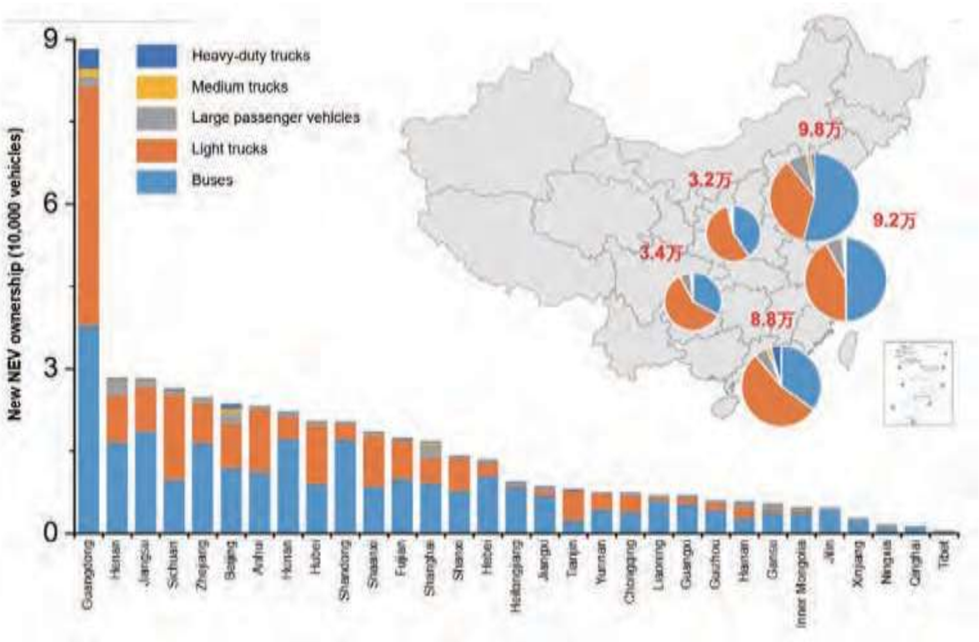



**Figure 4-2. Number of new NEVs in trucks and large passenger cars in China by province (excluding Hong Kong, Macao, and Taiwan), 2018-2020**

### 4.2.2. Policies for Promoting Electric Heavy-Duty Vehicles in China

With respect to consumption, the Chinese government has exempted eligible electric heavy-duty vehicles from the vehicle purchase tax, in addition to subsidies and preferential loans for buyers of such vehicles. With respect to use, the government has granted greater toll concessions to electric heavy-duty vehicles while vigorously promoting the construction of charging piles at logistics parks, highway rest areas, and other places. Meanwhile, some cities have set more stringent licence registration policies for traditional heavy-duty diesel vehicles, while electric heavy-duty vehicles are not subject to such restrictions. Chinese policies for supporting electric heavy-duty vehicles cover most of the life cycle ofNEVs, greatly facilitating the promotion of such vehicles.

Apart from national subsidies, some provinces and cities have also unveiled local policies for promoting heavy-duty NEVs. For example, Shenzhen has developed a feature of "government support and supervision, enterprise financing and operation, and technological innovation regulation" by further optimizing the business operation model of NEVs, which, on the one hand, gives play to the guiding role of the government and, on the other hand, has introduced financial institutions that implement the leasing system to stimulate market vitality. Moreover, the city has also encouraged the engagement of the power sector and all other stakeholders, basically achieving a breakthrough in economic benefits.

Government initiatives supporting battery-swapping trucks have played an important role in their recent success in China. Battery-swapping technology involves driving a battery EV into the battery-swap station where the depleted battery is removed and replaced with a fully charged power pack[62]. With the newest facilities, the whole process is automated and can be completed in a few minutes[63]. Time savings are especially important for commercial vehicles that are operating all day or drivers covering long distances away from stationary charging facilities[64].

#### 4.2.3. The Experience of Electric Heavy-Duty Vehicles in Typical Cities

Shenzhen is a pioneer in the promotion ofEVs in China. Since 2016, Shenzhen has continued to improve its system of standards for the NEV industry and has established a testing and certification system for operating vehicles and the use of power batteries, an information management system for power batteries, and a cascade utilization and recycling industry system for power batteries that provides continuous and solid support for the healthy development ofNEVs. In terms of supporting facility construction, Shenzhen has set the strict requirement of a 30% share of charging piles for new buildings and a 10% share for existing residential buildings and public parking lots. It has guided the participation of more social capital in the development of charging facilities, laying a solid foundation for the rapid development of EVs in the city.

In order to further improve the road environment and control the pollution from light diesel trucks, in 2018, Shenzhen took the lead in setting up an innovative pilot "green logistics zone" program in the city to demonstrate new energy logistics vehicles. Since July 2018, light diesel trucks have been banned from the "green logistics park" all day, which is only open to electric trucks. The "green logistics zone" program gives new energy logistics vehicles the right of way, solving the problem of low enthusiasm for operating logistics NEVs due to the absence of an advantage and playing a positive role in facilitating the promotion and use of such vehicles in the city. By the end of 2020, Shenzhen had a total of 86,000 new energy light trucks and a 91% increase in ownership from 2017, bringing the proportion ofNEVs in the light truck fleet to 22%.

After more than a decade of accumulation, Shenzhen has made remarkable progress in the promotion of electric heavy-duty vehicles in multiple areas, such as public transit, taxis, and logistics: it took the global lead in having all buses powered by electricity in 2017, and all of its taxies were powered by electricity at the end of 2018, making it the largest city with an all-electric taxi fleet. By the end of 2020, it also had 4,275 electric dumpers, ranking first in the world.

### 4.2.4. Challenges Facing the Promotion of Heavy-Duty EVs in China

Despite the rapid development in recent years, China's heavy-duty EVs still face real-world challenges, such as a short driving range and limited charging infrastructure. In the case of urban electric logistics vehicles, the average daily mileage and the average number of travel days are 109 km and 233 days, respectively, both far below those of diesel logistics vehicles (252 km and 320 days). The low activity level inhibits the potential of electric trucks for emission reduction during the fuel cycle. It directly leads to a higher total cost of ownership than diesel trucks and a loss of economic competitiveness. Besides, limited public charging infrastructure poses a challenge to the promotion of high-load, power-hungry, and frequently charged electric tractors.

## 4.3. California's Experience in New Energy HDT Policy

### 4.3.1. International Policy Context

The 27th United Nations Framework Convention on Climate Change Conference of the Parties (COP 27) marked the formal launch of the Global Commercial Drive to Zero initiative, which counted 27 nations as supporters by early 2023. These leading countries have committed to working together to achieve 100% sales of new zero-emission trucks and buses by 2040, with an interim target of 30% zero-emission vehicle sales by 2030. This effort aims to facilitate the attainment of net-zero carbon emissions by 2050. In addition to national commitments, an array of supporting subnational governments, automakers, truck parts suppliers, investors, and multilateral institutions has pledged their support.

In the U.S., heavy-duty commercial sales are projected to be on course for 39%--48% NEVs in 2030[65]. That forecast did not account for April 12, 2023, U.S. EPA proposal, which is expected to increase the share of NEV new vehicle sales, reaching 50% of vocational vehicles (such as buses and garbage trucks), 35% of short-haul freight tractors, and 25% oflong-haul freight tractors in 2032. The U.S. has also committed to 100% NEVs in federal procurement by 2027 for light-duty vehicles and by 2035 for heavy-duty vehicles[66]. In another major development, in early 2023 the European Union released a plan to accelerate NEVs' commercial vehicle adoption through ambitious new standards for trucks, requiring their tailpipe carbon emissions to fall by 45% in 2030, 65% in 2035, and 90% in 2040[67].

### 4.3.2. California Policy Case Study

In 2021, California's Advanced Clean Trucks policy put the state at the forefront of efforts specifically targeting the deployment of NEV freight trucks, requiring about 60% of new heavy-duty freight trucks and buses sold in 2035 in California to be NEVs[68]. As with China's dual credit policy, Advanced Clean Trucks is a technologically neutral policy, meaning either electric trucks or hydrogen fuel cell trucks qualify. Figure 4-3 charts the Advanced Clean Trucks policy's required NEV sales for different vehicle weight classes, as well as a weighted average based on forecasted future sales.

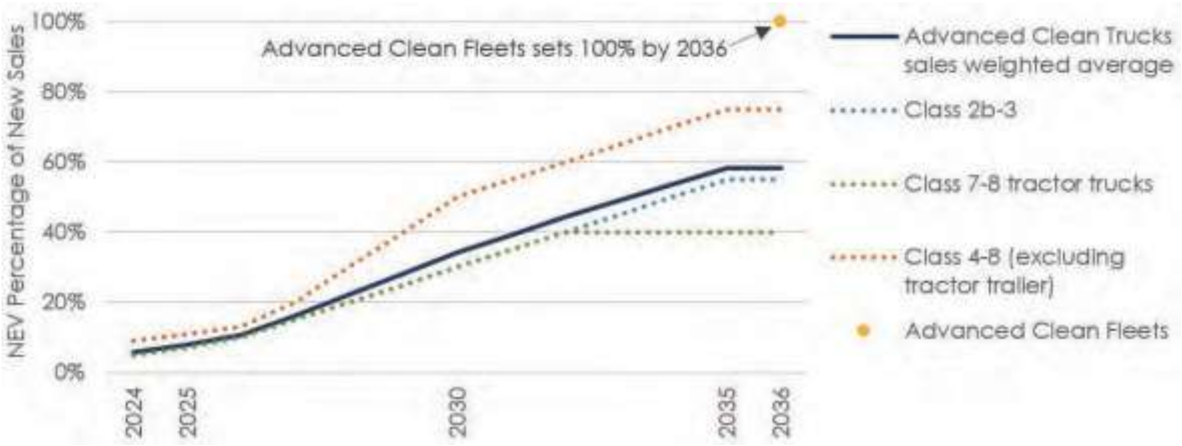



**Figure 4-3. NEV sales under California's Advance Clean Truck and Advanced Clean Fleets policies**[169,701]

NEV HDT technology and model availability have progressed substantially since 2020, when California first established the Advanced Clean Trucks policy. For example, Tesla has started delivering its tractor-trailer truck able to travel up to 800 km on a single charge amid a larger proliferation of available models. For these reasons, and considering its commitment to carbon neutrality in transportation and economy-wide by 2045, California recently accelerated the intended timetable for completing a full transition to NEV commercial vehicles.

On April 28, 2023, the California Air Resources Board's (CARB's) approval of the Advanced Clean Fleets rule opened a new chapter in commercial vehicle regulation, ramping up the state's NEV truck sales requirement to 100% by 2036 for all commercial vehicles above 3.86 tonnes, as shown in Figure 4-3. Another noteworthy feature of the Advanced Clean Fleets rule is a policy innovation that offers to reduce reliance on publicly funded consumer incentives, phasing in an increasing NEV purchase requirement for commercial vehicle fleets. This novel way to support the demand side of the market's transition to NEVs frees up government revenue for other investments[[711].

California's embrace of NEV sales standards to drive commercial deployment builds on the state's successful experience with its analogous policy for passenger cars (i.e., light-duty passenger vehicles). In 2022, NEV sales reached 20% of California's passenger car sales[[721], and the state's NEV sales standard for passenger vehicles has been an important driver of this result, including directly contributing to the success of Tesla[[731]. Since 2009, California NEV credits delivered an estimated USD 2.5 billion in monetary benefits for Tesla, the most of any state program by a large margin, providing cashflow at early critical junctures and making Tesla profitable in some quarters[741. Dan Sperling, founding director of the Institute for Transportation Studies at the University of California, Davis, concludes: "Tesla would have gone bankrupt and disappeared without California's [NEV] mandate."[74]

## 4.4. Assessment of the Pollution and Carbon Reduction Benefits of Electrifying Heavy-Duty Vehicles in China

### 4.4.1. An Analysis of the Potential of a Synergistic Sustainable Power System for Pollution and Carbon Reduction Throughout the Life Cycle of NEVs

The potential of NEVs for reducing pollutants and $CO_2$ emissions needs to be systematically evaluated through a life-cycle assessment (LCA). An LCA is a method for systematically evaluating the environmental impact of a product throughout its life cycle from resource exploitation, production, transportation, delivery, and use to scrapping and recycling. The Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by the Argonne National Laboratory (ANL) is an LCA model widely used in the transportation sector, including Well-to-Wheels (WTW) and Vehicle Cycle evaluation, with the former focusing on the application during energy production and driving and the latter on the entire process of vehicle materials/parts from raw material exploitation to scrapping and recycling.

However, considering the high reliance on coal-based electricity generation, there remains ongoing public debate on the actual impacts of Battery Electric Vehicles (BEVs) on mitigating $CO_2$ emissions. The early-stage LCA studies focused on the WTW research since the fuel cycle at that time was estimated to be the major proportion of total life-cycle $CO_2$ emissions. Previous studies concluded that around 2010, BEVs had very limited benefits in mitigating WTW $CO_2$ emissions relative to gasoline cars in coal power-rich regions (e.g., North China), whereas BEVs could effectively mitigate WTW $CO_2$ emissions in South China, given its relatively cleaner electricity mix. Thus, the spatial or temporal divergence of the electricity mix became a focus of several follow-up studies when analyzing WTW emissions of BEVs. In the past decade, the cleaner electricity mix has driven a rapid decline in WTW $CO_2$ emissions for BEVs in China, and BEVs could readily deliver WTW $CO_2$ mitigation, even in North China. Recent studies have attempted to introduce localized profiles regarding some elementary vehicle-cycle components into the full life-cycle boundary level and finding a considerable share (e.g. >25%) contributed by the vehicle cycle, including the production of batteries and their raw materials.

The GREET model-based analysis results suggest that the full life-cycle $CO_2$ intensity of EVs varies from region to region due to different electricity mixes in regional power grids. Under the average electricity mix in China in 2020 (a 60.2% share of coal power), life-cycle $CO_2$ emissions from EVs equipped with nickel manganese cobalt (NMC) batteries, EVs equipped with lithium iron phosphate (LFP) batteries, and vehicles powered by conventional fuels were 165 g/km, 153 g/km, and 280 g/km, respectively. This implies that EVs can achieve at least a 40% reduction in carbon emissions compared to vehicles powered by conventional fuels. The proportions of coal power and renewable energy in a region will have a great impact on this figure. For example, North China's power grid has the highest share of coal power (78.8%), and EVs in this region still enable a 30% reduction in $CO_2$ emissions. Meanwhile, Southwest China's power grid has the highest share of hydropower (68.3%), and EVs in this region can generate a more than 60% reduction in $CO_2$ emissions. On the whole, EVs possess an advantage of at least a 30% reduction in $CO_2$ emissions over traditional fuel-powered vehicles in China.

In the future, with a series of improvements in conditions for EV application, such as more electricity generation from clean energy, progress in battery technologies, and higher vehicle energy efficiency, the life-cycle $CO_2$ intensity of EVs in China will be significantly reduced, as shown in Figure 4-4. By 2030, the emission intensity of EVs equipped with NCM batteries will drop by 53% to 93 g/km. Differences between regions will also be further reduced. For example, the emission intensity of EVs will be 109 g/km in North China's power grid and 65 g/km in Southwest China's power grid.

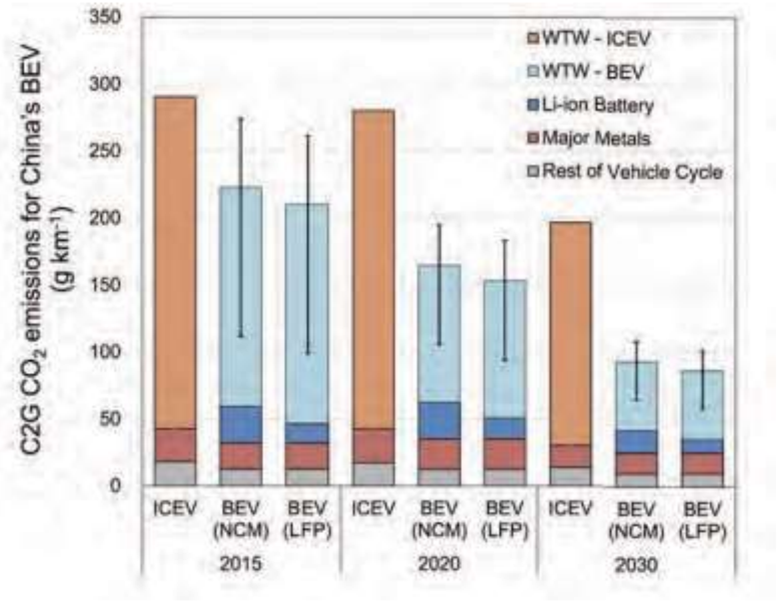



**Figure 4-4. Life-cycle $CO_2$ emissions of EVs and projections in China**

Under the scenario of coordinated charging, further reductions in $CO_2$ emissions from EVs and sustainable electricity generation can be achieved in a synergistic manner if EVs maximize electricity from renewable energy. A study found that coordinated charging enables a 20% reduction in WTW $CO_2$ emissions, a 50% reduction in charging costs, and a 95% reduction in the demand for new power units. The flexibility of EV charging facilities can be leveraged to create synergy between the power and transportation systems and ensure higher grid stability, lower fuel costs, and deeper emission reductions.

#### 4.4.2. Modelling and Evaluation of Different Policy Pathways to Accelerate the Electrification of Heavy-Duty Vehicles

To quantitatively evaluate emission reduction potential from NEV HDT deployment, we use the China Energy Policy Simulator (China EPS), a model developed by Energy Innovation: Policy & Technology, LLC and the innovative Green Development Program (iGDP). The China EPS is an open-source, peer-reviewed modd[751] that identifies the most effective policy combinations by comparing energy use, emissions, cost, and other model outputs under different policy scenarios. As a system dynamics model with economy-wide coverage, the China EPS calculates both the direct impacts on transportation due to increasing NEV HDT deployment and broader energy system effects encompassing the entire economy. The China EPS's online documentation provides a detailed description of its methodology.

We use the China EPS to analyze two accelerated NEV deployment scenarios, as Table 4– 1 details. In the Recommended Scenario, aligned with this chapter's suggested deployment targets, NEV HDT sales will reach 45% in 2030 and 100% in 2040. In the Mid Scenario, NEV sales will reach 30% in 2030 and 100% in 2045. Impacts for both the Recommended and Mid Scenarios are calculated in comparison to iGDP's 14th Five-Year Plan Scenario, which captures the effects of announced policies.

**Table 4-1. China EPS scenarios analyzed(% NEVs as a share of all new HDT sales)** [1751]

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 |
|---|---|---|---|---|---|---|---|---|
| Recommended Scenario | 13% | 45% | 75% | 100% | 100% | 100% | 100% | 100% |
| Mid Scenario | 9% | 30% | 55% | 75% | 90% | 100% | 100% | 100% |
| 14th Five-Year Plan Scenario | 6% | 19% | 36% | 44% | 45% | 46% | 47% | 47% |

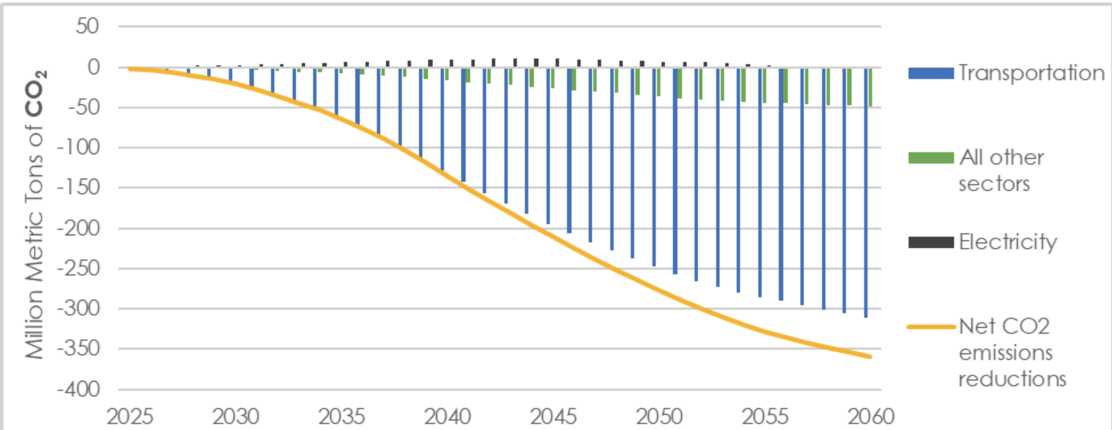
The first set of results focuses exclusively on Recommended Scenario impact analysis and disaggregates economy-wide effects using three categories: transportation, electricity, and all other sectors.

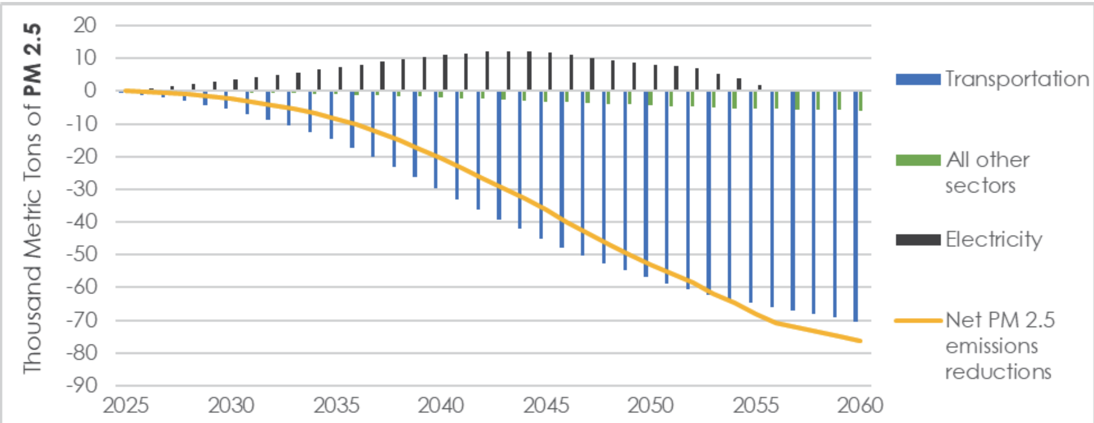
I.**Transportation.** The transportation sector impacts capture changes in pollutant emissions with a narrow focus on emissions for which vehicles themselves are the source, i.e., narrowly considering emissions emanating from vehicle tailpipes, which excludes emissions associated with petroleum refining to produce gasoline and diesel transportation fuels, as well as emissions from new energy sources. The China EPS separately tracks emissions associated with electricity generation, petroleum refining, and hydrogen production under industrial em1ss10ns.

2. **Electricity.** The electricity sector impacts account for added emissions from the increased use of electricity as a transportation fuel. Additional electricity-related emissions in the results that follow are based on pollutant emissions intensities calculated for the 14th Five-Year Plan Scenario in which the share of clean energy-including renewable, hydroelectric, and nuclear technologies-reaches 40% in 2030 and 52% in 2040.

3. **All other sectors.** The aggregation of effects outside of transportation and electricity: changes in petroleum refining emissions are the most significant single contributor.

4. **Net emissions reductions.** The net effect calculates the sum of economy-wide impacts across transportation, electricity, and all other sectors.



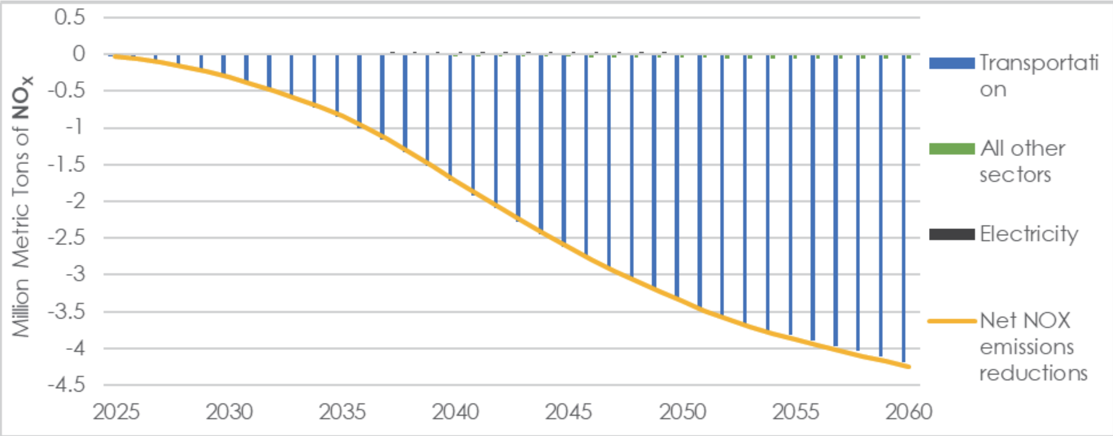



**Figure 4-5. Economy-wide emissions reductions for $CO_2$, $PM_{2\_5}$, and NOx in the Recommended Scenario**[1751]

Results graphed above illustrate that net benefits from NEV deployment depend on the pollutant emissions intensity of electricity generation, especially in the case of $PM_{2\_5}$. Only in 2026 do transportation-related reductions in $PM_{2\_5}$ emissions begin to outweigh $PM_{25}$ emissions increases due to the additional electricity generation demand from NEV HDTs. As more clean energy enters the electricity mix, transportation's $PM_{2\_5}$ advantage quickly grows. By 2030, there will be 1.5 units of avoided $PM_{2\_5}$ emissions from the transportation sector for every one unit of additional $PM_{2\_5}$ emissions from electricity. In 2035, this ratio of transportation-to-electricity benefits exceeds a two-to-one advantage. In later years, as clean electricity consumption in the 14th Five-Year Plan Scenario continues to grow and reaches the same levels in the Recommended Scenario, $PM_{25}$ emissions due to added electricity use for NEV HDTs decline, reaching such low levels that they are no longer readily visible in the charts above (Figure 4-5).

The public health impact is contingent on how exposed people are to air pollutants at the time of initial release, when they are most concentrated. Motor vehicle tailpipe emissions are more frequently released in densely populated urban areas, leading to a higher rate of exposure and intake. In China, transportation's share of the damage associated with exposure and ambient air pollution is on the rise. The percentage of health hazards attributed to transportation rose from 8% in 2005 to 14% in 2015, while failing from 13% to 6% for electricity production. In California, diesel engine emissions are estimated to be responsible for 70% of residents' cancer incidence attributable to toxic air contaminants. CARB concludes that particulate matter emission dangers are exacerbated by their location; they are "often emitted close to people so high exposures occur." Also amplifying the damage done by diesel exhaust are more than 40 cancer-causing substances also contained in diesel exhaust, "most of which are readily absorbed onto the soot particles."

The next set of results, Figure 4-6, compares net emissions reductions in the Recommended and Mid Scenarios.

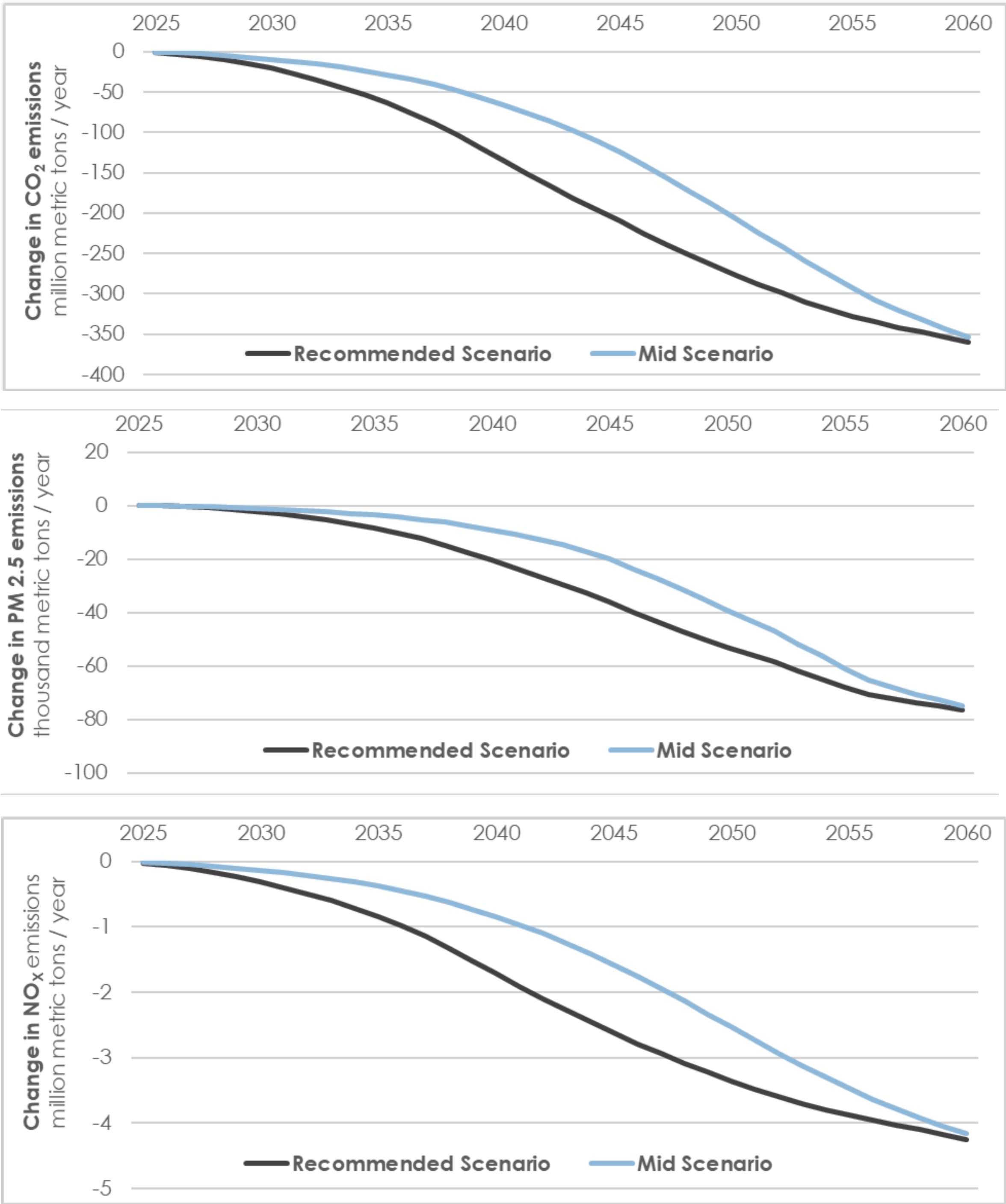



**Figure 4-6. Comparing net emissions reductions in the Recommended Scenario vs. Mid Scenario[1751]**

Source: China Energy Policy Simulator

Figure 4-6's comparison of net emissions reductions in the Recommended and the Mid Scenarios shows that the Recommended Scenario yields significantly greater emissions reductions in the next two decades. Through to 2030, the Recommended Scenario drives decarbonization at twice the rate of the Mid Scenario. However, the difference diminishes in later years as the Mid Scenario approaches 100% NEV HDT sales in 2050, equalizing the Recommended Scenario in the last decade of the analysis. Still, the Recommended Scenario generates 1,567 million tonnes-more than 1.5 gigatons-in additional cumulative $CO_2$ emissions reductions through 2060.

D Technical Feasibility

The respected International Council on Clean Transportation concludes: "Commercial availability and cost of ownership projections demonstrate that 45% zero-emission HDV sales in 2030 and 100% sales in 2040 are feasible goals."[76] This concluding section explores technological, investment, and market trends enabling a rapid shift to NEV HDT sales.

One indicator of recommended ambitious NEV HDT deployment feasibility is the fact that success would require a slower increase in NEV HDT sales than has occurred historically in China's NEV light-duty passenger market. China's light-duty passenger vehicle NEV sales grew at an annual average growth rate of 62% from 2015 to 2022. By comparison, a 41% annual growth rate from the actual 2022 level would achieve the recommended 2030 target for NEVs to reach 45% of HDT sales.

Continued market momentum is expected due to the trend of increasing industry investment, considering historical outlays and forward-looking commitments. Cleantech investment topped 1 trillion USD for the first time in 2022, with electrified transport growing faster than any other category. For the first time, investment in electrified transport came close to dethroning renewables, with 2022 investment amounting to 466 billion USD, 54% more than in 2021[nJ. A rise in model availability is one result of increasing investment. A global census of NEV HDT models available shows 158 in 2021, up to 352 in early 2023. Investment in mineral inputs is on an upward trajectory as well, and proven reserves of key minerals are growing[78]. For example, over the last 5 years, the lithium supply has grown by more than 60%[78].

Turning to technological trends, high confidence in the continuation of battery innovation in coming years exists because of the range of innovations with the potential to reach commercial success. Battery innovations advancing to commercial readiness range from incremental (e.g., sodium batteries that use no lithium at al1[79] and synthetic graphic cathodes[80]) to fundamental (solid-state batteries)[81]. The fact that rapid battery technology progress has regularly surprised energy and transportation modellers, outperforming even their optimistic scenarios, is another reason to expect most current outlooks to underestimate future learning curve effects for EV batteries[82].

Another promising techno-economic development concerns the rising commercial success of lithium-ion phosphate batteries, which require no cobalt and are offering an affordable alternative, albeit at the cost of less energy density. BloombergNEF forecasts lithium-ion phosphate battery market share to reach 40% in 2023, up from 25% in 2022, and less than 10% of the 2019 market share[83].

The increasingly diverse array of battery storage technologies boosts the feasibility of rapid NEV HDT deployment through related innovation and economic benefits. A greater number of commercially viable battery technologies increases the possibilities for technological programs. More battery diversity also provides downward cost pressure, creating more competitive pressure and substitution possibilities. We see evidence of this already in the market's embrace oflithium-ion phosphate batteries for their cost-effectiveness advantages.

Because of these trends and others, rapid NEV HDT deployment in line with recommendations is feasible, which is not to say simple or easy. The recommended NEV transition will present challenges, but efforts to overcome them will be well worth the effort, delivering a potent combination of air pollutant emissions, energy security, and economic benefits.

## 4.5. Economic Benefits: Innovation stimulus and Enhanced Economic Growth

Recommended policies would deliver economic co-benefits in technology innovation and economic growth, in addition to the local and global air pollutants that are their primary target. By accelerating the transition to NEV HDTs, China's policymakers can spur additional movement up the learning curve, delivering innovation, better performance, and lower cost.

A recent empirical analysis of China's Dual Credit Policy for light-duty passenger vehicles provides evidence for such benefits, due to improvements in innovation ability and enhancement of corporate reputation[84]. The Dual Credit Policy sets an industry-wide standard for all manufacturers but offers flexibility at the individual enterprise level. Leading NEV manufacturers receive NEV credits when they sell a higher percentage of NEVs than the average industry requirement. Enterprises below the overall industry requirement can purchase NEV credits to comply. Such flexibility allows enterprises to take different compliance approaches. In turn, allowing heterogeneous enterprises to vary their compliance strategies spurs market efficiencies by steering investment toward the highest value options and encourages innovation by rewarding enterprises that go beyond the minimum average compliance requirement.

Domestic innovation stimulus due to policies supporting accelerated NEV deployment will, in turn, enhance the competitiveness of China's NEV HDT producers. The significance of this benefit will grow more obvious over time, considering the growing consensus that NEVs are on track to become the preferred transportation technology.

China has considered NEVs an industry of economic importance since their designation as such in the 12th Five-Year Plan, and export data indicate that China's supportive NEV policies are already paying economic dividends. In the first quarter of 2023, China claimed the mantle of the globe's leading motor vehicle exporter, surpassing Japan for the first time. In 2020, surging NEV exports enabled China to pass Germany for the first time to become the second-largest motor vehicle exporter globally[ssi. In 2022, heavy-duty NEV exports climbed 131% over 2021, while passenger car NEV exports increased 120%[71]. Buses represent most of China's heavy-duty NEV exports so far, but the freight truck segment is growing.

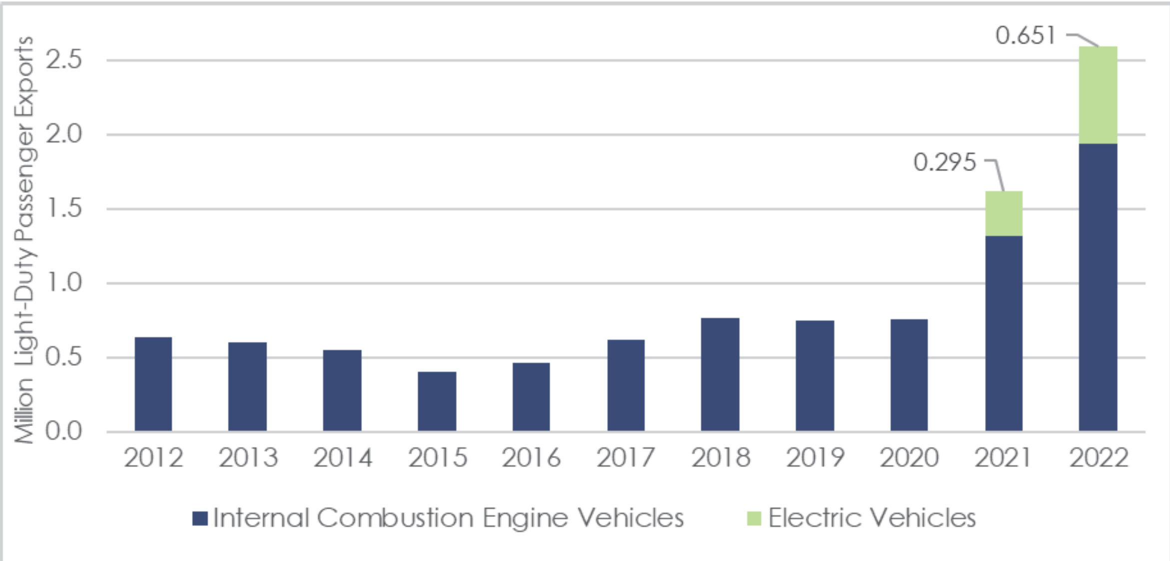



**Figure 4-7. China's light-duty passenger exports: Electric vs. internal combustion engine vehicles12**

## 4.6. Recommendations

We recommend a three-part strategy: (1) establish clear, ambitious long-term targets for NEV HDT deployment and help meet them by (2) establishing a NEV HDT sales standard and (3) continuing to refine and expand China's existing portfolio approach, recognizing the necessity of a multitude of instruments to optimally manage the transition. Increased certainty and clarity on future market conditions will help unlock greater investment, supporting supply chain development and stimulating additional innovation.

Regarding long-term targets for NEV HDT deployment, **we suggest setting quantitative NEV HDT sales targets of 45% by 2030, 75% by 2035, and 100% by 2040.** The Ministry of Industry

12 Source: China Automobile Manufacturing Association

and Information Technology (MIIT) is reported to be considering NEV HDT deployment targets and supportive policies, but these have yet to be announced. The State Council's NEV industry development plan calls for battery EVs to become the "mainstream" technology for passenger automobiles by 2035, specifically reaching at least 50% of passenger vehicle sales by 2035 in the China Society of Automotive Engineers' *Technology Roadmap 2.0*. Such long-term, numerical clarity is increasingly the norm in the largest new vehicle markets. The U.S. and several European countries are among 27 nations that have committed to NEV sales of commercial vehicles over 3.5 tonnes reaching 30% of sales by 2030 and 100% by 2040 at the latest.

The recommended long-term schedule aligns with International Council on Clean Transportation (ICCT) research, which, using the term heavy-duty vehicle to refer to both freight trucks and passenger buses over 3.5 tonnes, concludes: "Commercial availability and cost of ownership projections demonstrate that 45% zero-emission HDV sales in 2030 and 100% sales in 2040 are feasible goals"[76]. Maximum feasible ambition is needed due to inertia in the transportation energy system due to long vehicle life. Continuation of conventional combustion vehicle sales locks in pollution levels for years to come. A delayed transition to NEV HDTs would sacrifice local clean air, global climate, and economic development benefits, in addition to increasing the difficulty of reaching net-zero goals.

To reach ambitious targets, a second recommendation is to establish a NEV sales requirement for HDTs as soon as is practical. Such a policy can build on China's successful Dual Credit Policy for light-duty passenger vehicles, which the ICCT credits as "the main driver for the market growth in China." With respect to NEV HDT sales standard design, in its first phase, the Dual Credit Policy gave enterprises the choice to use surplus NEV credits for compliance with fuel efficiency regulations. Officials are rightly re-thinking this design feature to ensure no unintended weakening of overarching incentives for vehicle efficiency, because efficiency remains important for both conventional and new energy vehicles.

China's successful light-duty passenger NEV deployment strategy has used multiple, complementary policy instruments, and such a "portfolio approach" is important for NEV HDT deployment too. It should include measures encouraging vehicle energy efficiency, developing NEV industry standards, expanding infrastructure serving new energy vehicles, and continuing both fiscal incentives and non-fiscal inducements. Regarding fiscal incentives, the sales tax exemption for new energy commercial vehicles is scheduled to expire at the end of 2023, and we recommend its extension through the end of 2025. A promising non-fiscal policy option is to allow NEV HDTs preferential roadway access, alleviating significant restrictions that conventional HDTs currently face. For example, the Diesel Truck Pollution Control Action Plan prohibits diesel trucks from entering or exiting industrial enterprises involved in bulk material transport or ports during heavy pollution warning days[86].

We highlight one new policy meriting addition to China's NEV HDT portfolio: commercial fleet vehicle purchasing requirements, which are a novel policy recently adopted in California, as described further in our California Case Study, below. A comprehensive treatment of all the pillars of an effective NEV HDT portfolio is beyond the scope of this chapter but would also extend to consideration of opportunities for demand management, mode shifting (e.g., shifting of freight from motor vehicle-based transportation to shipping by rail or waterborne transportation), and measures addressing the life-cycle emissions from production of transportation energy sources and material inputs to vehicle production.

# Chapter 5. Regulatory and Enforcement Mechanisms for Coordinated Control

## 5.1. California's Experience in Coordinated Control

### 5.1.1. Introduction

The objective of this section is to describe strategies for effective action to address traditional pollution (e.g., ozone-forming pollutants, particulate matter, toxic pollutants) and climate change by holistically focusing on emission reduction goals, strategy design, and implementation. Specifically, as described below, many of the key emission sources for traditional pollution and GHGs are the same (e.g., transportation, combustion-based electricity generation, and industrial sources). Thus, properly chosen strategies can deliver reductions for each of the pollutants of interest, resulting in reduced costs, greater efficiencies, and better outcomes.

This section also explores the principles necessary to realize emission reductions anticipated from measures emphasizing that well-designed measures must be coupled with effective implementation to successfully deliver on their ambition.

### 5.1.2. The History of Air Pollution Control in California

CARB was created by state law in 1967 with the goal of establishing an approach to address the state's severe air-quality problems, particularly in southern California and the central valley. As remains the case today, there was broad public concern about air pollution, its impact on public health, and the need for action that led to the creation of CARB.

Since its formation, CARB has worked with the public, communities, the business sector, and local governments in its effort to identify solutions to California's air quality and climate problems. The federal Clean Air Act provided CARB unique authority to establish motor vehicle standards given California's extreme air-quality problems. Over the past several decades, the authority provided to CARB has set the stage for some of the most creative emission reduction strategies in the world. Many of the measures established by CARB have become the U.S. standard and have been adopted by international jurisdictions. Some of the innovative control strategies that have led to significantly cleaner air in California include:

- The nation's first tailpipe emissions standards for hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter from diesel-fuelled vehicles;
- Catalytic converters;
- On-board diagnostic, or "check engine" lights and systems;
- The nation's first zero-emission vehicle (ZEV) regulations, which require manufacturers to produce an increasing number of ZEVs (e.g., cars, trucks, buses);
- California's Advanced Clean Cars Program, which reduces both conventional "criteria" and GHG pollutant emissions from automobiles;
- Phasing out perchloroethylene use for dry cleaning; and
- Requiring marine vessels (e.g., cruise ships, cargo ships, oil tankers, and car carriers) to reduce emissions by over 90% when calling on California ports.

Over the past few decades, California's cars and trucks, along with the fuels they use (primarily gasoline and diesel), have become the cleanest in the world. CARE, which had already eliminated lead in gasoline, adopted standards for cleaner-burning gasoline, as well as standards for cleaner diesel fuel for trucks, buses, and other on/off-road equipment. CARE also began work to reduce smog-forming emissions from thousands of common household products (e.g., adhesive remover, air freshener, automotive brake cleaner, electrical cleaner, general purpose degreasers, and hair care products).

- Toxics Laws

In the 1980s, legislation was adopted in California that further focused on the identification and control of toxic pollutants. AB 1807 and AB 2588 supported identifying and prioritizing impacts from toxic pollutants by applying advanced risk assessment methodologies and public notification tools, as well as mitigation efforts. Together, these programs supported a series of actions that have driven down toxic pollutants, with the majority of benefits realized by the most impacted communities in the state. For example, adopted measures phased out perchloroethylene used for dry cleaning, reduced emissions of hexavalent chromium from chrome platers, reduced benzene levels in gasoline, and substantially reduced diesel PM emissions from the combustion of diesel fuel.

- AB 32/Climate Change

Many measures established in California over the past several decades have contributed to reducing GHG emissions (e.g., appliance efficiency standards). However, focused action to address climate change significantly escalated with the passage of AB 32 in 2006. AB 32 called for the development of a comprehensive plan or roadmap for how the state is to achieve legislatively-mandated reduction targets. The Scoping Plan, first developed in 2008 and subsequently updated several times, most recently in 2022, is the most comprehensive strategy ever developed and implemented for meeting climate change commitments. The Scoping Plan includes a broad portfolio of reduction measures that interact with every major sector in the economy (e.g., transportation, energy, industry, buildings, agriculture, forests, etc.). Since the passage of AB 32 several bills (e.g., SB 32, Pavley/Garcia) that support tighter GHG reduction targets have been adopted.

### 5.1.3. Principles of Effective Emission Reduction Programs

Based on the last several decades of air pollution control, we can apply learnings to the development and implementation of plans and measures that simultaneously focus on reducing emissions of criteria pollutants and toxic pollutants, as well as GHGs. Doing so will afford the opportunity to design more effective measures to deliver the needed reductions at reduced costs. These principles are foundational to prioritizing, developing, and implementing emission control measures.

- Clear and Measurable Targets

Establishing clear, trackable, and enforceable emission reduction targets that are subject to regular reporting, enabling stakeholders to easily assess progress, is the cornerstone of an effective program/measure. Below, Figure 5-1 presents the statutory statewide reductions for California, and Figure 5-2 presents the emission reduction target (oxides of nitrogen) necessary for the South Coast Air Basin in California (i.e., the region with the highest ozone levels in the country) to achieve the federal 8-hour ozone standard of 70 parts per billion.


Figure 5-1

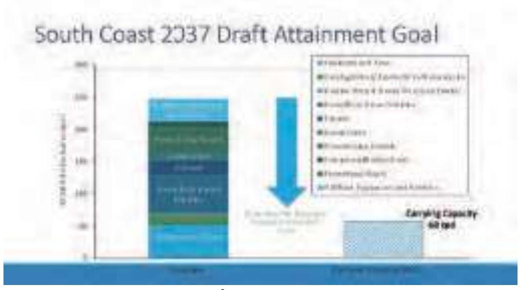



Figure 5-2

- Support for Action/Leadership

Progress in reducing emissions of GHGs, criteria pollutants, and toxic pollutants is predicated on actions that include establishing regulations, incentive programs, enforcement, and industry investment in new, cleaner technologies. However, without clear and sustained public and political leadership support, the steps necessary to establish and implement effective emission reduction programs are not possible. Continued support requires active communication on the impacts associated with poor air quality and climate change, as well as the effectiveness of the actions that are being taken.

- Authority to Act

Taking effective action to address air pollution and climate change requires a suite of measures, including the adoption of enforceable regulations. Regulatory organizations must have clear and unambiguous authority to develop, implement, and enforce the necessary requirements to provide the market certainty that it will prevail if challenged. The certainty that regulations are legal and will be enforced is necessary to provide the market confidence that investments in cleaner, more efficient technologies will be rewarded. It is these investments that deliver needed emission reductions and support innovation, resulting in progressively cleaner and more efficient solutions.

- Data/Analysis (i.e., robust technical foundation for proposed measures)

Rigorous analysis informs the development of effective plans and mitigation measures. The foundation for informing successful programs is robust emission inventories that are regularly updated and verified. Figure 5-3 presents California's statewide emissions inventory for 2019 for GHGs, nitrogen oxides, and diesel PM. One initial observation is that the transportation sector dominates emissions for each category of pollutant.

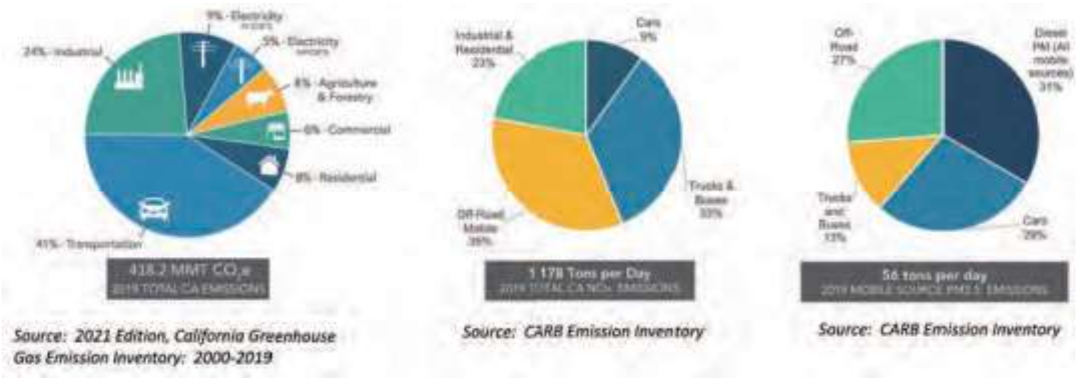



**Figure 5-3. California emissions of GHGs, NOx, and $PM_{2.5}$ by sector**

- Partnerships (e.g., academic, governmental, industry, community, environmental)

Effective control plans and measures rely on partnerships. This includes reaching out to academic institutions to identify the availability of useful studies as well as potential new work to address gaps. Government, community, industry, and non-profit partners are also key to identifying useful models near and abroad that can be drawn on to facilitate the development of successful programs. These programs can be replicated by other partners, thus sending a stronger signal to the market that supports investment and innovation and helps to expedite the transition to cleaner technologies.

- Establish Comprehensive Plans to Prioritize/Guide Measure Development

Achievement of emission reduction targets requires careful planning to inform a package of interrelated measures to understand how measures interact with one another. For example, measures that require a transition to electrification (e.g., transforming the motor vehicle fleet to EVs) must consider the source of electricity that will be needed, as well as its impact on GHG emissions, criteria pollutants, and toxic pollutants, among other potential impacts. Thus, a precursor to prioritizing, developing, and implementing measures is to establish comprehensive plans that consider the range of potential measures needed to achieve the required reductions, as well as how those measures interact with one another from emissions, public health, and economic perspectives.

- Capacity and Expertise to Develop and Implement Measures

Developing and implementing effective plans and measures requires a network of resources, including in-house experts; contractors, including those associated with academic institutions; and funding. The resource requirements to successfully implement major air pollution and climate change control programs frequently exceeds the resources necessary to develop and adopt the initial regulation. Thus, anticipating ongoing resource requirements needed to support implementation must be programmed into the design of the plans/measures to better ensure successful implementation.

- Transparency (i.e., open public process/ broad-based engagement)

The most effective plans and measures are developed through a public process that affords easy engagement for interested stakeholders in a variety of forms (e.g., web-based meetings, in-person workshops, one-on-one meetings, web postings outlining the development process with related resources) with proposals posted well in advance of meetings. Also, public comments should be posted and easily accessible, with written responses to stakeholder proposals that provide the rationale for why and how recommendations were or were not incorporated.

- Take Action (adopt/implement measures)

Ambitious and achievable emission reduction targets are important, but emission reductions result from taking action (e.g., adopting and enforcing regulations, providing incentive funding, etc.). The information to support reduction measures is dynamic-it changes with time. Thus, the information upon which to take action is never complete, requiring decisions for when a proposal is sufficiently robust to move forward (otherwise, measures are perpetually refined and never acted on). Applying the principles described in this paper help to guide the process of developing effective measures. But making progress toward achieving emission reduction targets is predicated on taking action by adopting and enforcing emission programs that provide the market with a clear signal that investment and innovation will be rewarded.

- Ongoing Measurement/Monitoring/Reporting

Once adopted emission control programs must be subjected to careful monitoring and reporting to assess their effectiveness. The reports should be updated frequently and be broadly available for independent analysis by academics and other stakeholders. For example, establishing a dashboard with key measure metrics to assess ongoing performance has been demonstrated to be a useful strategy. Doing so helps to strengthen programs by identifying potential weaknesses as well as informing interested stakeholders on a measure's effectiveness at reducing emissions.

- Vigorous Enforcement

The vast majority of regulated parties comply with emission reduction program requirements. That may include investing in newer/cleaner control technologies and fuels as well as meeting reporting requirements. It is incumbent upon the agency tasked with overseeing regulatory compliance that they establish a team of well-trained professionals to inspect sources and records for compliance. And, in the event violations are discovered, it is critical that appropriate enforcement actions are taken. This sends a clear signal to violators that they will be caught and penalized a message to the majority of regulated parties that play by the rules that there is an even playing field. It is recommended that enforcement actions that are taken are widely publicized to facilitate these objectives.

- Adjustments to Strengthen Measures

Throughout program implementation, staff must carefully evaluate program data as well as engage stakeholders to assess any elements of the program that are not working as intended. This ongoing assessment can be used to support issuing guidance or inform about where regulatory amendments may be needed.

- Results

The metric for assessing the effectiveness of programs is whether they meaningfully reduce emissions, as intended, in support of reaching targets. And, that the reductions and associated benefits (e.g., reduced premature mortality, reduced asthma cases, reductions in hospitalizations, and reductions in lost work and school days) are commensurate with the costs and associated resources. Section 5.1.5 provides examples of the experience with California's programs.

### 5.1.4. Results: Summary of emission reductions achieved

Emission reduction measures without the elements described in this paper are unlikely to be successfully implemented. The following figures illustrate the emission reductions observed in California for diesel particulate (Figure 5-4); GHGs (Figure 5-5); nitrogen oxides, which lead to the formation of ozone and secondary particulates (Figure 5-6); and benzene, a known human carcinogen (Figure 5-7). Many of the emission reductions reported in these figures were achieved from multipollutant measures (i.e., the same measure contributed to reductions in more than one pollutant). In addition to indicating emission reductions of GHGs over the past 20 years, Figure 5-5 illustrates that over the same period, California's GDP grew substantially while per capita GHG emissions continued to decrease.

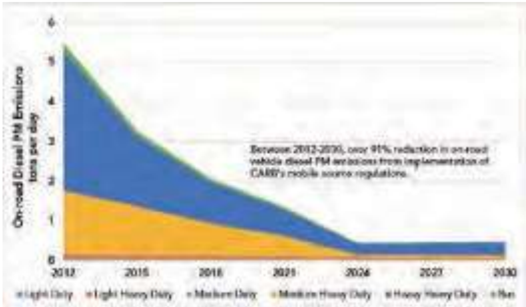


Figure 5-4

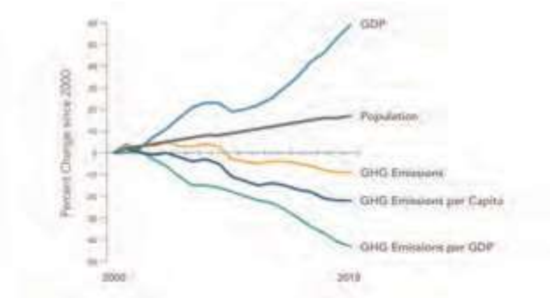



Figure 5-5

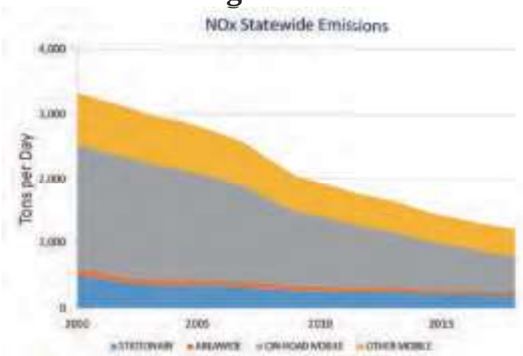



Figure 5-6

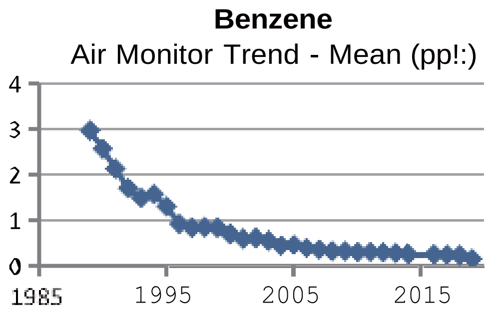



Figure 5-7

### 5.1.5. Applying the Principles: Identifying and developing multipollutant-focused measures

The objective of this section is to provide a few illustrations of multipollutant measures that have been successfully implemented in California. The measures deliver multipollutant benefits and are built on the principles described in this paper. But first, an abbreviated roadmap for prioritizing, selecting, and implementing measures is provided.

Prioritize Measures

The emission inventory helps to inform the most significant sectors of emissions as well as the potential opportunities for the greatest emission reductions. Considering the emission inventories for all pollutants of interest (i.e., GHGs, criteria, and toxic pollutants) guides the process of illuminating potential opportunities for addressing multiple pollutants. However, there are some notable exceptions, which are not the focus of this paper, where the development of a measure is a priority even though it may not afford a significant opportunity for co-pollutant reductions (e.g., reductions of hydrofluorocarbon emissions from air conditioning refrigeration systems).

A theme that emerges from holistically considering the emissions inventory is that transportation is the main source of GHG, $NO_x$, and diesel PM emissions in California, as well as in many regions across the globe. Guided by the principles discussed throughout this paper, multipollutant measures can be identified, developed, and implemented, thus delivering air quality, community, and climate benefits while more efficiently using limited resources and investments.

Measure Development

Measure development should be informed by data and analysis of the emission reduction opportunities, feasibility of the measures, costs, benefits, and implementation timetable. The analysis should be developed in close coordination with a broad spectrum of stakeholders, published/posted, and broadly distributed allowing for public engagement, questions, and the crafting of specific recommendations. A transparent public process is as important as the analysis and supports the development of more effective measures.

Implementation

As noted earlier, establishing a process for the careful monitoring of measures throughout the implementation process supports the early identification of problems that may arise. For example, to facilitate effective implementation, further guidance or potential amendments to regulatory requirements may be required. Also, lessons learned throughout the implementation process can be shared with all stakeholders to expedite the implementation learning curve and expedite the export and adoption of measures by other jurisdictions.

Illustrations

Below are summaries of three examples, including the underlying rationale for their selection: 1) zero-emission vehicles; 2) a low-carbon fuel standard; and 3) building standards.

Zero-Emission Vehicles (Cars, Trucks, and More)

California developed several programs that support the transition to zero-emission transportation. This includes zero-emission requirements for manufacturing cars, trucks, buses, and other equipment, as well as programs that support "market pull," such as fleet purchase requirements. Incentives also played a significant role in supporting the transition to zero-emission transportation, and, as previously noted, cleaner transportation results in reduced emissions of GHGs, criteria pollutants, and toxic. The efforts also reduce the reliance on petroleum-based fuels, saving consumers money at the pump while delivering billions in benefits due to reductions in premature mortality, asthma cases, hospitalizations, and lost work and school days.

Low-Carbon Fuel Standard (LCFS)

As jurisdictions around the globe transition to electrifying the transportation sector, it is clear that liquid and gaseous fuels will continue to play a role throughout the transition for several decades, particularly for the most challenging sectors to electrify (e.g., aviation). Thus, strategies that facilitate cleaner traditional fuels, as well as investments in next-generation fuels are integral parts of the solution.

The Low-Carbon Fuel Standard (LCFS) requires a progressive reduction in the carbon intensity of transportation fuels and, in doing so, is catalyzing unprecedented investments in fuels that reduce GHG, ozone, and particulate-forming pollutant emissions, as well as a myriad of toxic pollutants, including diesel particulates. The LCFS developed and successfully implemented in California is being replicated by other states/jurisdictions due to its effectiveness. For example, the LCFS has contributed to cutting diesel fuel consumption in the state nearly in half, primarily due to replacement with renewable diesel, which has lower particulate emissions. The program is also catalyzing investments in lower carbon-intensity ethanol, renewable natural gas, renewable hydrogen, and electricity.

Building/Appliance Standards

Commercial and residential buildings rely on a broad spectrum of appliances to provide space heating and cooling, hot water, and to support cooking. The fuel source for hundreds of thousands of buildings is natural gas. The natural gas supplied to these appliances is burned in water heaters, furnaces, boilers, and stoves, resulting in emissions of ozone and particulate-forming pollutants, as well as various toxic compounds. For example, emissions from this sector are estimated to represent one third of the maximum NO-"e-missions in southern California needed to achieve the health-based national ambient air-quality standard for ozone of 70 parts per billion by 2037. Efforts to require electric appliances in new construction as well as regulatory programs and incentives that support the replacement of appliances in existing buildings with electric options can improve regional, local, and indoor air quality, as well as reduce GHGs.

#### 5.1.6. Overcoming Barriers

The section identifies elements necessary for effectively developing and implementing co-pollutant mitigation efforts. However, several barriers must be identified and overcome to successfully implement co-pollutant control programs. The barriers may differ between jurisdictions, thus requiring a focused assessment of the problem, as well as the solutions. Two common barriers that must be overcome are administrative and legal institutional norms.

As traditional air quality programs have typically been operational in many jurisdictions for decades, there is an established institutional structure with staff, managers, organization reporting structure, communications, budget, oversight, etc. As a result, climate programs are typically established as separate and distinct units from traditional air-quality programs. The climate programs may have dedicated budgets, staffing, reporting relationships, and communications that operate independently of traditional air-quality programs and do not necessarily require or sufficiently incentivize coordination with traditional air-quality programs, creating inefficiencies and missing opportunities to develop and implement strong co-pollutant proposals. A key to breaking through these common institutional barriers includes clear and consistent expectations from the highest levels of leadership that well-coordinated co-pollutant programs are a priority. These priorities must be reinforced with structural adjustments (e.g., a common director overseeing traditional pollutant and climate programs, budgets that reward co-pollutant programs, and promotions of team members with a track record of cross-department collaboration).

Another institutional barrier is related to enabling legislation and authority. Traditional air-quality programs were typically established over decades with a series of laws and directives, as well as a track record on the rulemaking process that has evolved and been optimized. The optimization process may include modifications in response to legal challenges impacting how programs are designed and documented. Climate programs are typically more recent and established with new directives, priorities, and authorities. Thus, traditional air-quality programs and climate programs are often siloed from a legal and authority perspective. This translates into programs that are designed to meet their legal authority (e.g., regulations focused on meeting criteria pollutant standards) rather than fully considering opportunities for effective and efficient co-pollutant control. Directives (e.g., new legislation/executive actions) that underscore all air quality and climate program proposals must evaluate the opportunities for co-pollutant controls, including costs and benefits, and can serve as a bridge between traditional air pollution and climate programs. In addition, identifying conflicts, inconsistencies, and collaborative opportunities with existing law can inform opportunities for legislative alignment to better deliver on efficiencies with programs that fully consider the opportunities with co-pollutant control efforts.

### 5.1.7. Recommendations

The body of evidence underscoring the adverse impacts of air pollutants and climate change on public health and the economy is overwhelming. The commitment to action at the international, national, regional, and local levels is increasing at an unprecedented rate, recognizing both the science and growing pressure to respond; this is placing strains on government and industry resources. The need to focus limited resources more efficiently is paramount for organizations interested in targeting opportunities that deliver on multiple objectives. Emission reduction strategies that address air quality, toxic pollutants, and climate change will rise in importance, as will the focus on efficient and effective identification and implementation of holistic emission reduction measures. This paper proposes principles and processes foundational to successfully identifying, developing, and implementing multipollutant emission control measures and is intended to support a range of stakeholder forums focused on developing effective, comprehensive action plans.

## 5.2. The Extension of the Environmental Public Interest Litigation Mechanism to GHGs Control

### 5.1.1. Background

Environmental public interest litigation (EPIL) is a legal tool that has been used in the United States and some European countries through public interest groups (e.g., non-governmental organizations [NGOs]) to raise litigation cases against polluters for existing or potential environmental damages. For example, NGOs have successfully blocked all proposals to build new coal power plants in the past 10 years in the United States largely through EPIL cases. As such, EPIL has been approved as a powerful mechanism in fighting environmental pollution and climate change. For example, in the past years, environmental groups have sued the U.S. EPA for giving environmental permits to coal power plants. These lawsuits claim that the U.S. EPA failed to ensure that fine particle emissions from coal-fired power plants met federal standards meant to protect public health. As a result, the suit claimed that these coal-fired power plants could proceed as originally proposed.

Starting from January 1, 2016, when the Amendment of the Environmental Protection Law came into effect, EPIL became available in China as a new environmental enforcement tool. In the past seven years, EPIL practice has played a positive role in China's environmental governance.

- Thousands of EPIL cases have been raised and **adjudicated** or settled in recent years, signalling the emergence and rapid development of EPIL in China.
- In addition to China-based NGOs, the Procuratorates have also raised many EPIL cases since 2017. In many EPIL cases raised by the Procuratorates, NGOs provided the information regarding **the** litigation cases. Collaboration between the Procuratorates and NGOs is a special feature of EPIL in China that is not seen in other countries. The active and increasing role of the Procuratorates in EPIL cases has expanded the effectiveness of EPIL and significantly enhanced environmental governance in China.
- Chinese court and environmental authorities have been working together on EPIL cases. **Based** on EPIL procedure, after receiving an EPIL case, the court should refer the case to the local environmental authority. The court may request the environmental authority to provide information about the defendant, such as Environmental Impact Assessment (EIA), discharge permit, compliance, and violation records; the environmental authority is obligated to provide such information to the court. The responsible environmental authority may investigate the defendant and impose an administrative penalty on the defendant during and after the EPIL process.
- Some EPIL cases are very significant. For example, an EPIL case in Ningxia Autonomous Region resulted in the highest penalty in the history of environmental pollution cases in China: RMB 569,000,000 for soil restoration and pollution prevention, and RMB 6,000,000 for environmental public interest funds.
- Aiming to avoid potential EPIL claims against them, many companies-including state-owned enterprises, Chinese private companies, and multinational corporations-have become more vigilant in their environmental law compliance. This has been an important driving force for companies to achieve better compliance.

**2. Key Challenges**

Despite the positive developments and results of EPIL in China, there are still many challenges to the implementation of EPIL.

- Under the current legal system in China, the scope of EPIL is narrow, and there is no clear guideline that states that GHG emissions can be targeted by EPIL. Under the current legal system in China, EPIL cases can be raised against polluters based on environmental damages that have already happened, e.g., air pollution and soil contamination. Such EPIL cases are "damage-based" causes of action. China has not established a legal mechanism or practice through which NGOs or prosecutors can raise EPIL cases against future construction projects that may be harmful to the environment and climate (e.g., the planned coal power plants).
- The grounding capacity of EPIL and environmental governance is still weak. Only a very limited number of NGOs in China have raised EPIL cases since EPIL became available in China. Generally speaking, these NGOs do not have sufficient legal or environmental expertise to raise and handle EPIL cases in the most professional manner. In addition, EPIL is new for most prosecutors, particularly at the local level.

### 5.2.3. Policy Recommendations

With the above background and challenges established, CCICED has analyzed international experiences on EPIL and the local needs to improve EPIL and would like to provide the following policy recommendations to the Chinese government.

*Expand the scope of EPIL into GHG enforcement*

To address the urgent climate challenges and improve GHG enforcement, the scope of EPIL should be expanded from environmental damage to GHG enforcement.

- The National People's Congress (NPC), the Supreme Procuratorate of China, and the Supreme Court of China should issue a regulation or interpretation document that allows NGOs and procurators to raise EPIL cases targeting GHG emissions and climate damages.
- A practical guideline to raise, adjudicate, and settle EPIL cases targeting GHG emissions and climate damages should be provided by the Supreme Procuratorate of China, and the Supreme Court of China. It is a positive signal that the Supreme Procuratorate of China issued an opinion in February 2023 that calls for better justice service on carbon peaking and neutralization.
- Training programs should be provided to local NGOs and prosecutors so that they can obtain better knowledge and experience to raise EPIL cases on GHG enforcement.

- Case studies on EPIL targeting GHG emissions and climate damages should be collected, compiled, and distributed.
- National authorities should encourage NGOs and prosecutors to raise EPIL cases related to GHG emissions and climate damages, including cases involving coal power plants that were approved by provincial authorities in recent years but have not yet started construction.

*Provide further political support to EPIL mechanisms and implementation*

Generally speaking, the Chinese government has supported EPIL in China. EPIL language has been included in the overall National Economic and Social Development Five-Year Plan approved by the NPC and other high-level government documents. That said, it is still important for the Chinese government and top political leaders to further support EPIL mechanisms and implementation.

- In high-level documents and speeches, including those issued by the Party and/or the State Counsel, EPIL should be repeatedly emphasized.
- Chinese government agencies **-particularly** those at the provincial and local levels-should recognize that environmental enforcement by administrative agencies has been historically weak; therefore, China needs a new and additional approach (i.e., EPIL) for better environmental and climate enforcement. While government officials at the national level generally support EPIL as an alternative tool of environmental enforcement, some local environmental officials may be reluctant to support EPIL cases. Internal education should be conducted to build stronger and more consistent support of EPIL by local officials.

*Establish a preventative EPIL mechanism*

To avoid potential environmental and climate damages and reduce stranded costs, EPIL should be expanded to prevent potential environmental and climate damages. It is important for China to introduce "preventative EPIL" into China's legal system and practice so that certain future construction projects can be sued by NGOs or prosecutors and therefore potentially be stopped or delayed.

- National authorities-namely the NPC, the Supreme Procuratorate of China, and the Supreme Court of China-should issue a regulation or interpretation document through which the owner or proponent of a construction project may be sued for its potential environmental or climate damages.

- If a construction project is sued as an EPIL case for potential environmental and climate damages, such a construction project should be placed on hold unless a court decision is made.
- A clear definition of "potential environmental and climate damages" should be provided so that preventive EPIL is not abused.
- International experiences, best practices, and leading cases may be introduced in designing China's preventive EPIL mechanism and operational procedures.

*Promote provincial EPIL regulations*

Currently, most EPIL regulations are promulgated by national authorities. Generally speaking, provincial authorities are not active in setting up their own EPIL regulations and implementation details. Provincial regulations of EPIL should be promoted with the following actions.

- Provincial authorities should be allowed and encouraged to set up their own EPIL implementation details in areas and subjects where no national implementation details have been provided already.
- National authorities may organize 3-5 provincial governments as pilots to draft and promulgate provincial EPIL implementation details.
- National authorities may provide a "template" of EPIL implementation details that provincial and local governments may use to improve their environmental and climate governance.

*Build better capacity for EPIL operation*

The Chinese government may make efforts to build better capacity for EPIL operations and encourage other interested stakeholders to take such capacity-building efforts.

- Chinese government authorities, such as the NPC and the Ministry of Ecology and Environment (MEE), should organize or encourage EPIL training programs targeting stakeholders that include environmental officials, lawyers, NGO representatives, and industry managers.
- The Supreme Procuratorate of China and the Supreme Court of China should establish internal training systems through which the procurators and judges are trained from time to time. EPIL should be added to such internal training programs.
- Publication and information sharing on EPIL cases and experiences should be encouraged

by all government agencies.

- Leading Chinese social organizations, such as the China Environmental Protection Foundation (CEPF), should expand their existing programs to mentor and provide grants to grass NGOs at a more meaningful scope.
- International climate foundations and environmental NGOs should be encouraged to offer grants for EPIL training, publication, and other capacity-building actions.

# Chapter 6. Gender Analysis

This chapter is devoted to analyzing and identifying gender-related issues within the coordinated management of carbon reduction, pollution reduction, green expansion, and growth. We aim to understand the roles, rights, opportunities, needs, and contributions of different gender groups in the green transformation. Through gender analysis, we can better identify the origins of inequality and address these issues by designing and implementing more equitable and effective policies, mechanisms, and services. The specific research questions proposed in this study are:

1. What gender-related issues exist in the coordinated mechanism of carbon reduction, pollution reduction, green expansion, and growth?
2. In the key areas of carbon/pollution mitigation and green transition, how can gender equality be ensured through institutional design?

Given the current lack of research on gender equality in green, low-carbon development domestically, this study plans to use a literature review to identify specific gender issues. By combining the background of domestic carbon/pollution mitigation and the status of industry transformation, we provide preliminary policy suggestions, laying the foundation for subsequent research.

## 6.1. Gender Issues in the Coordinated Mechanism of Carbon Reduction, Pollution Reduction, Green Expansion, and Growth

The impacts of climate change and air pollution are not uniformly distributed worldwide; certain social groups, such as women and children[871, are commonly and often more severely affected[88-901. On one hand, natural disasters, extreme weather events, climate change, and exposure to air pollution particularly impact the health of pregnant women and children[911, increasing the risk of malnutrition, acute respiratory infections, diarrheal diseases, low birth weight, and premature death[921. On the other hand, traditional roles and socio-economic statuses influence how different gender groups access and manage resources, leaving women and other gender minorities often in weaker positions in public domains, such as pollution control.

The issue of gender equality is often overlooked in the transition to a green economy. The 20th National Congress of the Communist Party of China proposed to achieve the construction of a Beautiful China and collaboratively promote carbon reduction, pollution control, green expansion, and growth. The "dual-carbon" goal is a new driving force for economic growth and will prompt a transformation in China's development paradigm. While this shift will significantly reduce exposure risks, it may also have effects on different social groups in other aspects: currently, there is insufficient attention and consideration given to gender issues in climate change and pollution control sectors in China_[93] There is a risk of adopting a "gender-blind" approach in the economic transformation.[94] Consequently, the new policies established during the green revolution could potentially generate long-term negative effects on women's employment, participation, work environment, and opportunities for education and training.

Globally, many international initiatives, agreements, and policies have specifically highlighted issues of gender equality and social justice. Among these, the United Nations' Sustainable Development Goals (SDGs) are perhaps the most well-known framework. SDG 5 emphasizes achieving gender equality, empowering all women and girls, and eliminating all forms of discrimination against them,[95] while SDG 10 focuses on reducing economic, political, and social inequality at both the domestic and international levels[96] The achievement of these two goals forms the foundation of all other SDGs. On the matter of climate change, the United Nations Framework Convention on Climate Change, the Paris Agreement, and the Kyoto Protocol have all firmly consolidated the importance of gender equality at multiple levels, including policy framework, execution strategies, and financial mechanisms[93]. At the same time, many countries have actively integrated gender equality into their policies and practices while promoting green growth. For instance, Sweden, when formulating environmental policies, considers the impacts on different gender groups and strives to reflect fairness in these policies. Similarly, Denmark has introduced a "gender mainstreaming" policy, emphasizing the achievement of gender equality at all levels and in all fields, ensuring that both men and women can benefit equally from green growth.

Introducing gender issues and actively practising gender mainstreaming in the process of promoting green growth are not only key strategies for improving gender equality, but also important foundations for promoting sustainable development. China has shown unique advantages in the competition for green development. Not only do we possess a firm understanding of the new development concept, but we also have strong government coordination capabilities. Moreover, we have achieved some remarkable successes in promoting social fairness, as evidenced by our strong execution and coordination skills demonstrated in the fight against poverty. Now, as we shift our focus to the coordinated advancement of carbon reduction, pollution control, green expansion and growth, it is crucial to stress the importance of gender mainstreaming. We should also take this as an opportunity to further promote and practice the concept of gender equality.

## 6.2. Gender Equality in the Green and Low-Carbon Transition of the Power and Transportation Sectors

### 6.2.1. Power Sector

The green and low-carbon transition in the power sector contributes to eliminating gender inequalities caused by air pollution and climate change, but the process could potentially lead to new inequalities. Phasing out coal-fired power and widely adopting clean energy are major steps in the low-carbon transition of the power sector. The environmental and health co-benefits these steps generate often outweigh the policy costs[9, 97-99]. The coal phaseout process can also provide new job opportunities for women, increasing their confidence, self-esteem, and financial independence[100, 101]. Some studies found that women increasingly move from private to public spheres and shift from passive roles to active ones during the transition[102], and even witnessed a reinforcement and reshuffling of gender roles[103]. However, other studies pointed out that the coal phaseout process produces varying degrees of inequality risks to women at the individual, family, community, and labour market levels[104]. For example, changes in family members' jobs can potentially cause shifts in the distribution of household chores, which necessitates that women devote more time and energy to taking on additional household responsibilities[105, 106].

Given that coal-fired electricity still accounts for around 60% of China's total power generation, decarbonizing the power sector is of utmost importance among all economic sectors undergoing a transition. Hence, diverse strategies are needed to mainstream gender, especially in regions heavily invested in the coal-fired power industry. First, female workers in the coal industry should be given due attention. In the past, men did most of the direct labour in coal-dominated energy production, but this doesn't imply that women were not affected. In fact, the downturn in the coal industry and the phaseout of coal power could significantly impact women in terms of employment, income, and family life. Therefore, specific policies should be developed during the low-carbon transition to protect the interests of female workers, such as helping them adapt to the new job market through skill training and education. Second, we need to promote gender equality in the renewable energy industry. The development of the renewable energy sector presents new opportunities for gender mainstreaming. Policies can be implemented to encourage more women to participate in the renewable energy industry, such as in the solar and wind energy sectors. At the same time, we should improve the working environment for women in these industries and protect their rights and interests. Last, it is crucial to strengthen policy research and development from a gender perspective. We need more gender-sensitive data to better understand the different impacts of the low-carbon transition on men and women and how to formulate more equitable policies. By integrating a gender perspective, we can more comprehensively consider and address various issues arising in the low-carbon transition process, thereby achieving a more equitable and inclusive energy transition.

### 6.2.2. Transportation Sector

In the green and low-carbon transition process within the transportation sector, potential gender inequality issues might arise from four areas: travel behavior, job positions, traffic safety, and traffic pollution exposure. Regarding travel behavior, studies find that women tend to travel less frequently and less distance,[1071 and they are more likely to use walking facilities[1071 and public transportation,[tosi hence producing less environmental impact[1091. However, in many cities, the availability and convenience of public transportation services are often insufficient, and walking and cycling facilities are often lacking. This disproportionately impacts low-income women, who might be forced to walk or face travel restrictions[1101, leading to inequity in mobility. In terms of employment in the transportation industry, due to gender stereotypes and industry culture, women are still underrepresented in transportation engineering and technical positions, especially in research and development and decision-making positions related to green and low-carbon technologies. Additionally, as the green and low-carbon transition progresses, certain traditionally male-dominated jobs, such as fossil fuel mining and heavy industry, may decrease, and new employment opportunities, such as the development of the renewable energy industry, may not benefit all genders equally due to educational and skill barriers. In China's trucking industry, although a portion of women participate, the vehicle configuration and industry measures are mainly designed for male workers and lack support for female workers. Third, women's travel safety has long been an issue, especially in terms of public transportation. If public transportation systems do not sufficiently consider gender differences, it may make women feel unsafe during their travels (such as commuting). Harassment, both verbal and behavioural, often occurs whether on public transport, waiting for transportation, or walking on the streetsY11-113l Some studies suggest adding a "women's carriage" design in public transportation,[1141 while others believe that it is necessary to strengthen moral training and awareness and establish strict rule enforcement mechanisms to curb harassment.[It IJ Furthermore, a study suggests improving the "walkability" of cities by creating excellent walking conditions and facilities to promote inclusiveness and equalityY151 Last, women are more likely to choose slow modes of transportation, such as walking, cycling, e-bikes, and public transportation, exposing them more to exhaust pollution from motor vehicles, which poses higher potential risks to respiratory and cardiovascular health. Pregnant women exposed to exhaust pollution may risk adverse health effects for both the mother and the fetus.

To mainstream gender in the low-carbon transition of the transportation sector, we need to take action at multiple levels, including policy, planning, and practice. First, at the policy level, we need to ensure that all transportation and environmental policies take gender differences into account and develop specific measures based on this foundation. For instance, improving public transportation services and pedestrian and bicycle facilities would support women's low-carbon travel modes. Second, in terms of green employment, we should enhance women's skills and knowledge through education and vocational training, enabling them to find work in the emerging green transportation industry. Furthermore, at the planning level, we must ensure that city and transportation planning adequately consider the needs and interests of all genders, particularly in terms of public transportation and non-motorized travel facilities. In addition, we need to enhance women's representation and influence in transportation planning and decision making through public participation and social dialogue. Finally, at the practical level, we must boost women's leadership and influence in various ways, shattering gender stereotypes and elevating women's roles and status in the green, low-carbon transition. Specific measures could include providing leadership training, promoting professional networks and mentoring systems, and increasing the proportion of women in critical decision-making positions.

## 6.3. Gender Strategies in Collaborative Management

In summary, as China works to reduce carbon, decrease pollution, expand green development, and stimulate growth, gender mainstreaming is indispensable due to the varied impacts policy formulation and implementation often have on different genders. Gender equality in the green transition can be promoted from the following three perspectives.

**Establish scientific research plans, conduct continuous research, and provide periodic feedback**

A medium- to long-term research plan should be developed to track and thoroughly investigate the development of gender mainstreaming in our country's green transition process, providing a scientific basis for policy-making and improvement. The first step of the research plan should start with a literature review and setting research objectives to establish a solid theoretical foundation and clarify the direction of the study. The second step involves a deep analysis of the impacts of green low-carbon transition policies on both men and women, furthering our understanding of the specific roles of gender factors in the green transition process through case studies. The third step is to try to quantify the impacts of green transition policies on men and women through quantitative analysis, and based on existing analysis results, propose preliminary gender-sensitive policy suggestions. The fourth step could involve expert interviews and focus group discussions to gather more firsthand data and in-depth insights, further optimizing our policy recommendations. The fifth and final step is to compile the final research report and disseminate the research findings and policy recommendations to relevant decision-makers and stakeholders, serving as a reference for advancing gender mainstreaming in China's green low-carbon transition. This research process should continuously track specific industry situations and form a periodic feedback mechanism, providing timely advice to policy-makers and promoting gender equality in the green transition.

**Addressing universal gender issues while considering unique industry challenges**

In the green and low-carbon transition of various industries, there exist both universal gender issues and unique sector-specific challenges. Therefore, it is important to distinguish between these in problem identification, research methodology determination, and policy design. Universal measures should include the implementation of gender-responsive budgeting, where financial resource allocation takes gender impacts into account, thus reflecting fair treatment of the needs of both men and women. Gender indicators should be incorporated in the execution and evaluation of policies. In employment and skills training within relevant industries, there should be an increase in support and encouragement for women. Additionally, women's participation in decision-making should be amplified. For specific industries, for instance, during the phasing out of coal power, special attention should be given to unique issues in regions with a high concentration of coal (or coal power) industries, such as changes in the distribution of household chores or the emergence of gender discrimination due to job changes. In the transportation sector, there is a need to specifically address previously overlooked gender inequality issues in the transformation process, such as improving the inclusivity, accessibility, safety, and flexibility of public transportation and facilities for women.

**Learn from international practices, summarize our own experiences, and promote international communication**

In the early stage of promoting gender mainstreaming, it is essential to continuously learn from exemplary international practices and successful cases, setting a positive trajectory for promoting gender equality in China. At the same time, China can share its own experiences and achievements in advancing gender equality and social justice on a global scale. For example, China's poverty alleviation results, particularly the strides made in promoting gender equality and women's development, have received widespread recognition. Our successful experiences, such as encouraging and supporting rural women's participation in sustainable industries and actively tapping into women's potential in ecological protection, provide a significant demonstration of the global objectives of green growth and gender equality. Finally, as a major player on the global stage, China need to display responsibility and commitment. This not only requires China to make firm commitments in addressing climate change but also to actively drive the realization of gender equality. China should strive to foster international communications, influencing global policy-making, legislative processes, and the signing of related agreements by participating in them, thus advancing global environmental action and the progress of gender equality.

# Chapter 7. Policy Recommendations

## 7.1. Green Growth

- O **Carbon** neutrality is a major opportunity for China, and the dual-carbon goal is becoming a new driving force for China's economic growth. China must set visionary goals and develop strong programs, especially in the energy sector, to see that the goals are met.
- O The "1+N framework provides an excellent basis for building a comprehensive strategy. It must be followed by detailed plans, organized around a healthy race to the top, and supported with detail at the provincial and municipal level.
- O Controlling both conventional pollution ($NO_X$, $PM_{2.5}$, $SO_X$, and other particulates at the same time as the GHGs of $CO_2$, $CH_4$, and $N_20$) can save vast sums of money and steer investments to far better choices.
- O In its great progress in renewable energy investment and NEV development, China benefits the world by providing supply and lowering technology costs. The work to push important technologies down the learning curve offers broad and rapid returns. China should identify ever more realms where it can lower the cost of key technologies (and practices)-including, for example, industrial heat pumps, green steel, concrete, petrochemicals, more EVs, and so forth.
- O Besides advances in the economy and standards of living, co-control of conventional pollutants and GHGs will spur better health and livability.
- O Almost all of this can be wrapped up in a carefully designed mix of performance standards, sector-specific goals, and economic signals that can drive rapid environmental improvements while making new markets for advanced goods and services.

## 7.2. Cross-Sectoral Opportunities

- O The essence of our recommendations in this SPS is that China can reap vast health, economic, and environmental benefits from smart advances in policy. It is far less expensive to solve conventional pollutants together than apart: new buildings, for example, should entail quality construction (circular economy), be ultra-efficient, be heated and cooled and supplied with hot water from heat pumps, and use clean electricity for their power.

O In the early days, financial incentives can drive this four-part (economy, environment, health, and climate change) set of benefits. As prices drop and markets grow, high-performance buildings should get mandated by an advanced building code. Build once, build right, and reap forever.

O A synchronized administrative system requires the following:
- A robust technical foundation of data and analysis
- Clear and measurable targets
- Ongoing monitoring and vigorous enforcement
- Comprehensive plans that prioritize and measure deployment
- Increased capacity and expertise to develop and implement measures
- Thorough and accurate measurement and reporting

Important steps include:

O Developing a regulatory system and plans that simultaneously drive higher reliability and lower use of coal.

O Phasing down coal consumption and steadily and rapidly increasing the proportion of clean energy.

O Restricting enterprises with serious pollution and energy consumption, reducing excessive production capacity, and paying attention to source control.

O Promoting the pollution control of agricultural surface and dust sources.

O Expanding the scope of EPIL into GHG enforcement, providing further political support to EPIL mechanism and implementation, establishing preventive EPIL mechanism, promoting provincial regulations of EPIL, and building better capacity for EPIL operation.

## 7.3. Power

Clean electricity is at the heart of co-control. This requires leaders to:

O Ensure that there are no electric power shortages: reliability, affordability, and low- to zero-carbon must be achieved together. There are many examples of how to achieve all three.

- O Design a comprehensive coal phasedown strategy that takes account of technical attributes, profitability, stranded assets, health impacts, and environmental equality to realize the cost-optimal energy system transition from coal power to renewables.
- O Accelerate the flexibility modification of remaining coal power plants to improve the ability to accommodate the high penetration of variable wind and solar energies and to satisfy the requirement of peak load regulation.
- O Continue to focus on implementing economic dispatch, focusing on competitive exposure for less efficient coal plants.
- O Continue expanding electric system reliability obligations from the provincial scale to the regional scale, reducing the incumbent coal advantage and creating more opportunities for efficiency and faster renewable energy deployment.
- O Set newer, more ambitious clean energy deployment standards and storage deployment targets.
- O Change market structures to maintain much of the existing coal fleet as backup for reliability services, without also requiring them to dispatch a certain amount. Consider developing reliability reserve products if necessary.
- O Collaborate with other leading grid operators in other countries and implement best-practice modelling to better compare the reliability contributions of all types of resources.

## 7.4. Transportation

- O Keep up the transition to EVs. Make sure that vehicle manufacturers have a clear public and market signal to continue to switch to electrics; set charging station goals and assign responsibility; invest in R&D to develop ever-better battery chemistries.
- O Heavy-duty vehicles will require a smart mix of incentives, fleet requirements, and technological development. This pursuit is a top priority.
- O With fleet electrification, decarbonization in the transportation sector ties to the carbon intensity of the electricity grid. To further reduce emissions in the future, it is necessary to efficiently use sustainable power through measurements like coordinated charging.
- O Establish clear, ambitious long-term targets for NEV HDT deployment(% NEVs in HDT sales: 45% by 2030, 75% by 2035, 100% by 2040), and help meet them by
    - Establishing a NEV HDT sales standard

- Continuing to refine and expand China's existing portfolio approach, recognizing the necessity of a multitude of instruments to optimally manage the transition. Defining these NEV policies and the specific long-term NEV targets for heavy-duty vehicles will increase certainty and clarity on future market conditions, spurring greater investment, supporting supply chain development, and stimulating additional innovation.

O Update the vehicle fleet and optimize transportation methods

O Ensure cities are designed to:

- Support fast, reliable public transit
- Have a rich network of physically protected bikeways
- Have ample room for pedestrians on shaded walkways
- Make a "15-minute city" a reality for most Chinese
- New urban developments should follow the "Emerald Cities" principles, building a safe, pleasant, and efficient lifestyle.

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# Acknowledgments

We are immensely grateful to the China Council for International Cooperation on Environment and Development (CCICED) for spearheading and supporting this Special Policy Study on the topic of "Collaborative Mechanism for Carbon Reduction, Pollution Reduction, Green Expansion, and Growth," which provided a platform for extensive discussions and exchanges between Chinese and international experts.

Special thanks go to Mr. Liu Shijin, the Chinese Chief Advisor; Mr. Scott Vaughan, the International Chief Advisor; Dr. Knut Alfsen, the Supporting Expert of the Chief Advisor; as well as Mr. Sun Zhen, Director General of the Department of Climate Change Response of the Ministry of Ecology and Environment (MEE); Mr. Wang Feng, Director General of the Department of Atmospheric Environment of the Ministry of Ecology and Environment (MEE); and Mr. Feng Xiangzhao, Researcher of the Saidi Research Institute of the Ministry of Industry and Information Technology (MIIT), for their invaluable advice and suggestions throughout this research project.

We extend our heartfelt appreciation to the advising experts of the research group for their invaluable guidance and counsel. Additionally, we would like to express our gratitude to Professor Zhang Shiqiu of the College of Environmental Science and Engineering, Peking University; Director Hu Tao of the Hushi Sustainable Development Research Association; Senior Program Director Gong Huiming of the Energy Foundation China Transportation Program; Ms. He Hui, Director of the China Program of the International Council on Clean Transportation (ICCT); Mr. Felipe Rodriguez, Managing Director of the European Union Program of the International Council on Clean Transportation (ICCT); and Professor Lin Jiang of University of California, Berkeley， for their meticulous review of the report and their constructive suggestions during the project discussions. Special recognition goes to Kristine St-Pierre, Specialist at the International Support Office, for her exceptional guidance on gender issues. We also want to extend our thanks to Mr. Zhang Huiyong, Director; Ms. Liu Kan, Deputy Director; and Ms. Tang Huaqing of the CCICED Secretariat, as well as Ms. Wang Meizhen of the CCICED Secretariat International Support Office for their outstanding organizational and coordinating support throughout this project.