

# 2025

## 中国碳中和与清洁空气协同路径年度报告 Synergetic Roadmap on Carbon Neutrality and Clean Air for China

从“十四五”到“十五五”：深化协同治理  
From the 14<sup>th</sup> to the 15<sup>th</sup> FYP: Deepening Synergetic Governance

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Synergetic Roadmap on Carbon Neutrality and Clean Air for China (2025)

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# 2025

## 执行摘要 EXECUTIVE SUMMARY

# 执行摘要

## Executive Summary

中国碳中和与清洁空气协同路径年度报告（2025）

Synergetic Roadmap on Carbon Neutrality and Clean Air for China (2025)

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### 执行摘要 Executive Summary

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# 01 中国“十四五”降碳减污协同治理进展

## PROGRESS IN CHINA'S SYNERGETIC GOVERNANCE OF THE REDUCTION OF POLLUTION AND CARBON EMISSIONS DURING THE 14<sup>TH</sup> FIVE-YEAR PLAN PERIOD

### ► INDICATOR:

空气污染治理成效显著，碳排放强度持续下降

Remarkable achievements have been made in air pollution control, and the intensity of carbon emissions has declined continuously

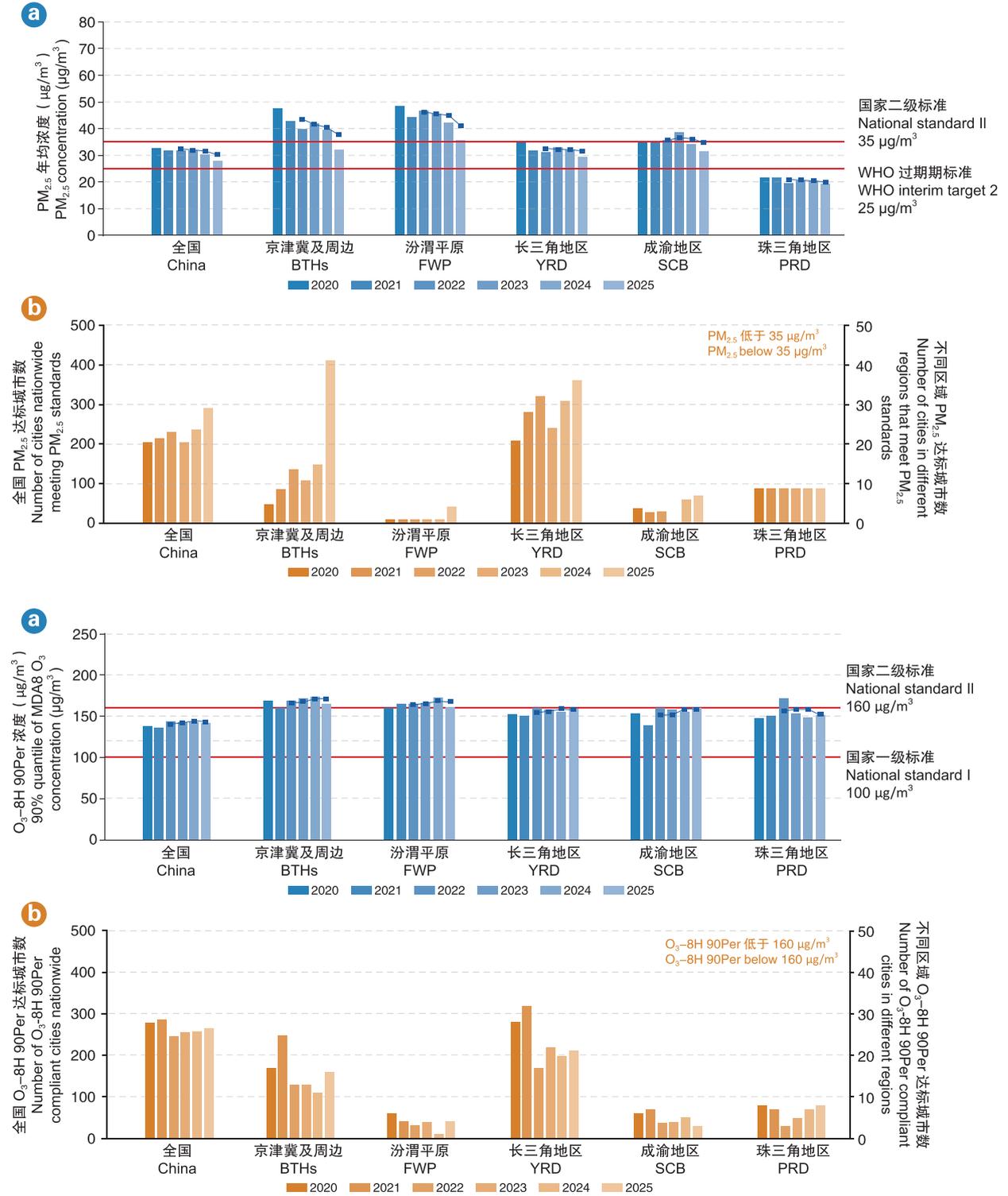
截至 2025 年 9 月，全国 339 个地级及以上城市 PM<sub>2.5</sub> 平均浓度为 27.9 μg/m<sup>3</sup>，低于国家空气质量二级标准（35 μg/m<sup>3</sup>），仍高于世界卫生组织（WHO）第二过渡期标准（25 μg/m<sup>3</sup>），较 2020 年（33 μg/m<sup>3</sup>）下降 15.4%，京津冀及周边和汾渭平原下降浓度最为明显，相比 2020 年分别下降 32% 和 27%，全国及各个重点区域的 PM<sub>2.5</sub> 年均浓度的三年滑动呈现持续下降，显示出“十四五”阶段大气污染防治措施取得了较显著的成绩。2025 年 PM<sub>2.5</sub> 年均浓度低 35 μg/m<sup>3</sup> 的城市数量为 290 个，比 2020 年多 86 个，其中京津冀及周边标城市数增加最明显（增加 36 个）。2020 年到 2025 年，全国 339 个地级及以上城市 PM<sub>2.5</sub> 重度及以上污染天数得到了有效的治理。从 2020 年的 1.1% 下降到 2025 年（1-9 月）的 0.6%。重点区域中，京津冀周边和汾渭平原下降最为明显，2025 年相比 2020 年分别下降了 3% 和 1.8%。珠三角地区近六年未出现 PM<sub>2.5</sub> 重度及以上污染。从 2020 年到 2025 年，全国气象条件评估指数呈下降趋势，表明气象条件总体有利于 PM<sub>2.5</sub> 浓度的降低。重点区域中除了长三角气象条件的变化利于 PM<sub>2.5</sub> 增加外，其余区域，尤其是京津冀及周边以及汾渭平原，气象条件的变化利于 PM<sub>2.5</sub> 浓度的降低。

As of September 2025, the average concentration of PM<sub>2.5</sub> in 339 prefecture-level and above cities across the country was 27.9 μg/m<sup>3</sup>, which was lower than the China's National Standard (35 μg/m<sup>3</sup>), but still higher than the WHO interim target 2 (25 μg/m<sup>3</sup>). Compared with the concentration in 2020 (33 μg/m<sup>3</sup>), it decreased by 15.4%. The concentration in the Beijing-Tianjin-Hebei region and its surrounding areas as well as the Fenwei Plain decreased most significantly, by 32% and 27% respectively compared with 2020. The annual average concentration of PM<sub>2.5</sub> across the country and in various key regions showed a continuous downward trend over the past three years, indicating that remarkable achievements were made with air pollution prevention and control measures during the 14<sup>th</sup> Five-Year Plan period. In 2025, there were 290 cities with an annual average PM<sub>2.5</sub> concentration below 35 μg/m<sup>3</sup>, with an increase of 86 cities compared with 2020, and most of them were cities in the Beijing-Tianjin-Hebei region and its surrounding areas (an increase of 36 cities). From 2020 to 2025, the number of days with heavy or worse PM<sub>2.5</sub> pollution was effectively controlled in 339 prefecture-level and above cities across the country. The figure dropped from 1.1% in 2020 to 0.6% in 2025 (January-September). Among key regions, the Beijing-Tianjin-Hebei region and its surrounding areas as well as the Fenwei Plain witnessed the most significant decline, with a 3% and 1.8% drop respectively in 2025 compared with 2020. There were no heavy or worse PM<sub>2.5</sub> pollution in the Pearl River Delta region in the past six years. From 2020 to 2025, the national meteorological condition assessment index showed a downward trend, indicating that meteorological conditions were generally conducive to the reduction of PM<sub>2.5</sub> concentration. Among key regions, except the Yangtze River Delta

Fig. 1

2020 年至 2025 年全国及重点区域年均  $PM_{2.5}$  与  $O_3$  浓度 (柱状) 以及三年滑动平均浓度 (黑色点线) 变化趋势

The changing trends of the annual average  $PM_{2.5}$  and  $O_3$  concentrations (columnar) and the three-year moving average concentrations (black dotted lines) across the country and in key regions from 2020 to 2025



where the changes in meteorological conditions were conducive to the increase of PM<sub>2.5</sub>, the changes in meteorological conditions in other key regions, especially in the Beijing-Tianjin-Hebei region and its surrounding areas as well as the Fenwei Plain, were conducive to the reduction of PM<sub>2.5</sub> concentration.

2020年至2025年全国城市大气O<sub>3</sub>浓度呈波动态势。2025年1-9月O<sub>3</sub>日最大8小时平均值第90百分位数(O<sub>3</sub>-8H-90Per)年平均浓度为141 μg/m<sup>3</sup>,比2020年(138 μg/m<sup>3</sup>)多2.2%。但低于2022-2024年的波动值,开始出现下降的趋势,其中珠三角地区下降趋势最为明显。2025年1-9月O<sub>3</sub>-8H-90Per平均浓度低于160 μg/m<sup>3</sup>的城市数量为265个,虽然相比2020年(279个)有所下降,但是相比2024年(256个)所有增加。由此可见“十四五”期间臭氧污染仍呈现波动态势,臭氧污染控制尚未进入稳健下降通道。2025年全国臭氧气象条件评估指数相对2020上升1.2%,表明气象条件整体利于全国臭氧浓度上升,并且重点区域中气象条件的变化均利于臭氧浓度的上升。

From 2020 to 2025, the concentration of atmospheric O<sub>3</sub> fluctuated in cities across the country. From January to September 2025, the annual average concentration of O<sub>3</sub>-8H-90Per was 141 μg/m<sup>3</sup>, which was 2.2% higher than that in 2020 (138 μg/m<sup>3</sup>). However, the value was lower than the fluctuating values in 2022-2024, and a downward trend began to emerge, with the most pronounced decline in the Pearl River Delta region. From January to September 2025, there were 265 cities with the average concentration of O<sub>3</sub>-8H-90Per below 160 μg/m<sup>3</sup>. Although this number was less than that in 2020 (279 cities), it increased compared with 2024 (256 cities). It can be seen that during the 14th Five-Year Plan period, ozone pollution still showed a fluctuating trend, and ozone pollution control was not yet steadily on the way down. In 2025, the national ozone meteorological condition assessment index rose by 1.2% compared with 2020, indicating that the meteorological conditions were generally conducive to the increase of ozone concentration in the whole country, and the changes in meteorological conditions in key regions were conducive to the increase of ozone concentration.



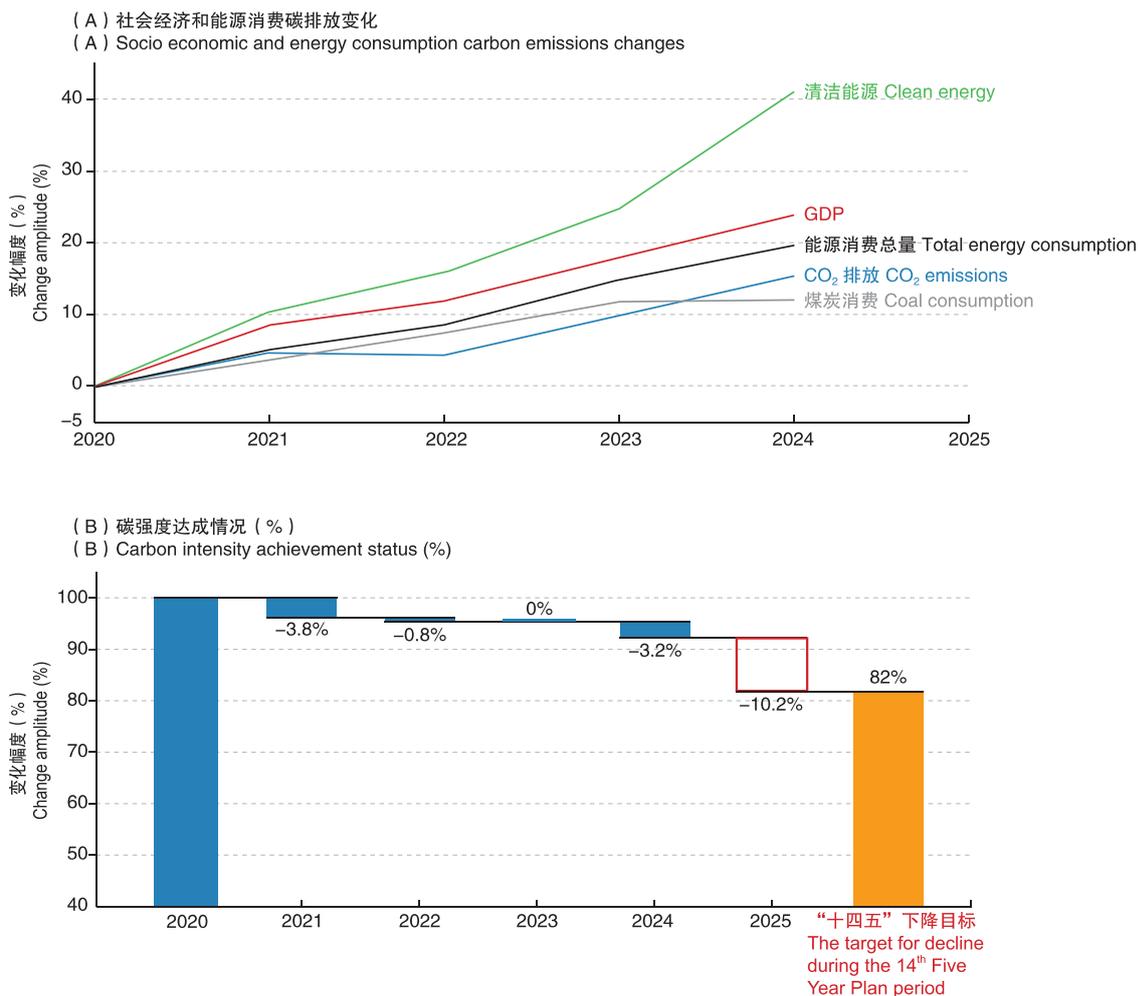
“十四五”期间，推动减污降碳协同增效已经成为我国生态文明建设的重点战略方向。为达成节能降碳目标，我国严格实施煤炭消费总量控制，积极推进清洁能源替代。期间，能源消费总量增速已经显著低于国内生产总值增速，清洁能源消费大幅增长40.9%，煤炭消费增速放缓并在2024年出现下降趋势。至2024年，中国碳强度（单位GDP二氧化碳排放量）相较于2020年累计下降幅度约为7.8%。

During the 14th Five-Year Plan period, making efforts to synergize the reduction of pollution and carbon emissions became the key strategic direction of China's ecological civilization construction. To achieve the goals of energy conservation and carbon reduction, China strictly implemented the control of total coal consumption and actively promoted the clean energy substitution. During this period, the growth rate of total energy consumption was significantly lower than that of gross domestic product (GDP), and clean energy consumption increased by 40.9%, while the growth rate of coal consumption slowed down and showed a downward trend in 2024. As of 2024, China's carbon intensity (carbon dioxide emissions per unit of GDP) cumulatively decreased by about 7.8% compared with 2020.

Fig. 2

2020–2024 年期间中国社会经济发展情况和碳强度达成情况

Socio-economic development and carbon intensity attainment in China in 2020-2024



中国陆地碳汇在“十四五”期间总体保持稳定，年际增长速率略有放缓，年均净碳汇估算为  $0.28 \pm 0.05 \text{ Pg C yr}^{-1}$ ，这一规模约抵消了超过 10% 的人为二氧化碳排放量。当前，土地利用和覆盖变化已成为推动我国陆地碳汇增长的首要驱动力。在 2001 - 2020 年期间，土地利用变化贡献的年均陆地碳汇达到约  $0.14 \text{ Pg C yr}^{-1}$ ，主要来源于生态工程推动下的森林面积扩张，以及大面积新造林进入快速生长阶段所带来的碳汇积累。

During the 14th Five-Year Plan period, China's terrestrial carbon sinks remained stable on the whole, with a slightly slower interannual growth rate. The annual average net carbon sinks were estimated to be  $0.28 \pm 0.05 \text{ Pg C yr}^{-1}$ , which offset more than 10% of anthropogenic carbon dioxide emissions. At present, LUCC (land use and cover change) has become the primary driving force to promote the growth of terrestrial carbon sinks in China. During the period from 2001 to 2020, the annual average terrestrial carbon sinks contributed by land use change reached approximately  $0.14 \text{ Pg C yr}^{-1}$ , which mainly came from the expansion of forest area driven by ecological engineering and the accumulation of carbon sinks brought about by the rapid growth of large-scale new forests.

《打赢蓝天保卫战三年行动计划》收官后，“十四五”期间我国虽面临末端控制潜力收窄的挑战，但主要大气污染物排放量总体仍能保持下降态势。其中，工业部门工艺过程的碳污协同减排成效尤为突出，能够在多数省份实现了  $\text{CO}_2$  排放与  $\text{PM}_{2.5}$  污染改善正协同效益。这一成效主要得益于重点工业行业的产业结构调整以及高耗能产品市场需求与供给的同步回落。

After the closing of the Three-Year Action Plan for Winning the Blue Sky Protection Campaign, although China faced the challenge of narrowing potential for end-of-pipe control during the 14<sup>th</sup> Five-Year Plan period, the emissions of main atmospheric pollutants still maintained a downward trend on the whole. In this context, the industrial sector achieved particularly remarkable results in the synergetic reduction of carbon emissions and pollution in the technological processes, and thus positive synergetic benefits of reducing  $\text{CO}_2$  emission and  $\text{PM}_{2.5}$  pollution were realized in most provinces. These results are mainly attributed to the adjustment of industrial structure in key industrial sectors and the simultaneous decline in market demand for and supply of energy-intensive products.



► INDICATOR:

治理体系不断完善

The governance system has been constantly perfected

协同推进降碳、减污、扩绿、增长已经成为中国式现代化建设的基本要求。2024年,《中共中央关于进一步全面深化改革、推进中国式现代化的决定》进一步强调协同推进降碳、减污、扩绿、增长是完善生态文明制度体系、深化生态文明体制改革的重要组成部分;《关于加快经济社会发展全面绿色转型的意见》也重申了2030年和2035年减污降碳协同增效的重要目标。通过完善制度体系、投放政策工具、推动地方实践,碳中和和清洁空气协同工作在我国取得显著进展。The coordinated advancement of carbon reduction, pollution reduction, green expansion and economic growth has become a fundamental requirement for modernization with Chinese characteristics. In 2024, the Decision of the Central Committee of the Communist Party of China on Further Comprehensively Deepening Reform and Promoting Modernization with Chinese Characteristics further emphasized that the coordinated advancement of carbon reduction, pollution reduction, green expansion and economic growth is an important part of perfecting the ecological civilization system and deepening the reform of ecological civilization system; and the Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development also reaffirmed the important goal of synergizing the reduction of pollution and carbon emissions for 2030 and 2035. By perfecting the institutional system, deploying policy tools and promoting local practices, China has made significant progress in the efforts to synergize carbon neutrality and clean air.

在制度体系方面,生态环境部自2021年以来,从加强源头治理、系统治理、整体治理的角度出发,在生态环境分区管控和重点行业排放控制等方面,提出协同控制大气污染物和温室气体的要求。2024年组织完成11个省90个城市融合清单的编制工作,为推动大气污染物和温室气体排放的精细化解析、支撑精准高效的碳污协同管理打下基础。In terms of institutional system, since 2021, the Ministry of Ecology and Environment has put forward the requirements on coordinated control of atmospheric pollutants and greenhouse gases in aspects such as ecological environment zoning control and emission control in key industries from the perspective of strengthening at-source treatment, systematic treatment and overall treatment. In 2024, the compilation of the integrated list of 90 cities in 11 provinces was completed, thus laying a foundation for promoting the refined analysis of the emissions of atmospheric pollutants and greenhouse gases and supporting precise and efficient systematic management of carbon emissions and pollution.

在治理政策方面,中国不断推进行政管理、经济激励、社会参与三个领域的政策工具逐步完善。通过出台省级减污降碳协同增效工作方案、制定50余项减污降碳协同增效相关标准基本构建了“自上而下”全面推进的协同治理局。碳市场从初期的探索运行,迈向法治化、规范化、体系化的新阶段。碳普惠、信息披露等社会治理机制进一步健全,绿色低碳治理的全民参与体系逐步深化。

In terms of governance policies, China has constantly promoted the gradual perfection of policy tools in three areas, namely administrative management, economic incentives and social engagement. A synergetic governance situation for "top-down" all-round advancement has been basically established through the introduction of provincial-level work plans for synergizing the reduction of pollution and carbon emissions and the formulation of more than 50 relevant standards for synergizing the reduction of pollution and carbon emissions. From the initial exploration and operation, the carbon market has moved towards a new stage of legalization, standardization and systematization. The social governance mechanisms such

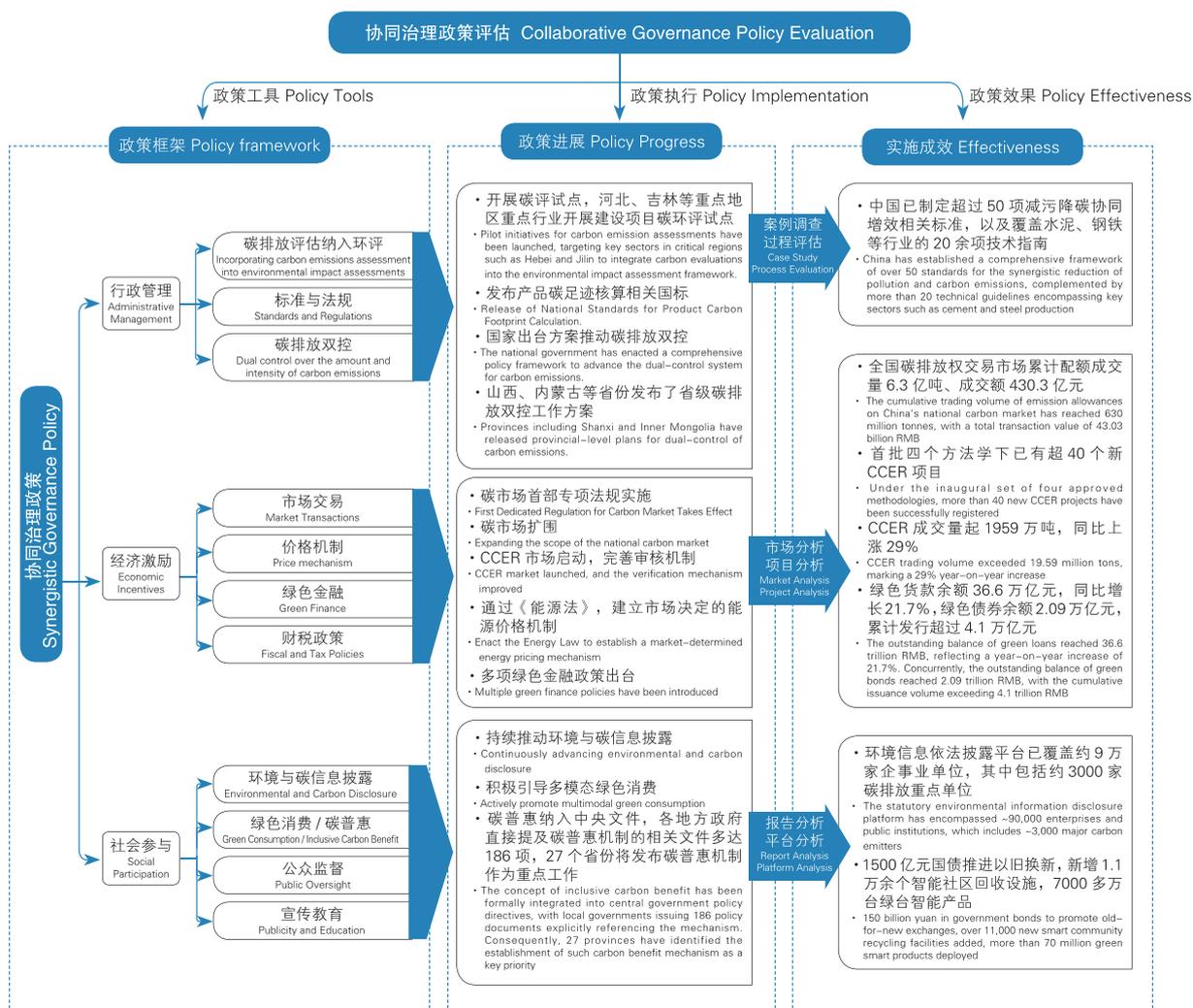
as inclusive carbon benefit and information disclosure have been further improved, and the system for participation by all people in green and low-carbon governance has been gradually deepened.

在地方实践方面，生态环境部组织 21 个不同类型的城市和 43 个园区开展了减污降碳协同创新试点工作，产生了一批典型案例。全国有 71 个城市实现了 PM<sub>2.5</sub> 年均浓度达标和 CO<sub>2</sub> 排放显著达峰，约占全部城市的 21%。In terms of local practice, the Ministry of Ecology and Environment has organized 21 cities of different types and 43 parks to launch innovative pilots for synergizing the reduction of pollution and carbon emissions, thus generating a number of typical cases. A total of 71 cities across the country have attained annual average concentration standard of PM<sub>2.5</sub> and a significant peak in CO<sub>2</sub> emissions, accounting for approximately 21% of all cities.

Fig. 3

中国的减污降碳协同治理政策框架

China's policy framework for synergetic governance of the reduction of pollution and carbon emissions



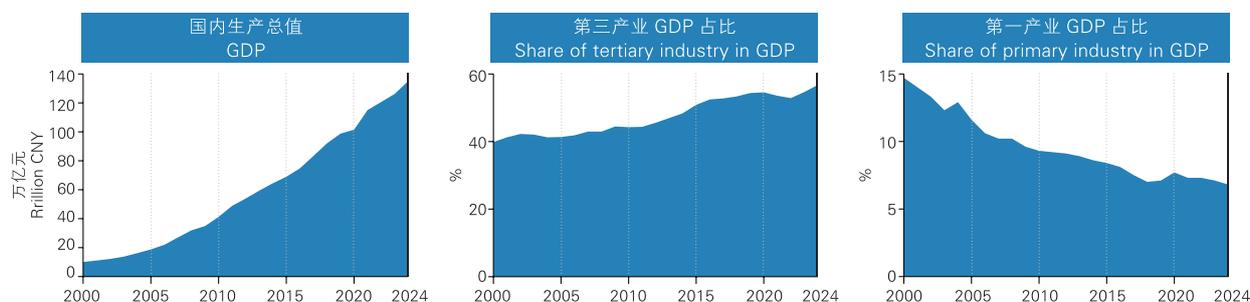
► INDICATOR: **结构转型促进降碳减污协同**  
**Structural transformation has promoted the synergetic reduction of carbon emissions and pollution**

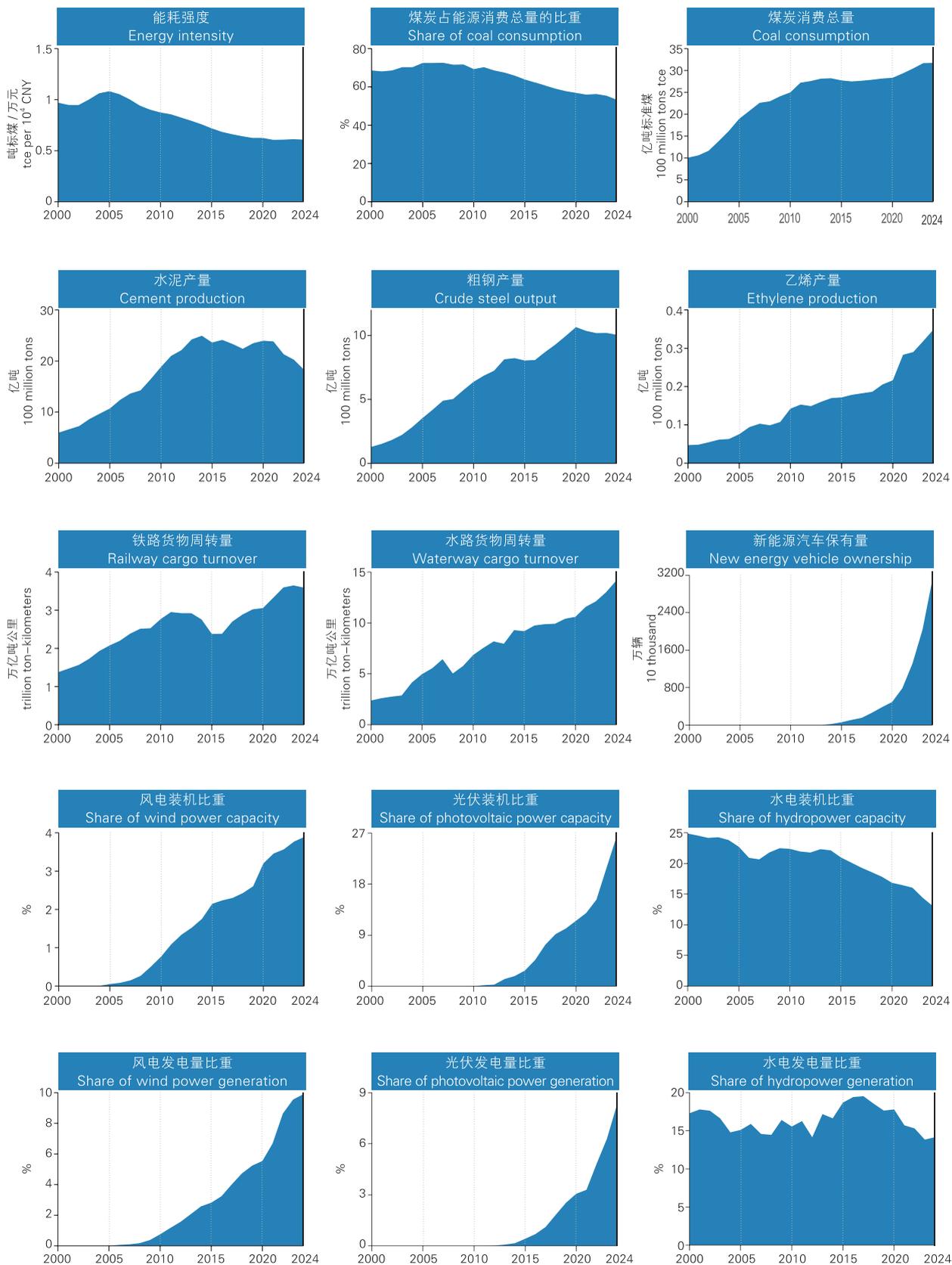
2024 年能源结构转型提质增速。能源和电力消费快速增长，同比增长 4.3%、6.8%。化石能源消费趋势分化，煤炭消费增速放缓至 1.7%，新增煤电核准装机同比减少 41.5%，是“十四五”以来首次下降，石油消费达峰趋势显现，天然气消费则保持 7.3% 的较快增长。非化石能源消费占比首次超越石油上升至 19.8%，发生历史性转变。能效提升速度较“十四五”前三年有所回升。新能源已成为新增装机主体，2024 年新能源装机占全国总装机的 42%，首次超越火电成为第一大电源。风电和太阳能发电累计装机达到 14.1 亿千瓦，提前六年实现 2030 年目标。在全球层面，中国清洁能源投资占全球近 40%，风光新增装机占全球 75%，是全球能源转型的重要推动力。

In 2024, the transformation of energy structure was upgraded in quality and accelerated in speed. Energy and electricity consumption grew rapidly, with a year-on-year increase of 4.3% and 6.8% respectively. The trends of fossil energy consumption became differentiated. The growth rate of coal consumption slowed down to 1.7%, and the approved newly-installed capacity for coal-fired power generation decreased by 41.5% on a year-on-year basis, marking the first decline since the 14th Five-Year Plan period. The trend of oil consumption peaked, while natural gas consumption maintained a relatively rapid growth of 7.3%. The proportion of non-fossil energy consumption surpassed that of oil for the first time and rose to 19.8%, marking a historic shift. Compared with the first three years of the 14th Five-Year Plan period, the pace of energy efficiency improvement picked up. New energy took the dominant position in newly-installed capacity for power generation. In 2024, the installed capacity for new energy power generation accounted for 42% of the total installed capacity in China, thus surpassing thermal power for the first time to become the largest power source. The cumulative installed capacity for wind and solar power generation reached 1.41 billion kilowatts, thus achieving the 2030 goal six years ahead of schedule. At the global level, China's investment in clean energy accounted for nearly 40% of the world's total, and its newly-installed capacity for wind and solar power generation accounted for 75% of the world's total, which was an important driving force for global energy transition.

**Fig. 4**

**2020–2024 年中国结构转型进展**  
**Progress of structural transformation in China in 2020-2024**





2024 年我国产业结构持续优化，在培育新动能、推动绿色低碳转型和制造业数字化高端化方面取得显著进展。战略性新兴产业加速壮大，高技术制造业增加值增长 8.9%，新能源汽车、锂电池、光伏等“新三样”出口突破万亿元，成为推动经济增长的新引擎。重点行业节能降碳与循环利用稳步推进，全国重点行业单位能耗同比下降 2.5%，绿色制造体系进一步完善。制造业数字化、智能化水平显著提升，关键工序数控化率达 72%，质量基础持续增强。国际上，全球绿色低碳和数字化转型同步加快，中国在电动汽车和光伏领域保持领先，为构建现代化产业体系、提升国际竞争力提供了有利环境和坚实支撑。

China's industrial structure maintained an on-going optimization in 2024, and significant progress was made in fostering new growth drivers, promoting green and low-carbon transformation, and advancing the digitalization and high-end development of manufacturing industry. Strategic emerging industries grew at an accelerated pace; the added value of high-tech manufacturing industry increased by 8.9%, and the exports of "new three types"—new energy automobile, lithium batteries and photovoltaic power—exceeded RMB one trillion Yuan, thus becoming new engines to drive the economic growth. Energy conservation, carbon emission reduction and recycling were steadily promoted in key industries; the unit energy consumption of key industries nationwide decreased by 2.5% on a year-on-year basis; and the green manufacturing system was further perfected. The digitalization and intelligence levels of the manufacturing industry were significantly enhanced, with the numerical control rate of key processes reaching 72%, and the quality foundation was continuously strengthened. Internationally, green, low-carbon and digital transformations were accelerating simultaneously worldwide; and China maintained a leading position in the fields of electric automobile and photovoltaic power, thus providing a favorable environment and solid support for building a modern industrial system and enhancing its international competitiveness.

交通领域绿色转型成效显著，结构性减排与终端脱碳协同推进。2024 年铁路货运量占比提升至 9.1%，水路占比 17.3%，多式联运量增长 15.6%；城市轨道交通客运量达 322 亿人次，铁路旅客发送量同比增长 11.9%。清洁装备推广提速，新能源汽车保有量达 3140 万辆，新能源乘用车销量占比达 48.9%；充电桩总数超 1280 万台，高速服务区覆盖率达 98%。铁路电气化率稳定在 75% 以上，岸电使用逐步常态化。这些成就为落实新 NDC 目标奠定了坚实基础，展现了交通系统在实现“双碳”目标中的关键作用。

Remarkable results have been achieved in the green transformation of transport sector, and structural emission reduction and end-of-pipe decarbonization have been promoted synergistically. In 2024, the proportion of railway freight volume increased to 9.1%, that of waterways accounted for 17.3%, and that of multimodal transport increased by 15.6%; the passenger volume of urban rail transit reached 32.2 billion person-times, and the number of railway passengers increased by 11.9% on a year-on-year basis. The promotion of clean equipment was accelerated, with the ownership of new energy vehicles reaching 31.4 million and the sales proportion of new energy passenger vehicles accounting for 48.9%; the total quantity of charging piles exceeded 12.8 million sets, with a coverage rate reaching 98% in expressway service areas. The electrification rate of railways remained stable at above 75%, and the use of shore power gradually became routine. These achievements have laid a solid foundation for the implementation of the new NDC (Nationally Determined Contribution) targets, and have demonstrated the crucial role of the transportation system in achieving the "Dual Carbon" Goals.

2025 年 7 月召开的中央城市工作会议标志着我国城市发展进入新阶段，核心是从规模扩张转向以存量提质增效为主，这一转变对建筑领域的绿色低碳转型提出了更高要求。“十四五”期间，我国建筑碳排放呈现增长趋势，特别是建

筑用热和电力消耗部分。2023 年建筑运行碳排放总量为 22 亿吨 CO<sub>2</sub>，其中电力间接排放占比最高（61%），热力间接排放呈下降趋势（占比 20%），直接排放持续降低（占比 19%）。

The Central Urban Work Conference was held in July 2025, marking a new stage of urban development in China, with the core shifting from scale expansion to the quality upgrading and efficiency improvement of existing stock resources. This shift has put forward higher requirements on the green and low-carbon transformation of construction sector. During the 14th Five-Year Plan period, carbon emissions from buildings in China showed an increasing trend, especially in terms of heat and electricity consumption in buildings. In 2023, the total carbon emissions from building operations reached 2.2 billion tons of CO<sub>2</sub>, of which indirect emissions from electricity consumption accounted for the highest proportion (61%), indirect emissions from heat consumption showed a downward trend (20%), and direct emissions continued to decrease (19%).

“十四五”期间，我国碳捕集利用与封存（CCUS）示范项目从百万吨级发展成千万吨级集群示范项目。首个海上 CCUS 项目（大亚湾集群）的建立成为陆海建设领域重要里程碑。甘肃正宁华能燃煤电厂与山东青州中联水泥 CCUS 项目将成为全球规模最大的示范工程。在技术成本上，电力、钢铁、水泥等行业碳捕集成本整体低于国际水平。我国 CCUS 政策体系也取得显著进展，已形成 7 项国家标准和 25 项行业标准。CCUS 的规模化突破与成本竞争力，为国家自主贡献目标提供了可行的技术路径。

During the 14th Five-Year Plan period, the CCUS (carbon capture, utilization and storage) demonstration projects in China were developed from million-ton scale to ten-million-ton scale cluster demonstration projects. The establishment of the first offshore CCUS project (Daya Bay cluster) became an important milestone in the field of land-sea construction. The CCUS project, which is jointly developed by the Huaneng Coal-fired Power Plant in Zhengning, Gansu Province and the China United Cement Qingzhou Co., Ltd. in Shandong Province, will become the world's largest demonstration project. In terms of technical cost, the carbon capture costs in such industries as power, iron and steel, and cement are generally lower than the international level. China has also made remarkable progress in forming the CCUS policy system, with the formation of 7 national standards and 25 industry standards. The large-scale breakthrough and cost competitiveness of CCUS provide a feasible technical path to the NDC targets.

中国新型电力系统建设取得显著进展：截至 2024 年底，可再生能源发电量突破 3.46 万亿千瓦时，占全社会用电量比例超过 1/3；可再生能源装机 18.5 亿千瓦，占全国装机 55% 以上；风光利用率保持在 95% 以上。以源网荷储一体化和智能电网为核心的新型电力系统体系初步成型，电力市场改革和电碳协同机制有所成效，新能源装机容量稳步上升，为 2035 年风光装机力争达到 36 亿千瓦的 NDC 目标奠定坚实基础。

China has made remarkable progress in constructing its new-type power system: As of the end of 2024, the power generation from renewable energy exceeded 3.46 trillion kWh, accounting for more than one-third of the total electricity consumption of the whole society; the installed capacity for renewable energy power generation was 1.85 billion kilowatts, accounting for more than 55% of the national total; and the utilization rate of wind and solar energy remained above 95%. A new-type power system with the integration of power supply, power grid, load and energy storage as well as smart grid as the core has taken initial shape; the power market reform and the electricity-carbon coordination mechanism have achieved certain results; and the installed capacity for new energy power generation has steadily increased, thus laying a solid foundation for the NDC target of striving to reach 3.6 billion kilowatts of installed capacity for wind and solar power generation by 2035.



“十四五”时期，中国持续深入开展蓝天保卫战，加强细颗粒物和臭氧协同控制，并着力同步推动各领域减污降碳协同增效。“十四五”以来，中国继续因地制宜推进北方地区清洁取暖改造，累计完成散煤治理4100万户，淘汰高排放车辆近2000万辆，完成11.2亿千瓦煤电机组和9.5亿吨粗钢产能全流程或者重点工程超低排放改造，有力推进能源、产业、交通等各领域绿色低碳发展，减污降碳协同效应不断显现。

During the 14<sup>th</sup> Five-Year Plan period, China persistently carried out the Blue Sky Protection Campaign in a deep-going way, strengthened the synergetic control of fine particles and ozone, and simultaneously made efforts to synergize the reduction of pollution and carbon emissions in various fields. Since the 14<sup>th</sup> Five-Year Plan period, China has continued to promote the clean heating renovations in the northern regions in a way that suits local conditions; it has completed the treatment of loose coal used by 41 million households, phased out nearly 20 million high-emission vehicles, and has carried out ultra-low emission renovations for the entire process or key projects of 1.12 billion kilowatts of coal-fired power units and 950 million tons of crude steel production capacity. Therefore, China has vigorously promoted the green and low-carbon development in such fields as energy, industry and transportation, and the synergy of the reduction of pollution and carbon emissions has been constantly demonstrated.

► INDICATOR: 健康影响与协同效益  
Health impacts and synergetic benefits

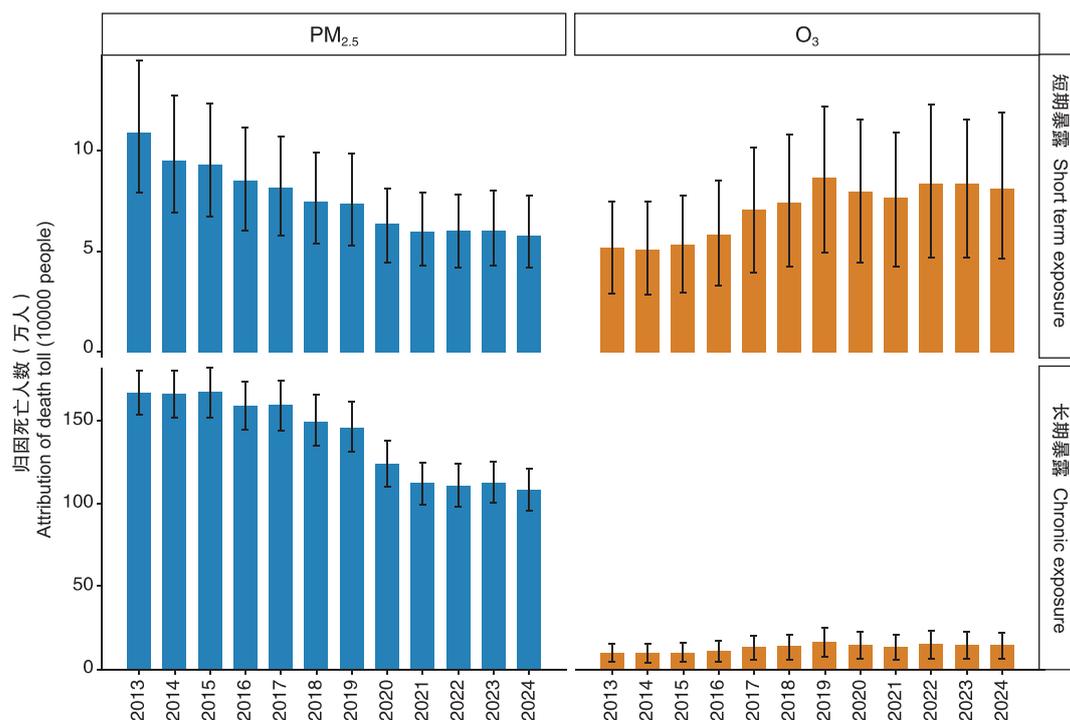
“十四五”期间（2021–2025年），中国在推动碳中和与清洁空气协同治理方面取得了显著成就，带来了巨大的公共健康效益。截至2024年，全国人口加权PM<sub>2.5</sub>年均浓度降至30.2 μg/m<sup>3</sup>，与2021年相比降幅2.5%，与PM<sub>2.5</sub>相关的过早死亡人数自2021年以来下降了3.2%。臭氧污染问题在“十四五”期间未显著缓解，全国O<sub>3</sub>浓度持续在高位平台期徘徊，其相关的健康负担每年超过14.3万人的过早死亡。家庭能源结构转型对公共健康和气候变化有显著影响。2012至2017年，中国生物质和煤炭消费量分别下降45%和12%，天然气消费增长204%。2004至2015年，家庭天然气使用量增加53%，死亡率下降12%；固体燃料消费每减少1%，婴儿死亡率下降0.11%。预计到2030年，室内PM<sub>2.5</sub>浓度将从39–43 μg/m<sup>3</sup>降至25–26 μg/m<sup>3</sup>。在碳中和目标下，2060年电炊具与空气源热泵将覆盖农村94%和72%的服务需求，尽管年均转型成本达130亿美元，但健康效益可在多数省份抵消成本。

During the 14<sup>th</sup> Five-Year Plan period (2021-2025), China made remarkable achievements in promoting synergetic governance of carbon neutrality and clean air, which brought about huge public health

benefits. As of 2024, the national population-weighted annual average  $PM_{2.5}$  concentration dropped to  $30.2 \mu\text{g}/\text{m}^3$ , with a decrease of 2.5% compared with 2021; and the number of  $PM_{2.5}$ -related premature deaths decreased by 3.2% since 2021. The ozone pollution was significantly alleviated during the 14th Five-Year Plan period; and the nationwide  $O_3$  concentration reached a high-level plateau, and there were more than 143,000 premature deaths every year due to relevant health burden. The transformation of household energy structure has a significant impact on public health and climate change. From 2012 to 2017, the consumption of biomass and coal in China decreased by 45% and 12% respectively, while the consumption of natural gas increased by 204%. From 2004 to 2015, household natural gas consumption increased by 53%, and the mortality rate dropped by 12%; for every 1% reduction in solid fuel consumption, the infant mortality rate decreased by 0.11%. It is estimated that by 2030, the indoor  $PM_{2.5}$  concentration will drop from  $39\text{-}43 \mu\text{g}/\text{m}^3$  to  $25\text{-}26 \mu\text{g}/\text{m}^3$ . Under the goal of carbon neutrality, electric cooking appliances and air source heat pumps will cover 94% and 72% of rural service demands respectively by 2060. Although the annual average transformation cost amounts to 13 billion U.S. dollars, the health benefits can offset the costs in most provinces.

**Fig. 5**

2013–2024 年我国归因于  $PM_{2.5}$  和  $O_3$  短期与长期暴露的成人过早死亡人数  
 The number of premature deaths of adults due to short-term and long-term exposure to  $PM_{2.5}$  and  $O_3$  in China in 2013-2024



# 02 挑战分析

## ANALYSIS ON CHALLENGES

Fig. 6

碳中和与清洁空气协同治理面临的关键挑战

Key challenges faced by synergetic governance of carbon neutrality and clean air



► INDICATOR:

臭氧浓度控制需要加强

The control of ozone concentration needs to be strengthened

尽管在降低 PM<sub>2.5</sub> 方面取得了显著成绩，但臭氧浓度却呈现不降反升的趋势，一方面归因于挥发性有机物 (VOCs) 排放源分布分散，控制难度较大，且部分地区 VOCs 减排力度不足，导致臭氧生成潜势 (OFP) 未能有效降低。另外，在全球加速变暖的背景下，夏季高温热浪日数增加，高温和强辐射条件显著加速了光化学反应速率，进一步推高了臭氧的生成。此外，全球变暖加剧了降水、风速和光照等资源条件的波动性，显著影响水电、风电和光伏发电出力，可能会对新一轮 NDC 目标的达成带来挑战。例如，干旱降低水电出力，强风损坏风机设备，持续阴雨等高影响天气削弱光伏发电效率。低风速 - 低光照复合事件在变暖背景下愈发频繁，对能源供应的稳定性构成严峻挑战。

Despite remarkable achievements have been made in reducing PM<sub>2.5</sub>, the ozone concentration has shown a trend of rising instead of falling. On the one hand, it is difficult to control the emission sources of volatile organic compounds (VOCs) because of their scattered distribution, and the insufficient efforts to reduce the emissions of VOCs in some areas have led to the failure to effectively reduce the ozone formation potential (OFP). In addition, against the backdrop of accelerating global warming, as the number of summer days with high-temperature heat waves increases, the high temperature and strong radiation conditions have significantly accelerated the rate of photochemical reactions, thus further boosting the formation of ozone. Moreover, global warming intensifies the fluctuation of resource conditions such as precipitation, wind speed and sunlight, and thus significantly affecting the output of hydropower, wind power and photovoltaic power generation. This may pose challenges to the achievement of a new round of NDC targets. For example, droughts can reduce the output of hydropower, strong winds can damage wind-driven generators, and high-impact weather conditions such as continuous overcast and rainy days can weaken the efficiency of photovoltaic power generation. The compound events of low wind speed and low light are becoming increasingly frequent against the backdrop of global warming, thus posing a severe challenge to the stability of energy supply.

针对这些挑战，与“十四五”目标及新 NDC 目标相比，极端天气气候事件（如高温热浪、强降雨和干旱）与污染物浓度之间的反馈关系，以及对风能太阳能资源的影响需要重点关注。特别是理清极端天气气候事件与空气污染之间的复杂反馈过程，给出未来风能太阳能资源变化准确的预测结果。

In response to these challenges, compared with the goals of the 14<sup>th</sup> Five-Year Plan and new NDC targets, it is necessary to pay close attention to the feedback relationship between extreme weather and climate events (e.g., high-temperature heat waves, heavy rainfall and droughts) and pollutant concentrations, as well as the impact on wind and solar energy resources. In particular, it is necessary to figure out the complex feedback process between extreme weather and climate events and air pollution, and give accurate predicted results of future changes in wind and solar energy resources.

► INDICATOR:

仍需进一步完善降碳减污协同治理体系

It is still necessary to further perfect the synergetic governance system for reducing carbon emissions and pollution

虽然减污降碳协同治理体系建设有了显著进展，但是由于不同部门核心工作目标的差异，在一些领域仍然缺乏有力的碳中和和清洁空气协同治理手段，导致二氧化碳排放控制和大气污染物排放削减力度不够协调。到2024年底，氮氧化物、挥发性有机物等污染物已提前完成“十四五”总量减排目标，但碳排放强度降低目标的完成情况与时序进度的要求仍存在差距。

Remarkable progress has been made in building the synergetic governance system for reducing carbon emissions and pollution. However, due to the differences in core work objectives of various sectors, there is still a lack of powerful synergetic governance measures for carbon neutrality and clean air in some fields, resulting in insufficient coordination between the efforts to control carbon dioxide emissions and reduce atmospheric pollutant emissions. As of the end of 2024, the total emission reduction targets for pollutants (e.g., nitrogen oxides and VOCs) during the 14<sup>th</sup> Five-Year Plan period were achieved ahead of schedule, but there was still a gap between the completion of carbon emission intensity reduction targets and the requirements of the time schedule.

除此之外，推动碳中和和清洁空气协调的引导政策多元化尚有不足。在财政奖补方面，国家层面尚未设立减污降碳协同专项资金，个别省份在污染防治专项资金中安排一定比例支持减污降碳协同项目，但相较于实际资金需求仍然不足。在金融支持方面，受绿色金融标准、绩效考核等多重因素制约，各类金融机构对减污降碳协同项目支持意愿不高，部分项目面临融资难的问题。

In addition, the diversification of the guiding policies to promote the coordination of carbon neutrality and clean air is still insufficient. In terms of fiscal rewards and subsidies, no special funds for efforts to synergize the reduction of pollution and carbon emissions have been set up at the national level; and some provinces have allocated a certain proportion of their special funds for pollution prevention and control to support the projects to synergize the reduction of pollution and carbon emissions, but the funds are still insufficient compared to the actual fund demands. In terms of financial support, constrained by multiple factors such as green finance standards and performance review, various financial institutions are not willing to support the projects to synergize the reduction of pollution and carbon emissions, and some projects are facing difficulties in financing.



► INDICATOR:

碳污协同治理的结构性、根源性问题仍然存在

The structural and root problems in the synergetic governance of carbon emissions and pollution still exist

“十四五”期间，在能源安全和能源转型“双重”刺激下，我国能源结构调整呈现煤炭和新能源“双向”增长新趋势新特征，能源消费总量保持刚性增长，2024年电力消费弹性系数创1.36新高，经济发展对能源（特别是电力）依赖加深。尽管新能源占比持续提升，但当前我国煤炭消费占比超过50%，仍是现阶段主体能源，2024年煤电装机核准量在“十四五”期间首次出现下降，但仍高于“十三五”期间年度新增核准装机容量的最高水平。与此同时，非化石能源消费占比距离国家2035年国家自主贡献（NDC）目标仍有超过10个百分点的差距，意味着未来十年仍需采取进一步努力，以突破当前能源转型所面临的结构性挑战。

During the 14<sup>th</sup> Five-Year Plan period, under the "dual" stimulus of energy security and energy transition, China's energy structure adjustment showed a new trend and new characteristics of "mutual" growth of coal and new energy, and the total energy consumption maintained a rigid growth. In 2024, the elasticity coefficient of electricity consumption reached a new high of 1.36, and the economic development became more dependent on energy (especially electricity). Although the proportion of new energy has been continuously increasing, the coal consumption in China still accounts for over 50% at present and remains the main energy source at this stage. In 2024, the approved installed capacity for coal-fired power generation declined for the first time during the 14th Five-Year Plan period, but it was still higher than the highest level of annual newly-approved installed capacity during the 13<sup>th</sup> Five-Year Plan period. Meanwhile, the proportion of non-fossil energy consumption is still more than 10 percentage points away from China's NDC targets for 2035, which means that further efforts are still needed in the next decade with an aim of breaking through the structural challenges faced by the current energy transition.

钢铁、水泥、化工等传统高碳行业低碳转型难度大，绿色氢能、碳捕集利用与封存等关键技术尚处于研发或示范阶段，转型成本高。新能源汽车、光伏等新兴产业供应链高度集中，面临地缘政治和贸易摩擦风险。新兴产业快速发展过程中，配套设备发展相对滞后，成为制约因素。如光伏产业发展过程中，储能系统和电网建设的相对滞后阻碍了清洁电力消纳；新能源汽车充电桩、换电站等配套设施的数量和功效仍无法满足用户需求。

Traditional carbon-intensive industries, such as iron and steel, cement and chemical industry, have great difficulties in low-carbon transformation. Key technologies such as green hydrogen energy and CCUS are still in the research and development or demonstration stage, and the transformation cost is high. The supply chains of emerging industries such as new energy automobile and photovoltaic power are highly concentrated and are facing the risks of geopolitical and trade frictions. In the process of rapid



development of emerging industries, the relatively lagging development of supporting equipment has become a restraining factor. For instance, during the development of photovoltaic industry, the relatively lagging construction of energy storage systems and power grid has hindered the consumption and absorption of clean electricity; the quantity and efficiency of supporting facilities (e.g., new energy automobile charging piles and battery swap stations) still fail to meet the demands of users.

交通部门的绿色低碳转型仍面临结构性挑战：铁路货运占比仍偏低，与“公转铁”目标存在差距；新能源商用车渗透率 17.9%，货运清洁化进程相对滞后；可持续航空燃料、氢能等绿色燃料应用仍处试点阶段，机场清洁能源消费占比仅约 1%，能源替代任务艰巨。此外，多式联运“最后一公里”衔接效率不足，关键技术与基础设施（如兆瓦级快充、氢能储运）支撑仍待突破。未来需在运输结构、装备清洁化、能源多元化和制度协同方面加大力度，以匹配“十五五”及新 NDC 目标的更高要求。

The green and low-carbon transformation of transport sector still faces structural challenges: The proportion of railway freight volume is still relatively low, and there is a gap between the actual situation and the "road-to-railway" target; the penetration rate of new energy commercial vehicles is 17.9%, and the process of clean freight transportation is relatively lagging behind; the application of green fuels (e.g., sustainable aviation fuel and hydrogen energy) is still in the pilot stage, and the consumption of clean energy at airports accounts for only about 1%, so energy substitution is an arduous task. In addition, the "last mile" connection efficiency of multimodal transport is insufficient, and it is still necessary to make breakthroughs in key supporting technologies and infrastructure (e.g., megawatt-grade fast charging, hydrogen storage and transportation). In the future, efforts should be intensified in terms of transportation structure, equipment cleaning, energy diversification and institutional coordination to match the higher requirements of the 15th Five-Year Plan and new NDC targets.

我国建筑领域实现低碳转型面临机遇和挑战。当前，我国建筑运行碳排放处于平台期。与国际对比，我国建筑运行的人均和单位面积碳排放虽低于美、加等国，但因能源结构仍以化石燃料为主，碳排放强度高于法国、瑞典等核电、水电占比高的国家。因此，实现建筑领域碳达峰碳中和，需在继续推进节能改造的同时，着力推动能源系统的低碳化转型。在“双碳”目标下，建筑的角色应从单纯的能源“用户”，转变为具备“用、产、调、储”四位一体功能的城乡能源系统重要枢纽，促进建筑用电碳排放的降低，同时应高度关注建筑用热系统的低碳转型，构建新型零碳的热力供应系统。China's construction sector is facing both opportunities and challenges in the process of achieving low-carbon transformation. At present, the carbon emissions from building operations in China are undergoing a plateau. Compared with the international level, per capita and per unit area carbon emissions from building operations in China are lower than those in the United States, Canada and other countries. However, due to the fact that China's energy structure is still dominated by fossil fuels, the carbon emission intensity in China is higher than that in France, Sweden and other countries with high proportion of nuclear power and hydropower. Therefore, to achieve carbon peaking and carbon neutrality in the construction sector, efforts should be made to promote the low-carbon transformation of energy systems while continuing to promote energy-saving renovations. Under the "Dual Carbon" Goals, the role of buildings should shift from merely being energy "users" to becoming important hubs of urban and rural energy systems with integrated functions of "consumption, generation, regulation and storage", so as to promote the reduction of carbon emissions from electric consumption in buildings. At the same time, close attention should be paid to the low-carbon transformation of thermal systems for buildings, and a new-type zero-carbon thermal supply system should be created.

当前中国 CCUS 技术发展面临三大核心挑战：一是技术短板突出，碳移除技术( BECCS 和 DACCS )尚未建成商业化示范，集成优化技术滞后于国际先进水平；二是标准体系不完善，基础标准缺失导致项目边界模糊，量化核查国家标准缺位制约绿色金融支持，管理标准不足影响产业规范化；三是经济性瓶颈，我国 CCUS 技术与其他减排技术竞争优势尚不明显，碳移除技术成本特别是 DACCS 成本偏高。这些挑战制约了“十四五”规划推动前沿技术发展及新 NDC 目标全经济范围净排放下降的目标。

At present, the development of CCUS technologies in China is confronted with three core challenges: First, the technical shortcomings are prominent; the carbon removal technologies (BECCS and DACCS) have not yet been commercialized and demonstrated, and the integrated optimization technologies lag behind the international advanced level. Second, the standard system is not perfect; the lack of basic standards leads to blurred project boundaries, the absence of national standards for quantitative verification restricts the support of green finance, and insufficient management standards affect industrial standardization. Third, there is an economic bottleneck; the competitive edge of China's CCUS technologies over other emission reduction technologies is still not obvious, and the costs of carbon removal technologies (especially DACCS) are relatively high. These challenges have restricted the goals of the 14<sup>th</sup> Five-Year Plan to promote the development of cutting-edge technologies and the new NDC target to reduce net emissions across the entire economy.

在高比例新能源并网下，我国电力系统仍面临电力低碳 – 安全 – 经济难以统筹的结构性矛盾：低碳灵活性资源仍存在缺口，电力保供能力存在不确定性，跨区输电与区域消纳能力不足，新型储能、氢能、生物质能及 CCUS 等关键支撑技术尚处发展阶段。电力体制改革进入深水区，多层次电力市场需进一步协同，电碳协同交易体系有待完善。电力系统在低碳、安全、经济三维目标间仍存在张力，成为影响 NDC 目标的关键挑战。

With a high proportion of new energy power connected to the grid, China's power systems still face the structural contradiction of difficulty in coordinating low carbon, safety and economic effectiveness of power: There is still a shortage of low-carbon flexible resources, the power supply guarantee capacity is uncertain, the cross-regional transmission and regional consumption and absorption capacities are insufficient, and key supporting technologies (e.g., new-type energy storage, hydrogen energy, biomass energy, CCUS, etc.) are still in the development stage. The organizational reform of electric power sector has entered a crucial and challenging stage, the multi-level power market needs further coordination, and the trading system based on electricity-carbon collaboration needs to be perfected. There is still tension among the three-dimensional goals of low carbon, safety and economic effectiveness in power systems, which has become a key challenge affecting the NDC targets.

2013 年以来，随着蓝天保卫战背景下一系列重大减排工程和综合治理措施的实施，中国大气污染物排放量已实现大幅削减，推动大气环境质量改善取得举世瞩目的成就。但从大气污染形势看，中国结构性、根源性、趋势性压力依然存在，产业结构仍呈现高耗能、高排放特征，能源消费仍将刚性增长，中国的大气污染治理已进入深水区，主要大气污染物协同减排难度大。Since 2013, with the implementation of a series of major emission reduction projects and comprehensive treatment measures under the background of the Blue Sky Protection Campaign, the emissions of atmospheric pollutants have been significantly reduced in China, and China's efforts to improve the quality of atmospheric environment have achieved remarkable results that amazed the world. However, according to the situation of atmospheric pollution, the structure, root and trend-based pressures still exist in China; the industrial structure is still characterized by high energy consumption and high emissions; energy consumption will continue to increase rigidly; China's atmospheric pollution treatment has entered a crucial and challenging stage; and it is difficult to achieve the synergetic emission reduction of main atmospheric pollutants.

► INDICATOR:

全行业碳污尚未实现协同减排

The synergetic reduction of carbon emissions and pollution from all industries has not yet been achieved

受疫情后经济复苏牵引，政策重心向稳增长倾斜，碳减排目标优先级有所下降。2020 - 2024 年间 CO<sub>2</sub> 排放增长率高达 15.4%，截至 2024 年，我国距“十四五”碳强度下降目标仍有约 10 个百分点的差距。若“十四五”碳减排目标未能如期完成，后续我国需以更强力度推动节能降碳转型，方可实现新一轮 NDC 目标。

Driven by the economic recovery after the COVID-19 pandemic, the policy focus has tilted toward maintaining steady growth, and the priority of carbon emission reduction targets has been lowered. From 2020 to 2024, the growth rate of CO<sub>2</sub> emissions was as high as 15.4%. As of 2024, there was still about 10 percentage points away from the carbon intensity reduction target in China's 14<sup>th</sup> Five-Year Plan. If the carbon emission reduction target in the 14<sup>th</sup> Five-Year Plan is not achieved as scheduled, China needs to make greater efforts in promoting the energy-saving and carbon-reducing transformation in the future with an aim of striving to achieve a new round of NDC targets.

从生态碳汇维度看，未来陆地碳汇稳定增长也面临多重挑战。我国当前陆地碳汇增长依赖未成熟人工林的强固碳能力，但随着现有未成熟人工林逐步进入老龄阶段，其碳汇能力将随林龄增长而自然下降。叠加气候变化对陆地碳汇稳定性构成的威胁，如何通过科学的森林经营管理手段保持陆地碳汇稳定增长，成为未来政策制定的关键方向。

From the perspective of ecological carbon sinks, the future stable growth of terrestrial carbon sinks also faces multiple challenges. At present, the growth of terrestrial carbon sinks in China relies on the strong carbon sequestration capacity of immature man-made forests. However, as the existing immature man-made forests gradually enter the aging stage, their carbon sequestration capacity will naturally decline along with the increase of forest age. In addition to the threat posed by climate change to the stability of terrestrial carbon sinks, how to maintain the stable growth of terrestrial carbon sinks through scientific forest operation and management means has become a key direction for future policy-making.

“十四五”期间我国全行业 CO<sub>2</sub> 与主要大气污染物尚未实现协同减排，面临“减污难降碳”的阶段性挑战。其中，电力与供热行业受煤电需求扩大、供热煤耗增长影响，燃煤过程碳污排放仍呈“双增长”趋势。民用和交通部门碳污协同治理进展相对不足，仅有少数省份在民用部门燃煤过程和交通部门非道路移动源实现了协同治理。

During the 14<sup>th</sup> Five-Year Plan period, China has not yet achieved the synergetic emission reduction of CO<sub>2</sub> and main atmospheric pollutants from all industries, so we are facing a phased challenge of "difficulty in reducing carbon emissions despite pollution reduction". Among the industries, the power and heating industries are affected by the expansion of coal-fired electricity demand and the increase of coal consumption for heating, and the carbon emissions and pollution still show a trend of "dual growth" during the process of coal combustion. The progress in synergetic governance of carbon emissions and pollution is relatively insufficient in the civil and transport sectors, and only a few provinces have achieved synergetic governance of the process of coal combustion in civil sector and the off-road mobile machinery in transport sector.

公平是未来实现碳中和与清洁空气协同治理目标的重要议题。面向“十五五”规划时期与新一轮国家自主贡献目标，中国的气候治理将构建绝对排放量控制、涵盖全经济范围温室气体的系统性约束。在此背景下，如何在历史责任、减排潜力和发展权之间取得平衡，已成为设计协同治理路径必须面对的重要挑战。

Equity is an important issue to achieve the goal of synergetic governance of carbon neutrality and clean air in the future. In light of the 15th Five-Year Plan period and a new round of NDC targets, China will establish a systematic constraint that controls absolute emissions and covers greenhouse gases across the entire economy for its climate governance. Against this backdrop, how to strike a balance among historical responsibility, emission-reducing potential and the right to development has become an important challenge that must be faced in designing a synergetic governance roadmap.

► **INDICATOR:** 臭氧相关死亡人数仍未下降  
The number of ozone-related deaths has not yet declined

空气污染与气候变化仍然是威胁中国人群健康的重大挑战。由 PM<sub>2.5</sub> 长期与短期暴露导致的成人过早死亡人数较 2015 年显著下降。NO<sub>2</sub> 暴露水平虽也明显降低，但其短期暴露仍导致约 4.65 万例非意外死亡。相比之下，O<sub>3</sub> 长期与短期暴露水平基本持平，且 O<sub>3</sub> 短期暴露相关死亡人数已超过 PM<sub>2.5</sub>，凸显 PM<sub>2.5</sub> 和 O<sub>3</sub> 污染协同治理的紧迫性。

Air pollution and climate change remain major challenges threatening the public health in China. The number of premature deaths of adults caused by long-term and short-term exposure to PM<sub>2.5</sub> decreased significantly compared with 2015. Although the exposure level of NO<sub>2</sub> also decreased obviously, its short-term exposure still led to approximately 46,500 non-accidental deaths. In contrast, the long-term and short-term exposure levels of O<sub>3</sub> are basically the same, and the number of deaths related to short-term exposure to O<sub>3</sub> has exceeded that related to PM<sub>2.5</sub>, thus highlighting the urgency of the synergetic treatment of PM<sub>2.5</sub> and O<sub>3</sub> pollution.

在气候变化健康影响方面，极端高温不仅显著增加心脑血管疾病住院风险，还会引发焦虑、抑郁等心理健康问题，并对认知功能产生长期影响，尤其加剧老年人群的死亡风险。洪水事件可导致流产风险上升及亲密伴侣暴力发生率增加，高温 - 干旱复合事件也会显著提高非意外死亡风险。为此，亟需构建个人防护、社区预警、健康服务及环境适应相结合的综合防护体系。

In terms of the health impacts caused by climate change, extreme high temperatures not only significantly increase the risk of hospitalization due to cardiovascular and cerebrovascular diseases, but also trigger mental health problems such as anxiety and depression, and have a long-term impact on cognitive function, especially on aggravating the mortality risk among the elderly. Flood events can lead to an increased risk of miscarriage and a higher incidence of intimate partner violence; and compound drought and high temperature events (CDHEs) can also significantly increase the risk of non-accidental death. Therefore, it is urgent to build a comprehensive protection system that combines personal protection, community early warning, health services and environmental adaptation.

## 03 政策建议

### POLICY RECOMMENDATIONS

► INDICATOR: 空气污染与气候变化  
Air pollution and climate change

**开展有关极端天气气候事件与大气污染反馈的机理研究:** 深入解析高温热浪、强降雨等极端天气如何通过光化学反应、气溶胶生成影响 PM<sub>2.5</sub> 和臭氧浓度。在此基础上, 强化监测与预测能力, 建设高分辨率大气 – 气候耦合模型, 集成卫星遥感、地基观测和数值模拟数据, 实时跟踪极端天气对 PM<sub>2.5</sub> 和臭氧浓度的动态影响。完善预警系统, 开发多场景预测工具, 提前发布污染风险提示, 指导应急减排和公众防护。

**Conducting research on the mechanism for feedback between extreme weather and climate events and atmospheric pollution:** It is necessary to deeply analyze how extreme weather conditions (e.g., high-temperature heat waves and heavy rainfall) affect PM<sub>2.5</sub> and ozone concentrations through photochemical reaction and aerosol generation. On this basis, it is necessary to strengthen the monitoring and forecasting capabilities, build high-resolution atmosphere and climate coupling models, integrate the data from satellite remote sensing, ground-based observations and numerical simulation, and track the dynamic impact of extreme weather conditions on PM<sub>2.5</sub> and ozone concentrations in real time. It is necessary to perfect the early warning system, develop multi-scenario forecasting tools, release pollution risk warnings in advance, and guide emergency emission reduction and public protection.

**阐明极端天气对风能太阳能波动性的影响过程:** 系统研究台风、热浪、强降雨等极端天气如何影响风能和太阳能资源稳定性。精准预测“十五五”期间风能太阳能资源的波动性变化特征。开发相应的发电波动预测系统, 优化调度策略, 减少因极端天气导致的发电不稳定性, 提升可再生能源利用率。

**Expounding the process of extreme weather affecting the fluctuation of wind and solar energy:** It is necessary to systematically study how extreme weather conditions (e.g., typhoons, heat waves and heavy rainfall) affect the stability of wind and solar energy resources. It is necessary to accurately predict the fluctuating change characteristics of wind and solar energy resources during the 15th Five-Year Plan period. It is necessary to develop the corresponding power generation fluctuation forecasting system, optimize the dispatching strategy, reduce the power generation instability caused by extreme weather, and improve the utilization rate of renewable energy.

**强化跨学科合作与数据共享:** 建立气象、环境和能源部门联合研究平台, 整合数据资源, 构建综合数据库。引入先进的机器学习算法, 提升结果的准确度。

**Strengthening interdisciplinary cooperation and data sharing:** It is necessary to establish a joint research platform for meteorological, environmental and energy departments, integrate data resources, and build a comprehensive database. It is also necessary to introduce advanced machine learning algorithms, and enhance the accuracy of the results.

► INDICATOR:

进一步深入开展宏观层面顶层设计和微观层面试点创新，双向发力推动协同治理实践

Further deepen macro-level strategic planning and micro-level pilot innovations, advancing synergistic governance through a dual-track approach

加强碳污协同治理建设需从顶层设计、协调机制、政策支持与试点创新四方面推动治理体系的进一步完善。一是**加强顶层设计**，利用好“十五五”这一推动美丽中国建设和完成碳达峰目标的关键时间窗口，在“十五五”规划中统筹谋划产业、能源、交通运输、城乡建设、农业农村等重点领域的关键政策和重大工程。二是**完善协调机制**，形成上下联动、齐抓共管的工作格局，通过碳中和和清洁空气协同推进的关键目标指标推动各部门协同发力推进相关工作。三是**强化支持政策**，在各级政府生态环境保护资金中对减污降碳协同项目进行倾斜，对研发和应用减污降碳协同关键技术的单位，研究降低综合成本和税费负担、优先金融支持的政策。四是**深化试点创新**，组织筛选协同成效显著、示范引领作用较强的典型案例进行推广，产生更加广泛适用的协同推进碳中和和清洁空气解决方案。

Strengthening the synergistic governance of carbon and pollution requires further improving the governance system by focusing on top-level design, coordination mechanisms, policy support, and pilot innovations. **First, it is necessary to strengthen the top-level design**, with the aims of making good use of the 15<sup>th</sup> Five-Year Plan period—a crucial time window to promote the construction of a beautiful China and achieve the goal of peaking carbon dioxide emissions, and making overall plans for key policies and major projects in key areas such as industry, energy, transportation, urban and rural construction, as well as agriculture and rural areas in the 15<sup>th</sup> Five-Year Plan. **Second, it is necessary to perfect the coordination mechanism**, with the aims of forming a working pattern of up-down linkage and concerted efforts, and promoting all departments to work together to advance related work through the key target indicators in the synergetic advancement of carbon neutrality and clean air. **Third, it is necessary to strengthen the supportive policies**; the governments at all levels should be encouraged to tilt their ecological and environmental protection funds toward the projects for synergizing the reduction of pollution and carbon emissions; for the institutions engaged in the research, development and application of key technologies for synergizing the reduction of pollution and carbon emissions, policies should be studied to reduce overall costs and tax burdens and give priority to financial support. **Fourth, it is necessary to deepen the pilot innovations**, with the aims of organizing and screening typical cases with remarkable synergetic effects and a strong demonstration and leading role for promotion, and generating more widely applicable solutions for synergizing and promoting carbon neutrality and clean air.



► INDICATOR:

深入推进多领域结构转型与低碳技术发展，加强源头减排、结构减排和科技减排

Intensify structural transformation and advance the development of low-carbon technologies, reinforcing emission reduction at the source, through structural adjustment, and via technological innovation

“十五五”时期是全面推进新型能源体系建设、助力如期实现碳达峰目标的关键时期，应做好“十五五”规划与2035年NDC目标统筹衔接，全面贯彻实施《能源法》，锚定2030年、2035年、2060年非化石能源占比达到25%左右、30%以上、80%以上的中长期目标，以风电和太阳能发电装机争取达到36亿千瓦以上的目标为关键抓手，坚持集中式与分布式、陆上与海上并举，加大新能源开发力度，推动能源消费侧协同转型，在工业、交通、建筑、数据中心等重点领域大力实施可再生能源替代行动，促进新能源就地消纳。建立能耗双控向碳排放双控转型新机制，统筹能源安全和能源结构转型，为实现2035年NDC目标、“美丽中国”目标和全面建设社会主义现代化建设提供有力保障。

The 15<sup>th</sup> Five-Year Plan period is a crucial period to comprehensively promote the construction of a new-type energy system and facilitate the on-schedule achievement of the goal of peaking carbon emissions. We should do a good job in coordinating and connecting the 15<sup>th</sup> Five-Year Plan with the 2035 NDC targets, fully implement the Energy Law, and anchor our efforts to the medium-and long-term goals of non-fossil energy accounting for around 25%, over 30% and over 80% by 2030, 2035 and 2060 respectively. We should focus on the goal of striving to increase the installed capacity for wind and solar power generation to over 3.6 billion kilowatt; adhere to the dual development of centralized and distributed, onshore and offshore energy; intensify the development of new energy; promote the coordinated transformation on the energy consumer side; vigorously implement renewable energy substitution actions in key areas such as industry, transport, construction and data centers; and facilitate the local consumption and absorption of new energy. It is necessary to establish a new mechanism for the transition from dual control over the amount and intensity of energy consumption to dual control over the amount and intensity of carbon emissions, coordinate energy security and the transformation of energy structure, and provide a strong guarantee for achieving the 2035 NDC targets, the goal of a "Beautiful China" and the modernization with Chinese characteristics.

加大对绿色低碳转型产业的财政金融支持，鼓励企业进行低碳技术改造和研发创新，并引导社会资本流向绿色低碳产业。强化碳定价机制，逐步扩大全国碳交易市场的覆盖范围，为传统高碳产业的绿色低碳转型提供经济激励。加强国际合作与技术交流，积极研发并推广关键低碳技术，建设安全有韧性的全球绿色供应链。加大对储能设备、电网、充电桩等新型基础设施制造的支持力度，为产业转型提供基础设备保障。

It is necessary to increase fiscal and financial support for the industries that are undergoing green and low-carbon transformation, encourage enterprises to carry out low-carbon technological transformation as well as research and development innovations, and guide social capital to flow into green and low-carbon industries. It is necessary to strengthen the carbon pricing mechanism, gradually expand the coverage of the national carbon trading market, and provide economic incentives for the green and low-carbon transformation of traditional carbon-intensive industries. It is necessary to strengthen international cooperation and technical exchanges; actively research, develop and promote key low-carbon technologies; and build a safe and resilient global green supply chain. It is necessary to intensify efforts in support of the manufacturing of new infrastructure such as energy storage equipment, power grid and charging piles, with an aim of providing basic equipment guarantee for industrial transformation.



交通运输行业碳减排工作已进入“结构控碳”和“效率控碳”双轮驱动新阶段。面向“十五五”，建议聚焦三方面：一是深化运输结构改革，推动大宗货物“公转铁”“公转水”，完善多式联运体系；二是加快构建清洁能源供给网络，推进充换电、加氢及岸电设施建设，突破高能量密度电池与燃料电池技术；三是完善制度体系，建立交通碳监测统计机制，推动碳足迹核算与市场交易，强化政策协同与标准引领，系统推进交通全链条绿色转型。

The carbon emission reduction in the transport industry has entered a new stage of two-wheel drive, including both "structure-based carbon control" and "efficiency-oriented carbon control". Looking ahead to the 15th Five-Year Plan period, it is suggested to focus on three aspects: First, it is necessary to deepen the reform of transportation structure, promote the modal shift for bulk goods from road transport to water or railway transport, and perfect the multimodal transport system. Second, it is necessary to speed up the construction of a clean energy supply network; promote the construction of charging and battery swapping, hydrogen refueling and shore power facilities; and make technological breakthroughs in energy-dense batteries and fuel cells. Third, it is necessary to improve the institutional system, establish a carbon monitoring and statistical mechanism for transport, promote carbon footprint accounting and market transactions, strengthen policy coordination and standard guidance, and systematically promote the green transformation of the entire transport chain.

为推动建筑绿色低碳转型，需从建筑节能、城乡建设模式、能源结构、技术创新及激励机制五个方面系统推进：推动建筑节能低碳转型需兼顾新建和既有建筑，严格执行节能规范，提升关键部品性能，并加快既有建筑节能改造。加强绿色建材和智能建造的推广，支持绿色低碳示范城市建设。推动建筑电气化，通过光伏、热泵等可再生能源技术，减少化石能源消耗。创新碳排放双控评估机制，突破关键技术，推动零碳建筑和建筑电气化示范应用。同时，利用绿色金融和绿色信贷政策，支持建筑领域的低碳项目，推广碳交易机制，并探索多种激励模式，推动建筑用能碳计量与奖励机制的落地。

To promote the green and low-carbon transformation of buildings, it is necessary to systematically make advancements from five aspects, including building energy conservation, urban and rural construction mode, energy structure, technological innovations and incentive mechanism: To promote the energy-saving and low-carbon transformation of buildings, it is necessary to take into account both new and

existing buildings, strictly implement energy conservation codes, enhance the performance of key components, and accelerate the energy-saving renovation of existing buildings. It is necessary to strengthen the promotion of green building materials and intelligent construction, and support the construction of green and low-carbon demonstration cities. It is necessary to promote the electrification of buildings, and reduce the consumption of fossil energy through renewable energy technologies such as photovoltaic power and heat pumps. It is necessary to make innovations in the dual-control assessment mechanism for carbon emissions, make breakthroughs in key technologies, and promote the demonstration and application of zero-carbon buildings and building electrification. Meanwhile, green finance and green credit policies should be used to support low-carbon projects in the construction field, promote the carbon trading mechanisms, and explore various incentive models with an aim of promoting the implementation of carbon measurement and reward mechanisms for building energy consumption.

面对当前中国 CCUS 技术发展面临的挑战，建议从技术创新、标准体系与激励机制三方面进一步推动 CCUS 部署。一是强化技术攻关，设立碳移除技术专项基金，加快碳移除中试与商业化示范，推动集成优化技术研发，缩小与国际差距；二是完善标准体系与核算支撑，优先制定碳运输、封存、监测核查国家标准，开发 CCUS 碳减排核算方法学，推进量化核查标准制定，支撑项目纳入自愿减排机制；三是创新激励机制，通过财税补贴、碳市场溢价等降低捕集成本，设立绿色金融专项支持 CCUS 项目，提升技术经济性与规模化应用水平。

Given the challenges confronting CCUS technology development in China, efforts should be undertaken to advance its deployment via technological innovation, standardization, and incentive mechanisms. First, it is necessary to make greater efforts to make technological breakthroughs, set up a special fund for carbon removal technologies, accelerate the pilot plant test and commercial demonstration of carbon removal, promote the research and development of integrated optimization technologies, and narrow the gap with the international level. Second, it is necessary to perfect the standard system and accounting support; give priority to the formulation of national standards for carbon transportation, storage, monitoring and verification; develop the CCUS carbon emission reduction accounting methodology, promote the formulation of quantitative verification standards, and support projects to be included in the voluntary emission reduction mechanism. Third, it is necessary to make innovations in incentive mechanisms; reduce the carbon capture cost through fiscal and tax subsidies, carbon market premiums, etc.; set up a green finance-based special fund to support CCUS projects, and enhance the economical efficiency and large-scale application level of technologies.

进一步推进新型电力系统建设，应系统考虑一体化规划思路，同时加强技术突破与市场机制创新。强化低碳 - 安全 - 经济协同的源网荷储一体化规划思路；加快柔性交直流输电与新型储能技术突破；完善多类型电力市场协同机制与容量补偿机制；推动电力系统与碳市场、电气化交通、能源数字化深度融合，构建电 - 碳协同机制。通过支撑新能源装机比例的进一步提升，新型电力系统的转型式发展成为中国实现新一轮 NDC 目标的重要保障。

To advance the construction of new-type power system, the integration of planning approaches should be systematically considered, while simultaneously strengthening technological breakthroughs and fostering innovation in market mechanisms. It is necessary to strengthen the planning idea of integrating power supply, power grid, load and energy storage for the coordination of low carbon, safety and economical efficiency; accelerate the breakthroughs in flexible AC/DC transmission and new energy storage technologies; improve the coordination mechanism and capacity compensation mechanism for multi-type electricity markets; promote the deep integration of power systems with carbon market, electrified

transportation and energy digitalization; and build the mechanism for electricity-carbon synergy. By supporting the further increase in the proportion of installed capacity for new energy power generation, the transformational development of new-type power systems has become an important guarantee for China to achieve a new round of NDC targets.

如何以加快发展方式的绿色转型、推动能源产业运输三大结构调整优化为方向，聚焦温室气体和大气多污染物协同减排领域，强化标准引领和制度创新，更好发挥有为政府和有效市场作用，加大源头减排、结构减排和科技减排力度，将是未来污染治理措施层面进一步挖掘减排空间的重要锚点。此外，加强甲烷、氧化亚氮、氢氟碳化物等非二温室气体治理也正逐渐成为深入推进大气污染与温室气体协同减排的重要议题和实践领域。

Some important anchor points for further excavation of emission reduction space in the future pollution control measures include how to take accelerating the green transformation of development modes and promoting the adjustment and optimization of three major structures (i.e., energy, industry and transportation) as the direction, focus on the field of synergetic emission reduction of greenhouse gases and multiple atmospheric pollutants, strengthen standard guidance and institutional innovation, better play the role of a proactive government and an effective market, and intensify efforts in at-source emission reduction, structural emission reduction as well as scientific and technological emission reduction. In addition, strengthening the treatment of non-CO<sub>2</sub> greenhouse gases (e.g., methane, nitrous oxide and hydrofluorocarbons (HFCs)) is gradually becoming an important topic and a practical field to further promote the synergetic emission reduction of atmospheric pollution and greenhouse gases.

► INDICATOR:

大气成分源汇匹配及减排路径

Source-sink matchmaking of atmospheric components and emission reduction pathways

随着我国大气污染治理已迈入深水期，新一轮 NDC 目标对温室气体与大气污染物协同减排提出了新要求。未来的碳中和与清洁大气协同治理逻辑，不仅需“以污促碳”转向“以碳促污”，更要将管控范围延伸至全经济领域的温室气体，形成更全面的协同治理框架。对此，需坚持以结构转型为核心抓手，从能源、产业、交通、农业等关键领域入手，为温室气体与大气污染物协同减排深度治理筑牢基础。同时，要强化精准化治理思维，通过聚焦重点区域、重点行业及关键排放源，让协同减排措施更具针对性和实效性。

As China's atmospheric pollution treatment has entered a crucial and challenging stage, a new round of NDC targets has put forward new requirements on synergetic emission reduction of greenhouse gases and atmospheric pollutants. In line with the logic of future synergetic governance of carbon neutrality and clean air, we should not only shift from "promoting carbon emission reduction through pollution reduction" to "promoting pollution reduction through carbon emission reduction", but also need to extend the scope of management and control to greenhouse gases across the entire economic sector, with an aim of forming a more comprehensive framework for synergetic governance. In this regard, it is necessary to adhere to taking structural transformation as the core approach, and start from key areas such as energy, industry, transport and agriculture, so as to lay a solid foundation for the in-depth governance of the synergetic emission reduction of greenhouse gases and air pollutants. Meanwhile, it is necessary to strengthen the thinking of precise governance; and the synergetic emission reduction measures should be made more targeted and effective by focusing on major regions, key industries and critical emission sources.

为充分发挥陆地碳汇对碳中和目标的支撑作用，未来应以科学管理为核心优化森林碳汇培育与保护策略。推进造林与树种管理科学化，结合区域气候、土壤条件精准规划造林时间，强化树种适地性选择，提升新造林固碳效率。建立采伐管理机制，严禁忽视森林年龄结构的粗放采伐行为，加快推广智慧采伐技术与策略，在保障木材供给刚性需求的同时，最大限度维持并强化森林碳汇功能，推动我国陆地碳汇能力稳步提升。

To fully leverage the supporting role of terrestrial carbon sinks in achieving the goal of carbon neutrality, the strategies for cultivating and protecting forest carbon sinks should be optimized with scientific management at the core in the future. It is necessary to promote scientific afforestation and tree species management, precisely plan the afforestation time based on regional climate and soil conditions, strengthen the selection of tree species suitable for local conditions, and enhance the carbon sequestration efficiency of newly created forests. It is necessary to establish a logging management mechanism, strictly prohibit extensive logging behaviors that ignore the age structure of forests, accelerate the promotion of intelligent logging technologies and strategies, maintain and strengthen the forest carbon sink function to the maximum extent while guaranteeing the rigid demand for wood supply, and promote the steady improvement of China's terrestrial carbon sink capacity.

为保障碳中和与清洁空气协同路径的可持续性，核心在于构建以高质量绿色发展为导向的减污降碳协同治理体系。一方面，需充分考量各省在资源禀赋、产业结构和经济发展阶段的显著差异，实施因地制宜及突出重点的降碳减污协同路径；另一方面，要明确区域间各减排主体责任与成本的合理分担，强化跨区域、跨部门治理机制，避免污染与碳排放的泄漏转移。

To guarantee the sustainability of the synergetic roadmap on carbon neutrality and clean air, the core lies in building a synergetic governance system for the reduction of pollution and carbon emissions oriented toward high-quality green development. On the one hand, it is necessary to fully consider the significant differences among provinces in terms of resource endowment, industrial structure and the stage of economic development; and implement the synergetic pathway of reducing carbon emissions and pollution according to local conditions and highlighting key points. On the other hand, it is necessary to make clear the reasonable sharing of responsibilities and costs among emission reduction subjects in various regions, strengthen the cross-regional and cross-departmental governance mechanisms, and avoid the leakage and transfer of pollution and carbon emissions.



► INDICATOR: 健康影响与协同效益  
Health impacts and synergetic benefits

“十四五”期间的清洁空气行动产生了巨大的协同健康效益，与中国更新的国家自主贡献（NDC）目标展现出强大的正向协同性。其核心逻辑在于，驱动空气质量改善的核心政策与实现碳减排目标的核心战略高度同源。然而，这种协同性并非无条件或自动实现的。持续的 O<sub>3</sub> 污染问题提示我们，单纯聚焦于减碳或减 PM<sub>2.5</sub> 的策略必须转向多污染物协同控制的综合性策略。此外，交通部门的电气化若无电网的同步深度脱碳作为支撑，则存在将污染从城市转移至发电侧的风险，甚至可能在全生命周期内增加某些污染物的排放。因此，为了在迈向新 NDC 目标的过程中最大化协同效益，未来的政策设计必须更加注重综合性、系统性和前瞻性，强化跨部门的统筹协调，确保脱碳路径能够带来最大化的健康和环境福祉。

The clean air campaign during the 14<sup>th</sup> Five-Year Plan period has generated significant synergetic health benefits, which shows a strong positive synergy with China's updated NDC targets. The core logic lies in the fact that the core policies for driving air quality improvement are highly homologous to the core strategies for achieving carbon emission reduction targets. However, this synergy is not unconditionally or automatically achieved. The persistent O<sub>3</sub> pollution problem reminds us that the strategy that merely focuses on carbon emission reduction or PM<sub>2.5</sub> reduction must shift to a comprehensive strategy for the synergetic control of multiple pollutants. In addition, if the electrification of transport sector is not supported by the synchronous deep decarbonization of power grid, there is a risk of transferring pollution from cities to the power generation side, and this may even increase the emission of some pollutants in the whole life cycle. Therefore, to maximize the synergetic benefits in the process of moving towards new NDC targets, greater attentions must be paid to comprehensiveness, systematicness and perspectiveness in the future policy design, and cross-sectoral overall coordination should be strengthened to ensure that the decarbonization path can bring maximum health and environmental well-being.



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