Unlocking the Potential of Carbon Cost Pass-Through in Cross-Regional Electricity Markets: A Switch-China Model Approach to Enhancing Price Fairness and Reducing Emissions

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Overview

The low-carbon transition of the power sector is essential to achieving carbon reduction goals, yet regional disparities in energy mixes and carbon pricing pose challenges to fairness and competitiveness. This study examines the carbon cost pass-through mechanism in cross-regional electricity markets, analyzing its effects on renewable energy competitiveness, electricity prices, and national carbon emissions. Using the Switch-China-Open model, the research simulates carbon pricing strategies, power generation structures, and emission factors across regions. Addressing gaps in previous studies, this work aims to identify the optimal carbon cost pass-through level to balance the competitiveness of renewable energy and consumers' electricity cost burden. The results show that high carbon pricing is essential to achieving China's dual carbon targets, reducing emissions by 19% by 2050 compared to the BAU scenario and aligning with IPCC goals, while low carbon pricing delays the emissions peak by five years. High carbon pricing also accelerates renewable energy growth, with wind and solar contributing 67% of power generation by 2050, as coal's share drops to 16%. Provincial carbon emission factors simulations reveal that high carbon pricing effectively lowers emission intensities and promotes balanced low-carbon development, though regional disparities persist, with high-carbon regions like Shaanxi remaining coal-dependent, while low-carbon regions like Fujian achieve successful transitions even under low-price scenarios.

Methods

This study employs the Switch-China model to optimize power system operations over the coming decades, minimizing total costs while analyzing the impacts of generation portfolios, carbon pricing strategies, and renewable energy penetration. To enhance analysis, the open-source software GridPath is utilized to simulate electricity prices based on grid operations influenced by fuel costs, renewable availability, demand, and transmission constraints. The electricity price data generated by GridPath is integrated into the Switch-China model to explore carbon cost pass-through mechanisms, enabling a comprehensive assessment of its effects on power system operations, generation mix decisions, and electricity prices.

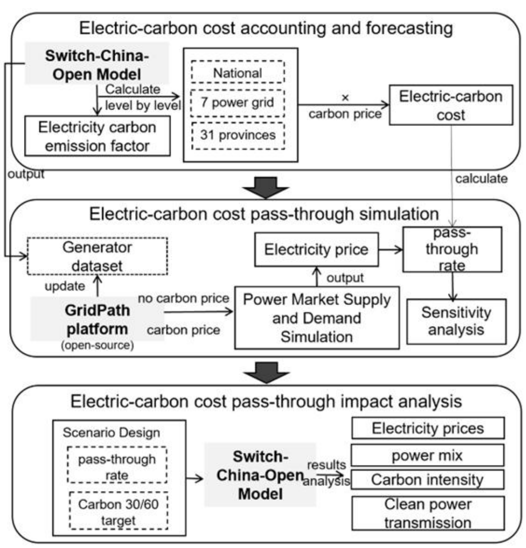

Fig 1. Research Framework

Results

1. National Carbon Emissions Simulation

Low carbon pricing can mitigate emissions but delays the carbon peak by five years, failing to meet carbon neutrality goals. High carbon pricing achieves a carbon peak by 2030 and reduces emissions to 19% of the BAU scenario by 2050, aligning with the IPCC target (<20%). Achieving China's dual carbon goals likely requires a high carbon pricing policy.

2. Simulation of National Installed Capacity by Energy Type

High carbon pricing significantly boosts renewable energy (shown in figure 1): wind capacity increases from 7% in 2025 to 24% in 2050, solar grows from 5% to 43%, and energy storage reaches 8%. Natural gas and coal capacity decline, with coal's share dropping to 16% by 2050, one-fourth lower than the BAU scenario. Hydropower's share also decreases, from 16%-17% under BAU to 5% by 2050, reflecting the flexible adjustment of energy resources.

3. Provincial Carbon Emission Factor Simulation

Simulations predict provincial and grid region emission factors for 2030, 2040, and 2050. Under low carbon pricing, significant reductions in emission intensity begin after 2040 in high-carbon regions such as Xinjiang (0.65 to 0.32), Inner Mongolia (0.75 to 0.61), and Heilongjiang (0.58 to 0.1). However, by 2050, regions like Inner Mongolia, Ningxia, Shaanxi, Chongqing, Anhui, Liaoning, and Jilin still exhibit emission factors exceeding 0.5, indicating that low carbon pricing alone cannot achieve nationwide low-carbon electricity by 2050.

Under high carbon pricing, emission factors drop significantly across most provinces, approaching minimal levels by 2050. However, some regions, such as Henan (0.79) and Shanghai (0.82), show increased emission factors. High carbon pricing effectively phases out high-emission energy sources and promotes balanced low-carbon development nationwide.

4. Provincial Installed Capacity Simulation in Regions with Different Carbon Emissions

In high-carbon regions like Shaanxi (shown in figure 2), coal remains dominant, with minimal growth in renewable energy, and even high carbon pricing fails to significantly reduce emissions. In contrast, low-carbon regions like Fujian achieve energy transitions with clean energy dominating the energy mix, even under low carbon pricing.

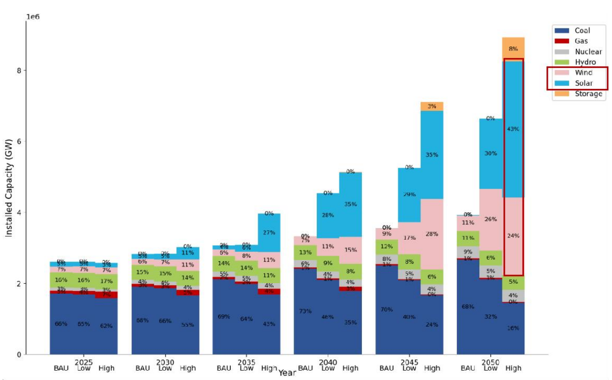

Fig.1 National capacity mix for three scenarios

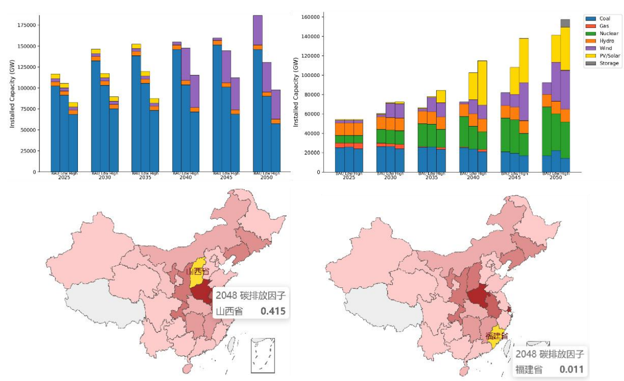

Fig.2 Comparison of installed capacity and factors in high or low carbon regions

Conclusions

This study highlights the critical role of carbon pricing in achieving China's dual carbon goals and transitioning to a low-carbon power sector. High carbon pricing proves essential for peaking carbon emissions by 2030 and reducing emissions to 19% of the BAU scenario by 2050, aligning with IPCC targets. It significantly accelerates the growth of renewable energy, with wind, solar, and energy storage becoming dominant in the energy mix, while coal and hydropower see substantial declines. However, regional disparities persist: high-carbon regions like Shaanxi remain coal-reliant despite high pricing, whereas low-carbon regions like Fujian successfully transition to clean energy even under low carbon pricing. Provincial emission factor simulations further reveal that low carbon pricing fails to achieve nationwide low-carbon electricity by 2050, while high carbon pricing effectively reduces emission intensities and phases out high-emission energy sources. These findings underscore the necessity of differentiated carbon pricing policies and tailored regional strategies to promote a balanced, equitable, and effective national low-carbon transition.