META-ANALYSIS OF LOW-CARBON INVESTMENT NEEDS FOR CHINA

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Overview

Achieving China’s dual-carbon goals—peaking carbon emissions by 2030 and attaining carbon neutrality by 2060 (Xi, 2020)—necessitates substantial investments in the low-carbon transition. While extensive research has explored various decarbonization pathways, there remains a fragmented and incomplete understanding of the associated economic costs. These gaps hinder policymakers from obtaining a clear picture of the total financial requirements and setting investment priorities for critical decarbonization technologies. This study aims to bridge these gaps by systematically analysing investment needs across key technologies and providing actionable insights to support China’s climate objectives through strategic financial planning.

Methods

We conduct a meta-analysis of 38 relevant studies, including peer-reviewed articles and institutional reports, to estimate China’s low-carbon investment needs. These studies are selected based on their monetary estimates of low-carbon investments. The analysis covers macro-level sectors—energy, industry, buildings, and transportation—and micro-level technologies, such as renewable energy and emerging innovations like bioenergy, hydrogen, and carbon capture. To construct low-carbon investment pathways, we emphasize the technological dimension of the energy sector and use the multi-level perspective (MLP) framework to evaluate feasibility across niche, regime, and landscape levels. (Geddes & Schmidt, 2020). The analysis discusses challenges to decarbonization pathways based on complexity and maturity of key technologies (Malhotra & Schmidt, 2020), policy dependencies and market dynamics that shape investment priorities (Emodi et al., 2022), and broader societal and global climate pressures, along with international technological competition and collaboration (Matos et al., 2022).

Results

We found significant variations at both the macro-level (sectoral) and micro-level (technological) perspectives, primarily driven by differences in scenario assumptions and energy models. As 47% of macro-level studies focus on 2020-2050, 2021-2050, or 2015-2050, we standardized the time frame to 2020-2050 for consistent comparisons, as shown in Figure 1. The energy sector emerges as the primary focus for investment, with the ‘Toward 1.5 degrees’ (1.5°C) scenario requiring a cumulative average of USD 13.6 trillion from 2020 to 2050— around 2 times higher than the ‘Nationally Determined Contributions’ (NDC) scenario. At technological level, a comparison of six energy models (Figure 2) reveals a shared focus on renewables and grid upgrades, with differences arising from dependence on fossils, energy efficiency, and nuclear. To address the significant variability in investment pathways of key decarbonization technologies, we identify the most feasible pathways by applying the MLP framework. Our results show that near-term investments (2026–2035) will focus on standardized and mature technologies such as onshore wind and solar power, which can be rapidly deployed due to their scalability and strong market acceptance. However, the choice of near-term investment strategies can have cascading effects on medium- and long-term investment priorities. For

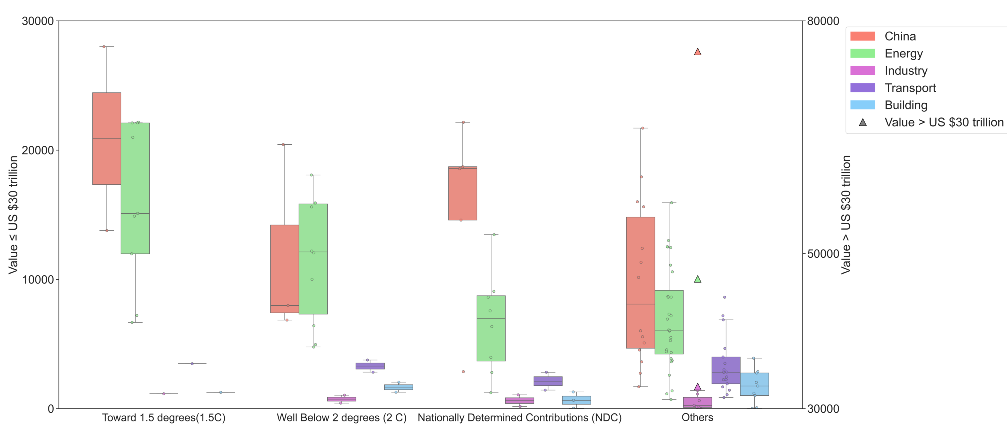

Fig.1Cumulative Investment Needs Across Sectors and Scenarios (2020–2050) in USD Billion: This box plot illustrates all data points derived from the meta-analysis for investment needs between 2020 and 2050, categorized by sectors and scenario groups. The center lines in the box plots represent the median, while the box limits denote the upper and lower quartiles. The whiskers extend to 1.5× the interquartile range (IQR), capturing the range of most data points. The three outlier points represented by triangles correspond to China-specific values in the energy and industry sectors, reflecting exceptional data points that exceed US $30 trillion (use second y-axis on the right).

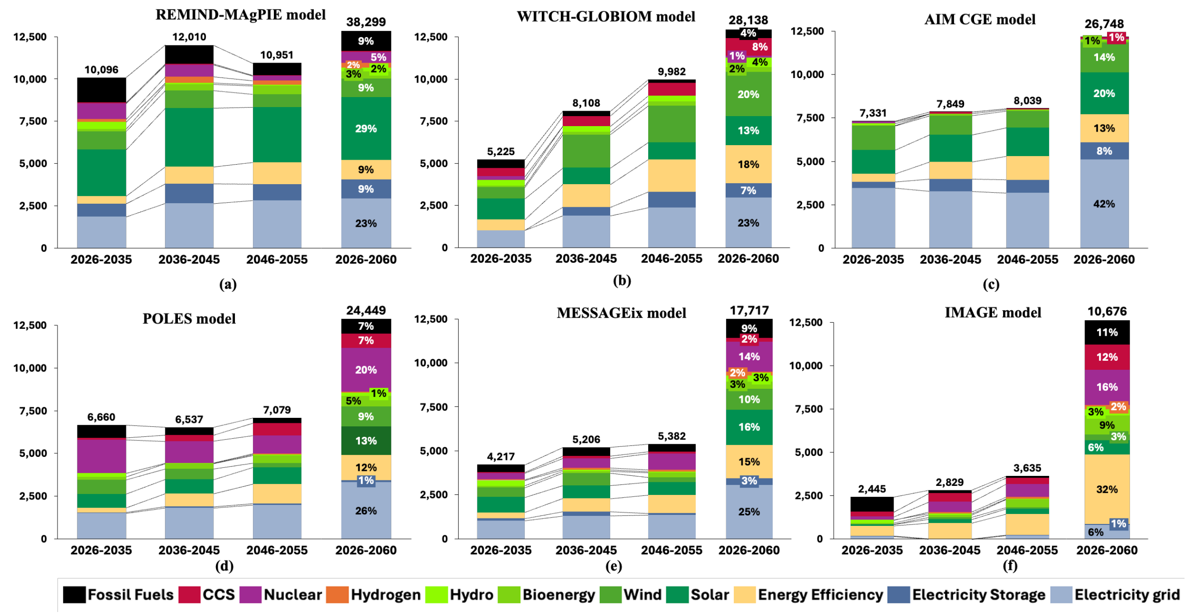

Fig.2 Cumulative Investments and Proportional Shares of Key Technologies (2026–2060, USD Billion): Panels (a)–(f) show projections from different energy models. The first three columns represent cumulative investments in key technologies during 2026–2035, 2036–2045, and 2046–2055, measured in USD billion. The stacked bar on the right illustrates the proportional share of each technology in total investments over the 2026–2060 period. Connecting lines indicate changes in investment priorities across time periods.

instance, prioritizing renewable energy deployment early could reduce dependence on fossil fuel infrastructure and ease the transition to flexibility-focused technologies in the medium term. Medium-term investments (2036-2045) require a choice between system flexibility with storage and grid upgrades, fossils with CCS, or nuclear, with considerable levels of energy efficiency in each case. Each of these choices faces niche level challenges including high costs, technical complexity, and fulfilment of aggressive learning curves, regime level challenges such as stable policy incentives and coordinated infrastructure development, and landscape level challenges such as financial market adaptation (Foxon, 2011), especially with reduced international cooperation in recent years. For example, as seen in figure 2, the correlation between coal and CCS investments risks regime level failure if large-scale CCS cannot be deployed, highlighting the importance of coordinated investment strategies. Over the long term (2046–2055), as technologies mature and costs decline, emerging solutions like bioenergy and green hydrogen are expected to complement efforts toward dual carbon targets, enhancing system flexibility and decarbonization potential.

Conclusions

This study highlights the critical importance of strategic investments in achieving China's dual-carbon goals. A meta-analysis of 38 studies reveals significant variability in low-carbon investment pathways across scenarios and models. Using the MLP framework, we evaluate these pathways across niche, regime, and landscape levels, highlighting the need for a socio-technical transition. Near-term investments should prioritize standardized technologies like onshore wind and solar power. Medium- and long-term strategies must adapt based on near-term emissions outcomes, overall decarbonization goals, technology maturity, and risk considerations, ensuring decisions are interconnected and aligned with overarching decarbonization goals rather than operating in isolation. Long-term success depends on deploying complex solutions such as hydrogen, CCS, and nuclear power, despite challenges including high costs and technical complexity. Coordinated strategies, stable policies, and international collaboration are essential to address these challenges, mitigate risks, and ensure the effective allocation of resources for China's low-carbon transition.

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