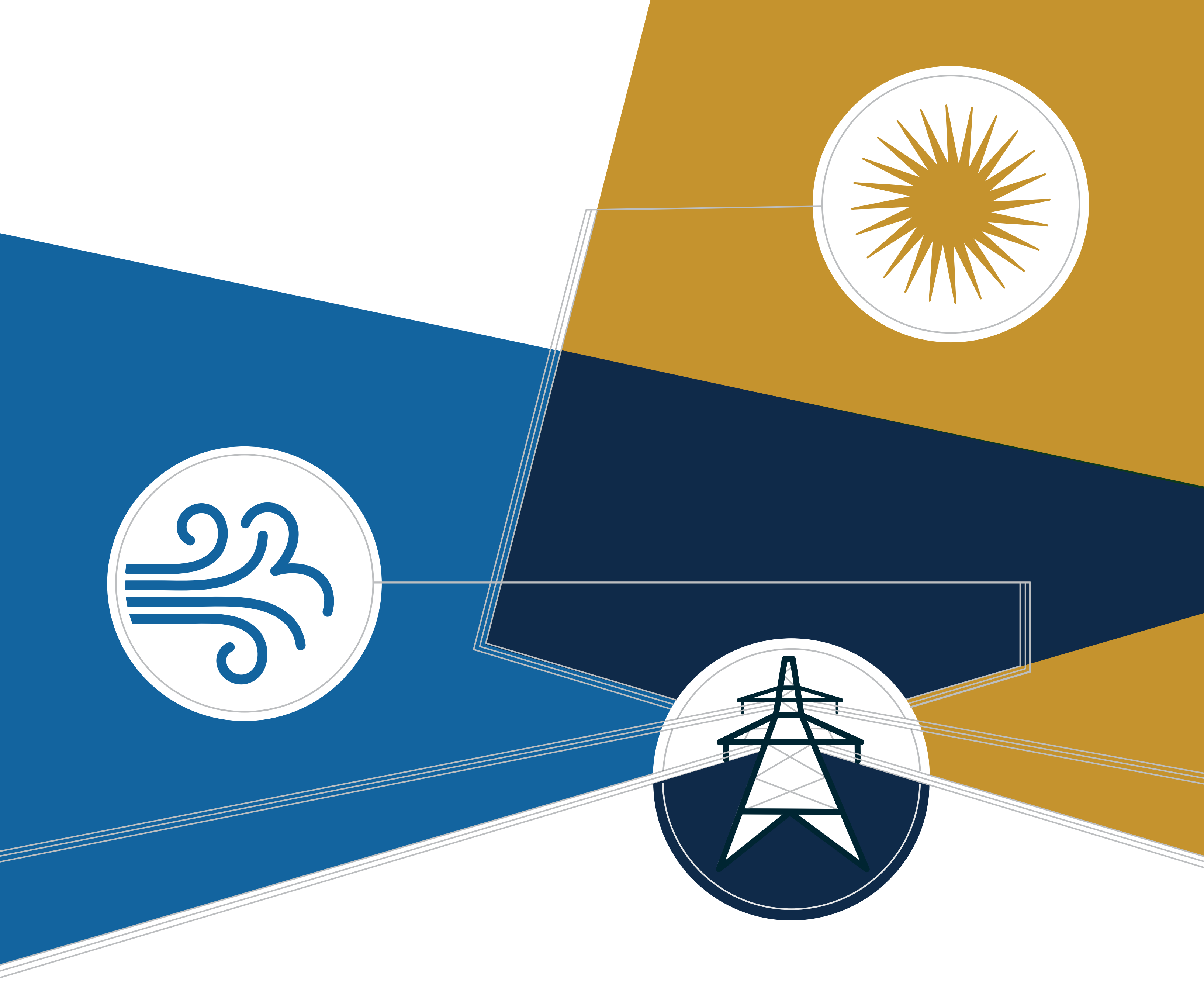

Renewable Energy Pathways to Carbon Neutrality in China

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Summary for Policymakers

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POWER TRANSFORMATION LAB

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About the California-China Climate Institute:

The California-China Climate Institute was launched in September 2019 and is a University of California-wide initiative housed jointly at UC Berkeley's School of Law (through its Center for Law, Energy, and the Environment) and the Rausser College of Natural Resources. It is chaired by Jerry Brown, former Governor of the State of California, and vice-chaired by the former Chair of the California Air Resources Board Mary Nichols. The Institute also works closely with other University of California campuses, departments, and leaders. Through joint research, training, and dialogue in and between California and China, the Institute informs policymakers, fosters cooperation and partnership, and drives climate solutions at all levels.

About the Power Transformation Lab:

The Power Transformation Lab at the University of California, San Diego studies the engineering and institutional requirements to deploy low-carbon energy at scale. We work with academic, government, civil society, and industry partners to advance research and solutions to the climate challenge centering on the role of the power grid. Our areas of focus include renewable energy resource planning, affordable and reliable low-carbon power markets, and the political economy of industrial policy and low-carbon transitions in firms.

About the Institute of Energy, Environment and Economy, Tsinghua University (3E):

The Institute of Energy, Environment and Economy, Tsinghua University (3E), established in 1980, is an interdisciplinary research and education institute at Tsinghua University. The institute's mission is to create, develop and disseminate the knowledge, ideas, and methodologies crucial for building sustainable energy systems and mitigating climate change for China and the world. As an important think tank for China's energy and climate change research, the institute has been continuously providing policy advisory services to the National Development and Reform Commission (NDRC), the Ministry of Ecology and Environment (MEE), and the National Energy Administration (NEA). The institute has long-time collaborations with prestigious universities and international organizations.

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SUMMARY FOR POLICYMAKERS

China has announced ambitious climate policy goals of reaching peak carbon emissions by 2030 and carbon neutrality by 2060.[1] To achieve these goals, it is crucial to decarbonize the largest carbon-emitting source, the power sector, which further enables the electrification of other sectors such as transportation, industry, and buildings. This process requires a large increase in low-carbon renewable energy and complementary infrastructure, including storage and transmission. While these long-term objectives are clear, the deployment structure, pace, and distributional impacts are uncertain. To address this gap, we developed a novel modeling approach with a high spatial and temporal resolution to identify feasible and efficient pathways for deploying renewables, storage systems, and transmission lines, by decade, from 2020 to 2060.[2] From a policy-making perspective, understanding low-carbon pathways provides national and subnational governments information needed to anticipate, plan for, and address a wide range of bottlenecks that will arise with this unprecedented transformation. Our analysis helps support a more effective, efficient, and equitable clean energy transition for China.

SPM Table 1 | Deployment Priorities Across Decades

<table>
<tr><th></th><th>Utility-scale solar</th><th>Distributed solar</th><th>Onshore wind</th><th>Offshore wind</th><th>Storage</th><th>Transmission lines</th></tr>
<tr><td>2020-2030</td><td colspan="2">Deploy in high-quality regions in the north and west</td><td rowspan="2">Deploy in northern regions and coastal regions</td><td rowspan="2">Ensure deployment efforts are sufficient in driving down costs in spite of unfavorable economics</td><td>Deploy in high-variable renewable energy regions to manage diurnal variations</td><td>Expand three regional clusters (northwest, south, and north)</td></tr>
<tr><td>2030-2040</td><td colspan="2">Extend to major load centers driven by continuous renewable cost declines</td><td rowspan="3">Prioritize battery storage in regions with limited hydro resource availability while promoting further battery cost declines</td><td>Strengthen major north-south corridors through both central and eastern regions</td></tr>
<tr><td>2040-2050</td><td rowspan="2">Largely exploit the available land near major load centers and continue the expansion in northern and western regions due to increasing land use and coal phasedown</td><td rowspan="2">Prioritize coastal regions due to proximity to load centers driven by lower transmission and integration costs</td><td rowspan="2">Prioritize coal-rich regions in the north to coordinate with the phasedown of coal plants</td><td rowspan="2">Ramp up deployment in coastal regions due to rapid cost declines</td><td rowspan="2">Expand both interprovincial networks and long-distance national networks to accommodate renewable integrations</td></tr>
<tr><td>2050-2060</td></tr>
</table>

1 United Nations, 2020

2 Zhang et al., Under Review

Energy Transition: Structure and Pace

The annual capacity additions of wind and solar will need to increase from around 70 gigawatts (GW) per year in the first decade (2020-2030) to 210-300 GW per year in the last decade before its carbon neutrality goal (2050-2060), while total installed capacities reach 2100-3200 GW by 2040, 3300-4800 GW by 2050, and 5200-5300 GW by 2060. Integrating these variable energy resources into the grid requires storage and transmission lines to address inter-regional imbalances and inter-temporal variations. Annual storage additions increase from 105-173 gigawatt hours (GWh) per year in the first decade to 180-260 GWh per year in the last decade, while the transmission network expands at rates of 13-16 GW/year (2020-2030), 13-38 GW/year (2030-2040), 18-24 GW/year (2040-2050), and 5-35 GW/year (2050-2060). Historical rates of manufacturing capabilities are likely to be sufficient to meet domestic demand, though crucially depending on the scale of clean energy technology exports.

Geographic Distribution

The geographical distributions of different technologies over four decades are highlighted in Summary For Policymakers (SPM) Table 1. Our results demonstrate, under feasible and efficient pathways, that utility-scale and distributed solar will start in the north and west regions of the country due to higher capacity factors, and then extend to major demand centers starting from the next decade (2030-2040). This shift is largely driven by renewable cost declines and high transmission costs. Notably, distributed solar will be more prominent along the coast since the costs will become similar to western regions over time. In addition, onshore wind has a wide footprint both in northern China and along the coast, while continuous cost declines will incentivize the deployment of offshore wind in coastal provinces. Relatively high transmission costs drive renewable deployment in lower-quality regions such as eastern China, but low-cost storage alters this dynamic by allowing renewable deployment in high-quality regions such as northern China in later decades. This suggests that regional prioritizations and renewable targets at the provincial level will be valuable for guiding local governments and sustaining the current deployment momentum.

Land Use, Economic Impacts, and Electricity Market Challenges

Solar deployment will exhaust the majority (51-82%) of suitable land in eastern provinces by 2060, while wind will significantly impact coastal province lands (14-48%), driven by promising renewable energy potentials and proximity to demand. While further guidance on siting and permitting from the national government is needed, local governments should establish project pathways and regional standards for co-location uses to reduce project uncertainties and mitigate land use impacts. Furthermore, as the transmission network becomes more interconnected, the total trading volume will likely see a three-fold increase by 2060. Efficient inner- and inter-regional trading mechanisms are thus essential in integrating renewables and reducing system costs.

Policy Recommendations

National and subnational governments have a strong role to play in achieving China's clean energy transition. To address large challenges and uncertainties, we identify near- and long-term priorities to design and implement supporting policy programs to ensure goals are met over time. The recommendations are highlighted in SPM Table 2.

SPM Table 2 | Policy Recommendations		
	National Government	**Provincial Governments**
Near-term (2020-2035)	• Incorporate and enforce clear deployment targets or portfolio standards in the upcoming five-year plans for renewable energy • Integrate storage and transmissions into the renewable planning processes with specific deployment targets • Set standards for regional electricity markets to allow more efficient power trading and balancing	• Promote retail and wholesale market reforms (e.g., time-of-use pricing, spot market trading) to improve renewable project economics • Identify strategies to facilitate coal retirement and mitigate local financial and social impacts
Long-term (2035-2060)	• Provide national guidance on renewable siting and permitting processes • Develop proper compensation mechanisms mainly for flexible conventional resources, and ensure continuous cost declines of renewables via auctions	• Monitor global markets for wind and solar equipment to ensure a sufficient supply to meet deployment targets • Establish project pathways and regional standards on installing renewables on agricultural lands • Strengthen effective compensation mechanisms to facilitate the least-cost deployment options for distributed energy resources