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Research article

Impact of dual-carbon attention competition from local government on regional carbon emissions in China

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ABSTRACT

Extreme climate change induced by carbon emissions has received extensive attention from governments worldwide. Strong competition in local governments' dual-carbon attention (GCA) produces an effective influence on the reduction of regional carbon emissions, confirming crucial policy implications. In this study, textual content analysis is employed to measure the GCA level and GCA competition, and the mechanism by which GCA competition reduces regional carbon emissions in China is explored from the perspective of competition behaviors. The findings demonstrate that the increase of GCA competition positively influences the reduction of regional carbon emissions. Influence mechanism analyses verify that increasing GCA competition primarily stimulates the greater reduction of regional carbon emissions by intensifying competition in energy consumption reduction and the optimization of the energy consumption structure. The influence of GCA competition on reduced regional carbon emissions is significantly related to industrial structure upgrading, the energy consumption structure, and environmental governance investment, as well as inter-government competition in these areas. The detailed findings of this research can provide economic and environmental benefits for policymakers, and can provide corporations with more targeted policy recommendations related to dual-carbon attention and carbon emission reduction.

1. Introduction

Global warming and extreme climate change directly or indirectly produce long-term risks to regional economies and societies, and have thus received worldwide attention. On September 22, 2020, the Chinese government pledged to increase its nationally determined contributions, adopt more favorable policies and measures, and strive to peak its carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality before 2060; these latter two goals are referred to as the dual-carbon targets. Under the concept of sustainable development, local governments (LGs) are guided and supervised by the central government to overcome urgent problems including the reduction of energy consumption and greenhouse gas and pollutant emissions. Furthermore, these dual-control constraints and targets force LGs to continuously strengthen the competition mechanism in terms of energy conservation and emission reduction, environmental governance, and green and low-carbon transformation.

Especially, LGs play important roles in resource allocation, policy systems, benefit distribution, and responsibility-sharing mechanisms. They transmit the changes of behavioral motivations in the allocation of dual-carbon resources and the policy systems of government decision-makers through annual government work reports (GWRs), which convey crucial social signals of specific concern to the market, public, and firms. Therefore, the main purpose of the present study is to investigate whether competition in LGs' dual-carbon attention (GCA) can promote the transformation of the LG competition mode in terms of industrial structure upgrading, technological progress, and the energy consumption structure (ECS), and to better explain whether such competition can promote the reduction of regional carbon emissions.

Therefore, the following three important questions are addressed. First, is there an inherent correlation between GCA competition and regional carbon emissions? Second, does GCA trigger stronger competition in energy consumption control, ECS optimization, and environmental investment? Third, is there an effective transmission channel between GCA and regional carbon emissions, and what factors affect the transmission effects? Additionally, these problems have valuable theoretical and empirical implications, and the results can lead to the adoption of more effective policies and measures to promote the

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efficiency of inter-provincial carbon emission reduction.

Extant studies demonstrate that decision-making competition by LGs is the crucial factor influencing regional carbon emissions. Under the hierarchical governance system, the dual incentives of fiscal and environmental decentralization and official promotion trigger potential competitive relationships between LGs in terms of economic development, industrial layout, resource allocation, and ecological environment governance (You et al., 2019; Wu et al., 2020; Li et al., 2021a,b). However, LG competition influences regional carbon emissions by distorting factor markets and implementing "race-to-the-bottom" environmental policies (Li and Xu, 2022; Li, 2022). Neighboring provinces exhibit significant mutual imitation and convergence in environmental governance and carbon peak competition (Yang et al., 2022; Shen et al., 2024). In reality, LG competition and environmental decentralization greatly improve the emission intensity of regional pollutants (Li et al., 2021a,b), and also reduce the efficiency level of regional green development due to the race-to-the-bottom effect (Wu et al., 2020; Qin et al., 2023; Yan et al., 2023). Compared with the economic, industrial and environmental competitities measurement (You et al., 2019; Wu et al., 2020; Li et al., 2021a,b; Yang et al., 2022; Shen et al., 2024), this study enriches the measurement gaps of GCA competition from the perspective of attention behaviros. And this study extends the significant effect of GCA competition on regional carbon emission reduction, expands the study gaps between LG compeition and carbon and pollutants emisions (Li et al., 2021a,b; Li and Xu, 2022; Li, 2022; Qin et al., 2023; Yan et al., 2023).

Moreover, government environmental attention (GEA) and climate risk attention can decrease the carbon emissions of firms (Liu et al., 2023b,c;Liu et al., 2024a; Chen et al., 2024b). Previous studies have uncovered valuable and interesting relationships between LG competition and carbon emissions (environmental governance, green development). However, current research is characterized by some deficiencies in investigating the nexus of GCA and regional carbon emissions and the related influence mechanism. To fill in this research gaps(Liu et al., 2023b,c; Liu et al., 2024a;Chen et al., 2024b), the improvement of GCA can influence regional carbon emissions through government decision-making behaviors, such as energy consumption and the ECS, enriches the theoretical and practical gaps of both LG competition and environmental governance. Thus, herein, dual-carbon-related textual information extracted from GWRs is used to measure the GCA level and GCA competition, and provincial carbon emissions are adopted to examine the nexus and influence mechanism between GCA competition and regional carbon emissions. Moreover, the relationship between GCA competition and regional carbon emissions is found to be strengthened via competition in energy consumption and the ECS. This article makes the following three contributions to the existing literature.

First, local GWRs contain a large amount of textual information related to dual-carbon governance. Dual-carbon attention strengthens competition in government decision-making, the allocation of various resources, and the capacity for environmental regulation and policy implementation. In this study, a comprehensive dual-carbon-related attention dictionary comprised of 301 keywords from seven dimensions is created, and the GCA level and GCA competition are measured from annual GWRs using the textual analysis method. Moreover, different governments are confirmed to exhibit greater GCA competition, which exhibits regional divergence. Compared with the previous GEA measure (Liu et al., 2023c; Chen et al., 2024a; Fang and Liu, 2024; Wang et al., 2024a), the proposed GCA measure is characterized by expaned measurement dimensions and improved measurement accuracy. Previous studies measured LG competition using financial competition and official turnover (Wu et al., 2020), economic growth competition (Hong et al., 2020), and tax and fiscal expenditures (Yan et al., 2023; Zhou et al., 2023). Compared with previous measures of government competition, this study deepens the measurement of GCA competition behavior from the perspective of dual-carbon attention information. It also extends attention resource allocation theory and tournament theory.

Second, from the perspective of government competition behavior, this study explores the influence of GCA competition on regional carbon emission reduction, which expands the understanding of the relationship between GCA and carbon emission governance. GCA competition is found to significantly decrease regional carbon emissions, a result that enriches the extant research on how environmental governance influences the carbon emissions of firms (Liu et al., 2023a; Chen et al., 2024b). Furthermore, optimizing the ECS, enhancing industrial structure upgrading, and increasing environmental protection investment, as well as competition in these factors, are found to improve the effect of GCA competition on regional carbon emission reduction. Additionally, these interesting findings further extend the comprehension of the nexus between government attention and carbon emissions (Liu et al., 2023c; Chen et al., 2024b), as well as that between government competition and carbon emissions (Li and Xu, 2020; Li, 2022; Yang et al., 2022). Thus, the results enrich attention competition theory and sustainable development theory.

Third, this study expands the understanding of how GCA competition influences regional carbon emission reduction through two key pathways, namely increasing competition in energy consumption and strengthening the optimization of the ECS. Especially, the increase of GCA competition is demonstrated to promote competition in regional energy consumption and ECS optimization. Previous studies confirm that factor market distortion, investment bias, government investment, and environmental governance policies influence the relationship between government competition and carbon emissions (Li and Xu, 2022; Li, 2022; Yang et al., 2022). Comparred with previous studies, this study extends the knowledge of how GCA competition affects carbon emissions via competition in energy consumption and ECS optimization from the perspective of government information, thus enriching both industrial structure theory and resource allocation theory.

Furthermore, how can this study contribute to economic and environmental benefits for the government and firms? Recently, the Chinese government coordinates economic development and carbon emission reduction. Specifically, it incentivizes LGs to transform their industrial development mode and shape sustainable industrial competitiveness, and thus to benefit from rational economic and environmental competition. The Chinese government optimizes continuous competition in energy conservation, emission reduction, and dual-carbon targets, and strengthens the competition between LGs in terms of these indicators. Consequently, LGs increase the appropriate competition mechanism of dual-carbon attention, and optimize the dual-carbon themes in the reduction of energy consumption and carbon emissions. Notably, LGs should optimize the industrial layout and structure, accelerate industrial structure upgrading, encourage green technology innovation and progress, and promote clean energy use and energy intensity reduction. Notably, LGs can fully utilize market mechanisms to increase environmental governance investment, promote renewable energy usage, optimize the ECS, accelerate the reduction of greenhouse gas and pollutant emissions, and ultimately achieve the synergistic benefits of green economic growth and environmental governance. Meantime, firms should implement the self-interested competitive strategy of sustainable development, accelerate clean energy usage and clean production, promote corporate environmental governance, and enhance corporate environmental information disclosure and environmental, social, and governance (ESG) performance. Additionally, local firms with excellent green governance performance can easily obtain subsidies and tax refunds from LGs, enhance their green financial resources and green policy supports, and internalize environmental costs. Many firms can benefit from dual-carbon governance policy supports, promote resource allocation efficiency, and thus obtain the synergistic benefits of green governance and financial performance.

The remainder of this paper is organized as follows. An overview of related literature is provided in Section 2. The theoretical analysis and research hypotheses are developed in Section 3. The variable selection,

research design, and data sources are presented in Sections 4 and 5. The analysis and discussion of the empirical results are provided in Section 6. Finally, the main conclusions and policy implications are offered in Section 7.

2. Related theoretical background and literature review

2.1. Theoretical concept of GCA competition

GWRs reflect that LG decision-makers are shifting more economic resources toward ecological environment governance, achieving the dual-carbon targets, and achieving sustainable development goals. GEA refers to how LG officials prioritize environmental issues and allocate related resources in environmental decision-making, emphasizing the pivotal role of the government in advancing environmental governance (Bao et al., 2022; Liu et al., 2023c; Du et al., 2024).

GCA refers to the increased attention paid to important environmental issues and resource allocation, and concerns energy conservation, emission reduction, ecological environment governance, resource-intensive and efficient utilization, sustainable development, carbon peaking and carbon neutrality, and dual-carbon technology implications in dual-carbon governance decision-making. GCA changes reflect not only the behavioral motivations, logic, and preferences of LG decision-making institutions in achieving dual-carbon targets and environmental governance, but also the level of awareness and social attention of the public, media, and firms toward dual-carbon governance. GCA can emphasize the crucial role of LGs in promoting environmental governance, pollution and carbon emission reduction, and the dual-carbon targets.

Due to their own interests and the external institutional constraints of LGs, they strengthen the resource allocation of dual-carbon governance and thus incentivize the public, market, and firms to allocate more social and economic resources toward energy conservation, emission reduction, and ecological environment governance. GCA competition concerns dual-carbon attention and environmental governance as indicated by the GWRs of LGs, which mainly reflect the pivotal signals of competition in related resources, such as policy inclination, funds, talents, technology, etc. This competition in GCA has become the most important means by which to compete for resources, and exhibits significant regional variation in China.

Inter-regional governments strengthen fierce competition in capturing various resources via green finance, energy conservation, emission reduction, green innovation, and environmental protection investment attention. GCA competition effectively promotes the transformation and upgrading of the industrial structure, improves the efficient utilization of energy and resources, optimizes the ECS, and ultimately facilitates the reduction of inter-provincial CO_2 emissions.

2.2. Overview of related literature

The response to climate change and the dual-carbon targets has attracted widespread attention from governments worldwide. Current research on LG attention focuses on the assessment of two primary influencing factors, namely GEA and climate risk attention. GEA significantly contributes to regional pollutant emission reduction and environmental quality improvement via environmental enforcement and environmental fees (Liu et al., 2023d; Li et al., 2024a,b; Zhang et al., 2024a). GEA has a significant and positive effect on the improvement of urban energy efficiency (Wang et al., 2024a). Local GEA can improve the quality and promote the sustainable development of the local ecology (Bao and Liu, 2022; Shen et al., 2024). However, some scholars believe that local GEA can increase local carbon emission levels (Tu et al., 2024). LGs' attention to climate risks can enhance local environmental regulation, promote local agricultural green technology innovation, and reduce local agricultural carbon intensity and carbon emission levels (Chen et al., 2024b). Thus, the increase of LGs' environmental and climate risk attention improves regional energy efficiency and reduces pollution and carbon emissions.

Firms play an important role in coordinating economic development and environmental governance, and GEA improves the carbon emission governance and reduction actions of firms (Liu et al., 2023c; Zhu et al., 2023). LGs pay attention to promoting the scale of green credit and enhancing government environmental supervision, stimulating firms to accelerate green investment (Chen et al., 2024a). GEA facilitates the ESG performance of firms by altering their green investment, environmental information disclosure, and green technology innovation (Liu et al., 2024a,b). GEA has an inverted U-shaped relationship with firm environmental responsibility (Meng et al., 2024), and it strengthens environmental regulatory policies, improves environmental information disclosure, and enhances corporate social responsibility (CSR) (Fang and Liu, 2024). Table 1 summarizes the relationship between government attention and environmental governance as reported in the literature.

Environmental and economic sustainability attract significant attention for corporations to promote their sustainable development. Carbon-related news sentiment and textual information are favorable for enhancing ESG performance and corporate sustainable growth (Xie, 2024). ESG and CSR attitudes negatively moderate the returns of corporate assets and corporate stock price (Candio et al., 2024), while ESG practice and environmental information disclosure improve corporate financial performance (Habib, 2022, 2023a, 2023b; Dagestani et al., 2024a; Habib and Mourad, 2024). Moreover, trade networks generate a negative effect on corporate ESG performance (Zhang et al., 2024c). ESG performance and climate change exposure significantly improve carbon emission efficiency via easing financing constraints, promoting green innovation, and strengthening environmental supervision (Qian and Liu, 2024; Qing et al., 2024), and sustainable development policies strengthen corporate environmental disclosure and reduce corporate green-washing behavior (Dagestani et al., 2024b). Furthermore, CSR enhances green innovation via environmental regulation rules (Chen and Dagestani, 2023c), and green innovation and circular economy practices improve corporate financial performance (Chen and Dagestani, 2023a; Qing et al., 2023). Green-washing behavior and environmental regulation increase corporate value via alleviating financing constraints and improving stakeholder concerns (Chen and Dagestani, 2023b; Dagestani et al., 2023).

Different LGs have significant competitive relationships in terms of

Table 1
The empirical evidence of the linkage between government attention and environmental governance.

Authors	Dimensions	Main findings
Liu et al. (2023d)	Government attention and environmental quality	Government attention reduces regional pollutant emissions.
Li et al. (2024)a,b	GEA and environmental pollution	GEA mediates the relationship between environmental decentralization and regional pollution reductions.
Zhang et al. (2024a)	GEA and pollution governance	GEA promotes regional pollution governance.
Cao et al., 2022	Government attention and carbon emission	Government attention decreases regional carbon emissions.
Wang et al. (2024a)	GEA and energy efficiency	GEA enhances urban energy efficiency.
Bao and Liu (2022)	GEA and air pollution	GEA improves urban air quality.
Tu et al. (2024)	GEA and green development	GEA increases regional carbon emissions.
Liu et al. (2023c)	GEA and firm emission governance	GEA reduces corporate carbon emissions.
Zhu et al. (2023)	GEA and firm emission reduction	GEA improves corporate carbon reduction actions.
Meng et al. (2024)	GEA and CSR	GEA has an inverted U-shaped relationship with CSR.
Chen et al. (2024a)	GEA and green investment	GEA promotes corporate green investment.

economic growth, fiscal and environmental regulations, and industrial development. From the perspective of the effectiveness of environmental regulation, its legitimacy and external pressure, as well as LG competition, are important factors that constrain regional environmental governance and emission reduction potential. Environmental regulation alleviates the impact of LG competition on the promotion of regional total factor productivity (Qin et al., 2023). Promotion tournament theory holds that environmental tournaments and official promotion tournaments are effective modes by which to promote environmental governance efficiency. China's economic promotion tournament exerts a significant threshold effect on environmental pollution and local official promotion (Pu and Fu, 2018; Tang et al., 2021). Competition in economic growth targets drives local officials to relax the environmental regulation intensity and reduce investment in regional environmental protection and environmental governance (Li et al., 2020; Zhong et al., 2022). Environmental protection tournaments mitigate regional pollution emissions through direct policy intervention and official environmental behavior changes (Tan et al., 2021; Wang and Lei, 2021), and local environmental tournaments are favorable for reducing urban pollution and CO_2 emissions (Xiao et al., 2024). China's political promotion leads environmental regulation to prohibit firms' eco-innovation and eco-investment (You et al., 2019). Regional economic competition distorts the effect of environmental decentralization, which greatly improves the emission intensity of regional pollutants (Li et al., 2021a,b), and decision-making competition from LGs produces a significant "green paradox" effect on regional carbon emissions (Li and Xu, 2022). Economic promotion tournaments greatly decrease urban carbon and pollutant emissions, while local official promotion greatly weakens urban carbon emission reduction (Jiang and Tang, 2023). LG competition effectively promotes the regional technological innovation level and innovation efficiency, and has a masking effect on the relationship between government competition and technological development benefits (Zhao et al., 2021; Wan et al., 2023). Greater political ambitions of LG officials result in a greater decline in the regional carbon emission intensity by elevating the levels of environmental attention and green innovation (Wang et al., 2024). However, economic growth pressure increases regional carbon emissions by reducing technological innovation and foreign trade (Zhang et al., 2022b). Competition between LG officials increases their dependence on polluting industries and amplifies the intensity of SO_2 and pollutant emissions (Zhou et al., 2023; Ding et al., 2024). However, LG investment competition leads to concentrated carbon emissions, increases the level of regional environmental pollution, and produces significant spatial spillover effects (Hong et al., 2020). Furthermore, LG competition increases the carbon emission level of manufacturing industries within the region (Liu et al., 2022).

When LGs engage in the strategic interactive behavior of imitation in the formulation and implementation of environmental regulation, the competitive effects are divided into bottom competition and top competition. China is characterized by the coexistence of race-to-the-top and race-to-the-bottom strategies of environmental regulation competition (Peng, 2020; Yang et al., 2021; Zhang et al., 2022a). Environmental governance competition has not been found to significantly improve regional environmental governance (), and competition among LGs produces the race-to-the-bottom effect and decreases the efficiency level of regional green development (Wu et al., 2020). Competition pressure from LGs has a U-shaped relationship with environmental governance performance (Guan, 2023). Race-to-the-bottom competition is a mutual relaxation of environmental regulations and a vicious competition when strengthening environmental regulations increase (Li et al., 2022; Zhang et al., 2023a,b). Global environmental regulatory competition predicts a race to the bottom of standards (Holzinger and Sommerer, 2011; Heyvaert, 2013). Local environmental policy in the US and China directly influences the regulatory behavior of LGs, thus mitigating race-to-the-bottom competition (Kim, 2011; Zhao and Percival, 2017). The environmental regulatory behavior of LGs transforms from a race-to-the-bottom competition to strategic imitation, resulting in the spatial dependence of environmental regulation among provinces with similar economic levels (Zhang et al., 2020; Wu et al., 2021). Race-to-the-bottom competition in environmental governance prompts LGs to reduce their investment in economic development and environmental protection (Yang et al., 2021). Furthermore, environmental governance policies among LGs are characterized by bottom-up competition, and race-to-the-bottom environmental governance policies have a significant effect on regional environment governance (Li and Xu, 2022; Yang et al., 2023a).

Recently, environmental regulation, such as environmental laws and standards, has triggered the emergence of new race-to-the-top competitive patterns (Heyvaert, 2013; Zhang et al., 2023a,b). The theories of regulatory competition suggest that voluntary environmental self-regulation may facilitate a race-to-the-top competition (Flowers et al., 2020). China's LGs exhibit such behavior in environmental regulation and governance (Li, 2022; Wang and Lu, 2023; Cao et al., 2024). Table 2 summarizes the linkage between government competition and environmental governance as reported in the literature.

Fewer studies have investigated whether competition can promote a decrease in regional carbon emissions from the perspective of GCA. In the competitive environment of LGs, the correlation and transmission effects between GCA competition and regional carbon emissions must be addressed, and the differential influence mechanisms of carbon emission reduction in different provinces should be more thoroughly analyzed.

3. Theoretical mechanism and research hypotheses

With the continuous increase of GCA, LGs continue to strengthen their responsibility to meet ecological civilization construction targets, including energy conservation, emission reduction, pollution control, energy consumption, and the dual-control system of total carbon emissions and intensity. Under the constraints of the dual-carbon targets and ecological civilization construction targets set by the central government, LGs face normalized external governance pressures comprising environmental assessments and target responsibility systems. This governance pressure drives LGs to continuously increase their dual-carbon attention, and accelerates the construction of dual-carbon policy systems. The increase of GCA and environmental regulation has a significant peer effect on the dual-carbon governance of neighboring regions (Liu et al., 2023a). The external learning effect and competition mechanism strengthen environmental regulation and dual-carbon governance among geographically adjacent regions (Xu et al., 2022a, b; Shen et al., 2023), and they have a significant exemplary effect on the

Table 2
An empirical investigation of the linkage between government competition and environmental governance.

Authors	Dimensions	Main findings
Hong et al. (2020)	Government competition and environmental pollution	Local government competition aggravates regional environmental pollution.
Wu et al. (2020)	Local government competition and green development	Local government competition reduces regional green development efficiency.
Li et al. (2021)a, b	Regional competition and pollutant emissions	Regional economic competition improves regional pollutant emission intensity.
Yang et al. (2023a)	Environmental governance competition and industrial green transformation	Local environmental governance competition has a U-shaped relationship with industrial green transformation.
Yang et al. (2023b)	Local government competition and green development	Local fiscal spending competition enhances green development efficiency.
Zhou et al. (2023)	Government competition and polluting industry development	Government official competition amplifies regional pollutant emissions.

dual-carbon policies in neighboring areas. This effect promotes the construction of dual-carbon policies in geographically adjacent areas, creates significant peer pressure regarding policy, and enhances GCA competition.

The central government has established a system for the evaluation of LG officials in terms of the ecological civilization construction targets. Carbon and pollutant emission reduction has gradually been considered in the performance evaluation of local officials to tackle the challenges of climate change and the dual-carbon targets (Jiang and Tang, 2023). LGs face decision-making conflicts between economic growth and pollution reduction, and the essential agents behind pollution and emission reduction actions are LG officials, who are confronted with a promotion incentive mechanism that competes for the coordination of economic growth and dual-carbon governance. Promotion tournament theory suggests that LGs continuously increase their attention to carbon peaking and carbon neutrality and attempt to input more economic and financial resources. The environmental attention of LGs strengthens the internal motivation of local participation in the environmental tournament through policy orientation. This improves China's environmental governance policy system and promotes the governance efficiency of LGs (Xiao et al., 2024), which implement more effective policies and measures to achieve the expected economic growth and ecological civilization construction targets. LGs focus on the dual-carbon targets through effective incentive systems, such as economic incentives and financial support. Promotion tournament theory holds that local officials with greater political ambition attempt to increase dual-carbon attention and enhance green innovation, which thus contributes to the decline of energy consumption and carbon emission intensity (Wang et al., 2024b). These incentive measures encourage firms to improve energy conservation and emission reduction efficiency, promote low-carbon technological innovation and progress, and thus accelerate pollution and CO_2 emission reduction efforts.

The dual-carbon targets of the central government require effective implementation by LGs. LGs have significant same group effects in dual-carbon attention, resource allocation, and environmental governance activities. Due to the geographical agglomeration in various regions, LGs consume large amounts of ecological and environmental resources during population gathering and economic development. Various environmental pollutants and carbon emissions, such as wastewater, exhaust gas, solid waste, SO_2, and CO_2, have significant spatial agglomeration effects and temporal scale effects in neighboring areas (Huang et al., 2022; Wang et al., 2023). This imitation and exemplary behavior is called the "peer effect" in sociology. Regional environmental governance and CO_2 emission reduction have significant peer effects and spatial spillover effects, and adjacent regions have mutual influence and similar decision-making behaviors regarding ecological environment quality (Guo et al., 2024; Tang and Li, 2024). In the process of CO_2 and pollutant reduction, neighboring areas have a strong demonstration effect and an endogenous driving effect on regional CO_2 reduction.

GCA competition incentivizes LGs to strengthen environmental regulations and dual-carbon emission governance. GCA enhances resource allocation efficiency, improves environmental governance and carbon emission reduction synergy, and thus accelerates the spatial spillover effects of regional pollution and carbon emission reduction (Cao et al., 2024). The spatial spillover effects in energy conservation, emission reduction, and environmental governance also promote the improvement of local environmental quality and accelerate the intensity of CO_2 emission reduction in geographically adjacent areas, forming a "favorable competition" to reduce pollution and carbon emissions in neighboring regions. Geographically adjacent regions exhibit imitative learning behavior and draw on experience in environmental governance and carbon reduction processes. LGs reduce pollution and carbon emissions through the transformation of the ECS, industrial structure upgrading, and green innovation (Du et al., 2019; Liu et al., 2023b; Zhang et al., 2024b). Geographically adjacent LGs also learn from and imitate these successful experiences, which effectively promotes the reduction of pollution and carbon emissions in neighboring and local regions. According to this review, the following hypothesis is posited.

Hypothesis 1. GCA competition promotes regional carbon emission reduction.

GCA competition strengthens the competition for environmental regulation and promotion incentive systems between regions, which play a key role in promoting the reduction of regional energy intensity. The pollution refuge hypothesis suggests that stronger environmental regulation leads to increased competitive pressure on local businesses for environmental governance, energy conservation, and emission reduction, which in turn raises their production costs (Millimet and Roy, 2016; Wang et al., 2019). LGs set clear targets for energy conservation, emission and pollution reduction, total energy consumption reduction, and energy intensity reduction in their GWRs. LG decision-makers are gradually strengthening important issues such as energy conservation, emission reduction, and the dual control of total carbon emissions and intensity (Xu et al., 2022a,b; Miao et al., 2023). They raise design standards and entry barriers in energy conservation, emission reduction, and energy intensity, which have significant filtering effects in heavily polluting and energy-intensive industries. LGs mobilize the rational allocation of economic and social resources and promote the development of green industries. Fast industrial development in energy conservation, emission reduction, and clean production force the upgrading of the regional industrial structure and the rapid transformation of clean energy consumption (Lu et al., 2017; Feng et al., 2023). These measures effectively intensify the competition intensity of energy consumption and carbon emissions among regions.

As an important assessment of LG officials, China's central government has established a performance evaluation system of economic growth and ecological civilization construction targets, into which environmental governance and the dual-carbon targets are incorporated (Yang et al., 2024). The theory of official promotion holds that the performance evaluation of the dual-control system of energy conservation, emission reduction, and energy consumption is another factor affecting the promotion of LG officials (Ren et al., 2024; Xiao et al., 2024); it motivates local officials to strengthen their incentive effect as an internal mechanism, and promotes the symbiotic integration between local economic growth and energy consumption reduction (Meng et al., 2019; Jiang and Tang, 2023). Supported by agency theory, LGs achieve constrained goals in energy conservation, pollution and carbon emission reduction, dual-energy control, and dual-carbon targets. LG officials are the decision-makers and implementers of local policies; they promote the use of clean energy, improve energy efficiency, enhance the implementation of energy conservation, emission reduction, and dual-energy control policies, and thus intensify competition in regional energy consumption.

Increasing GCA competition intensity is beneficial for optimizing scientific and technological innovation systems. LGs actively follow the progress and efficiency improvement of energy conservation, emission reduction, clean production, environmental governance, and energy efficiency technologies, which results in firms actively accelerating the innovation of related technologies and improving the use of clean energy (Wang et al., 2022; Fang and Liu, 2024). The Porter hypothesis suggests that local firms increase research and development (R&D) investment in energy conservation and emission reduction technologies and clean energy use, improve the absorption capacity of clean energy technologies, enhance the energy usage efficiency, and thereby promote significant compensation effects of clean energy technologies (Wang et al., 2022; Ren et al., 2024; Yuan et al., 2024). LGs should increase their dual-carbon attention and accelerate the regional progress of clean energy technologies and the improvement of energy efficiency. In this way, they will reduce both energy consumption and carbon emissions, and can accelerate the decarbonization and low-carbon transformation of regional energy consumption systems (Ren et al., 2024; Zhao et al., 2024). According to the preceding content, the following hypothesis is

put forward.

Hypothesis 2. GCA competition promotes the competition intensity of regional energy consumption, which results in a decrease of regional carbon emissions.

Motivated by the desire to obtain more economic resources and political benefits, an increase in GCA can correct the behavioral preferences of LG officials and those related to formulating industrial policies. Tournament theory holds that the competition mechanism of dual-carbon governance among LGs promotes the upgrading of the local industrial structure and the low-carbon transformation of the ECS. LG decision-making competition synergistically promotes regional pollution, carbon emission reduction, and green transformation (Li, 2022; Pan et al., 2022). LGs promote a competitive incentive mechanism for the industrial structure, and vigorously develop clean industries such as high-tech, energy conservation, environmental protection, and renewable energy industries. These green industries accelerate industrial structure transformation and upgrading, and increase competition for local industrial structure upgrading. This can promote the behavioral preference of resource allocation among regional industries and optimize resource allocation in the development of green industries. Industrial structure upgrading improves energy and resource utilization efficiency, reduces the energy consumption and carbon emission intensity of the industrial structure, and thus promotes the reduction of regional carbon emissions (Dong et al., 2020).

The increase of GCA contributes to the vigorous growth of the renewable energy industry, accelerates the reduction of the proportion of fossil energy consumption, promotes the process of electrification consumption, and gradually optimizes the competition of the regional ECS (Li and Dai, 2019; Liu et al., 2023b). This, in turn, accelerates the progress of energy conservation, environmental protection, and renewable energy technologies, which improves the efficiency of energy usage and carbon emissions, enhances the structural dividend effect generated by optimizing the ECS, and thus accelerates the decline of regional carbon emissions (Du et al., 2019; Li et al., 2024a,b).

The theory of endogenous technology and industrial upgrading suggests that an increase of the GCA level can accelerate the progress and efficiency of regional green technologies, thus enhancing the development of green industries. Green industries promote the transformation and upgrading of the regional industrial structure and the green transformation of the ECS, thus reducing the level of regional carbon emissions (Liu et al., 2024a,b; Zeng et al., 2024). Tournament theory holds that LGs exhibit benchmark competition in pollution prevention and dual-carbon targets. To obtain more political promotion opportunities, LG officials must create higher achievements in coordinating economic growth and pollution and carbon emission reduction. Under the promotion pressure of benchmark competition, LG officials are able to allocate large amounts of economic, financial, and political resources to the rapid development of green and clean energy industries. They accelerate the transformation and upgrading of the regional industrial structure and optimize the regional ECS, and thus increase the competition in the optimization of the ECS by reducing the proportion of fossil energy use. According to the preceding analysis, the final hypothesis is put forward.

Hypothesis 3. GCA competition reduces regional carbon emissions by optimizing the ECS.

4. Research design and method

4.1. Sample selection and data sources

Due to the lack of regional carbon emission data after 2021, panel data from 30 provinces were used as the initial sample. The study period ranged from 2005 to 2021.

Web crawling technology was used to collect and clean the text of the GWRs from the Peking University Treasure Database and the official websites of the central government and 30 provincial governments from 2005 to 2021. All the GWRs in PDF format were converted into TXT format. A total of 301 keywords related to dual-carbon attention were used, and Chinese word segmentation technology and textual vector space processing technology were employed to obtain the GCA level and GCA competition intensity of the central government and provincial governments. GCA competition (GCA competition intensity) was measured based on the ratio of the GCA level (GCA competition intensity) from provincial governments to the GCA level (GCA competition intensity) of the central government.

Data on the carbon emission levels of the 30 provinces were sourced from the China Carbon Accounts and Datasets (CEADs) and the Wind database, which cover the carbon emission levels of 47 socioeconomic sectors and 17 processes related to fossil fuel combustion and cement production. The initial data related to the provincial economic development level, population size, industrial structure, urbanization process, energy consumption, ECS, and environmental protection investment were all sourced from the Economic Prediction System (EPS) database and the Wind database. Data in the EPS database primarily include authoritative data published by international institutions or organizations, and the database provides a series of professional global statistical data/analysis platforms aimed at different user needs.

4.2. Variable selection and measurement

Regional CO_2 emissions are the dependent variable considered in this study. The natural logarithm of provincial CO_2 emissions, as sourced from the CEADs, was utilized. Provincial CO_2 emissions were calculated using a validated multi-scale carbon emission accounting method system with high spatial accuracy, divided by social and economic sectors, and energy variety quality (Shan et al., 2016, 2018a, 2018b; Shao et al., 2016; Guan et al., 2021; Xu et al., 2024).

The level of regional carbon emissions is related to the decision-making behavior of dual-carbon governance and the competitive behavior among LGs. GCA competition is the explanatory variable in this study. In previous research, GEA was measured using approximately 20 keywords (Bao et al., 2022) or 70 keywords (Liu et al., 2023c) related to environmental governance, or 110 keywords from eight dimensions (Wang et al., 2024a; Chen et al., 2024a). In the present work, 301 keywords related to dual-carbon attention from seven dimensions were utilized. The GCA level and GCA competition intensity were measured using the textual analysis method, and the comprehensive dual-carbon attention dictionary was extended to measure the GCA level. There were five main steps for measuring GCA competition, which are subsequently detailed.

First, a comprehensive dual-carbon attention dictionary was created. Seven dimensions were selected: (1) carbon peaking, (2) carbon neutrality, (3) energy conservation and emission reduction, (4) the ecological environment, (5) green finance, (6) sustainable development, and (7) dual-carbon technology application. Relevant policy texts were crawled from the Peking University Treasure Database using the website crawling method. Chinese word segmentation technology was then used to segment all the policy-related texts from the seven dimensions. All the related dual-carbon keywords with a word frequency greater than 5 were selected, and industrial experts were then invited to choose valid keywords related to the seven dimensions as the dual-carbon attention dictionary. This dictionary included 39 carbon peaking keywords, 55 carbon neutrality keywords, 39 energy conservation and emission reduction keywords, 46 ecological environment keywords, 42 green finance keywords, 47 sustainable development keywords, and 33 dual carbon technology application keywords, for a total of 301 dual-carbon attention keywords.

Second, provincial GWRs were collected and cleaned. Text crawling technology was used to collect GWRs from the official websites of provincial governments and the central government from 2005 to 2021, and

the PDF reports were converted to TXT format. The "Jieba" segmentation technique was used to accurately segment the text of the GWRs from the 30 provinces and the central government. The cleaned GWR texts were ultimately obtained after removing useless text information such as line spacing, punctuation marks, underscores, hyphens, numbers, and stop words.

Third, the total word frequency of dual-carbon attention keywords was obtained. The number of each dual-carbon keyword in the provincial and central GWR texts was tabulated, and the total word frequency of the 301 keywords appearing in the segmented texts of the purified GWRs was then counted.

Fourth, the GCA level and GCA competition intensity were measured. To better reflect the potential impact of GCA on regional carbon emissions, the natural logarithm of the total word frequency of dual-carbon attention keywords was used to measure the GCA level. The total frequency of dual-carbon attention keywords was multiplied by 100, and the result was then divided by the total number of words in the GWR texts to measure the GCA competition intensity.

Finally, according to the fiscal competition measurement method proposed by Liu et al. (2022) and Xu et al. (2023), GCA competition was measured by the ratio of the provincial GCA level to the national GCA level. GCA competition intensity was measured by the ratio of the local GCA competition intensity to the national GCA competition intensity.

Energy consumption competition intensity and ECS competition were selected as mediating transmission variables. The competition intensity of provincial energy consumption was calculated as the ratio of the provincial energy consumption to the national energy consumption. Energy intensity was calculated by the total energy consumption (standard coal) divided by the provincial gross domestic product (GDP). The competition of the ECS was calculated by the ratio of provincial coal consumption divided by the ratio of national coal consumption. The coal consumption ratio was calculated by the provincial coal consumption (standard coal) divided by the total energy consumption (standard coal). The provincial population, GDP per capita, energy consumption, industrial structure upgrading, and urbanization level were selected as control variables. The selection and definitions of relevant variables are reported in Table 3.

Table 3
The selection and measurement of variables.

Variable type	Variable name	Variable symbol	Variable measurement
Explained variable	CO_2 emissions	CE_{it}	Provincial CO_2 emissions
Explanatory variable	GCA competition	$PGCA_{it}$	Provincial GCA level/ National GCA level
	GCA competition intensity	$PGCAI_{it}$	Provincial GCA competition intensity/ National GCA competition intensity
Mediating variable	Energy consumption competition intensity	PEI_{it}	Provincial energy intensity/National energy intensity
	Energy structure competition	PES_{it}	Ratio of provincial coal consumption/Ratio of national coal consumption
Control variable	Population size	P_{it}	Total provincial population
	Economic development	ED_{it}	Provincial GDP per capita
	Technological level	EI_{it}	Provincial energy consumption
	Industrial structure upgrading	IS_{it}	Value added of the tertiary industry/Value added of the secondary industry
	Urbanization level	US_{it}	Urbanized population/ Provincial population

4.3. Research method

Under a specific policy system, different governments exhibit greater divergence in environmental governance capacity, the environmental regulation and supervision level, and attention allocation. GCA contributes to the influences of the green innovation level, environmental investment regulations, energy conservation, and emission reduction on the competitive behavior of LGs. LGs put forward stronger resource competition for regional green innovation development, the environmental protection investment scale, and the energy conservation and emission reduction potential.

GCA competition directly determines tax reduction policies, environmental policy implementation, and environmental regulation intensity among LGs. These measures optimize resource allocation efficiency and the structural dividend effects of production factors in different industries, and enhance the rate of regional carbon emission reduction. GCA competition causes shifts in the industrial structure, the ECS, the urbanization level, and other regional aspects toward green and low-carbon development, which is closely related to the reduction of regional carbon emissions. LG competition affects the efficiency of regional environmental governance and the potential for emission reduction. GCA promotes various types of resource competition, such as competition for green innovation, environmental funds, and technological progress, thereby affecting the reduction of regional carbon emissions.

In many previous investigations, the IPAT model proposed by Ehrlich and Holdren (1971) has been used to study the relationship between human activities and the ecological environment. This model involves the impacts of the population size (P), economic development (A), and the technological level (T) on carbon emissions (I), and is written as follows:

$$I_{\mathrm{it}} = aP_{it}^{b}A_{it}^{c}T_{it}^{d}e_{it} \tag{1}$$

where I_{it} represents the regional carbon emission level (CE_{it}). Previous studies have demonstrated that GEA can improve urban energy efficiency (Wang et al., 2024), enhance the urban green total factor productivity (Du et al., 2024), and improve green efficiency and environmental governance quality (Liu et al., 2023d; Tu et al., 2024). LGs generate competition in regional environmental regulation (Yang et al., 2023a) and environmental governance (Yang et al., 2022, 2023b; Guan, 2023). Competition resulting from LG decision-making behaviors and environmental regulation produces significant green paradox effects on regional environmental governance (Guan, 2023; Yang et al., 2023b) and carbon emissions (Li, 2022; Li and Xu, 2022). Recently, the competition mode of LGs has gradually shifted from the traditional mode of competing for economic growth to competing for environmental regulation and reaching the dual-carbon targets. This change in the GCA competition mode may improve industrial structure upgrading and energy consumption, and thus may have a significant impact on regional carbon emission reduction.

In previous studies, the industrial structure (Zheng et al., 2023), the ECS (Wu et al., 2018; Li et al., 2021a,b), and the urbanization process (Zhang et al., 2017; Chen et al., 2020), which have significant impacts on regional carbon emission reduction, were incorporated into the STIRPAT model. In this study, GCA competition as determined from the GWR texts was considered as the transformation of the competition mode of LGs. GCA competition ($PGCAI$), industrial structure upgrading (IS), and the urbanization level (US) were incorporated into the IPAT model, thus creating an extended STIRPAT model. The GDP per capita was used to measure economic development and energy consumption at the technological level. The specific empirical design is as follows.

$$\ln I_{it} = a + \alpha PGCAI_{it} + \beta_1 P_{it} + \beta_2 ED_{it} + \beta_3 EI_{it} + \beta_4 IS_{it} + \beta_5 US_{it} + \xi_{it} \tag{2}$$

GCA competition may accelerate the support for dual-carbon policies and local fiscal and financial resources, thus strengthening the

competition behaviors of regional resource allocation and environmental regulation. Variations in competition behavior alter the regional industrial structure layout, the ECS, and environmental governance investment, and thus greatly accelerate their competitive intensity. To examine the influence channels, the competition behaviors of energy consumption and the ECS were incorporated into the influence mechanisms of GCA competition and regional carbon emissions. The influence mechanisms are enriched from the perspective of competition behaviors, and the models are expressed as follows:

$$\ln X_{it} = a + \alpha PGCAI_{it} + \beta_1 P_{it} + \beta_2 ED_{it} + \beta_3 EI_{it} + \beta_4 IS_{it} + \beta_5 US_{it} + \xi_{it} \quad (3)$$

$$\ln I_{it} = a + \alpha_1 PGCAI_{it} + \alpha_2 X_{it} + \beta_1 P_{it} + \beta_2 ED_{it} + \beta_3 EI_{it} + \beta_4 IS_{it} + \beta_5 US_{it} + \xi_{it} \quad (4)$$

where X represents the competition behaviors of the energy consumption and ECS among LGs.

5. Empirical results analysis and discussion

5.1. Descriptive statistics

Table 4 exhibits the descriptive statistical results of the relevant variables. The average carbon emissions of the 30 provinces are 19.2653, with a standard deviation of 0.7692. These results indicate significant regional differences in carbon emission levels among provinces. The mean values of GCA competition intensity, energy consumption competition intensity, and ECS competition are 0.1099, 0.1094, and −0.0829, respectively, with respective standard deviations of 0.2668, 0.4599, and 0.5290. These results indicate the significant regional heterogeneity of these variables.

5.2. Impact of GCA competition on regional carbon emissions

Regional energy consumption was selected to measure the technological level, and driving factors such as the population, the economy, technology, GCA competition, industrial structure upgrading, and the urbanization process were selected to empirically investigate the impact of GCA competition on regional carbon emissions. The empirical results are reported in Table 5.

As presented in the first column, the coefficients for the population size, economic development, and energy intensity are 1.0870, 0.9761, and 1.1675, respectively, and these factors have significant and positive impacts on regional carbon emissions at the 1% level. The results confirm that rapid population growth and economic development can increase regional carbon emissions, while a decrease in energy consumption can reduce regional carbon emissions.

The second column reports the results for GCA competition intensity. Its coefficient is −0.1283, which is significant at the 1% significance level. This supports Hypothesis 1, namely that GCA competition intensity reduces regional carbon emissions. As the main actor of environmental regulation and dual-carbon governance, the LG's competitive behavior can affect the policy effectiveness of dual-carbon policy instruments, as well as the government behavior of neighboring regions in dual-carbon governance. LGs are increasing their dual-carbon attention, which strengthens the pressure of normalized external dual-carbon governance, generates significant peer pressure on dual-carbon governance in neighboring regions, and intensifies the dual-carbon attention competition among different LGs. Promotion tournament theory suggests that LG officials, to gain better promotion advantages, gradually increase their GCA competition and optimize policy tools related to dual-carbon governance competition, and thus establish stronger competition between governments.

Table 4
The descriptive statistics of related variables.

Variable	Mean	Standard deviation	Maximum	Minimum	Median
ln CE_{it}	19.2653	0.7692	20.6690	16.6189	19.2951
ln $PGCAI_{it}$	0.1099	0.2668	0.8045	−0.9209	0.1399
ln PEI_{it}	0.1094	0.4599	1.4474	−0.8936	0.0362
ln PES_{it}	−0.0829	0.5290	1.1734	−4.1953	−0.0499
ln P_{it}	8.1844	0.7449	9.4481	6.2971	8.2515
ln ED_{it}	10.5440	0.6666	12.1226	8.5275	10.6197
ln EI_{it}	−0.1940	0.5671	1.4313	−1.6754	−0.2178
ln IS_{it}	0.0093	0.4118	1.6696	−0.6949	−0.0690
ln US_{it}	−0.6152	0.2504	−0.1098	−1.3142	−0.6104

Note: The statistical results of the relevant variables in Table 2 were processed using the natural logarithm.

Table 5
The empirical results of the effect of GCA competition on regional carbon emissions.

Variable	ln I_{it} *(1)*	ln I_{it} *(2)*	ln I_{it} *(3)*	ln I_{it} *(4)*
Intercept term	0.3034 (0.9927)	0.1419 (0.4594)	0.4801* (1.5782)	1.7306*** (2.7881)
ln P_{it}	1.0870*** (83.1993)	1.0912*** (83.5689)	1.0511*** (73.2712)	1.0585*** (92.3108)
ln A_{it}	0.9761*** (39.9308)	0.9897*** (39.9911)	0.9879*** (41.2689)	0.8775*** (16.4266)
ln EI_{it}	1.1675*** (46.4070)	1.1769*** (46.6943)	1.1088*** (41.1050)	1.1053*** (41.0906)
ln $PGCAI_{it}$		−0.1283*** (−2.8193)	−0.1471*** (−3.3349)	−0.1332*** (−3.0044)
ln IS_{it}			−0.1720*** (−3.3349)	−0.1897*** (6.3157)
ln US_{it}				0.2433** (2.3081)
Fixed effect	Year	Year	Year	Year
R^2	0.9406	0.9416	0.9455	0.9461
F-statistic	406.6312	394.1019	402.9137	388.2519

Note: *** and ** respectively represent significance at the 1% and 5% significance levels, and the values in parentheses are the t-statistics. The notations are the same for subsequent tables.

As presented in the third column of Table 5, the coefficient of industrial structure upgrading is −0.1720. The findings indicate that this factor significantly reduces regional carbon emissions at the 1% level. Actually, industrial structure rationalization and optimization produces the asymmetric influences on regional carbon emissions in different countries and industries (Jiang et al., 2022; Hu et al., 2023). LGs accelerate the transformation and upgrading of the industrial structure and improve the energy efficiency of different industries in China. In the GCA competition circumstance, they reduce the energy consumption and carbon emission intensity of different industries, which then accelerates the reduction of regional carbon emissions.

Finally, the fourth column of Table 5 indicates that the coefficient of the urbanization level is 0.2433. This factor is found to promote the increase of regional carbon emissions at the 5% significance level. Really, urbanization level appears positively associated with regional energy consumption and carbon emissions (Liddle, 2014). Fast urbanization with higher population density, land utilization rate and lower energy consumption may be decrease regional carbon emissions. However, in this study, the increase of the urbanization level increases local economic development and urban infrastructure construction, and promotes energy usage efficiency, leading to an increase in regional carbon emissions.

5.3. Influence mechanism test

Energy consumption competition intensity and ECS competition were selected as intermediary transmission mechanisms, and the mechanisms by which GCA competition reduces regional carbon

emissions were empirically investigated. The relevant empirical results are reported in Table 6.

As presented in the first column, the coefficient of GCA competition intensity is 0.1575, which is significant at the 5% level. Thus, GCA competition intensity significantly promotes the competitive level of regional energy consumption. When LGs increase their GCA competition, they raise the standards for regional energy conservation, including carbon and pollutant emission reduction. These measures drive firms to reduce their fossil energy consumption and increase the use of clean energy, and accelerate the energy consumption competition intensity among LGs.

As exhibited in the second column of Table 6, the coefficient of GCA competition intensity is −0.1332, indicating that an increase in this factor can significantly reduce regional carbon emissions. Moreover, the coefficient of energy consumption competition intensity is 1.1053, indicating that the reduction of this factor can significantly decrease regional carbon emissions. The increase of GCA competition by LGs incentivizes firms to compete in the improvement of their energy technology progress and energy usage efficiency, and to strengthen their competition in decreasing energy consumption; this further accelerates the decline of regional carbon emissions.

As shown in the third column of Table 6, the coefficient of GCA competition intensity is −0.2053. Thus, GCA competition can significantly reduce the proportion of coal energy consumption and optimize the ECS at the 1% significance level. Competition incentive theory suggests that LGs increase their GCA competition level and incentivize firms to accelerate the development of green industries and clean energy use.

As presented in the fourth column of Table 6, the coefficients of GCA competition intensity and ECS competition are −0.0561 and 0.3762, respectively. The increase of GCA competition intensity by LGs optimizes the ECS, which further enhances the reduction of regional carbon emissions. This also accelerates the progress of energy conservation, environmental protection, and clean energy technologies, which strengthen the influence of GCA competition intensity on optimizing the ECS. This ultimately accelerates the decline of regional carbon emissions. The theory of industrial structure upgrading suggests that LGs increase their dual-carbon attention competition, and should compete to enhance industrial structure upgrading and the green transformation of the ECS, which will further accelerate the reduction of regional carbon emissions. LGs should reasonably guide the coordinated competitiveness of energy use efficiency and ECS in green energy transfer across industries, and thus avoid vicious competition in energy intensity and ECS between neighboring regions.

Table 6
The empirical results of the mechanisms by which GCA competition intensity influences regional carbon emissions.

Variable	ln PEI_{it} *(1)*	ln I_{it} *(2)*	ln PES_{it} *(3)*	ln I_{it} *(4)*
Intercept term	9.0436*** (9.3551)	1.3952** (2.2365)	2.8250** (2.2418)	0.5598 (1.3748)
ln P_{it}	−0.3110*** (−15.3869)	1.0585*** (72.3108)	0.1920*** (6.4959)	0.9854*** (99.4552)
ln A_{it}	−0.5942*** (−6.9274)	0.8775*** (16.4266)	−0.3649*** (−3.3622)	1.0245*** (29.0293)
ln EI_{it}			0.5884*** (10.8336)	0.8829*** (45.3792)
ln $PGCAI_{it}$	0.1575** (2.1207)	−0.1332*** (−3.0044)	−0.2053*** (−2.2944)	−0.0561** (−1.9393)
lnPEI_{it}		1.1053*** (41.0906)		
ln PES_{it}				0.3762*** (25.7980)
ln IS_{it}	−0.4775*** (10.4550)	−0.1897*** (−6.1357)	−0.6194*** (−10.1297)	0.0498** (2.3003)
ln US_{it}	0.2213 (1.2496)	0.2433** (2.3081)	0.8029*** (3.4780)	−0.0782 (−1.1200)
Fixed effect	Year	Year	Year	Year
R^2	0.5718	0.9461	0.5355	0.9773
F-statistic	31.0319	388.2519	25.4679	907.6404

5.4. Robustness test

To further examine the robustness of the impact of GCA competition on regional carbon emissions, the intensity of energy consumption competition was chosen to represent the technological level. Moreover, the driving factors of the ECS, environmental investment, and environmental investment competition were selected to investigate the robustness of the relationship between GCA competition and regional carbon emissions. The relevant empirical results are exhibited in Table 7.

The natural logarithm of the total word frequency of all the dual-carbon keywords crawled from the provincial GWR was used as a measurement of the GCA level. The ECS was measured using the ratio of the amount of coal consumption to the total amount of energy consumption, the natural logarithm of which was then taken. As indicated in Columns (1), (2), and (3) of Table 7, GCA competition can significantly reduce regional carbon emissions at the 1% level, indicating good robustness. Both industrial structure upgrading and the reduction of the proportion of fossil energy in the ECS can reduce regional carbon emissions, and the findings indicate good robustness when compared with the empirical results reported in Table 3.

Optimizing fossil ECS should pay much attention to altering elasticity of China's carbon emission intensity to industry structure and energy efficiency (Lin and Agyeman, 2019; Wang et al., 2020). LGs optimize industrial structure upgrading and raise green technological progress level, especially promote coal usage efficiency and thus decrease the carbon emission intensity of different industries. The synergy of ECS and industrial structures significantly reduce carbon intensity, especially those regions with abundant energy resource endowments increase their synergy effects (Lin and Liao, 2023).

Environmental protection investment was calculated as follows: the ratio of the investment in industrial pollution control to the investment in forestry and grassland was multiplied by 100, the result was divided by the total regional fiscal expenditure, and, finally, the natural logarithm was taken. As indicated in the fourth column of Table 7, increased environmental protection investment by LGs can reduce regional carbon emissions at the 1% significance level. Compared with the empirical results listed in the third column, the upgrading of the industrial structure has a slightly negative impact on amplifying regional carbon emissions, while the ECS has a slightly smaller and positive impact.

Environmental protection investment competition was calculated as follows: the local environmental protection investment ratio was divided by the national environmental protection investment ratio, and the natural logarithm was then taken. As listed in column (5), the increase of environmental investment competition by LGs was found to significantly reduce regional carbon emissions at the 1% level.

Effective environmental regulation instruments are crucial for mitigating regional environmental pollution and carbon emissions. LGs adopt imitative and competitive strategies, resulting in a "race to the top competition" in regional environmental investment (Cao et al., 2024). LGs increase environmental protection investment and environmental regulation intensity, enhances the effectiveness of carbon emission reduction through environmental investment. However, LGs with pollution-prevention and resource-intensive regions may adapt "race to the bottom" competition strategies in order to improve regional competition advantages, trapped in a polluted paradise.

The findings of this study confirm that the population scale, economic development, the energy consumption competition intensity, and the ECS have significant and positive impacts on regional carbon emissions. Moreover, GCA competition, industrial structure upgrading, environmental protection investment, and environmental protection investment competition were found to have significant and negative

Table 7
The robustness test of the effect of GCA competition on regional carbon emissions.

Variable	ln I_{it} *(1)*	ln I_{it} *(2)*	ln I_{it} *(3)*	ln I_{it} *(4)*	ln I_{it} *(5)*
Intercept term	4.8935*** (24.9178)	4.6150*** (24.0627)	5.3785*** (42.0638)	5.4524*** (41.8356)	5.4277*** (42.0590)
ln P_{it}	1.0150*** (81.3754)	0.9502*** (73.0492)	0.8843*** (100.2485)	0.8862*** (100.1856)	0.8869*** (99.9807)
ln A_{it}	0.5673*** (39.8180)	0.6447*** (43.1205)	0.6427*** (66.3950)	0.6362*** (64.0808)	0.6358*** (63.7159)
ln PEI_{it}	0.9002*** (42.0268)	0.8213*** (38.0464)	0.5969*** (35.9784)	0.6054*** (35.9463)	0.6067*** (35.7931)
ln $PGCA_{it}$	−0.1649*** (−7.3348)	−0.1188*** (−5.3755)	−0.0886*** (−6.1668)	−0.0883*** (−6.1476)	−0.0886*** (−6.1699)
ln IS_{it}		−0.3367*** (−13.6541)	−0.1577*** (−9.0020)	−0.1599*** (−9.1209)	−0.1571*** (−8.9722)
ln ES_{it}			0.3561*** (24.9432)	0.3556*** (24.9100)	0.3554*** (24.8902)
ln EPI_{it}				−0.0242*** (−2.9331)	
ln $PEPI_{it}$					−0.0239*** (−2.8224)
Random effect	Year	Year	Year	Year	Year
R^2	0.8865	0.9073	0.9365	0.9369	0.9369
F-statistic	985.8050	986.8713	1234.4570	1063.2300	1062.6910

impacts on regional carbon emissions. These empirical results have good robustness when compared with the results reported in Table 3.

5.5. Discussion and policy implications

The climate risk and environmental attention of LGs can reduce the carbon intensity and improve regional environmental governance (Chen et al., 2024b; Zeng et al., 2024;Zhang et al., 2024a). Increasing environmental attention from LGs can reduce corporate carbon emission levels (Liu et al.,2023), and LG competition has a U-shaped relationship with regional environmental governance and carbon emissions (Li and Xu, 2022; Li, 2022; Guan, 2023). Moreover, fiscal expenditure competition by LGs increases regional green development efficiency (Yang et al., 2023b). The findings of this study confirm that GCA competition can significantly reduce regional carbon emissions, which enriches the extant knowledge from the perspective of attention behaviors. The results have significant novelty as compared to the previously mentioned studies.

Actually, serious "race to the bottom" and "free riding" are unable to motivate the action logic of LGs in China on carbon emissions issues. The GCA competition gives rise to a special "benchmark competition" or "political tournament mechanism" among LGs. These measures mobilize LGs provide more economic and financial resources and accelerate the reduction of regional carbon emissions. This incentive mechanism effectively solves the problem of information measurement of LGs' carbon emission performance and motivates LGs to stimulate dual-carbon governance actions. This negative effect of dual-carbon attention competition on regional carbon emissions will generate significant same-group competition among neighboring areas, with spatial spillover effects of carbon reduction. Finally, the LGs' competitive strategy will gradually shift towards "race to top competition".

Relevant research confirms that the transformation and upgrading of the industrial structure effectively reduce regional carbon emissions (Dong et al., 2020; Wu et al., 2021b; Zhu, 2022; Bian and Meng, 2023). While some research has found that the increase of the urbanization level reduces the regional carbon intensity level (Qiao et al., 2024), other studies have indicated that it promotes an increase in regional carbon emissions (Du et al., 2019; Siqin et al., 2022; Bian and Meng, 2023). This study confirms that fast industrial structure upgrading can decrease regional carbon emisions, however, rapid urbanization level can increase regional carbon emissions. The former results is similar to the negative effects of the present study(Wu et al., 2021a,b; Bian and Meng, 2023), the latter result is in according with the results of the present work (Du et al., 2019; Bian and Meng, 2023).

Strict environmental regulation and industrial structure upgrading can reduce regional pollution and carbon emissions (Cheng et al., 2017; Danish et al., 2020; Du and Li, 2020; Ouyang et al., 2020). The upgrading of industrial structure is an important factor driving the reduction of regional carbon emissions. Stronger GCA competition forces firms to compensate for environmental regulatory costs through industrial structure adjustment and upgrading, incentivizes them to promote green technology innovation and industrial structure upgrading, creating more innovative compensation benefits. Upgrading regional industrial structure promotes the improvement of resource allocation efficiency in various industries, enhances inter-industry and cross-industry interaction and agglomeration effects, and improves the energy usage efficiency and carbon emission efficiency levels between industrial structures.

The correlation between key factors such as industrial agglomeration, population density, and land use is an important factor in urbanization and carbon emissions. The second and third industries are gathering towards urbanization, driving industrial and population urbanization, and thus enhancing industrial structure agglomeration and population density. The urbanization of industry and population is expanding the demand for construction land, consuming a large amount of resources and energy, which are the main source determining regional carbon emissions (Liddle, 2014; Zhang et al., 2014; Wang and Li, 2022). Meantime, the scale, structure, and efficiency of industries and population are related to the scale, structure, and efficiency of carbon emissions. LGs should pay much attention to the correlation among population intensity, industry structure, land usage and urbanization, and thus determine regional carbon emissions.

LGs' competition promotes the agglomeration of new energy industries, which has short-term spatial spillover effects on regional energy usage (Yan et al., 2023). Competition between informal sectors effectively reduces the energy consumption of manufacturing (Zhao et al., 2022) and improves the energy usage efficiency (Otrachshenko et al., 2023). Optimizing industrial structure and ECS are crucial driving determinations of reducing regional carbon emissions. This reduces the proportion of fossil energy in the ECS, thus optimizing it. Optimizing ECS, increasing renewable energy usage and energy usage efficiency are crucial driving factors to decrease regional carbon emissions. LGs should increase dual-carbon attention competition and accelerate competition in energy conservation and emission reduction technologies, as well as in the R&D of clean energy technologies. They should also accelerate the improvement of clean energy consumption and energy usage efficiency, and promote the competition intensity related to energy consumption.

Import competition can significantly reduce the energy consumption of Chinese firms (Feng and Wei, 2023), and the energy consumption competition intensity differs among different industries (An et al., 2023). Compared with these results, the negative impact of the GCA competition intensity on competition in ECS optimization identified in the present study has significant novelty. Thus, government intervention and environmental regulation can optimize the industrial structure and the ECS (Wu et al., 2021c; Zhang et al., 2023a,b; Fan et al., 2024). Related studies have confirmed that ECS optimization can reduce carbon emissions (Wu et al., 2018; Yu et al., 2018). The intensity of GCA competition increases the competition level of energy consumption from the perspective of competition behaviors. This finding extends the understanding of the nexus between government competition and energy

consumption, thus exhibiting significant and marginal contributions as compared to the previously mentioned results. GCA competition intensity accelerates the reduction of regional carbon emissions by increasing the energy consumption competition intensity, a finding that makes greater marginal contributions as compared with the previously identified positive results of energy intensity. However, the effect of GCA competition intensity accelerates this effect by promoting ECS competition, a finding that enriches the understanding of the relationship between government competition and carbon emissions. The identification of this influence channel makes a significant marginal contribution as compared to the extant literature.

Environmental regulation mitigates carbon emissions, and financial institution competition promotes these reduction effects (Yan et al., 2023; Chen et al., 2024a). If local authorities strengthen the competition in environmental protection and low-carbon technology, the regional environmental performance can be effectively improved (Yang et al., 2020) and carbon emissions can be reduced (Shu and Dai, 2024). The findings of this study enrich the understanding of the reduction effect of environmental protection investment on regional carbon emissions, and are similar to the previous research results regarding environmental regulation. This study enriches the extant literature from the perspective of GCA competition behavior, and extends the understanding of the nexus between environmental regulation and carbon emissions. Scale effects, structural effects, and technical effects might be three potential influencing channels through which environmental investment contributes to the CO2 reduction effect (Ai et al., 2023). LGs increase environmental investment and its competition, incentive firms enhance green technology innovation and technical efficiency in energy-intensive industries, creating innovation compensation effect. Stronger environmental regulation intensity motivates firms increase environmental investment, and optimizes their ECS and energy usage efficiency via upgrading industrial structure.

Based on the empirical results, the following policy recommendations are proposed.

First, LG decision-makers should fully utilize dual-carbon attention and its competition to reduce carbon emissions. GCA incentivizes the public, the market, and firms to convey social signals of dual-carbon governance and optimize the allocation of production factor resources in green low-carbon transformation industries. This promotes industrial structure transformation and upgrading, which ultimately accelerates the reduction of regional carbon emissions. LGs should optimize the policy mechanisms for reducing pollution and carbon emissions, optimize the performance evaluation mechanism for LG officials, and enhance the intensity of regional environmental regulation via administrative management and market mechanisms. They should also strengthen the competition mechanisms related to energy conservation and carbon and pollution emission reduction to accelerate the reduction of regional carbon emissions. GCA competition in the coordinated development of the economy, the industrial structure, the urbanization process, and green technology innovation should also be enhanced. LGs should reasonably guide their behavior and the behavior of the public, the market, and firms via market and competition mechanisms, strengthen the race to the top between LGs and firms, and ultimately optimize a "competition-to-the-best" environment.

Second, LGs should make reasonable use of GCA competition to accelerate the competitive advantage of the resource allocation of production factors in green and low-carbon industries. Such measures strengthen industrial structure competition, reduce the intensity of energy consumption competition, and optimize competition in ECS optimization, thus further enhancing the role of government competition in reducing carbon emissions. LGs should also reasonably use competition mechanisms to reduce energy consumption and optimize the ECS, and should incentivize firms to reduce the proportion of coal use, increase the proportion of clean energy use, and optimize the ECS. These measures would improve the energy usage efficiency and reduce regional energy consumption through external institutional pressure and market competition pressure. Moreover, LGs should optimize the green technology innovation system to incentivize firms to accelerate their investment in green technology R&D. The improvement of green technology progress and efficiency will accelerate firms to reduce their energy consumption and carbon emissions, which will ultimately promote the reduction of regional carbon emissions.

Third, LGs should introduce competition mechanisms for the industrial structure and the ECS via dual-carbon attention and market mechanisms. These measures would promote the transformation and upgrading of the industrial structure, reduce fossil energy consumption, increase the use of renewable energy, optimize the ECS, and then promote the reduction of regional carbon emissions. LGs should make reasonable use of the competition mechanism of dual-carbon attention, and fully leverage its promotion effect on environmental protection investment. They should optimize healthy competition between firms with different natures of ownership and scales, and should encourage firms to increase their environmental protection investment and improve the related competition mechanism. This will further strengthen the role of environmental protection investment in reducing regional carbon emissions. Market competition mechanisms for environmental protection investment among LGs will incentivize firms to increase their environmental protection investment, improve the energy usage efficiency, and increase the energy conservation and emission reduction potential. These measures will ultimately enhance pollution and carbon emission reduction capabilities, and can fully leverage the spatial spillover effect of environmental protection investment on regional carbon emission reduction.

Nevertheless, this study was characterized by tentative limitations, and many aspects require further study. One limitation is the limited understanding of the influence mechanisms of both GCA competition and regional pollutant emissions. In future research, the reduction effect of GCA competition on regional pollution and carbon emissions can be examined from the perspectives of environmental regulation and policy effectiveness. Another limitation is the lack of insight into the promotion effects of GCA competition from the perspectives of races to the bottom and top. In future research, the study of the spillover effects between different types of GCA competition and the reduction of regional pollutant and carbon emissions, especially different impacts of race-to-the-bottom and race-to-the-top competition, can be expanded.

6. Conclusions

LGs play important roles in the adjustment of scarce resources, resource allocation, policy systems, and benefit distribution, including energy conservation and the reduction of pollution and carbon emissions. Dual-carbon attention is a favorable social signal for LGs to transmit dual-carbon governance information to the market, the public, and firms. LGs, the public, markets, and firms promote fierce competition for various social, economic, and financial resources. In this study, the web crawler and textual analysis techniques were used to obtain the total frequency of 301 keywords related to dual-carbon attention from 30 provincial and central GWR texts to measure the GCA level and GCA competition intensity. Competition in GCA, energy consumption, and the ECS was measured, and these three competition types were incorporated into an extended STIRPAT model. The ways in which GCA competition promotes the reduction of regional carbon emissions via competition in energy consumption and the ECS were investigated. The main findings of this study are summarized as follows.

Different provinces engage in significant competition in terms of dual-carbon attention, energy consumption, and the ECS, and significant regional heterogeneity was identified. The population size, economic development, and the urbanization level were found to increase regional carbon emissions, whereas the reduction of energy consumption, the increase of GCA competition, and the improvement of industrial structure upgrading were found to significantly reduce regional carbon emissions. The finding of the negative impact of industrial structure

upgrading on carbon emissions is similar to some previous research results (Dong et al., 2020; Wu et al., 2021; Zhu, 2022). The increase of the climate risk and environmental attention of LGs reduces regional carbon intensity and carbon emissions (Liu et al., 2023; Chen et al., 2024b) and enhances pollutant emissions (Bao and Liu, 2022, Chu et al., 2024; Li et al., 2024a,b; Zeng et al., 2024). However, this study demonstrates that GCA competition promotes a significant decrease in regional carbon emissions. This finding extends the understanding of the nexus between government attention and carbon and pollutant emissions from the perspective of government competition behaviors. This represents substantial research novelty, especially as compared to the U-shaped relationship between government competition and carbon emissions (Li and Xu, 2020; Li, 2022).

The influence mechanism analysis confirmed that GCA competition can significantly promote the intensity of energy consumption competition at the 5% level, which can accelerate the reduction of regional carbon emissions. Government competition and informed section competition have previously been found to reduce energy consumption (Zhao et al., 2022) and promote energy usage efficiency (Otrachshenko et al., 2023; Yan et al., 2023). However, the findings of the present study expand the knowledge of the influence mechanism between government competition and carbon emissions from the perspective of energy consumption competition behaviors, which enriches the understanding of the promotion effect of government competition on energy usage efficiency (Yan et al., 2023). GCA competition was found to promote the reduction of the proportion of fossil energy in the ECS, thus accelerating ECS optimization and ultimately reducing regional carbon emissions. Previous studies have confirmed the mutual relationship between government intervention and industrial structure optimization (Zhang et al., 2023a,b), as well as both environmental regulation and ECS optimization (Fan et al., 2024). However, the present study deepens the understanding of the relationship between government competition and the ECS and enriches the knowledge of the influence mechanism between government competition and carbon emissions from the perspective of competition behaviors. The findings further support the role of GCA competition in reducing regional carbon emissions through two competition mechanisms, thus making greater marginal research contributions.

The robustness test confirmed the robustness of the results, namely that GCA competition and industrial structure upgrading reduce regional carbon emissions. The ECS of fossil fuels has a significant positive impact on regional carbon emissions, and reducing the proportion of fossil fuels in the ECS can significantly decrease regional carbon emissions. Moreover, increases in environmental investment and its competition among LGs were found to significantly reduce regional carbon emissions at the 1% level. These empirical results were found to have good robustness. Previous studies have confirmed that environmental regulation and protection can decrease regional carbon emissions and improve environmental governance performance (Yang et al., 2020; Yan et al., 2023; Shu and Dai, 2024). This study extends the understanding of how environmental governance investment reduces carbon emissions from the perspective of competition behaviors.

CRediT authorship contribution statement

Kai Chang: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Susheng Wang:** Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

No conflict of interest exists in the submission of the manuscript, all authors accept that this manuscript is submitted to Journal of Environmental Management. I would like to declare that this paper is our original unpublished work and it has not been submitted to any other journal.

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Data availability

Data will be made available on request.

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