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Editorial: Incentive policies for green innovation, energy efficiency, environmental protection, and sustainability

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Editorial on the Research Topic
Incentive policies for green innovation, energy efficiency, environmental protection, and sustainability

1 Introduction

In the 12th to 14th Five-Year Plan periods of the People's Republic of China, energy conservation and emission reduction have been consistently regarded as central components of the national strategy, aimed at actively promoting the transformation of the industrial economic development model. The Third Plenary Session of the 20th Central Committee of the Communist Party of China underscored the imperative to bolster the ecological civilization framework. It advocated for the collective advancement of carbon and pollution mitigation, the expansion of green initiatives, and economic progression. The session also called for an active engagement with climate change challenges, a hastened enhancement and execution of policies equating environmental sustainability with economic prosperity, optimization of the ecological governance architecture, and the establishment of a green and low-carbon development paradigm.

Over an extended duration, China's industrial economic growth model has been excessively dependent on high levels of investment, consumption, and emissions, leading to increasingly severe energy and environmental challenges. With the establishment of the "carbon neutrality" objective, the sustainable growth of China's industrial economy and environmental management are facing significant challenges. In the progression of China's green and low-carbon economic development, the roles of manufacturing green innovation, energy efficiency, environmental protection, resource recycling and reuse, green consumption, and green total factor productivity are significant. These elements constitute the essential foundations that drive the growth of the green and low-carbon economy. The core strategies for achieving the harmonious development of economic growth with energy and environmental sustainability are seen in the low-carbon transformation of China's industrial manufacturing, the innovation progression of green and low-carbon technologies, the optimization of environmental efficiency, and the enhancement of green total factor productivity (Xiu et al., 2023a,b; Tian et al., 2023).

Currently, Chinese manufacturing enterprises are facing numerous challenges in the advancement of environmental technological innovation and the generation of green patents. Specifically, the endeavors of micro-economic entities in green research and development (R&D) and the procurement of green patents are significantly inadequate, which directly contributes to the sluggish growth of the manufacturing sector's green total factor productivity (GTFP). Additionally, the relatively underdeveloped state of green technological advancement and the scarcity of green patents are issues that require immediate attention. Therefore, the exploration of effective incentive mechanisms for green technological innovation within manufacturing enterprises, the enhancement of energy and resource efficiency to promote green technological progress, and the further acceleration of the promotion of green and low-carbon development within the manufacturing sector are the central issues for advancing the green and low-carbon transformation and achieving high-quality development of China's manufacturing industry (Zhao et al., 2021).

This Research Topic delves into the exploration of the mechanisms, pathways, and optimization strategies of incentive policies for green innovation within the manufacturing sector, environmental pollution control, climate protection investments, energy efficiency, and sustainability performance. The goal is to foster a comprehensive enhancement of the green and low-carbon transformation. Figure 1 (Xiu et al., 2023a,b) depicts a flowchart delineating the interrelationship between macroscopic and microcosmic dimensions of climate investments. The diagram encompasses incentive policies, climate investments, and technological advancements, culminating in the enhancement of green-low carbon productivity. It underscores the pivotal roles of governmental environmental stewardship, green financial mechanisms, carbon emission trading systems, corporate R&D, and technological innovation.

Finally, we have accepted four research articles covering incentive policies for green innovation in China and the entire world.

2 Porter hypothesis and green paradox

2.1 Porter hypothesis effect

Porter suggested that in the initial stage, strict and flexible environmental policies may increase the cost for enterprises to carry out environmental innovations. The Porter effect highlights the dynamic nature of enterprise innovation and takes into account both short and long-term impacts. The Porter effect can be divided into the strong and the weak form.

The weak porter hypothesis stated that the cost of environmental innovation can be partially offset by penalties for violations and compliance costs. Porter emphasizes that although environmental regulations increase the direct costs of enterprises, it also stimulate enterprises to engage in green innovation, thereby offsetting the costs invested in environmental governance. The strong-porter hypothesis emphasizes the significance of compliance costs and compensation. This innovative compensation will enhance production efficiency and increase the competitiveness of enterprises (Porter and Linde, 1995; Jaffe and Palmer, 1997; Lanoie et al., 2011).

Numerous domestic and international scholars have conducted extensive empirical research on "the examination of the strong and weak effects of environmental regulations and Porter's hypothesis." Some researchers endorse the strong-weak effect of Porter's hypothesis and substantiate their perspectives through empirical research or quasi-natural experimental policy evaluations. However, some researchers have proposed about the "strong-weak Porter effect" theory. This study has indicated that upon scrutinizing the nonlinear relationship between environmental regulations and the total factor productivity of industrial enterprises, there exists a divergence in the quantitative methodologies employed for environmental regulations. For example: the research findings of Ren et al. (2019) posited that the implementation of an emission trading system policy notably augments the total factor productivity of firms, primarily through the encouragement of technological innovation and the optimization of resource allocation. Zhang et al. (2020) determined that the carbon emission trading policy within heavily polluting industries, the effects are not observed.

In our Research Topic, Li and Borojo posited that technological innovation and digital infrastructure exhibit a nonlinear dynamic relationship with the material footprint within resource-abundant nations. Utilizing the pooled mean group-auto-regressive distributed lag model and moments quartile regression, this research analyzed data from 1990 to 2021. Additionally, this research explored the impact of environmentally-related technological innovation on the material footprint. The empirical study revealed that both technological innovation and digital infrastructure exert a nonlinear dynamic effect on the material footprint, indicating a long-term inverted U-shaped correlation among technological innovation, digital infrastructure, and material footprint. Consequently, technological innovation and digital infrastructure contribute to a resource curse up to threshold values of 2.8 and 2.1, respectively, beyond which they improve resource efficiency in nations with high levels of income.

2.2 Green paradox

The "Green Paradox" was first proposed by Hans-Werner Sinn. This theory posits that upon a nation's declaration of policies aimed at conserving energy and reducing emissions, conventional suppliers of fossil fuels will promptly alter their strategies to adapt to the environmental regulations. Such strategic adaptations are likely to expedite the development and exploitation of fossil fuels, consequently accelerating the temporal trajectory of carbon emissions.

Zhang (2014) employed a spatial dynamic panel data model, integrating the STIRPAT framework and the Logarithmic Mean Divisia Index (LMDI) approach, to account for the energy consumption structure, industrial structure, technological level, per capita income, and population size of each region. This research conducted an examination of the regional carbon emissions Kuznets curve and revealed the spatial spillover effect of environmental regulation policy competition. The results indicated that environmental regulation measures in a region and its neighboring areas had effectively curbed the growth of carbon emissions. However, the spatial strategic interaction of

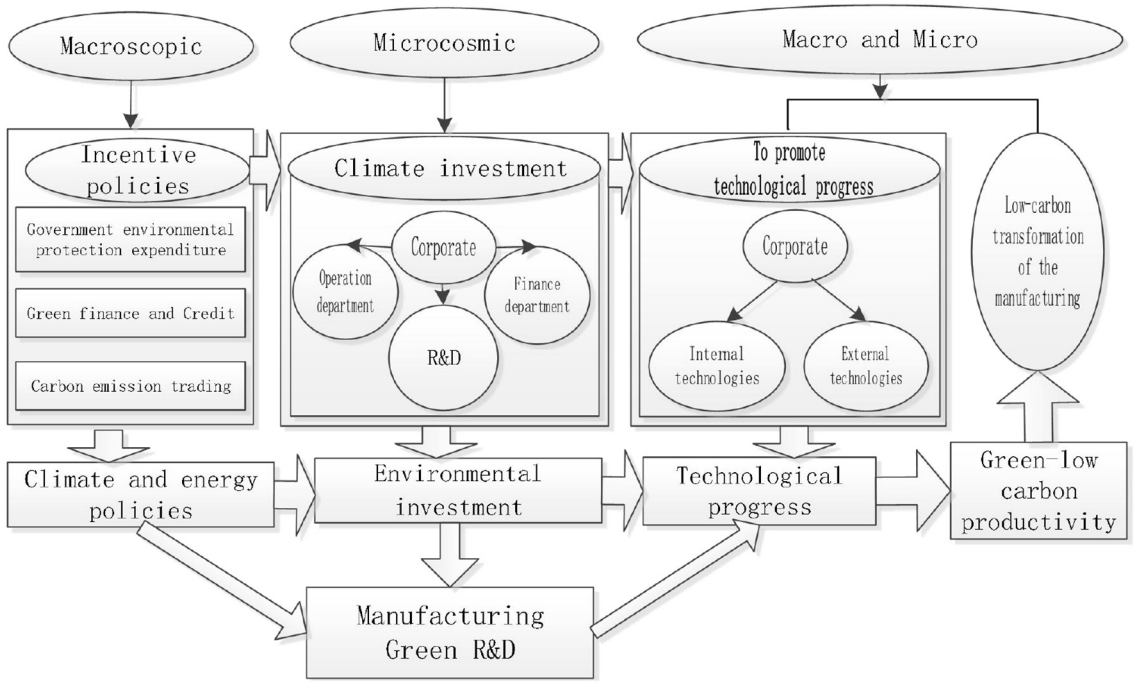

FIGURE 1
Theoretical mechanism of the green and low-carbon economic efficiency growth.

environmental regulation exhibited a competitive upward trend. Influenced by the competition among local governments, the environmental regulation in this region and its neighboring areas not only failed to suppress carbon emissions but also significantly contributed to their increase. This outcome led to the ineffectiveness of environmental regulation. By combining the principal-agent theory with the central-local decentralization phenomenon, local governments pursued GDP growth by increasing energy consumption, creating the so-called "promotion tournament competition bottom effect," which subsequently triggered the "green paradox" phenomenon. Ge et al. (2024) conducted an in-depth assessment of the impact of China's carbon emission trading policy using the difference-in-differences method. By comparing the data of pilot areas with those of non-pilot areas, the research results revealed the phenomenon of the "green paradox" in the construction process of China's carbon emission trading policy.

3 Incentive policies and carbon emission reduction

3.1 The government's energy conservation and environmental protection expenditure policies

Government's energy conservation and environmental protection expenditure policy (GEPE) functions as an instrument of governmental fiscal policy. It denotes the financial resources allocated by the government to tackle environmental and ecological challenges. This approach to environmental regulation, which is market-oriented, entails the government's utilization of fiscal expenditure and administrative capabilities to oversee economic activities pertaining to resources and the environment. The central aim is to diminish environmental pollution, curtail energy usage, and foster innovation in green low carbon technology. Furthermore, this policy seeks to stimulate societal and corporate engagement in environmental preservation endeavors, thereby augmenting the efficacy of market resource distribution (Zhang and Dong, 2023).

Empirical studies have examined the impact of government expenditures on energy conservation and environmental protection on environmental pollution control, and have generally concluded that these expenditures positively contribute to environmental governance. However, some scholars have raised concerns. Li (2024) suggested that GEPE can markedly enhance green innovation and GTFP, albeit with notable geographical and spatial variations. Research findings indicate that in China's central region, the impact of government expenditures on energy conservation and environmental protection on green total factor productivity is not significant. There remains a considerable disparity in the investigation of the relationship between government expenditures on energy conservation and environmental protection and green innovation or green technological progress, both domestically and internationally, particularly with respect to the potential U-shaped effect and spillover effect.

In the Research Topic, Lin and Gao address the challenges faced by 69 resource-depleted cities in China, including resource scarcity, a coal industrial structure, and ecological deterioration.

The objective of these resource-exhausted cities is to foster sustainable development by implementing measures such as fiscal transfer payments and industrial substitution. This research has conducted the Difference-in-Differences (DID) method, utilizing Chinese industrial enterprise data to investigate the influence of support policies for resource-depleted cities on the carbon intensity of industrial enterprises. The control variables encompassed enterprise total factor productivity, external openness, industry concentration, asset return rate, and enterprise size, among other factors. Through the application of a fixed-effects model and policy practice adjustments, and after accounting for interferences such as forestry policies, robust research outcomes were procured. These outcomes demonstrate that the Resource-Exhausted City Policy (RECP) notably diminishes the carbon emission intensity of enterprises ($\beta = -0.004$). The policy exhibits a more pronounced emission reduction impact on larger enterprises ($\beta = -0.008$), and its effect is most pronounced on enterprises with high carbon emission intensity (90th percentile). Mechanistic analysis reveals that the exit of enterprises from high-pollution industries positively moderates the emission reduction effect of RECP. Concurrently, the expansion of the tourism sector reduces the carbon emission intensity of enterprises: for each unit increase in the proportion of tourism revenue, the carbon emission intensity decreases by 0.004 ($p < 0.01$). Policy recommendations include the reinforcement of environmental assessment and dynamic monitoring, the establishment of an "Industrial Transformation Fund" to support the research and development of low-carbon technologies, and the creation of a market-based exit mechanism for high-pollution enterprises to facilitate the allocation of resources toward low-carbon, renewable energy, and new energy industries.

3.2 Green credit policies

The notion of green credit emerges from the principles of green finance, also known as sustainable development finance, and serves as a fundamental element of the green financial framework. The genesis and evolution of green finance are intricately linked to the inception of the Equator Principles (EPs). As China's ecological conservation efforts become increasingly intertwined with its economic progression, endeavors in energy conservation, emission reduction, the advancement of a green low-carbon economy, and the enhancement of manufacturing quality have emerged as significant catalysts propelling China's economic expansion. The "13th Five-Year Plan," specifically in its segment titled "Accelerating the Improvement of the Ecological Environment," explicitly outlines the establishment of a green financial system and the encouragement of green credit development as pivotal priorities for the "13th Five-Year Plan" era.

Credit funds, serving as a crucial impetus for economic progression, fulfill a supportive and directive role in the advancement of the real economy. Nevertheless, confronted with the constraints of a singular administrative strategy in tackling ecological challenges, such as environmental degradation and global warming precipitated by economic expansion, China has proactively promoted the implementation of green credit by financial entities. This initiative involves extending preferential loan facilities to manufacturing enterprises or projects that adhere to environmental protection criteria. Green credit and green finance support mechanisms are instrumental in fostering the sustainable development of a green and low-carbon economy and in encouraging enterprises to embrace heightened social and environmental stewardship roles.

Nevertheless, the advancement of green credit in our nation encounters numerous obstacles, encompassing inadequate enforcement of green credit policies, an incomplete ancillary policy framework, and a deficiency in the environmental risk assessment expertise among credit institutions. Liu et al. (2015) undertook a study employing the CGE model. The findings indicated that in the short to medium term, green credit policies can significantly diminish the investment and output levels of industries targeted, yet these policies may also exert detrimental impacts on affiliated upstream and downstream industries. Over the long term, the suppressive influence of green credit policies is anticipated to gradually diminish.

The differences impact of green credit on different type of enterprises. He et al. (2019) have found that the improvement of green credit levels has a significant promoting effect on the technological innovation of energy conservation and environmental protection enterprises, and there is a certain lag effect. The research results show that for energy conservation and environmental protection enterprises with a higher degree of financing constraints, the promoting effect of the improvement of green credit levels on their technological innovation is more significant. Ding (2019) research pointed out that under the influence of the green credit policy, the total factor productivity of non-state-owned heavy-polluting enterprises significantly decreased, while that of state-owned heavy-polluting enterprises did not undergo significant changes. Wang (2020) research indicated that green credit did not promote the technological progress of green and low-carbon technologies in various regions. The regression coefficient of the spatial interaction term W of green credit is significantly negative, indicating that it has an inhibitory effect on the surrounding regions.

The green credit policy has a positive impact on industrial structure adjustment, environmental pollution control, financial institution development, and economic growth. Xie and Liu (2019) verified through empirical analysis the significant promoting effect of green credit on green technological progress and the driving effect on industrial structure upgrading, revealing the lag effect of green technological progress and the dynamic change characteristics of green total factor productivity. Li et al. (2020) research results show that green credit can effectively promote the industrial structure, it has a positive promoting effect on upgrading of the secondary industry, but it has a reverse inhibitory effect on the development of the tertiary industry, also this research has pointed out that this effect has regional heterogeneity. Dai and Luo (2022) based on the analysis of the green total factor productivity of 284 prefecture-level industrial enterprises, confirmed the synergy between the number of violations by enterprises as an proxy variable for administrative environmental regulation and the research and development expenditure of industrial enterprises as a proxy variable for government technological support, which has a promoting effect on green total factor productivity, and

this effect has long-term stability. Their research further explains the synergy effect of market-based environmental regulation and administrative-based environmental regulation in promoting green total factor productivity.

In the Research Topic, Sun et al. have undertaken a study on the independent and interactive effects of the components within environmental, social, and governance (ESG) performance on corporate risk-taking. This research has augmented the theoretical framework of ESG and corporate risk management, particularly through the lenses of environmental technology innovation and institutional ownership. The empirical findings indicate that for each unit increase in the ESG defense line, corporate risk-taking (CRT) experiences an increment of 0.0009, thereby corroborating the notion that ESG, in its entirety, promotes corporate risk-taking. The results concerning heterogeneity suggest that as environmental performance enhances, evidenced by increased investment in environmental initiatives, the propensity for corporate risk-taking decreases. This implies that investment in environmental measures may supplant investment in risk assets. In contrast, superior governance performance is correlated with an elevated CRT, indicating that effective decision-making processes enhance the efficiency of risk allocation. From a practical standpoint, companies must assess the risks they are willing to undertake, refine their ESG structure, and avoid the pitfalls of under-investment and over-investment in opportunities.

3.3 Carbon emission trading policies

The policy of carbon emission trading, which is grounded in the theoretical framework of the pollution discharge rights trading system, represents an environmental economic strategy that seeks to diminish carbon dioxide emissions by leveraging market-based mechanisms. At the heart of the carbon emission rights trading policy is the establishment by the government of a cap on corporate carbon dioxide emissions, coupled with the promotion of market-based trading to incentivize enterprises to curtail their carbon output. China's inaugural pilot policy for carbon emission rights trading commenced in October 2011, following the issuance of the "Notice on Carrying out Carbon Emission Rights Trading Pilot Work" by the National Development and Reform Commission. This directive granted authorization to seven regions—Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen—to undertake pilot projects for carbon emission rights trading. Subsequently, in 2016, Fujian Province initiated its own pilot project as the eighth designated region for carbon emission rights trading.

In the context of the implementation of the carbon emission pilot policy, the industries impacted by the carbon emission rights trading policy encompass eight major energy-intensive sectors, namely power generation, petrochemicals, chemicals, construction materials, steel, non-ferrous metals, paper manufacturing, and domestic civil aviation. In July 2021, the national carbon emission rights trading market was inaugurated, achieving a cumulative trading volume of 2,344.04 million tons, thereby establishing itself as the largest carbon market globally. By the conclusion of 2023, the national carbon emission trading market had expanded to include 2,257 power generation enterprises, with total transaction value of 24.9 billion yuan.

China's implementation of carbon emission trading systems has lagged behind that of European nations. Presently, there is a paucity of scholarly inquiry into the impact of carbon emission trading policies on the green total factor productivity of manufacturing entities. The majority of extant literature concentrates on the beneficial effects of carbon emission trading on corporate green technological innovation. However, there exists a divergence of perspectives within the evaluation of the efficacy of carbon emission trading.

Firstly, there is a standpoint on the promoting effect. Shi and Li (2020) suggested that the emission trading system has the potential to augment green innovation, thereby elevating the green total factor productivity of industrial enterprises. Liu et al. (2019) discovered that the carbon trading policy exerts a positive influence, significantly diminishing provincial regional carbon emissions. Shen and Huang (2019) proposed that the carbon emission trading policy can enhance the value of enterprises in the short term and significantly reduce the carbon emission intensity of the industry. Du et al. (2021) utilized spatial econometric models to reveal the spatial spillover effect of China's carbon emission trading policy on green technological innovation in neighboring regions. However, Fan et al. (2022) indicated that the carbon emission trading does not have a significant spatial spillover effect on the total factor productivity of neighboring enterprises, but it can enhance total factor productivity through two paths: technological innovation and internal resource allocation of enterprises.

Secondly, regarding the inhibitory or non-linear viewpoints. Li and Chen (2019) emphasized the dynamic nature of enterprises' green total factor productivity, and measured the bargaining power of enterprises from three dimensions: industrial output (Output), total tax (Tax), and number of employees (Worker). The study pointed out that the enhancement of enterprises' bargaining power enables them to obtain a certain degree of exemption in terms of environmental regulation intensity. Using industrial three-waste as a proxy variable for market-based environmental regulation intensity, short-term environmental regulation may suppress enterprises' green total factor productivity, but in the long term, environmental regulation will have a positive promoting effect on enterprises' green total factor productivity. Zhang et al. (2020) found in their heterogeneity analysis that the carbon emission trading policy in the power industry shows a positive effect, while the carbon emission rights trading policy in heavily polluting industries does not show the expected effect. This may be due to the lag effect of the policy or the lag effect of technological progress.

In our Research Topic, Syafina and Oluleye conducted an investigation into the optimal cost-effectiveness of the implementation pathway for carbon neutrality in Indonesia, as well as the trajectory of the Innovation Diffusion Theory. This research has developed a multi-period nonlinear optimization framework that incorporates dynamic learning rate technology, thereby quantifying the impact of various policy combinations [including policy instability such as frequent adjustments to Feed-in Tariffs (FiT) and tax incentives] on the long-term diffusion of capacity. The study introduced the Innovation Diffusion

Theory into the energy policy model, simulating the influence of varying consumer adoption behaviors (ranging from innovators to early majority to lagging groups) on photovoltaic capacity. The economic performance of linear, supply-oriented, and IDT pathways was compared, demonstrating that the IDT pathway reduces unit costs by facilitating medium-term explosive growth and circumvents the issue of high-cost expansion inherent in the later stages of the supply pathway. The study quantified the sensitivity of the pathway under different learning rate scenarios (low, medium, high), thereby enhancing the robustness of the findings. Additionally, a Feed-in Tariff (FiT) rate optimization algorithm was proposed, aimed at achieving a cost balance between government and industry (50%/50%), and automatically generating segmented subsidy recommendations, thus eliminating the costly trial-and-error associated with traditional policy design. Based on the findings, Indonesia needs to integrate the carbon tax and Feed-in Tariff (FiT) funds through legislation and introduce a market bidding mechanism as a transitional measure to achieve policy synergy and efficiency. The current policy fragmentation has resulted in the Levelized Cost of Electricity (LCOE) for photovoltaic power being 22% higher than in the optimal scenario. If reform is not carried out before 2025, it will delay the achievement of the net-zero target by at least 7 years.

4 Conclusions and suggestions

The four research articles featured in this Research Topic are intricately linked to the sustainable development goals. These articles encompass a range of topics, including an examination of Indonesia's photovoltaic solar energy policies and the trajectory toward national carbon neutrality (Syafina and Oluleye), also alongside an exploration of digital infrastructure and the nonlinear dynamic impacts of material footprint within a national panel level in resource-based economy, and this articles delve into the effects of green technological innovation on material footprint (Li and Borojo); the other two papers are in city or industrial enterprises level, the ramifications of support policies for resource-exhausted cities on industrial carbon intensity and the management policies (Lin and Gao). Lastly, the research investigate the influence and management strategies of ESG performance on corporate risk-taking (Sun et al.). Each article conducted a framework that involves "problem identification-mechanism analysis-policy recommendations," underscoring the importance of policy optimization grounded in empirical evidence. The 4 studies jointly promote the refinement of sustainable development policies, each with its own breakthroughs-the Indonesian photovoltaic policy and carbon neutrality implementation focus on path design, the highlights of ESG performance and corporate risk taking within mechanism analysis, the research on resource-exhausted cities' support policies emphasized transformation model, and the nonlinear dynamic effects of digital infrastructure and material footprint threshold identification are the strengths.

An intriguing discovery arises from the scrutiny undertaken by the four papers, which have explored the risks associated with carbon reduction and the transition points to a low-carbon economy across multiple levels, encompassing national-industrial and urban-enterprise dimensions. Subsequent scholarly work has the potential to further refine and innovate existing theories, such as innovation diffusion, the resource curse, the green paradox, Porter's hypothesis, green finance theory, and policy evaluation theoretical model. Additionally, further studies could delve into pertinent matters, such as the carbon accounting of enterprises, through a comprehensive macro and micro multi-scale perspective.

Author's note

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