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Editorial: Advancing carbon reduction and pollution control policies management: theoretical, application, and future impacts

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Editorial on the Research Topic
Advancing carbon reduction and pollution control policies management: theoretical, application, and future impacts

1 Introduction

The global imperative to combat climate change has necessitated a strategic shift from dual control of energy consumption to dual control of carbon emissions. This transition is more than a policy evolution; it represents a fundamental reorientation toward sustainable development, demanding a profound reassessment of energy production and consumption patterns with a focus on their environmental and carbon footprints. The theoretical underpinnings of this shift are rooted in ecological economics, environmental justice, and the pursuit of a low-carbon economy. Recent progress is evident in advancements such as carbon pricing mechanisms, renewable energy grid integration, energy efficiency standards, and carbon capture and storage technologies, all of which are pivotal in reducing emissions from existing infrastructure.

Against the backdrop of intensifying global climate change and increasingly prominent environmental pollution, strengthening carbon reduction and pollution control has become a core task for countries worldwide in achieving sustainable development. As the world's largest carbon emitter and a major developing country, China has set strategic goals to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, while advancing comprehensive management of air, water, and soil pollution.

This Research Topic aims to construct an integrated, interdisciplinary framework bridging the theoretical and practical dimensions of the transition to carbon-centric control mechanisms. It seeks to identify, analyze, and overcome inherent barriers in this transition while exploring innovative solutions for effective transformation. Through rigorous review, 44 high-quality research papers have been gathered, covering theoretical exploration, policy

application, and future impact prediction in carbon reduction and pollution control, providing valuable academic support for advancing high-quality environmental governance.

2 Theoretical foundation: unveiling the mechanisms of policy-pollution-innovation interaction

Theoretical exploration forms the cornerstone of optimizing carbon reduction and pollution control policies. This Research Topic delves into the intrinsic links between environmental policies, economic factors, and environmental outcomes, making in-depth progress in revealing nonlinear relationships and regulatory mechanisms.

A key area of focus is the interplay between environmental regulation, technological innovation, and emission reduction. Yin et al. examine the nonlinear and diminishing marginal returns of environmental technological innovation on emission reduction under command-and-control regulation, finding that technological constraints limit effectiveness and underscoring the need for tailored innovation strategies and region-specific support. Similarly, Zhang and Gao investigate the nonlinear effects of heterogeneous environmental regulations on green innovation, revealing U-shaped relationships for command-and-control and public participation regulations, and an inverted U-shaped relationship for market-incentive regulations, with common prosperity acting as a positive moderator, highlighting the importance of context-aware policy design. Gu and Liu explore the formation mechanism and continuity of the peer effect in local governments' green governance within China's broader historical and governance reform context. The research highlights how historical administrative decisions and interest mechanisms shape peer influences, leading to convergence behaviors that affect resource allocation and green governance effectiveness. The findings emphasize understanding these dynamics to enhance policy design and governance modernization.

Economic dynamics also play a complex role. Zhang et al. investigate financial globalization's nonlinear relationship with carbon emission intensity across 144 countries, uncovering an inverted U-shape: low financial openness increases emissions via fossil-fuel investments, while higher openness shifts capital to renewables, reducing emissions through improved energy efficiency, renewable share, and technological innovation, with spatial spillovers affecting neighboring countries. Meanwhile, Güler et al. find that GDP and foreign direct investment (FDI) generally exacerbate environmental degradation, supporting the pollution haven hypothesis, though urbanization and value-added agriculture contribute positively to sustainability.

Technological and regional mechanisms further enrich theoretical landscape. Wu and Yang demonstrate that CCUS significantly boosts enterprises' total factor productivity, mediated by improved external environments, enhanced financing, and innovation, with stronger effects in large, state-owned firms and key emitting industries. In urban transportation, Sheng et al. highlight fuel quality improvement as critical for synergistic greenhouse gas and pollutant reductions, while rail transit and low-carbon travel offer notable linkage effects. Regional studies, such as the analysis by Chen et al. of the Wuhan metropolitan area, reveal spatial and temporal homogeneity between PM2.5 and carbon emissions, influenced by factors from meteorology to energy efficiency, with impacts varying across time and space.

Alomair et al. empirically distinguish the effects of natural resource use on environmental sustainability in G20 countries from 1995 to 2019, using carbon emissions and ecological footprint as indicators within a STIRPAT framework. Employing advanced econometric techniques (CS-ARDL, AMG, quantile regression), it finds that both production and consumption of coal and oil significantly harm environmental sustainability, with production exerting a stronger influence. Natural gas exhibits mixed direct and indirect effects. The research also confirms that green policies, including green energy, technology, finance, and environmental taxes, positively promote sustainability. Xie and Wang investigate the impact of green innovation on carbon emissions among publicly listed companies from 2000 to 2022. The results indicate that green innovation significantly reduces enterprise carbon emissions, primarily through improvements in energy efficiency and management specialization. Notably, green invention patents have a stronger carbon reduction effect than green utility model patents. The emission reduction effect is more pronounced in non-state-owned enterprises and in industries characterized by higher pollution intensity and technological complexity.

3 Policy tools: innovation and application of multi-dimensional regulation strategies

The effective implementation of carbon reduction and pollution control goals depends on scientific, multi-dimensional policy tools. This Research Topic explores environmental regulation, green finance, carbon quota allocation, and incentive mechanisms, analyzing their application effects and optimization paths.

Green finance emerges as a powerful lever. Zhang et al. find it significantly curbs urban carbon emissions and intensity, with stronger effects in northeastern, southeastern, non-resource-based, and financially efficient cities, while focusing on intensity reduction in central, western, and resource-based regions. Deng et al. highlight its role in reducing reliance on high-carbon energy and promoting cleaner alternatives, with nonlinear effects beyond a threshold and stronger impacts in eastern regions with mature financial systems. The Green Credit Guidelines Policy (GCGP), as studied by Zhang et al. reduces manufacturing carbon intensity through macro-level industrial upgrading and energy efficiency gains, and micro-level improved investment efficiency and environmental disclosure, with stronger effects in well-governed, low-constraint, and digitally transformed firms, and regions with stricter regulations.

Environmental regulation and public participation also matter. Chen et al. show stronger regulation promotes environmental equity via green innovation transformation, particularly in innovative regions, with green finance and the digital economy enhancing this effect. Wu et al. find increased public participation reduces carbon intensity, with official characteristics like non-local origin and shorter tenure enhancing effectiveness.

Incentives and coordination are key. Lin and Liu reveal that 20%–30% tax incentives combined with ESG digital tools (e.g., blockchain) accelerate stakeholder convergence in emission reduction by 35%. Guo and Xiong develop a flexible inter-provincial carbon allowance allocation scheme, addressing shortcomings in historical or industry-benchmark methods. Meanwhile, Yi et al. note FDI promotes green technology progress, though trade openness weakens this effect, with the Belt and Road Initiative mitigating regional disparities to better leverage trade for green advancement.

Yu and Feng analyze a joint production and green investment decision model for manufacturers financed through green credit under uncertain demand. Using a min-max regret framework, the research derives optimal strategies to enhance decision robustness, validates them through real-world cases, and provides managerial insights for effectively implementing green credit financing in unpredictable market environments. Guo et al. investigate the complex relationship between green trade and carbon emissions in G20 countries from 2000 to 2022 using OLS, moderating effect, and quantile regression models. Contrary to expectations, green trade is found to increase carbon emissions, especially at higher emission quantiles. Political stability weakens the emission-reduction potential of green trade, whereas trade diversification mitigates its carbon-increasing effects. These results suggest that expanding green trade alone may not rapidly achieve carbon reduction goals. The study emphasizes the necessity for governments to adopt cautious, well-designed green trade policies that balance environmental protection with sustainable economic growth and efficient resource allocation, recognizing the challenging and lengthy nature of the green trade development path.

Tang et al. employ a quadrilateral evolutionary game model to examine the strategic interactions among steel producers, construction companies, scrap steel recyclers, and the government in the steel industry's carbon emission reduction efforts. Key findings highlight that government subsidies are effective in promoting low-carbon production and green consumption. Cost considerations heavily influence steel manufacturers' and recyclers' willingness to adopt technological innovations, with subsidies serving as critical incentives. Moreover, carbon benefits from innovation motivate steel producers to comply with environmental regulations. Construction companies' strategies depend on production costs and the carbon benefits related to steel manufacturers, showing notable threshold effects. Guo et al. use a multi-period difference-in-differences approach to examine the impact of environmental justice reforms, specifically the establishment of environmental courts, on corporate green innovation. Findings reveal that environmental courts significantly promote substantive green innovation more than strategic green innovation. The environmental resources trial courts have a stronger effect than the environmental resources panel courts. Environmental courts improve regional environmental justice efficiency, enhance government environmental awareness, and increase the cost of corporate illegal activities, thereby encouraging green innovation. The effect is more pronounced in regions with a higher presence of non-state-owned enterprises, better legal environments, and lower industry competition.

4 Regional and industry practices: exploring differentiated emission reduction paths

Regional and industry differences significantly influence policy effectiveness, making differentiated paths essential. This Research Topic focuses on typical regions and key sectors to explore tailored emission reduction strategies.

In carbon markets and industry linkages, Xu and Zhu analyze dynamic price spillovers between China's carbon markets (eight pilots and the national market) and the carbon-intensive building materials industry, revealing strong short-term connectivity (1-day to 1-week) and heterogeneous long-term impacts, emphasizing industry-specific strategies. Shu et al. find that low-carbon city pilot policies reduce carbon intensity over time via enhanced carbon sinks and industrial upgrading, with effects varying by economic development, geography, and resource endowment.

Industrial and agricultural practices show nuanced dynamics. Qin et al. quantify NOx-CO_2 reduction synergy in Guangzhou's industrial sector, finding CO_2 cuts drive NOx declines, though natural gas use and energy intensity measures do not enhance this synergy. In agriculture, Jia et al. evaluate the Low-Carbon Agricultural Pilot (LCAP) policy, noting participating companies reduce environmental spending while nonparticipating rice farmers face income losses, with sustainable practices (organic fertilizers, waste recycling) improving both income and ecology, unlike costly energy-saving machinery subsidies.

Regional case studies highlight tailored approaches. Li et al. (2025) identify an environmental Kuznets curve in Qinghai, with population growth driving emissions and primary electricity management offering reduction potential, enabling 2030 carbon peaking under stringent policies. Sun and Onuh simulate Shaanxi's coal-dominated energy transition, projecting coal's share falling to 57.8% by 2030, with non-fossil energy at 21% and natural gas at 16%. Urban transportation, as studied by Peng et al. reveals significant emission reduction potential in Wuhan's "unlocking zone" via targeted transit improvements, supporting sustainable mobility aligned with SDG11.

Collaboration and risk also feature. Xia et al. analyze Yangtze River Basin ecological governance, finding technology enhances relationship-driven cooperation, while institutional frameworks strengthen interactive governance, with internal and external factors playing complementary roles. Chen et al. note geopolitical risks challenge low-carbon economic development (LCED) but stimulate renewable advancements, while LCED mitigates risks via reduced energy dependence and international cooperation.

Xu et al. use Chinese urban panel data and a staggered difference-in-differences (DID) model to assess the impact of the service trade innovative development pilot policy on regional environmental performance. Results show that institutional innovation significantly improves environmental outcomes, primarily by enhancing green innovation capacity and industrial upgrading. The effect is stronger in regions with greater government support, more developed service sectors, and higher openness, providing important policy implications for environmental governance in developing economies. Su et al. address the significant carbon emissions and energy

consumption associated with mega sporting events, focusing on transportation, venue construction, and event operations. It critiques existing research for limited case scope, insufficient attention to indirect emissions, and lack of interdisciplinary approaches. By systematically analyzing various types of sporting events and highlighting successful carbon management practices, the study identifies effective strategies such as optimizing venue location, encouraging green transportation, and adopting energy-saving measures throughout event lifecycles. Guan et al. evaluate the efficiency of industrial solid waste management across China's 31 provinces from 2016 to 2022 using a two-stage Data Envelopment Analysis (DEA) model. Results reveal heterogeneous improvements in circular economy efficiency, with the resource reuse stage averaging below 0.4, indicating considerable room for advancement. The western region exhibits higher waste treatment efficiency (0.65) compared to the eastern (0.53) and central regions. Sensitivity analysis confirms the robustness of these findings.

5 Digital empowerment and governance innovation: new drivers of environmental governance

Digital technology is reshaping environmental governance, with data-driven approaches emerging as a new trend. This Research Topic explores open data, big data, and digital infrastructure's application potential in carbon reduction and pollution control.

Digital transformation drives emission reductions. Shi et al. find that the digital economy has direct and indirect carbon reduction effects, with technological innovation as a stronger mediator than industrial structure, and an inverted U-shaped urbanization threshold. Ren et al. highlight Broadband China's role in cutting emissions via green technology investment and industrial upgrading, with stronger effects in eastern, larger, and more economically developed cities with stricter regulations.

Digital tools empower specific sectors. Li et al. show digital rural construction reduces agricultural carbon intensity, mediated by improved rural human capital and enhanced by agricultural financial support, with regional and dimensional variations. Zhang et al. note digitization boosts farmers' environmental awareness and compliance, promoting adoption of green practices, with mandatory and incentive policies both effective, varying by gender and education.

Open data and infrastructure matter. Zhou et al. find that open government data reduces PM2.5 via enhanced regulation, green innovation, and industrial optimization, strengthened by market size and openness, with regional heterogeneity. Yang et al. reveal digital infrastructure improves urban carbon performance via firm green innovation and consumer behavior shifts, with stronger effects in higher-income, better-educated cities, and non-state-owned, high-tech enterprises.

Innovative frameworks emerge. Raza et al. propose a resilience-based haze pollution framework, with resilience driving green infrastructure and sustainability via smart technologies, nature-based solutions, and digital platforms, offering strategies for developing countries. Xu and Wan identify the digital economy's emission reduction channels: while scale expansion increases emissions, structural upgrading and technological progress outweigh this, with the National Big Data Pilot Zone policy enhancing effects, particularly in eastern and resource-rich regions.

Yang et al. employ a Difference-in-Differences (DID) approach to examine the impact of digital infrastructure on urban total-factor carbon emission performance in China, extending analysis to micro-level mechanisms involving household consumption and enterprise production. Findings show that digital infrastructure improves carbon performance by fostering green innovation in firms and shifting consumer behavior. Heterogeneity analysis reveals stronger effects in cities with higher income and education levels, with non-state-owned and high-tech enterprises exhibiting greater carbon savings. The results underscore the critical role of micro-level actors in leveraging digital infrastructure for sustainable development.

Chen et al. analyze public attitudes toward major waste sorting policies across 46 key Chinese cities using Weibo data and Latent Dirichlet Allocation (LDA) topic modeling. Findings reveal a slight predominance of negative sentiments focused on policy details and implementation challenges, with no major difference in attention topics between sentiment types. High engagement was observed in developed eastern cities such as Shanghai and Beijing, with regional clustering of discussions.

Xu et al. analyze the impact of digital technological innovation on urban carbon emission intensity using panel data from Chinese cities (2012–2019). Results reveal an inverted U-shaped relationship, mediated nonlinearly by energy intensity and government environmental attention. Notably, this pattern is significant only in non-environmentally prioritized cities and consistent across both Broadband China pilot and non-pilot cities.

6 Conclusion and future prospects

The 44 studies in this Research Topic provide in-depth insights into the theoretical mechanisms, policy tools, regional/industry practices, and digital empowerment of carbon reduction and pollution control, yielding rich findings. They verify the complexity and diversity of environmental policy effects while offering practical policy recommendations for coordinated pollution and carbon abatement.

Looking forward, key research directions include: strengthening cross-regional and cross-industry synergistic governance to address pollution spillovers and avoid "free riding" or "race to the bottom"; deepening integration of multiple policy tools (e.g., regulation, carbon markets, green finance) to form synergies; exploring emerging technologies (AI, IoT) to enhance policy precision and efficiency; and conducting long-term dynamic research to account for policy time-lag and cumulative effects.

This Research Topic provides a valuable academic platform for scholars to exchange ideas on carbon reduction and pollution control policies. Its findings offer theoretical support and practical guidance for governments to formulate scientific environmental policies, contributing to global sustainable development and building a community with a shared future for mankind.

Author contributions

JP: Writing – review and editing, Writing – original draft, Conceptualization. HW: Writing – review and editing, Investigation. LW: Investigation, Writing – review and editing.

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