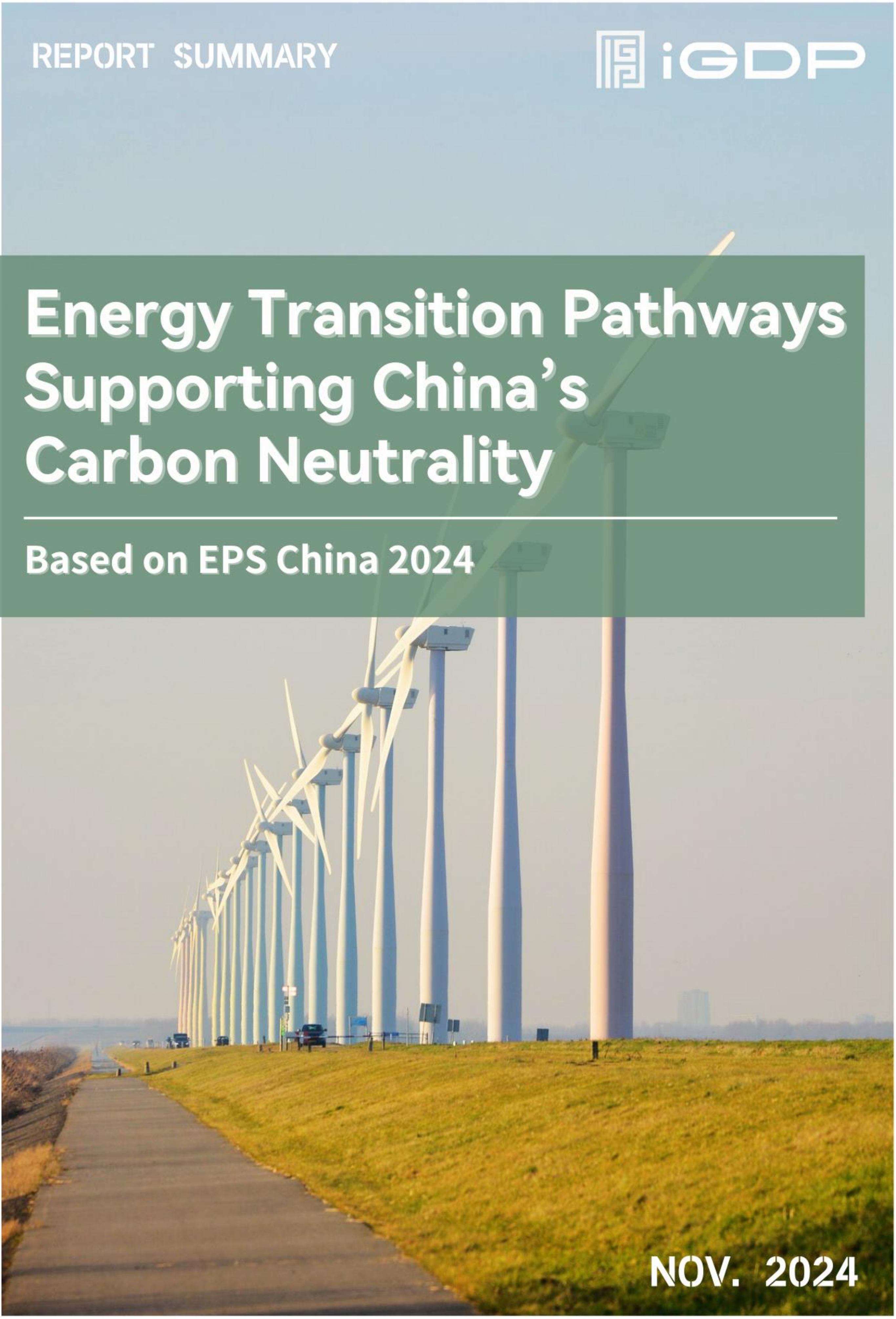
REPORT SUMMARY

iGDP

Energy Transition Pathways Supporting China's Carbon Neutrality

Based on EPS China 2024



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PREFACE

Steadfastly promoting the realization of the "Carbon Peaking and Carbon Neutrality" target is not only China's long-term strategic goal but also a commitment to address global climate change. This endeavor is complex and challenging, demanding profound transformation and innovation across all sectors, that is, to move towards a high-quality development stage through optimization and upgrading of economic structure.

The long-term trajectory of China's greenhouse gas emissions (GHG) and energy demand will be affected by multiple factors. Understanding and evaluating the impact of changes in socio-economic policies and measures requires rigorous analysis and a multi-dimensional assessment. The iGDP modeling team co-developed and used the China Energy Policy Simulator iGDP 2024 (referred to as EPS China 2024)(EI & iGDP, 2024) to simulate and analyze China's energy consumption and GHG emissions from 2020 to 2060. The scenario settings incorporate China's Dual Carbon (Carbon Peaking and Carbon Neutrality) "1+N" Policy Framework (referred to as "1+N" Policy Framework) and future development trajectories. The analysis evaluates the carbon reduction potential of key policies at different stages, identifies policy pathways that can support the realization of the Dual Carbon Target, and offers a quantitative analysis that aims to support the enhancement of low-carbon transition policy framework going forward.

Over the past three years, by extensive and in-depth communications and verifications with experts, scholars, and industry leaders both domestically and internationally, we continuously incorporated the latest findings and updated model setup to ensure the scientific rigor and timeliness of our research. However, we acknowledge that economic and social development carry uncertainties, and all models have limitations. Through modeling and research, iGDP modeling team attempts to adopt various perspectives and methods to analyze China's GHG reduction trends and pathways, foster dialogue and provide support and reference for enhancing China’s green and low-carbon policy framework.

The iGDP modeling team summarized the interim analysis results of the research in the soon-to-be-released research technical report "China's Mid- and Long-Term GHG Scenario Analysis Report". The content of this report summary is excerpted from the above-mentioned report, mainly focusing on showing the economy-wide and sector-specific policy pathways and opportunities essential to reach carbon neutrality.

The analysis found that implementation of China's current "1+N" Policy Framework can support China's Carbon Peaking by 2030 and is likely to facilitate the overachievement of certain targets, for instance, EV penetration and renewables. To achieve Carbon Neutrality before 2060, China's "1+N" policy framework still need continuous reinforcement. Compared to carbon dioxide (CO_2), near-zero emissions of non-CO_2 greenhouse gases face greater technical and policy challenges even with the most advanced technology and best policy practice to date, more policy focus is necessary in the mid-to-long term.

This report summary also identifies key policy areas that need to be emphasized going forward. Accelerating electrification in building, industry and transportation sectors is fundamental for achieving substantial emission abatement. At the same time, end-use sectors need to consistently improve energy efficiency and decarbonize the energy structure while strictly controlling the total energy consumption. The decarbonization of the power sector is necessary for achieving carbon neutrality. In the near-to-mid-term, implementation of carbon pricing mechanism will have a significant emission abatement benefit before 2035. The reduction of non-CO_2 GHG emissions, especially the control of methane and F-gases (e.g. SF_6 and PFC), is crucial for China to achieve the carbon neutrality target by 2060 or earlier.

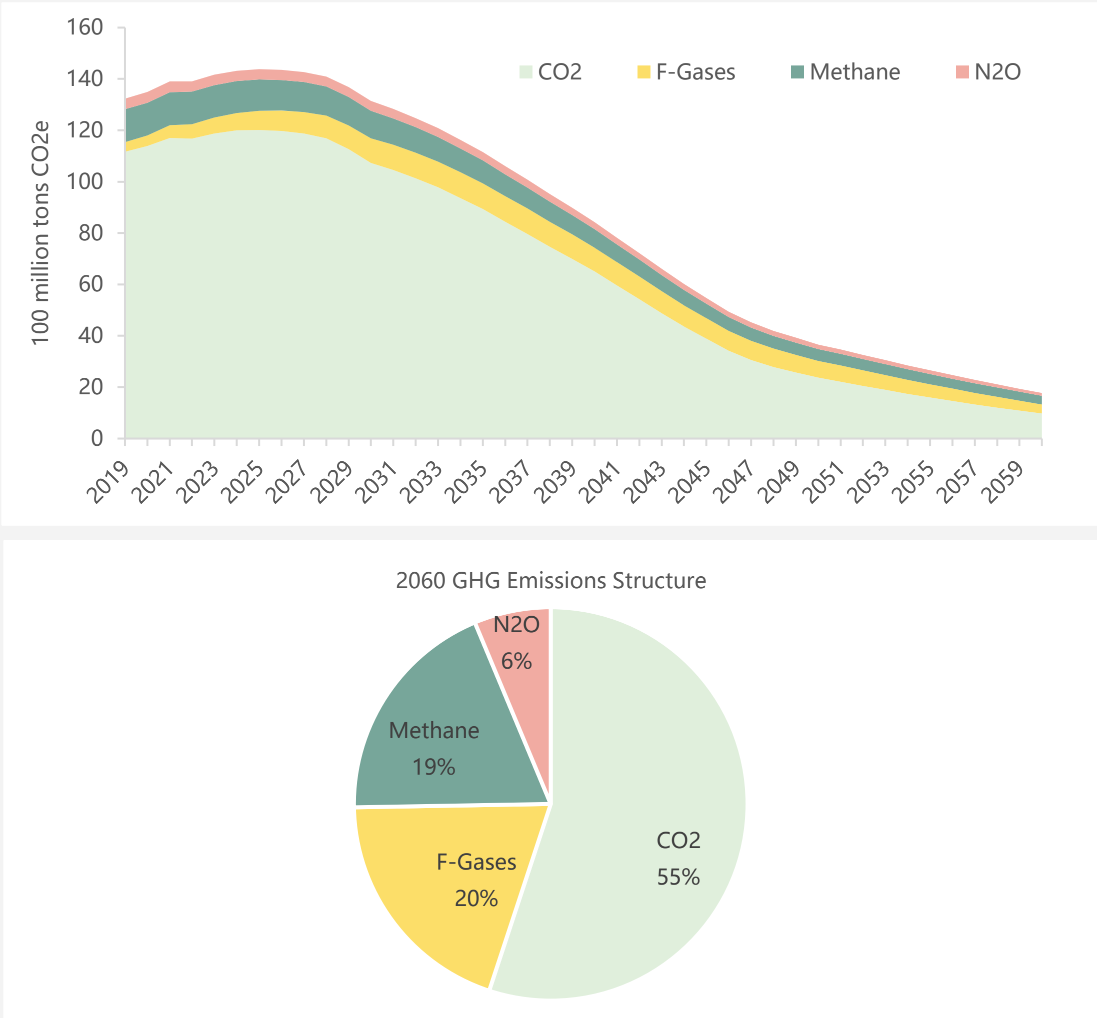
CONTENT

Carbon Neutrality Scenario Outlook

Greenhouse Gas Emissions[1]

Under Carbon Neutrality Scenario (CNS), CO_2 and total GHG emissions peak before 2030; by 2060, without considering changes in land use and forestry, GHG emissions decrease to approximately 1.8 billion tons CO_2e, an 88% reduction from peak. In 2060, GHG emissions are comprised of approximately 1 billion tons of CO_2 emissions and about 800 million tons of non-CO_2 greenhouse gases (referred to as "non-CO_2 GHG"), with respective reduction rate of 92% and 67% from peak. As CO_2 emissions will reduce to near-zero level, there is still a considerable gap in the near-zero emissions of non-CO_2 GHG provided the most advanced technology and policy measures to date.

Figure 1 GHG Emission Trends Under CNS and Structure in 2060

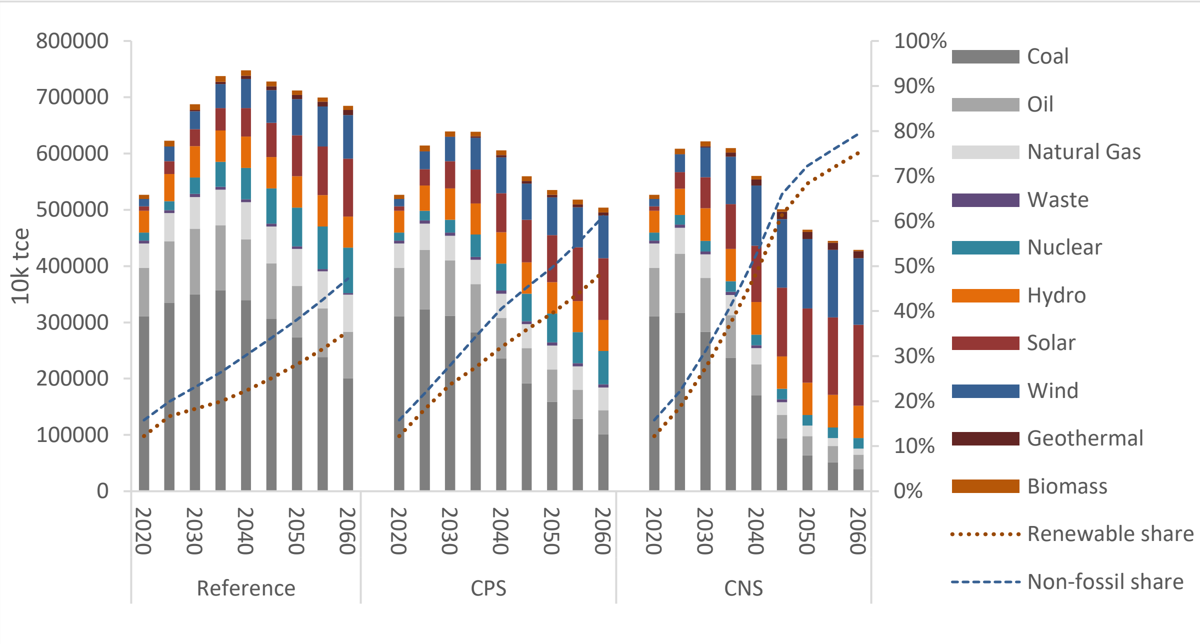


[1] In this report summary, all GHG emissions mentioned refer to GHG emissions excluding emission from LULUCF, unless otherwise noted.

Primary Energy Consumption

In CNS scenario, under the combined effects of renewable development and electrification rate, the share of non-fossil energy is projected to exceed 50% in around 2040 and reach about 80% in 2060. The share of renewable in primary energy consumption will reach 27% in 2030 and 75% in 2060. Stronger policies will also accelerate the decline of coal consumption. In 2021, coal accounted for about 56% in primary energy consumption, this share drops to around 9% in 2060 under CNS.

Figure 2. Primary Energy Consumption Structure by Scenario [2]



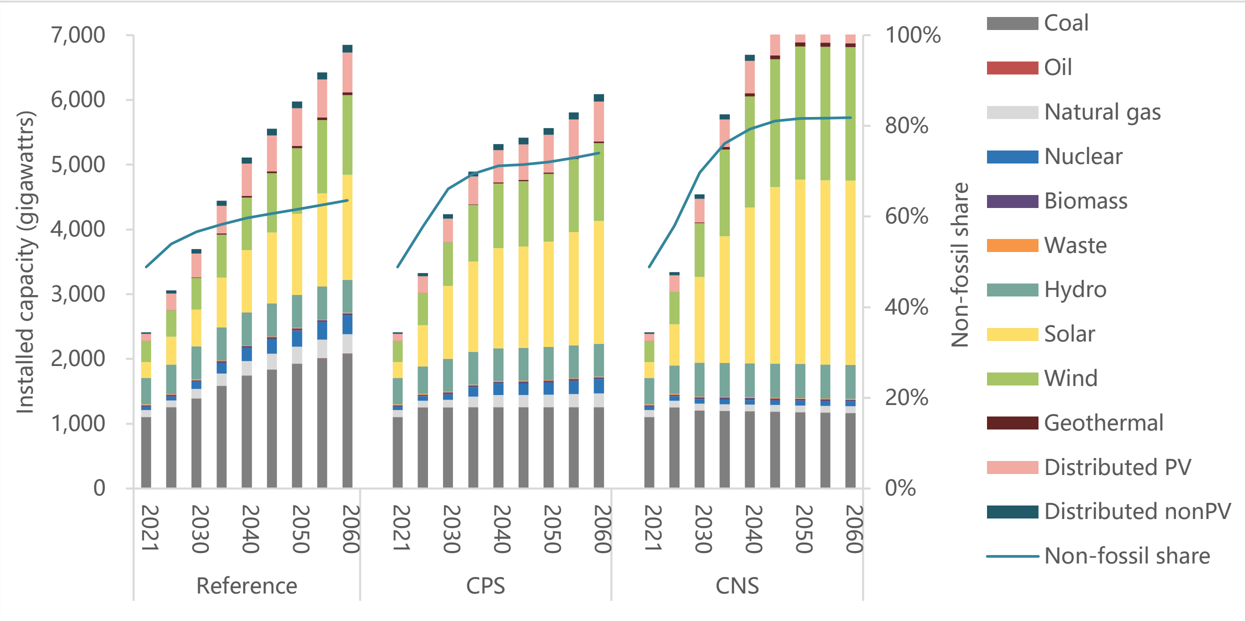
[2] Renewable energy power generation was converted to standard coal equivalent based on coal consumed to produce one unit of coal-fired generation.

Power Generation Structure

As living standards improve and end-use sectors electrify, electricity demand will increase evidently(GEIDCO, 2021; National Grid, 2022; Huang et al., 2022). As shown in Figure 3, by 2030, electricity power demand increases by about 50% compared to that in 2020 and increase by about 71% in 2035 from 2020.

In CNS, non-fossil electricity generation will exceed coal-fired generation in around 2028, and the share of coal-fired electricity will drop below 50% in around 2027. Non-fossil electricity generation reaches about 56% in 2030 and about 91% in 2060. Total wind and solar generation capacity reaches about 2,516 gigawatts in 2030, and exceed 5,500 gigawatts in 2060, while installed nuclear power capacity reaches about 70 gigawatts.

Figure 3. Power Generation Structure Under Different Scenarios



Electrification of End-use Sectors

In CNS, the end-use electrification rate will rise to about 38% in 2030 and 77% in 2060. The electrification rates of industry and transportation reaches 71% and 75% respectively in 2060, while buildings sector being almost fully electrified by then.

Table 1. Electrification Rate by Sector and Scenario [3]

Sector	Reference				CPS				CNS			
	2020	2025	2030	2060	2020	2025	2030	2060	2020	2025	2030	2060
Industry	27%	29%	30%	40%	27%	30%	33%	52%	27%	31%	33%	71%
Building[4]	43%	49%	52%	61%	43%	52%	64%	97%	43%	53%	66%	98%
Transportation	3%	5%	10%	43%	3%	6%	13%	62%	3%	6%	14%	75%
End-use sectors	27%	30%	32%	47%	27%	31%	37%	63%	27%	31%	38%	77%

[3] The conversion of electricity consumption to standard coal equivalent is calculated using calorific values. Energy consumed as feedstock is excluded in the calculation of industrial electrification rate.

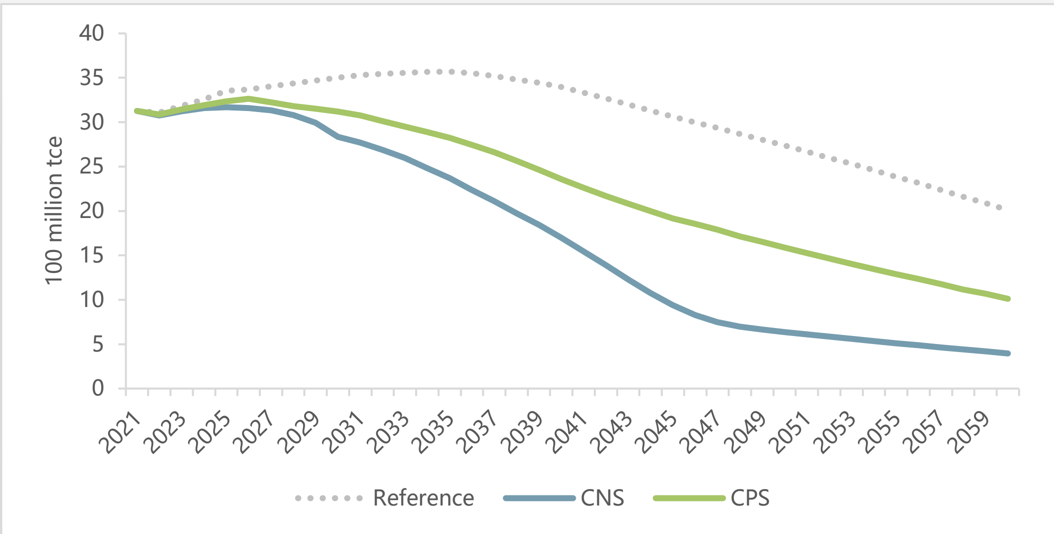
[4] Unless otherwise specified, all buildings in this report refer to only energy consumption and emissions from building operation.

Low-Carbon Development Targets Need Further Reinforcement

The Current "1+N" Policies Can Help Achieve Carbon Peaking on Schedule and Reduce Emission Peak

Driven by end-use electrification and the expansion of non-fossil electricity generation, coal consumption entered a fluctuating plateau in 2020. Under Current Policy Scenario (CPS), with the implementation of the "1+N" policies, the peak value of CO_2 emissions will begin to decline steadily in around 2028. The "1+N" Policies have accelerated peaking process and faster decline of coal consumption (Figure 4), effectively controlling CO_2 emissions.

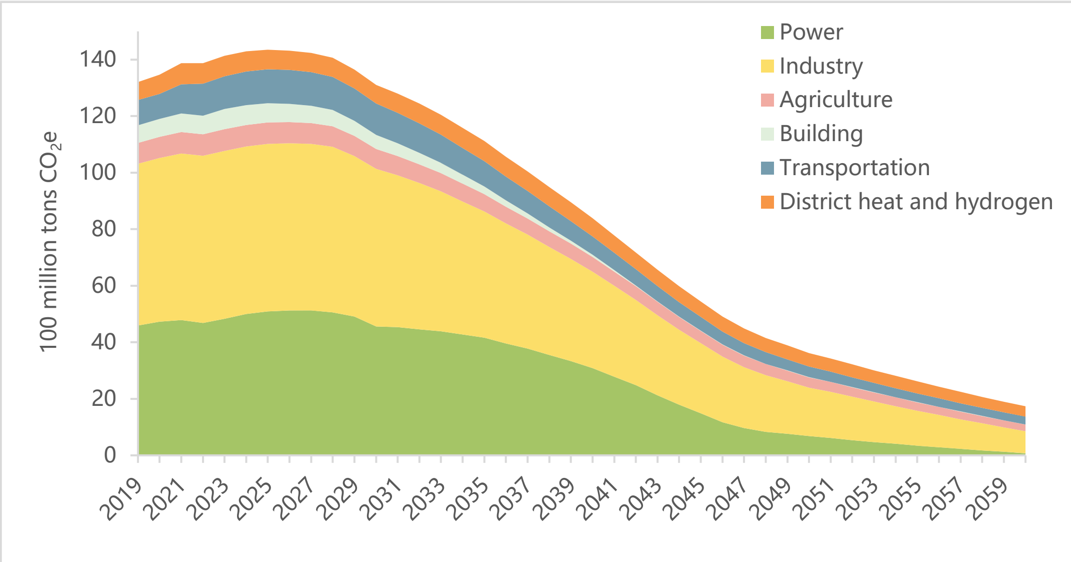
Figure 4. Coal Consumption Projection by Scenario



Fast Emission Reduction After Peaking Will Depend on Continuous Reinforcement of the "1+N" Policy Framework

This analysis shows that under the "1+N" Policy, CO_2 emissions in 2035 are reduced by 8% from 2030 level, and total GHG emissions are reduced by 7%, aligned with the goal of "Carbon emission steadily decline after peaking". However, the gap to Carbon Neutrality remains. Under CNS, strengthened policy measures will lead to a significant reduction in GHG emissions starting from 2028. By 2060, total GHG emissions are expected to decrease by about 88% from the peak level, with CO_2 emissions dropping by 92%. Compared to CO_2, achieving near-zero emissions for non-CO_2 GHG emissions remains a significant challenge.

Figure 5. GHG Emissions by Sector in CNS (including process emissions)



Achieving substantial emission abatement requires reinforcing of 2035 targets. Under CNS, targeting carbon neutrality by 2060, the cumulative reduction rate of GHG emissions in 2035 from 2030 should be no smaller than 15%. See Table 2 for expected performance of key indicators in 2035.

Table 2. Key indicators performance in 2035[5]

Indicators	CPS	CNS
2035 CO_2 Emission Reduction From 2030	8%	17%
2035 GHG Emissions Reduction From 2030	7%	15%
Non-Fossil Share in Primary Energy Consumption	34%	41%
Non-Fossil Share in Generation	56%	64%
Coal Share in Primary Energy Consumption	44%	39%
Renewable Share in Generation	48%	60%
Wind And PV Installed Capacity	2,692 gigawatts	3,720 gigawatts

To accelerate energy transition, the share of non-fossil fuel in primary energy consumption should reach more than 40% by 2035; the share of coal in primary energy consumption should drop to about 39% (Table 2). By 2060, the share of non-fossil fuel in primary energy consumption should reach about 79%. Meanwhile, there should only be 0.4 billion tce of remaining coal, primarily used in industry as feedstock, accounting for about 9% in energy consumption.

The results from CNS show that, by 2035, the share of non-fossil energy in power generation needs to reach 64%, with renewable generation accounting for roughly 60%. The total installed capacity of wind and solar power should reach approximately 3,721 gigawatts, more than three times that of 2023.

By 2060, the share of non-fossil fuel power generation should reach about 91%, with renewables accounting for around 87%. The installed capacity of wind and solar power should reach about 5,521 gigawatts, and the share of non-fossil power in total installed capacity should be around 82%, significantly higher compared to that in CPS.

Key Actions and Timeline

Emission Reduction Policy Pathways

According to the modeling results, key policies throughout different periods include electrification, improving energy efficiency, low-carbon transition in power generation,

[5] GDP projections adopts OECD projections, and historical values are sourced from the National Bureau of Statistics of China; the conversion of electricity consumption to standard coal equivalent adopts calorific values

carbon pricing, and control of methane and F-gases. The timeline of these policies is shown in the following table.

Table 3. Key Emission Reduction Policies and Timetable

Time	Emission trend	Key policies and actions (Ranked based on abatement potential)[6]
2024-2030	Peak CO_2 emission as soon as possible	In 2030 • Building electrification rate exceeds 60%. • Renewable electricity accounts for more than 40% of power generation. • Energy savings in various industrial sectors improve by approximately 2% to 4.5% compared to the Reference scenario. • The electrification rate within the industrial sector reaches around 33%. • Advance the development of high-star-rated buildings and buildings with ultra-low or near-zero energy consumption. • The carbon price reaches 130 RMB/ton, with the carbon market expanding to include the industrial sector starting in 2025. • Transportation electrification rate reaches 13%; new energy vehicles sales penetration reaches 65%-75% for passenger transport and 25%-30% for freight.
2030-2035	Substantial abatement of CO_2	In 2035 • Renewable accounts for 60% of total power generation. • Energy savings in various industrial sectors improved by approximately 7% to 14% compared to the Reference scenario. • Based on 2025 level, energy savings in commercial and urban residential buildings increase by 20%~30%, with extended promotion of high-star-rated and ultra-low or near-zero energy consumption buildings. • The electrification rate of buildings reaches approximately 75%. • The electrification rate within the industrial sector reaches around 40%. • The transportation sector's electrification rate reaches 28%, new energy vehicles sales penetration reaches 100% for passenger transport. • The carbon price reaches approximately 157 RMB/ton, with the carbon market further expanding to include the construction and transportation sectors.
2035-2045	Steady abatement of GHG emissions	In 2045 • Renewable electricity accounts for 82% of power generation. • Industrial electrification exceeds 50%. • Compared to 2035, the energy efficiency level of commercial and urban residential buildings will increase by 20%~30%; ultra-low energy consumption/near zero energy consumption buildings will be expanded to cover all new buildings. • Building electrification rate is about 95%. • Industrial energy conservation in various industries increases by about 18%~35% compared to Reference Scenario. • CCS are equipped for process emissions from chemical, cement, and iron and steel industry. • Transportation electrification rate reaches about 58%; new energy vehicles sales penetration reaches 100% for freight. • Strengthen F-gases emissions reduction measures, especially for other F-gases besides HFCs.
2045-2060	Reach net-zero GHG emissions	In 2060 • Renewable electricity accounts for more than 85% of power generation • The industrial electrification rate reaches 70%, with hydrogen energy substituting high-temperature heat sources. • Chemical, cement and steel industry process CO2 emissions will be reduced by 95%, 90% and 60% respectively by 2060 through CCS. • All remaining fossil fuel power plants will be fully equipped with CCS. • Building energy use will be nearly 100% electrified.

[6] In the calculation of electrification rates in the table, the conversion of electricity to standard coal equivalent adopts the electric-thermal equivalent method, and the calculation of industrial electrification rate excludes non-energy use

Time	Emission trend	Key policies and actions (Ranked based on abatement potential)[6]
		• Strengthen measures to reduce F-gases emissions, with particular focus on controlling F-gases besides HFCs. • The electrification rate of the transportation sector reaches approximately 75%. • Industrial energy-saving policies across various sectors will be enhanced by approximately 29% to 55% compared to Reference Scenario.

Key Emission Reduction Measures Before 2030

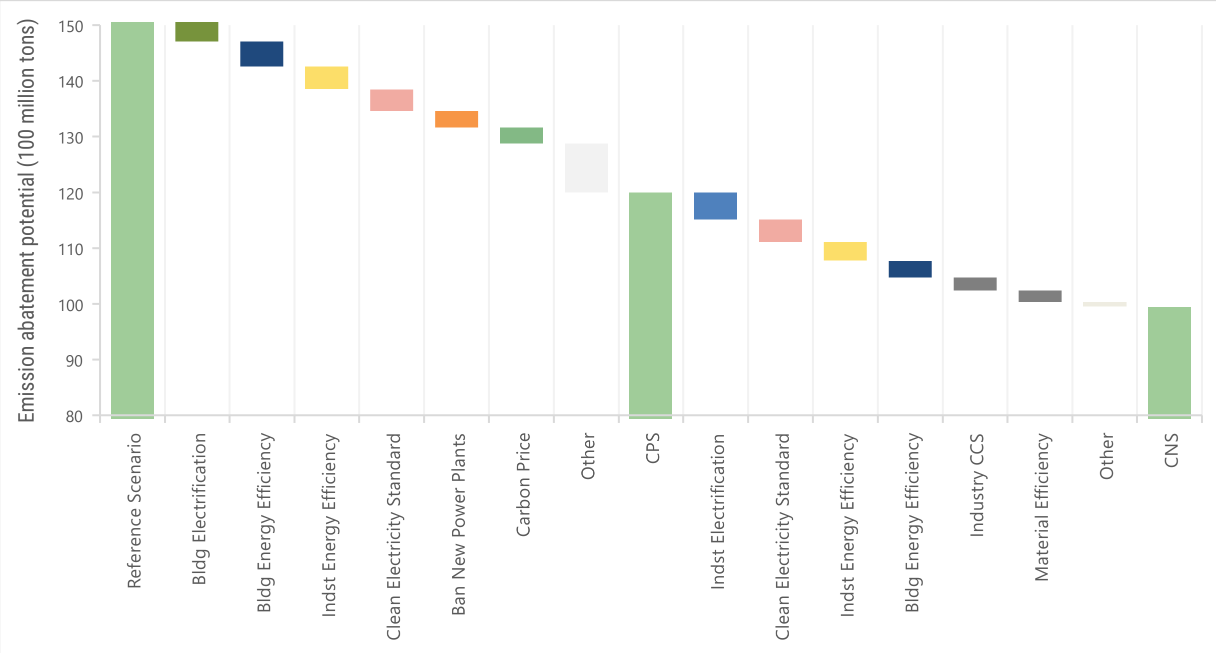
The model results show that during the 15th FYP period, continuing to prioritize clean electricity development, end-use electrification and energy-saving policies, which are in accordance with existing policy priorities, will enhance emission reduction. As shown in the figure below, from 2025 to 2030, the development of non-fossil electricity generation and building electrification have the greatest abatement potential, with cumulative emission reduction contribution of roughly 20%; industrial energy conservation and electrification contributed 18% and 12% respectively. The abatement potential for energy conservation in buildings accounts for about 12%; emission reduction through electrification of transportation accounts for about 5%. In addition, carbon market and pricing (7%) and transportation structure optimization such as "shifting road to water and rail" for freight transport also have significant emission reduction effects (2%).

Figure 6. Key CO_2 Emission Reduction Policies Before Peaking (2025-2030, CPS compared with reference scenario)

From Carbon Peaking to Carbon Neutrality

There is still a considerable gap to reaching net zero in 2060 under CPS, 7% decrease of GHG emissions is observed from 2030 to 2035, only half of that in CNS (15%). In order to bridge the gap, further increasing the share of non-fossil power generation, accelerating the development of high-star-rated green building and ultra-low energy consumption buildings, improving the industrial electrification rate, are critical to further reduce emission and facilitate a solid foundation for reaching carbon neutrality (as shown in Figure 7).

Figure 7. GHG Emissions in 2035 and Abatement Potential by Key Policies



To align with the Carbon Neutrality trajectory, developing clean electricity primarily from renewables is still the most critical action from 2031 to 2060. After 2045, CCS should be a supplement and only equipped for remaining fossil-fuel-fired power plants to achieve net-zero emissions in power sector. The accelerated construction of new type of power systems will effectively reduce wind and solar curtailment and increase the security and reliability of power system. Energy storage and demand-side management will play a vital role in this regard. According to existing policy and planning, a preliminary national unified power market will be built in 2030, then enhanced step-by-step with the construction of spot market, capacity and ancillary service markets. Cross-regional green power trading mechanism will further optimize resource allocation, help allocate costs more effectively, and promote the sustainable development of renewable power.

Electrification of end-use sectors will be pivotal. Compared with the Reference Scenario, the electrification and hydrogen substitution in industry, buildings, and transportation in CNS contribute to a total emission reduction up to about 30% from 2031 to 2060, within which industrial electrification and hydrogen substitution alone accounts for up to 15%. The supply of low-temperature heat should be fully electrified by 2060. Since high-temperature heat electrification technology is still in its early stages, hydrogen substitution will be needed to reach net-zero[7]. The "Action Plan for Promoting Large-Scale Equipment Renewal and Consumer Goods Replacement"[5] issued by China in April 2024 provides a great opportunity to promote electrification and improve efficiency in key industry sector, buildings, and transportation sector.

After 2030, it will become increasingly important to focus on non-CO_2 GHG abatement, especially, the policy requirements for F-gases besides HFCs should be reinforced as soon as possible. Based on the current projection, F-gases emissions will continue to rise. For example, as more air conditioners are installed, the delayed emission of F-gases during the use of air conditioners will also increase. In addition, the leakage of sulfur hexafluoride (SF_6) from power transmission infrastructure and PFC emissions from aluminum manufacturing are contributing to the increase in F-gases emissions. From 2031 to 2060, F-gases control measures account for about 10% in the total cumulative GHG emission reduction potential. The contribution from dietary structure adjustment, emission reduction in livestock and other methane abatement policies account for about 6%, with nitrous oxide accounting for about 1%.

[7]Assuming that by 2060, all fuel consumption in China's industrial sector comes entirely from electricity and hydrogen. Assume 100% electrification substitution for low-temperature heat sources, with exceptions in agriculture and construction, and a 90% electrification rate applied to account for certain energy needs that are challenging to fully electrify. The electrification rate of heat sources for each industry follows the analysis by (Madeddu et al., 2020) on the achievable electrification rate of different temperature heat sources in the EU industrial sector. Heat sources that cannot be electrified are substituted with hydrogen. In the carbon neutrality scenario, by 2060, the hydrogen substitution rate in the cement industry is 73%, approximately 19% in chemicals, petrochemicals, and coking, 81% in steel, and about 53% in rubber and plastics manufacturing.

Figure 8a. GHG Emission Reduction Key Policies (2031-2060), CNS Compared with Reference Scenario

Figure 8b. GHG Emission Reduction Key Policies (2031-2060), CNS Compared with Reference Scenario

Figure 8c. GHG Emission Reduction Key Policies (2031–2060), CNS Compared with Reference Scenario

About the Scenarios

Three scenarios are established to simulate the energy consumption and GHG emissions reduction pathways. The base year for all scenarios is set as 2020, year 2021-2060 are projection by the model.

The Reference Scenario reflects the natural development of the policy measures and technology before the Dual Carbon Target was stated in 2020, and it does not take into account policies released after 2020. This scenario is used as a baseline for comparison and is a hypothetical and unrealistic scenario.

The "1+N" and 14th FYP Policy Scenario, referred to as Current Policy Scenarios (CPS), reflect the "1+N" Policy Framework and the 14th FYP planning and policy measures that China has gradually built after the Dual Carbon Target was proposed, and it does not consider the additional efforts to reach Carbon Neutrality in 2060. This scenario is used to evaluate the emission reduction effect of the existing Policy Framework.

The Carbon Neutrality Scenario (CNS) is the most ambitious combination of policy measures and best feasible practices that support China's achievement of its Carbon Neutrality target in 2060. This scenario is used to identify existing policy gaps and policy priorities for reaching net-zero GHG emissions.

Table 4. Scenario setting

Scenario	Setting
Reference Scenario	Only energy and low-carbon policies before the Dual Carbon Target was stated in 2020 are considered.
"1+N" and 14th Five-year-plan policy scenario (Current Policy Scenario, CPS)	Includes energy and low-carbon policies covered the "1+N" Policy Framework, the 14th FYP and other related mid- and long-term development plans.
Carbon Neutrality Scenario (CNS)	With the goal of achieving carbon neutrality by 2060, a combination is selected based on best practices in China and around the world considering technical and economic feasibility.

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About iGDP and authors

About iGDP

The Institute for Global Decarbonization Progress (iGDP) is a non-profit think tank focusing on green and low-carbon development. Established in 2014, iGDP is committed to China's decarbonization and the global effort to address climate change. iGDP provides policymakers, impact investors, and practitioners with forward-thinking solutions and knowledge products from an international perspective.

Through interdisciplinary, systematic, and empirical policy research, iGDP promotes robust energy and climate solutions with high implementation and investment feasibility. iGDP works with its partners to promote a zero-emissions future.

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