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on China's Carbon Neutrality

ELECTRIFICATION IN CHINA'S CARBON NEUTRALITY PATHWAYS

SUMMARY FOR POLICY MAKERS

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China's climate targets indicate a serious commitment toward climate change mitigation. Achieving these goals in China, as in other countries, will require significant energy system transformation. This report provides an overview of policies and energy and emissions trends since 2020 in China; analyzes the alignment between China's near-term policy targets and its long-term goals; evaluates the role of electrification in the low-carbon transition; and identifies sectoral near-term actions and long-term strategies that can accelerate electrification and power sector decarbonization and put China on a successful pathway to low-emissions growth.

CHINA'S CARBON NEUTRALITY COMMITMENT

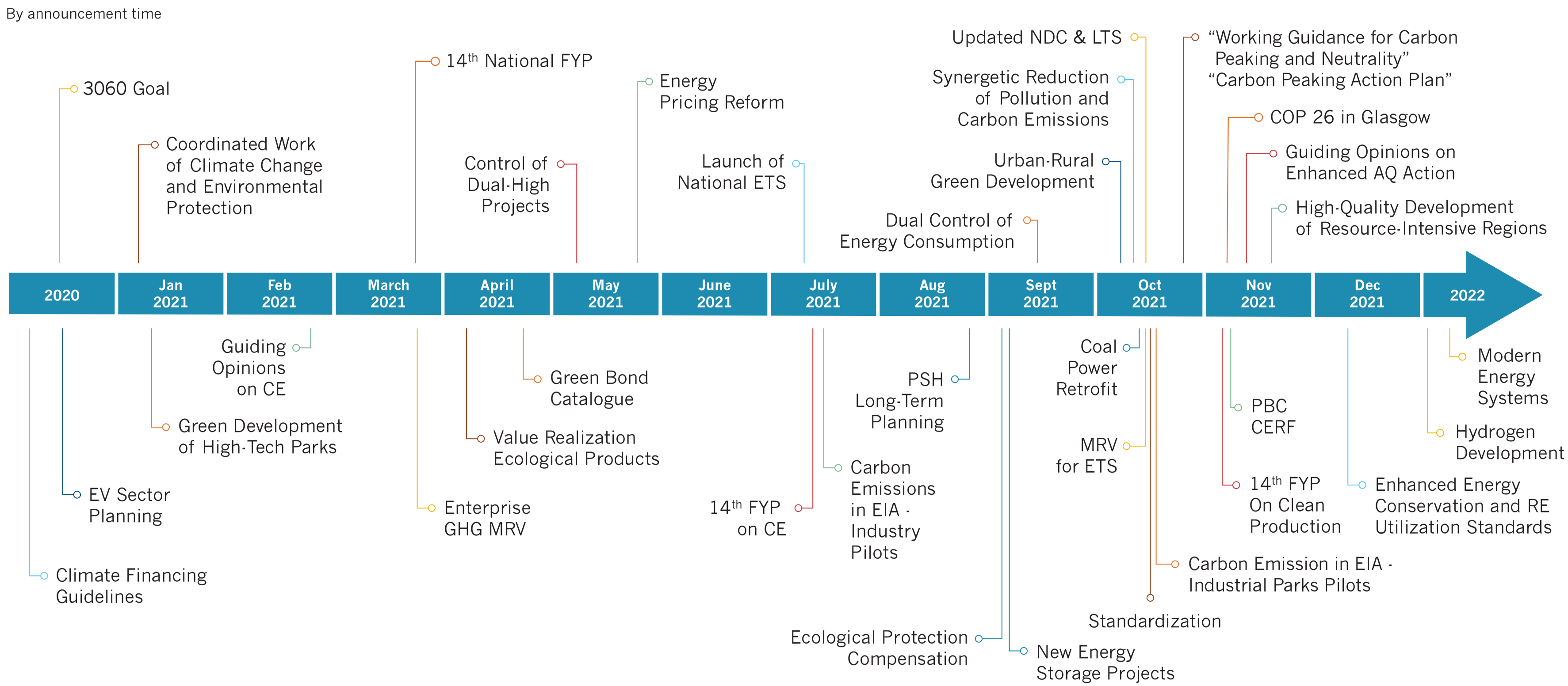
In September 2020, President Xi pledged that China would peak its carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality before 2060. In April 2021, he announced China's plan to strictly limit the increase in coal consumption over the 14th Five Year Plan (FYP) then begin phasing it down in the 15th FYP. In September 2021, President Xi pledged that China would stop building new coal-fired power plants overseas.

These pledges, along with a number of climate policies enacted since 2021 (Figure 1), signal China's serious commitment to climate change mitigation. But, like other countries moving forward on climate change action, reaching these goals will require overcoming obstacles and making choices about which transition pathways China should take.

Energy security is one of the top priorities of China's development strategy. Current world events have made it even more critical. The Russia-Ukraine conflict has thrown global energy markets into turmoil with rising oil and gas prices. Consequently, China, as an energy importer, has been experiencing higher energy costs and commodity prices this year. Domestically, China struggled with several power shortages in 2021 and 2022, making stable and reliable energy supply a prime concern.

Fulfilling China's climate pledges will require significant energy system transition. Ensuring energy security in this transition is key. Electrification is a core part of China's pathway to carbon neutrality, but it must be approached correctly. Electrification of end-use sectors, coupled with power system decarbonization, can help achieve a low-emissions future while promoting energy security by reducing pressure on energy supply. By replacing fossil fuels in buildings, industry, and transportation with electricity generated from low- or zero-emissions fuels, significant CO_2 emissions reduction can be achieved. Meanwhile, modernizing the grid system and using more local, renewable resources to generate electricity can foster a flexible and reliable power system while improving energy security.

FIGURE 1: TIMELINE OF CLIMATE POLICIES RELEASED IN 2021 AND 2022.



RE	Renewable Energy	CERF	Carbon Emission Reduction Facility	CC	Climate Change
MRV	Measurement, Reporting, and Verification	CE	Circular Economy	EP	Environmental Protection
ETS	Emission Trading Scheme	PSH	Pumped Storage Hydropower	LTS	Long-Term Low Greenhouse Gas Emission Development Strategies
EIA	Environmental Impact Assessment	FYP	Five Year Plan		
GHG	Greenhouse Gas	NDC	Nationally Determined Commitment		
PBC	The People's Bank of China				

This report is the second in a series of synthesis reports that analyze China's carbon neutrality transition. The first report, published in 2020, highlights China's pathways towards carbon neutrality and transitions throughout the economy. This second report provides an overview of China's new policies and energy and emissions trends since 2020; analyzes the alignment between China's near-term policy targets and long-term goals; conducts deep dives into the role of electrification, focusing on the simultaneous transitions of electrifying end-use sectors while decarbonizing the electricity sector to achieve China's "30/60" goals; and identifies a set of near-term sectoral actions and long-term sectoral strategies that can accelerate electrification and power sector decarbonization and put China on a successful pathway to low-emissions growth.

The assessment is based on multiple model results, deep-dive working papers on specific sectors, and existing research (Box 1).

BOX 1. ANALYSES USED IN THIS REPORT.

This report synthesizes the recent progress of policies, and reviews and summarizes existing research related to China's carbon neutrality transition. This report also assesses a number of quantitative analyses from national and global models, including: China DREAM, China TIMES, GCAM-China, AIM-China, MESSAGEix-China, PECE_LIU_2021, and PECE V2.0. These modelling results are presented based on two coordinated scenarios: *Updated NDC to Carbon Neutrality* and *Original NDC to Carbon Neutrality*. These scenarios achieve net-zero greenhouse gas (GHG) emissions by 2060, but have different peaking times. We do not attempt to harmonize assumptions across models. The results shown in this report reflect model-specific interpretation of socioeconomic and technological development in China. Building on these analyses, some modeling teams also developed deep-dive analyses to address key issues and to explore technology options for electrification in different sectors. These deep-dive papers include provincial-specific renewable energy investment needs, stranded assets, and credit risks in China's coal power transition, and electrification and transition strategies in industry, transportation, and buildings. Insights from these deep-dive papers are synthesized to provide additional sectoral, spatial, and technological granularity to the analyses. These papers are published with this report to provide additional context and information.

CARBON NEUTRALITY PATHWAYS

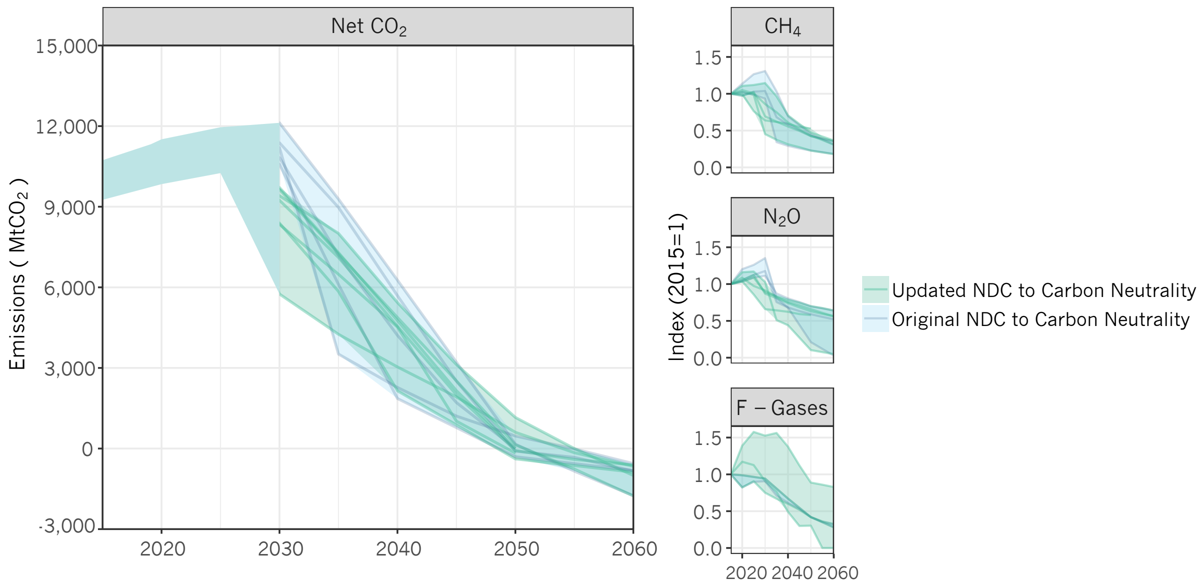
This report explores two main scenarios designed to assess the implications of reaching net-zero GHGs by 2060[1]. The scenarios are identical in that they require GHG emissions to reach net-zero by 2060, but they differ in how quickly China's emissions would peak before declining. The *Updated NDC to Carbon Neutrality* scenario is in line with the updated Nationally Determined Contribution (NDC) submitted by China to the United Nations Framework Convention on Climate Change. The updated NDC commits to peaking before 2030, and, since models operate in five-year timesteps, China's emissions would peak between 2025 and 2030 in the *Updated NDC to Carbon Neutrality* scenario. The *Original NDC to Carbon Neutrality* scenario explores the consistency between current policies that are aligned with China's original NDC submission in 2015, and the long-term goals. In this scenario, current policies are kept in place, and China's emissions peak around 2030.

[1] In China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy, China reiterated the goal of achieving carbon neutrality before 2060. In a speech delivered in 2021, Minister Xie mentioned that China is working towards net-zero GHG emissions by 2060. The target of net-zero GHG emissions by 2060 reflects our understanding of China's long-term climate goals and is consistent with the target of achieving carbon neutrality before 2060.

To achieve carbon neutrality before 2060, as shown in the multi-model results (see Figure 2), China needs to peak its CO_2 emissions before 2030, then dramatically reduce emissions afterwards. The peak amount of net CO_2 emissions[2] between 2025 and 2030 is within the range of 10.3–11.7 and 10.5–12.1 $GtCO_2$ in the *Updated NDC to Carbon Neutrality* and *Original NDC to Carbon Neutrality* scenarios, respectively. China's CO_2 emissions from energy and industrial processes peak around the same time, with the range of 11.0–11.9 and 11.3–12.2 $GtCO_2$ in the *Updated NDC to Carbon Neutrality* and *Original NDC to Carbon Neutrality* scenarios, respectively. To offset remaining non-CO_2 emissions, China's net CO_2 emissions reach zero around 2050/2055 and get to about negative 0.6–1.8 $GtCO_2$ by 2060. In terms of net GHG emissions, China's GHG emissions peak between 2025 and 2030 at the level of 12.3–14.3 and 12.9–14.7 $GtCO_2$-eq in the *Updated NDC to Carbon Neutrality and Original NDC to Carbon Neutrality* scenarios, respectively, and get to net-zero by 2060.[3]

FIGURE 2: EMISSIONS PATHWAYS TO NET-ZERO GHG EMISSIONS BY 2060.

The left panel shows China's net CO_2 emissions across models in *Updated NDC to Carbon Neutrality* pathways (green) and *Original NDC to Carbon Neutrality* pathways (blue); these two scenarios indicate larger variations in system transition and emissions reduction in the near term across models and between scenarios. The right panels present normalized trajectories (2015=1) of emissions reductions for non-CO_2 GHGs. Absolute emission levels of non-CO_2 GHGs are not used here due to large inventory uncertainties: CH_4 ±30%; N_2O ±60%; F-gases ±30%.



To accelerate the long-term transition from fossil fuels, several short-term targets have been adopted, including the 14th FYP targets of reducing the country's carbon intensity (i.e., energy CO_2 per unit Gross Domestic Product (GDP)) by 18% in 2025, compared to the 2020 level. In addition, China's updated NDC requires carbon intensity reduction by more than 65% in 2030, compared to the 2005 level. The multi-model results show that China's 14th FYP and updated NDC targets on carbon intensity reduction are roughly aligned with the net-zero transition pathways but can be further enhanced (Figure 3).

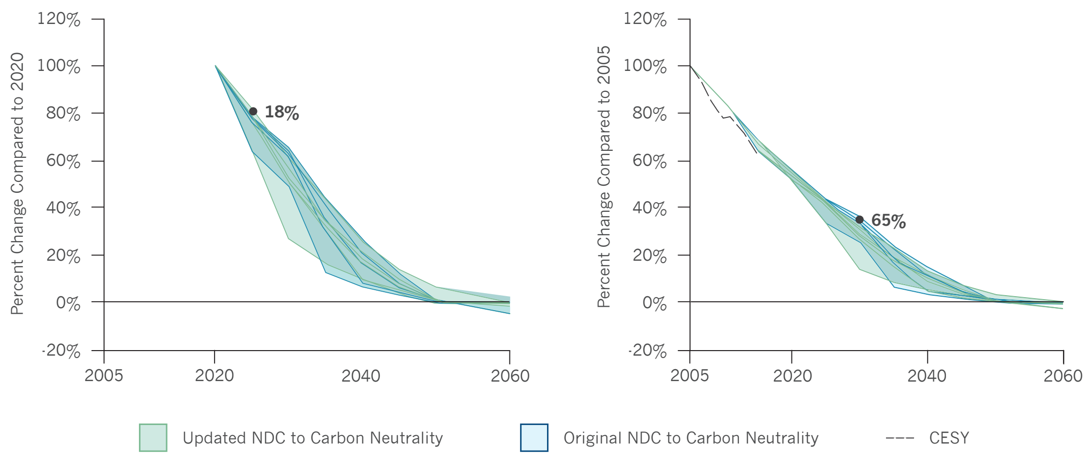
[2] Net CO_2 emissions include CO_2 emissions from both fossil fuel and industrial activities and land use, land-use change and forestry (LULUCF) activities.

[3] Not all models can report total GHG emissions. Results are from the four models that include total GHG emissions. Other models reached net-zero CO_2 by 2050.

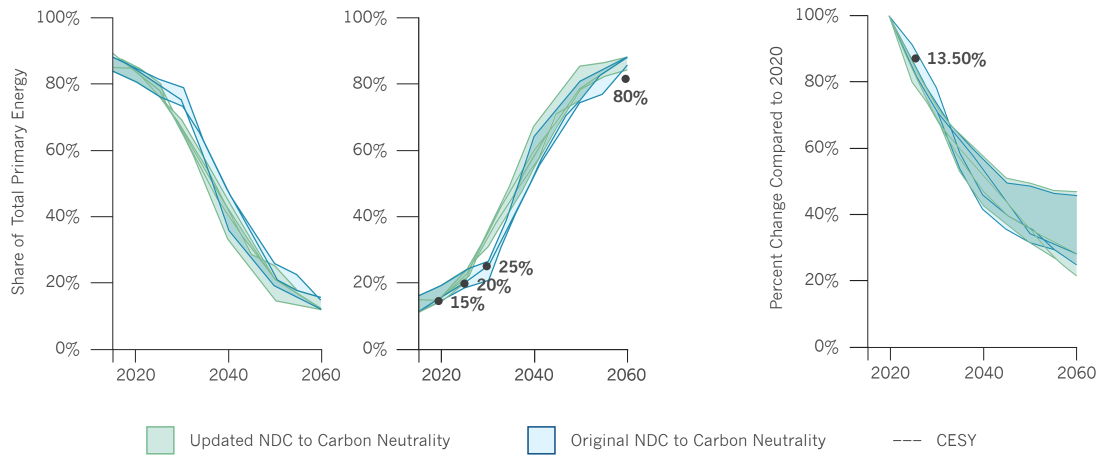
FIGURE 3: NATIONAL POLICY TARGETS AND COMPARISON WITH MODELING ANALYSIS. (A) ENERGY CO_2 PER GDP MER, (B) FOSSIL AND NON-FOSSIL SHARES IN PRIMARY ENERGY AND (C) PRIMARY ENERGY PER GDP MER.

Carbon intensity is measured as energy-related CO_2 emissions per unit of GDP. To assess the alignment with China's updated NDC target (over 65% reduction in 2030 compared to the 2005 level), we use model data for models that report 2005 data and use historical 2005 CO_2 emissions and GDP data for models that do not have 2005 data. Non-fossil sources include solar, wind, geothermal, hydro, nuclear, and biomass with and without carbon capture, utilization, and storage (CCUS). Fossil sources include coal, oil, and gas with and without CCUS.

(A) Energy CO_2 Intensity per GDP MER



(B) Fossil Shares in Primary Energy **Non-Fossil Shares in Primary Energy** **(C) Primary Energy per GDP MER**



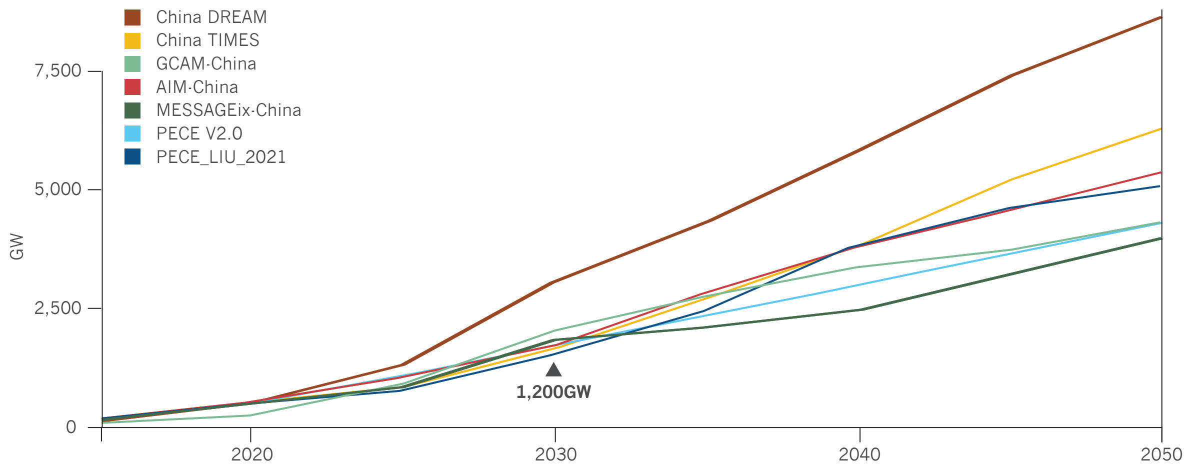
Most models in the *Updated NDC to Carbon Neutrality* scenario surpass the 13.5% below 2020 primary energy per unit of GDP target, with a 14–20%[4] reduction by 2025, compared to 2020 (Figure 3C). Modeling analysis also shows the projected non-fossil share of primary energy meets or exceeds Chinese policy targets in 2025. Non-fossil energy use in 2030 is affected

[4] Range across models without MESSAGE is 14–20% reduction compared to 2020 of primary energy per unit of GDP. Range across models with PECE V2.0 is 10–31% reduction of primary energy per unit of GDP compared to 2020.

by peaking times. In the *Updated NDC to Carbon Neutrality* scenario, models show 29–54% non-fossil primary energy, exceeding the national target of 25% non-fossil primary energy in 2030. Non-fossil share continues to increase to 84–97% by 2060, exceeding the 80% target outlined in China's long-term strategy. All models project combined solar and wind capacity to significantly exceed 1,200 GW, with estimates ranging from 1,600–3,000 (1,600–1,800 GW without China DREAM) GW in 2030 (Figure 4).

FIGURE 4: INSTALLED SOLAR AND WIND CAPACITY IN THE *UPDATED NDC TO CARBON NEUTRALITY* SCENARIO COMPARED TO THE 2030 TARGET IN THE UPDATED NDC.

China's updated NDC commits to over 1,200 GW of combined solar and wind capacity by 2030.



ELECTRIFICATION ROADMAP

Electrification is an important low-carbon transition option, not only because it will be feasible to achieve substantial emissions reductions in electricity more quickly than in other sectors, but it also offers the opportunity to curb, and eventually reduce, final energy consumption due to significantly higher efficiencies in many applications.

Our analyses indicate an average electrification rate (share of electricity in final energy use) of 80% (66–93% across models) in buildings and about 65% and 60% direct electrification in industry (58–69% across models) and passenger transportation (56–64% across models) by 2060, suggesting that electricity becomes the dominant fuel source in these three sectors (Figure 5). The freight transportation sector reaches an average of only 35% (22–39% across models) electrification. This sector, along with passenger aviation and high temperature heat in heavy industries, needs further research and development to understand how alternative fuels, such as hydrogen and synthetic fuels, can help these sectors indirectly electrify and reduce emissions. Table 1 further discusses near-term actions and long-term strategies in each sector to advance electrification.

To meet the increasing electricity demand, which grows by an average across all models of 125% (80–161%), almost 5,000 GW (4,380–5,200 GW) of capacity needs to be added between 2020 and

2060. Rapid capacity expansion is accompanied by accelerated fuel switching, i.e., phasing out unabated coal use by 2050 or earlier, while increasing the deployment of solar, wind, nuclear, and carbon capture, utilization, and storage (CCUS) technologies with biomass or fossil fuels. As a result, all models project the power sector will see significant emissions reduction and reach zero, or even negative, emissions by 2050. While all models are in agreement on significant emissions reduction and unabated coal phaseout, the pathways to getting there are different. All models agree on the expansion of solar and wind generation, but contributions from other energy sources, including biomass with CCUS, fossil fuel generation with CCUS, and nuclear, vary across models. Future power sector portfolios will reflect policy choices, technology availability, and economic costs.

Ensuring that supply equals demand, and vice versa, is a constant challenge for the power grid. The low-carbon transition will place additional constraints on and opportunities for the power sector in this balancing act. Meeting increasing demand with intermittent renewable resources, adjusting manufacturing supply chains, and replacing existing infrastructure pose grid instability risks. However, electric vehicles, battery storage, and consumer behavior programs can help reduce peak load; micro-grids and small-scale renewable energy systems can help provide electricity access in remote locations; and expanding grid infrastructure can help increase power supply diversity and improve overall reliability.

Promoting electrification in the context of carbon neutrality requires comprehensive and cross-sectoral integration (Figure 5). Enhanced coordination between end-use sectors and the power sector will help develop cost-effective and efficient policies. For example, the benefits of distributed PV systems are maximized when combined with smart vehicle charging stations. Emissions reduction in the industrial manufacturing sector that produces solar and wind technology is dependent on decarbonization in the power sector. There are several near- and long-term sectoral options to decarbonize China through accelerated electrification and power system transition (see Table 1). Other actions that can promote electrification include: offering financial incentives for replacing end-use infrastructure with market-available electric options; expanding research and development in end-uses that don't have an existing feasible electric alternative; updating power grid market mechanism; improving transmission and distribution capabilities across provinces; and developing cross-sectoral electrification policy.

FIGURE 5: ELECTRIFICATION ROADMAP.

Power supply make-up and electrification rate across sectors are the mean value across models. Near-term and long-term policy options are summarized from actions outlined in Table I and corresponding chapters in the full report.

	2030	2050	2060
POWER SECTOR	Adjust electricity market design, deploy demand response programs, time-varying pricing and other digital tools Solar + Wind · **Up to 35%** Coal without CCUS. · **Down to 35%**	Further increase the adjustable capacity of existing sources and expand the long-term and seasonal energy storage Solar + Wind · **Up to 60%** Coal without CCUS. · **Down to 0%**	Develop a new grid system for high share of renewable power and increase inter-connectivity between grid regions Solar + Wind · **Up to 65%** Coal without CCUS. · **Down to 0%**
ELECTRIFICATION RATE	Building · **50%** Industry · **30%** Freight Transportation · **5%** Passenger Transportation · **15%** **Total 2030 - 35%**	Building · **75%** Industry · **50%** Freight Transportation · **25%** Passenger Transportation · **55%** **Total 2050 - 55%**	Building · **80%** Industry · **65%** Freight Transportation · **35%** Passenger Transportation · **60%** **Total 2060 - 65%**

END-USE SECTORS

RATES AND POLICIES:
NEAR-TERM CHANGES

- Convert to electric space heating in public buildings
- Offer financial incentives for switching to electric heating, stoves and water heaters
- Transition to industrial heat pumps and electric boilers for low and medium temperature heating in light industries
- Develop an industry electrification technology standard
- Implement low carbon fuel standards for trucks
- Adopt public or municipal fleet electrification targets
- Offer subsidies for direct purchase of EVs and charging infrastructure

RATES AND POLICIES:
LONG-TERM CHANGES

- Promoting the application of PEDF (Photovoltaic, Energy storage, Direct current, and Flexibility) solution in buildings to utilize more renewable power from distributed PV by better demand side management
- Deploy public education programs to change residential energy use behavior
- Research and develop advanced industrial electrification technology for medium and heavy industry
- Develop hydrogen fuel cell technologies and advanced electrification technologies that can provide longer ranges for heavy-duty utility trucks
- Research and develop fuel alternatives for air and water transport
- Promote the coordinated and effective expansion of charging infrastructure

SECTOR KEY Building · Industry · Freight Transportation · Passenger Transportation

TABLE 1: SUMMARY OF ACTIONS FOR ELECTRIFICATION ACROSS END-USE AND POWER SECTORS.

Sector	Near-term Actions	Long-term Strategies
Buildings	► Incorporate electric space heating into public procurement and facilitate adoption of electric space heating in government office buildings and the public buildings that receive government funds. ► Develop national standards and criteria for regulating the commercial licensing of related building equipment manufacturers, parts suppliers, and project contractors to ensure the quality of implemented projects to meet relevant national standards and criteria. ► Adopt financial incentives to promote the market share of electrification technologies, including tax incentives and subsidies to contractors, related appliance manufacturers, and consumers. ► Promote the use of digital technologies in buildings to facilitate the course of electrification in buildings.	► Design specific long-term development plans for electric space heating in administrative jurisdictions. ► Deploy public education programs to change. residential energy-use behavior in buildings. ► Promoting the application of PEDF (Photovoltaic, Energy storage, Direct current, and Flexibility) solution in buildings to utilize more renewable power from distributed PV by better demand side management. ► Cover current coal-fired or gas-fired district space heating plants by the current emissions trading system (ETS) in China.

Industry	► Transition to industrial heat pumps and electric boilers for low and medium temperature heating needs in light industries.
	► Deploy demand response programs and electricity market design, time-varying pricing, and other digital tools.
	► Develop an industry electrification technology standard.
		► Expand hydrogen use as a reduction agent in the steel industry and as a feedstock for ammonia and methanol production in the chemical industry for indirect electrification.
		► Increase production of steel from scrap in electric arc furnaces.
		► Develop and disseminate industrial electric boilers, electric heating furnaces, electric metallurgical furnaces, and industrial heat pumps.
		► Promote and research advanced industrial electrification technology, including:
		  ► Induction or microwave heat technology for cement clinker production.
		  ► Direct reduced iron technology based on green hydrogen.
		  ► Infrared and ultraviolet heating technology for process heating: electronic heating technology, induction melting.
		► Establish transition finance mechanism, taking into account the demand for electrification funds and the function of risk management.

Sector	Near-term Actions	Long-term Strategies
Transportation	► Electrify passenger light-duty and medium-duty vehicles, including cars and buses, along with light and medium duty trucks, more rapidly through: ► NEV fleet-wide targets or sales bans on internal combustion engine (ICE) vehicles. ► Incentives for early retirement of ICE vehicles. ► Implement freight incentives and policies: ► Low carbon fuel standards for trucks. ► Zero emission vehicle (ZEV) freight sales requirements/targets. ► Weight exemptions for ZEVs (heavy-duty vehicles). ► Direct incentives for ZEV purchases. ► Direct and utility investments in EV charging. ► Implement passenger incentives and policies: ► Car license plate restrictions and traffic restrictions. ► Public or municipal fleet electrification targets. ► Direct ZEV purchase subsidies and subsidized charging infrastructure use. ► ZEV direct access and waivers for zero-emission zones. ► Preferential parking policies for ZEVs.	► Develop hydrogen fuel cell technologies and advanced electrification technologies that can provide longer ranges for heavy-duty utility trucks: ► Expanded use of hydrogen and hydrogen-derived fuels produced by electrolysis. ► Advance biojet/synthetic fuel development for air and water transport, potentially through: ► Subsidies. ► Government pilots. ► Carbon pricing/taxes. ► Compulsory blending quota for new fuels. ► Promote the coordinated and effective expansion of charging infrastructure: ► Public investment. ► Priority permitting and guarantees of land.
Power	► Encourage increase in renewable generation, along with other flexible low-carbon power sources (nuclear, carbon capture, utilization, and storage). ► Adjust energy consumption intensity and time periods through market mechanisms. ► Increase digitalization of the grid and demand response programs to reduce consumption. ► Policy and technology coordination between energy sector and other sectors to integrate energy infrastructure, including removing some obstacles for construction of renewable energy projects, such as land supply constraints.	► Further increase the adjustable power capacity of existing sources (thermal, hydropower, gas, and concentrated solar power). ► Increase use of micro-grids in areas with weaker power grids. ► Promote smart demand side response management, such as smart charging, vehicle-to-grid, and virtual power plants, to reduce peak-load grid costs and avoid excessive new investment in power distribution. ► Increase inter-network interaction between grid regions. ► Expand the energy storage capacity (especially long-term and seasonal storage) and improve ancillary services market design to support energy storage development. ► Strengthen electricity market reform to support renewable development and significantly increase the integration of renewables into the grid.

AREAS OF FUTURE RESEARCH

This report builds on multi-model, multi-institution research on China's carbon neutrality transition. It discusses high-level transition pathways and sectoral-specific transition strategies and focuses on deep dives into electrification and power sector transition. In conducting this research, several key issues have emerged to address achieving China's carbon neutrality. These include: (1) just transition that covers energy affordability, regional distributional impacts, and fiscal and economic analysis; (2) the role of hydrogen in low-carbon transition from both production and consumption sides; (3) non-CO_2 emissions across sectors and gases. These issues can be further explored in a future report series to provide a more comprehensive understanding of China's carbon neutrality transition.

Additional efforts are also needed to improve China's policy framework to facilitate deep decarbonization. Several thematic areas are not given sufficient consideration in the current policy framework, including cross-sectoral coordination at the subnational level and an overall plan for orderly subnational action roadmaps; and enabling policies to take care of the stranded assets for retired capacity and vulnerable communities. In particular, transition risks became a major concern for subnational governments and sectors that have high dependence on fossil fuels. More research is needed to explore a fair and just transition mechanism that can help ease the pain exerted upon affected populations and enterprises, and guarantee that no one is left behind in China's low-carbon transition.

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