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Original Research

Creating a Favorable Political Environment for Reducing Regional Carbon Emissions: A Study Based on fsQCA and the Entropy Method

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Abstract

Based on 30 provincial-level regions in China from 2008 to 2017, we empirically analyze the comprehensive impact of the government accounting function on regional carbon emissions using the entropy method and fuzzy-set qualitative comparative analysis (fsQCA) method. We found that the comprehensive functions of government accounting can significantly inhibit regional carbon emissions. Second, based on the fsQCA methodology, we found four main paths to promote the regional carbon emission performance: government financial accounting-debt function-promoted, government cost management function-promoted, government budget management function-performance management function-promoted, and generalized government accounting function integrated-promoted. Among them, the one with the strongest influence is the government financial accounting function-debt function. The study's conclusion provides a reference for the government financial department to strengthen the governance of regional carbon emissions.

Keywords: entropy method, fsQCA, government accounting function, regional carbon emissions

Introduction

Climate change stands as one of the most formidable global challenges confronting humanity. In an effort to regulate carbon dioxide (CO_2) emissions and to decelerate the progression of global warming [1], nations across the globe have convened and ratified multiple agreements since the 1990s. In a significant declaration in 2020, President Xi communicated to the international community China's ambition to reach the zenith of CO_2 emissions by 2030, a milestone known as "Carbon Peak," and to realize carbon neutrality by 2060, a goal termed "Carbon Neutrality." This dual-carbon objective delineates a definitive timeline for China's endeavors in emission control and carbon reduction. Consequently, the erstwhile economic growth paradigm, propelled by resource and energy consumption and marked by its unsustainability, necessitates a transformation and enhancement. The pivot towards an innovation-led, quality-focused economic development model is imperative for China's successful attainment of the dual-carbon target [2].

Simultaneously, local governments, serving as the executors of centralized policies and regulations, are tasked with a multitude of responsibilities, including fostering economic growth, enhancing

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the quality of life for citizens, and stimulating innovation. Government accounting, functioning as an informational framework that mirrors economic activities, systematically encapsulates policy resources and instruments, adapting its role in accordance with varying functions. Nonetheless, the precise functions of government accounting remain inadequately delineated. Consequently, it is imperative to define these functions and examine the nexus between government accounting and regional carbon emissions, which will offer strategic direction for local governments to mitigate carbon emissions. We intend to utilize a variety of methodologies and models to assess the holistic impact of government accounting functions on regional carbon emissions, to dissect the specific amalgamation of driving mechanisms and developmental trajectories, and to broaden the research perspectives on the determinants influencing regional carbon emissions.

The innovations of the study are as follows. (1) Comprehensive framework for government accounting functions. Existing research often examines the functions of the government accounting system from a singular or limited perspective, lacking a holistic and systematic analytical framework. This study addresses this gap by systematically constructing a comprehensive framework for government accounting functions. Specifically, it defines government accounting functions as encompassing four key components: government financial accounting, government auditing, government management accounting, and government financial management. Building on prior research, this study refines, supplements, and integrates measurement indicators for each branch of government accounting functions, thereby establishing a more robust and unified analytical framework.

(2) Multifaceted examination of regional carbon emissions. This study adopts a multidimensional approach to analyze regional carbon emissions. First, it examines regional per capita carbon emissions, focusing on the relationship between carbon emissions and population density. Second, it investigates regional carbon emissions intensity, addressing the interplay between carbon emissions and economic development. Third, it evaluates regional carbon emissions performance using the Data Envelopment Analysis (DEA) model, which incorporates undesired outputs, to comprehensively assess the relationship between carbon emissions and factors such as energy consumption, capital investment, and labor. This multifaceted approach enables a thorough and nuanced analysis of the impact of government accounting functions on regional carbon emissions.

(3) The study explores the comprehensive impact of government accounting functions on regional carbon emissions. To achieve this, it employs advanced methodologies, including entropy and fsQCA methods. These techniques are used to empirically test the effects of the comprehensive functions of government accounting on regional carbon emissions and to determine the relative importance of different functions. This approach not only provides empirical insights but also enhances the understanding of how various government accounting functions collectively influence carbon emissions at the regional level.

The remaining study sections are arranged as follows: Section 2 presents a literature review and hypothesis development. Section 3 shows the materials and methods. Section 4 presents the empirical results and discussion. Section 5 provides conclusions and recommendations.

Literature Review and Hypothesis Development

Impact of Government Financial Accounting Functions on Regional Carbon Emissions

Fiscal transparency serves as an effective regulatory mechanism for standardizing the use of financial funds, a vital tool for enhancing government efficiency and a critical measure for ensuring the rational allocation of resources [3]. Additionally, it acts as a key mechanism for mitigating the principal-agent problem between the government and the public [4]. A lack of fiscal transparency may directly or indirectly result in adverse consequences, such as an increased local debt burden [5], heightened corruption [6], and excessive government redundancy [7]. These issues collectively hinder regional economic development and undermine green innovation capacity.

On the one hand, improving government fiscal transparency facilitates public access to critical environmental information, including data on environmental accidents, illegal pollutant emissions, environmental protests, and new environmental policies [8, 9]. This reduction in information asymmetry lowers the uncertainty associated with enterprises' green innovation efforts and mitigates rent-seeking behaviors that exploit market information advantages. As a result, it bolsters market confidence and stabilizes expectations for enterprises, enabling them to undertake greater R&D risks and thereby fostering regional green innovation. On the other hand, enhanced government fiscal transparency contributes to reducing corruption [6], curbing budget irregularities, and ensuring effective implementation of carbon emission reduction policies and financial subsidies [7]. This creates a more favorable environment for enterprises, increasing their willingness to adopt energy-saving measures and reduce emissions, ultimately supporting sustainable development goals.

Impact of the Government Audit Function on Regional Carbon Emissions

Government auditing serves as a mechanism for monitoring and constraining power through legal means, functioning as an endogenous "immune system"

within government governance. It plays a critical role in prevention, revelation, and defense.

The preventive function of government auditing is manifested through its inherent deterrent effect and independence. These characteristics help deter behaviors that harm the interests of the state and the public while providing early warnings of potential issues. Recent studies further highlight that the independence of audit institutions significantly enhances their preventive role, particularly in environmental governance and fiscal transparency. Cao et al. found that improving the independence of government auditing promotes public environmental concern and guides pro-environmental behavior, which is crucial for achieving sustainable development goals [10]. As a regular supervisory mechanism, government auditing offers robust early warnings for irregularities that may arise during carbon reduction processes, such as inappropriate policy formulation and implementation, as well as insufficient scientific management and utilization of financial funds [11].

The revealing function is reflected in the ability of government auditing to uncover the actual conditions of audited entities and expose their problems using specific methods and tools. Studies have shown that the revealing function of government audits significantly impacts controlling corruption levels and enhancing government financial security [12]. By auditing the entire process of carbon emission reduction funds [10], auditing organizations can ensure the efficient and secure use of financial resources allocated for carbon reduction, thereby promoting low-carbon development.

The defensive function of government auditing is demonstrated by using audit institutions to provide recommendations, guidance, corrective actions, and penalties [12]. This function involves urging the rectification of identified issues and implementing measures to continuously standardize, improve, and refine relevant systems. Its goal is to eliminate various "ills" in economic operations. Furthermore, the defensive function not only identifies and discloses problems in carbon reduction and emission reduction processes but also investigates the root causes of these issues. Based on this analysis, it proposes targeted and comprehensive development guidance, encouraging relevant departments to strengthen laws and regulations related to low-carbon development. This approach aims to mitigate risks throughout the carbon emission reduction process and ensure effective implementation [13, 14].

The Impact of Government Management Accounting Functions on Regional Carbon Emissions

Impact of Government Budget Management Functions on Regional Carbon Emissions

The government budget is a critical tool for overseeing social and economic operations and intervening in the allocation of macroeconomic resources. It serves as a constraint on administrative behavior [14]. A key criterion for evaluating the effectiveness of government budget management is the extent of deviation from the budget. A smaller deviation indicates more efficient budget management, reflecting greater scientific rigor in planning financial revenues and expenditures.

Currently, local fiscal revenue budget deviations in China display a trend of "over-collection," suggesting that local governments often collect taxes over projected levels [15]. This practice undermines the principles of tax smoothing and neutrality, thus increasing the tax burden on market participants. As a result, government budgets fail to stabilize market expectations, diminishing enterprises' incentives to conserve energy and reduce emissions.

The Impact of Government Cost Management Functions on Regional Carbon Emissions

Government financial expenditure on environmental protection serves as a crucial tool for environmental regulation. It represents the economic foundation, material support, and direct manifestation of governmental responsibility towards environmental governance. It plays a pivotal role in reconciling the often conflicting interests between local economic development and environmental conservation.

At the macro level, government financial expenditure on environmental protection is an integral component of public finance. These funds are allocated to environmental infrastructure projects and the construction of facilities, establishing a solid foundation for future environmental governance and the remediation of pollution sources. Moreover, they provide essential financial security for regulating and guiding enterprises and the public in environmental protection efforts, thus mitigating market risks [16].

At the micro level, government financial expenditure on environmental protection reflects the government's commitment to ecological conservation. This commitment helps to raise environmental awareness among various economic entities, directing social resources toward low-carbon, green industries [17]. This redirection stimulates investment in carbon management by non-governmental actors and supports the green transformation and upgrading of regional industrial structures [18].

Impact of Government Performance Management Functions on Regional Carbon Emissions

Enhancing government performance management is not only crucial for modernizing China's governance system but also an essential requirement for achieving high-quality economic development [19]. At the local level, following the State Council's clarification of central government accountability in local environmental assessments and the inclusion of pollution emission

reduction in local officials' performance evaluations, local governments have increasingly prioritized ecological and environmental concerns alongside economic development.

On the one hand, regions with effective governance can ensure the enforcement of environmental regulations through rational decision-making processes and implementation strategies [20]. According to Porter's hypothesis, government environmental regulations incentivize technological innovation and enhance the competitiveness of enterprises to offset the higher costs associated with environmental compliance [21]. Thus, robust governance capabilities facilitate the enforcement of environmental regulations, fostering green technological innovation, enterprise development, and reducing regional carbon emissions [22]. On the other hand, improving government performance management enhances the government's information disclosure mechanisms, accelerates the sharing of regional environmental governance data, and cultivates a favorable business environment. This fosters greater public engagement in building an eco-civilization, creating a positive environment for green development. These efforts contribute to the effective implementation of carbon and emission reduction goals [23].

Impact of Government Financial Management Functions on Regional Carbon Emissions

Impact of Government Investment Functions on Regional Carbon Emissions

Local governments in China are not only key participants in the economic system but also exert considerable influence over the country's energy structure and environmental protection efforts. Their investment decisions are crucial in the coordinated development of the "economy-energy-environment" system. Historically, under the model of economic decentralization combined with vertically centralized governance, local governments often led economic activities with a strong focus on tangible infrastructure projects [19]. This approach resulted in a bias towards heavy production and limited innovation in social investment [24]. There are two primary pathways through which local government investments can promote carbon emission reduction. First, they can facilitate the optimization and upgrading of the regional industrial structure, shifting the focus from energy-intensive industries to the development of low-energy-consumption industries, particularly in the service sector [25]. This transition can lead to a reduction in carbon emissions. Second, government investment can directly support energy conservation operations and emission reduction projects, enhance funding for critical carbon reduction initiatives, and increase investment in environmental pollution control [26]. These efforts collectively contribute to advancing carbon emission reduction goals.

The Impact of Government Debt Function on Regional Carbon Emissions

The persistent growth of local government debt has significantly constrained China's pursuit of high-quality economic development [27]. From the perspective of microenterprises, local government financing platforms reduce market liquidity, exacerbating liquidity constraints. The issuance of government debt also impacts the allocation of credit resources. The competition between price and capital tends to limit enterprises' access to leverage, increasing challenges associated with external financing and raising the cost of debt financing. Consequently, this reduces enterprises' incentives to invest in technological innovation [28].

From a macro-governance perspective, excessive debt issuance by local governments significantly heightens their debt burden, prompting them to seek higher tax revenues to alleviate fiscal pressures. In efforts to expand the tax base, local governments may intentionally lower environmental protection standards and reduce regulations to attract economically efficient but environmentally intensive industries [29], thereby increasing tax revenues and employment. However, the financial strain caused by expanding local government debt directly reduces funds allocated for environmental regulation and governance [30]. It also limits financial support for green technology innovation and development, thus constraining local green initiatives and potentially increasing regional carbon emissions [31].

Building on the analysis presented, the impact of government accounting functions on regional carbon emissions results from the combined influence of various factors. Existing research often examines carbon emissions reduction from the perspective of individual government accounting functions, neglecting their potential interactions. As a result, this paper seeks to guide policymakers in coordinating the allocation of different accounting functions to explore whether these functions collectively contribute to reducing regional carbon emissions and to identify the optimal combination of accounting functions that enhances the positive impact of government accounting. Based on this, we propose the following hypothesis:

Hypothesis 1: An integrated mechanism of government accounting functions exists that affects regional carbon emissions, and integrated government accounting functions can reduce regional carbon emissions levels.

Materials and Methods

Variable Definitions and Data Sources

Explained Variable

Building on the previous review of existing regional carbon emission studies, regional per capita carbon

emissions (*Average*) are calculated by dividing each region's total carbon emissions by its population.

Carbon emission intensity (*Intensity*) analyzes the impact of regional economic growth on total CO_2 emissions. It is obtained by dividing each province's total carbon emissions by its GDP. A higher carbon emission intensity indicates a greater energy dependence on regional economic development, signaling a failure to achieve the decoupling of economic growth from energy consumption.

Carbon emission performance (*MCPI*) is assessed using the DEA method, which has been widely applied in efficiency evaluation. The DEA method is particularly well-suited for handling multi-output production activities with undesirable outputs. In this study, we adopt the approach used by Miao et al. [32] and employ the DEA model with undesired outputs to construct the Malmquist index. This index enables the measurement of dynamic changes in CO_2 emission performance. By considering energy, capital, and labor as inputs and carbon emissions as undesirable outputs, the model provides a comprehensive analysis of the dynamic changes in carbon emission performance across regions.

Explanatory Variable

Before constructing a comprehensive index for government accounting functions, it is essential to first determine the measurement method for each individual function index.

Fiscal transparency (*Ft*) is selected as a proxy variable for the government's financial accounting function. It is measured using the *China Fiscal Transparency Report* published by the Shanghai University of Finance and Economics. This report is currently the only and most authoritative measure of fiscal transparency at the provincial level. It covers the disclosure of various government financial resources, including general budget funds, governmental funds, and state-owned enterprise funds.

The government audit function (*Aud*) is measured according to the definitions of each function of government auditing provided by the Audit Office. Specifically, the preventive function is measured by the natural logarithm of the number of cases transferred to judicial organs, disciplinary inspection and supervision departments, and other relevant departments. A higher value indicates better performance for the preventive function. The revealing function is measured by the natural logarithm of the number of major problems detected by government audits. A larger value indicates better performance for the revealing function. The natural logarithm of the number of audit implementation results measures the defensive function. A higher value indicates better performance for the defensive function. Subsequently, the entropy method is employed to construct the indexes for the government audit function.

The deviation of local fiscal revenue and expenditure from the pre-budget (*Deb*) is commonly used to measure the government budget management function. Wang [33] defined the formula for calculating the degree of deviation from the final account as follows. The degree of deviation from the final account = (government final account expenditure - government budget expenditure) / government budget expenditure. If the value is positive, the final account expenditure exceeds the budget, which is classified as "overspending." Conversely, a negative value indicates "saving," where the final account expenditure is less than the budget.

This paper measures government fiscal expenditure on environmental protection (*Fis*) by adopting the proportion of local governments' energy-saving and environmental protection expenditures relative to their general public budget expenditures. This approach, inspired by Wei et al. [34], effectively measures local government investment in carbon reduction and emission reduction initiatives. The higher the proportion, the greater the government's financial commitment to environmental protection efforts.

Table 1. Government performance management functional indicator construction and indicator description.

Primary Indicator	Secondary Indicator	Tertiary Indicator	Variable Definition or Measurement
Innovation	Innovation Input	R&D Funding Intensity	Total number of invention patents authorized per 10,000 people (units)
	Innovation Output	Number of Patent Authorizations	R&D Expenditure as a Percentage of GDP (%)
Coordination	Urban-Rural Coordination	Urban-Rural Income Coordination	Urban per capita disposable income / rural per capita disposable income (%)
		Urbanization Rate of Permanent Residents	Urban year-end permanent residents / total year-end residents (%)
	Regional Coordination	Regional Development Gap	Per capita GDP / consumption level in the most developed province
		Regional Consumption Gap	Consumption level / consumption level in the most developed province

Openness	Investment Openness	Foreign Direct Investment	Total foreign investment / GDP (%)
		Outward Foreign Direct Investment	Non-financial outward foreign direct investment / GDP (%)
	Trade Openness	Total Import and Export Volume	Total import and export volume / GDP (%)
Sharing	Culture	Total Collection of Public Libraries	Per capita GDP / consumption level in the most developed province
		Number of Museums	Number of museums per 10,000 people (units)
	Health and Wellness	Number of Doctors	Number of practicing (assistant) physicians per 1,000 people (persons)
		Number of Hospitals	Number of hospitals per million people (units)
	Public Transportation	Public Transport Vehicles	Number of public transport vehicles per 10,000 people (units)
		Road Area	Per capita road area (square meters)
	Education	Teacher-Student Ratio in Primary Schools	Number of primary school teachers / number of Primary school students (%)
		Teacher-Student Ratio in Junior High Schools	Number of junior high school teachers / number of junior high school students (%)
	Social Security and Employment	Basic Pension Insurance Coverage	(Number of employees in basic pension insurance + number of residents in basic pension insurance) / urban and rural employment-population (%)
		Urban Unemployment Rate	Year-end registered urban unemployment rate (%)
		Resident Income	Per capita disposable income of residents (yuan)

The academic community has not yet established a unified standard for examining the government performance management function (*Gov*). To more comprehensively assess the level of government performance, this paper constructs a comprehensive indicator based on data availability. The specific construction of this indicator is detailed in Table 1. To minimize subjectivity, the paper employs the entropy value method to determine the weights of each secondary and tertiary indicator, and the data are standardized accordingly. This approach ensures an objective and systematic evaluation of government performance management.

The government investment function (*Inv*), based on the research of Lian et al. [35], is measured by using the natural logarithm of the state budget funds relative to the actual funds allocated for investment in fixed assets across the entire society. This measure reflects the government's financial commitment to supporting fixed asset investments, which are critical for infrastructure and economic development.

The existing literature mainly measures government debt function (*Debt*) from the perspectives of municipal investment bond balance, local government debt balance, explicit debt, and implicit debt. Drawing on the research of related scholars [36], this paper calculates China's total local government debt from 2008 to 2017 based on the financial risk matrix and uses its natural logarithm to measure the government debt function.

Control Variables

The factors that influence regional carbon emissions are complicated. Therefore, according to the existing literature [32, 37], this paper chooses the following control variables: economic development (*Eco*), energy structure (*Ener*), industrial structure (*Ind*), technological level (*Tech*), ownership structure (*Ownership*), and opening up to the outside world (*Open*); the calculation of specific indicators is shown in Table 2.

Models

The Entropy Method

(1) Index construction

To better explore the comprehensive impact of government accounting functions on regional carbon emissions, this section employs the entropy value method to construct a comprehensive government accounting function index. The first-level indexes include the government financial accounting function (*Ft*), the government auditing function (*Aud*), the government management accounting function (*Ma*), and the government financial management function (*Fin*). The second-level indexes for the government management accounting function are the government budget management function, the government cost management function, and the government performance management function. The second-level indexes for the government financial management function

Table 2. Variable definitions and measurements.

Type	Variables	Name	Measurement
Control variables	Economic development	*Eco*	The natural logarithm of GDP per capita
	Energy structure	*Ener*	Total energy consumption by region / Total GDP by region
	Industrial structure	*Ind*	Value added of the tertiary industry by region / Value added of the industry by region
	Technical level	*Tech*	R&D expenditure by region / Total GDP by region
	Level of opening up	*Open*	Total trade by region / Total GDP by region
	Ownership structure	*Owner*	Number of employees of state-owned enterprises by region / Number of employed persons by region

are the government investment and government debt functions.

The entropy method is calculated by Eqs. (1-3):

In the first step, the secondary indicators were standardized, where $Y_{ij,k}^{+}$ denotes positive indicators and $Y_{ij,k}^{-}$ denotes negative indicators:

$$Y_{ij,k}^{+} = \frac{X_{max,k} - X_{ij,k}}{X_{max,k} - X_{\min,k}}, Y_{ij,k}^{-} = \frac{X_{ij,k} - X_{\min,k}}{X_{max,k} - X_{\min,k}} \quad (1)$$

Where $X_{ij,k}$ is the value of the kth indicator in year i, province j; $X_{max,k}$ is the maximum value of all values in the kth indicator, and $X_{min,k}$ is the minimum value of all values in the kth indicator.

In the second step, find the information entropy of each secondary indicator:

$$P_{ij,k} = \frac{Y_{ij,k}}{\sum_i \sum_j Y_{ij,k}}, E_k = -\frac{1}{\ln(nm)} \sum_i \sum_j P_{ij,k} \ln(P_{ij,k}) \quad (2)$$

where n is the total number of years and m is the total number of provinces.

In the third step, the weights of the indicators are determined, and a composite score is calculated:

$$W_k = \frac{1 - E_k}{k - \sum E_k}; M_{ij} = \sum_k W_k Y_{ij,k} \quad (3)$$

Where E_k is the entropy of the information sought in the second step and M_{ij} is the composite score.

In line with the calculations using the above steps, the first-level indexes of the government management accounting function and the government financial management function index can be obtained. By combining the government financial accounting function, the government auditing function, the government management accounting function, and the government financial management function and then again utilizing the entropy value method, the comprehensive government accounting function index (*Total*) can be obtained.

The specific construction process is in Table 3 and Table 4.

(2) Modeling

The model is constructed based on the entropy value method to calculate the comprehensive function index of government accounting, as shown in Eqs. (4-6). Where $Average_{it}$ is the regional per capita carbon emission, $Intensity_{it}$ is the regional carbon emission intensity, and $MCPI_{it}$ is the regional carbon emission performance, $Total_{it}$ is the five composite indices obtained from the above calculations; $Control\_variables_{it}$ is the control variables listed in Table 2. μ_i and λ_t represent the province fixed effect and time fixed effect, respectively, ε_{it} is the error term; and β_0 is the intercept term.

$$Average_{it} = \beta_0 + \beta_1 Total_{it} + \beta_2 Control\_variables_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$Intensity_{it} = \beta_0 + \beta_1 Total_{it} + \beta_2 Control\_variables_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

$$MCPI_{it} = \beta_0 + \beta_1 Total_{it} + \beta_2 Control\_variables_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

The fsQCA Method

Qualitative Comparative Analysis (QCA) is a case-oriented and asymmetric research method. Unlike traditional regression, which focuses on the "net effect" of a single variable, QCA focuses on the comprehensive effect of each condition based on set theory and Boolean arithmetic methods and adopts a holistic, systematic, and combinatorial approach to analyze the different paths of the complex relationships among antecedent variables. The QCA approach measures the conditions' necessity and sufficiency by calculating the indicators' consistency and coverage, in which the consistency is higher than the critical value of 0.8, indicating that the grouping constitutes a sufficient condition for a particular outcome. Moreover, the coverage reflects the importance of combining the antecedent variables.

Table 3. System for constructing indicators.

Primary indicators	Secondary indicators	Weights
Government management accounting function (*Ma*)	Government budget management function (*Deb*)	32.72%
	Government Cost Management Function (*Fis*)	33.61%
	Government Performance Management Function (*Gov*)	33.67%
Government Financial Management Function (*Fin*)	Government investment function (*Inv*)	50.02%
	Government Debt Function (*Debt*)	49.98%

Table 4. Composite Functional Index Construction System.

Composite Functionality Index	Level 1 indicators	Weights
Total	Government financial accounting function (*Ft*)	24.69%
	Government Audit Function (*Aud*)	23.88%
	Government management accounting function (*Ma*)	25.47%
	Government Financial Management Function (*Fin*)	25.96%

Since the condition variables involved in this study are all continuous variables between 0 and 1, which do not apply to the clear set comparative analysis method (csQCA) and the multi-valued set comparative analysis method (mvQCA), this paper uses the fuzzy qualitative comparative analysis method (fsQCA) as a research tool to analyze the influence of the accounting function of the municipal governments in China on the regional carbon emission grouping.

Based on the applicability of the fsQCA method, the 10-year sample mean of each variable is calculated as the research sample to test and analyze whether and how the combination of the four main government accounting functions influences regional carbon emission levels. The indicators' definitions and calculations align with those described in the previous section.

Data Sources

In this paper, data from 30 provinces (autonomous regions and municipalities directly under the central government) in China (excluding Hong Kong, Macao, and Taiwan; Tibet was excluded due to incomplete data) are selected as the research sample, with the data spanning from 2008 to 2017 (due to reasons such as less early disclosure of government budget data, the data for the government budget expenditure deviation indicator spans from 2009 to 2016). The raw data for each indicator are mainly obtained from the website of the National Bureau of Statistics, the China Statistical Yearbook, the China Energy Statistical Yearbook, the China Stock Market & Accounting Research (CSMAR) database, the Wind database, and the statistical yearbooks of each region, and interpolation is used to make up for the missing individual data in some provinces.

Results and Discussion

Comprehensive Impact Analysis Based on the Entropy Method

The above indexes are regressed with *Average, Intensity,* and *MCPI* to fully explore the impact of the comprehensive functions of government accounting on regional carbon emissions, and the regression results are shown in Table 5.

It can be observed that the regression coefficient of *Average* with *Total* is negative and significant at the 10% level, indicating that the integrated function of government accounting can significantly reduce regional per capita carbon emissions. The regression coefficient of *Intensity* with *Total* is also negative and significant at the 5% level, suggesting that the integrated government accounting function can significantly inhibit regional carbon emission intensity. Conversely, the regression coefficient of *MCPI* with *Total* is positive and significant at the 5% level, indicating that the combined generalized government accounting function can significantly improve regional carbon emission performance.

The regression results reveal three key impacts of government accounting functions on regional carbon emissions. This study explores the underlying mechanisms as follows:

First, the negative correlation between government accounting functions and per capita carbon emissions suggests several possible explanations. On the one hand, efficient government accounting enhances fiscal transparency and resource allocation efficiency, ensuring that public expenditures are directed toward green infrastructure, renewable energy projects, and low-carbon technologies, reducing per capita carbon emissions. On the other hand, a well-functioning

Table 5. Regression results of comprehensive impact analysis based on the entropy method.

Variables	*Average*	*Intensity*	*MCPI*
	(1)	(2)	(3)
Total	-7.705*	-0.412	0.129
	(-2.28)	(-2.40)	(2.54)
Control	Yes	Yes	Yes
Year FE	Yes	Yes	No
Province FE	Yes	Yes	No
N	240	240	240
R^2	0.370	0.778	0.872

Notes: t-statistics in parentheses. * p<0.01, p<0.05, * p<0.1. Standard errors clustered at the firm level.

government accounting system enables precise tracking of carbon-related fiscal revenues and expenditures, improving the implementation of carbon reduction policies such as clean energy subsidies and carbon taxes. Additionally, by strengthening regulatory oversight and incentive mechanisms, government accounting encourages enterprises to adopt more environmentally friendly production methods, ultimately lowering regional per capita carbon emissions.

Second, the negative correlation between government accounting functions and carbon emission intensity suggests that government accounting plays a crucial role in reducing carbon emissions per unit of economic output. Several factors may contribute to this relationship. First, a government accounting system that emphasizes sustainability fosters investments in low-carbon industries, technological innovation, and industrial upgrading, thereby reducing carbon intensity. Second, a well-established government accounting framework ensures that public investment prioritizes energy efficiency, circular economy initiatives, and cleaner production technologies, leading to a decline in carbon emissions per unit of economic output. Third, precise fiscal expenditure accounting facilitates better coordination between environmental policies and economic development, ensuring that carbon reduction goals are achieved without compromising economic growth.

Furthermore, the positive correlation between government accounting functions and carbon emission performance suggests that while government accounting helps reduce per capita carbon emissions and carbon intensity, it also enhances overall carbon efficiency. First, government accounting enables precise tracking of carbon-related fiscal expenditures and emission reduction outcomes, making carbon reduction policies more targeted and effective, thereby improving overall carbon performance. Second, governments with well-developed accounting systems can more effectively implement market-based mechanisms such as carbon emissions trading and green bonds, which enhance carbon productivity while achieving environmental goals. Additionally, government accounting promotes fiscal transparency and accountability, ensuring that public funds are allocated more effectively toward technological innovation and cleaner production methods, thereby improving carbon reduction efficiency while maintaining economic growth.

Comprehensive Impact Analysis Based on fsQCA Methodology

Variable Calibration

We used the direct method to calibrate the data, converting the fuzzy set data into a truth table, which offers the dual advantages of qualitative and quantitative analysis. In this paper, the 95%, 50%, and 5% quantile points of each variable in the sample data are designated as three calibration points: the full affiliation point, the crossover point, and the full non-affiliation point. The calibration anchors for each variable are presented in Table 6.

Individual Conditional Necessity Analysis

This paper employs fsQCA 3.0 to analyze the conditional groupings of 30 provinces that achieve high regional carbon emission performance driven by the broad government accounting function. First, a univariate necessity analysis is conducted for each conditional variable. Following the previous research practices of fsQCA, the consistency threshold is set to 0.9. A consistency score higher than 0.9 is considered a necessary condition for promoting regional carbon emission performance. The specific results of the necessity analysis for each variable are presented in Table 7.

It can be observed that most of the antecedent variables have achieved high consistency scores; however, all of them fall below the desired threshold of 0.9. This indicates that they cannot be considered necessary conditions for the outcome variable. In other words, these variables need to be combined in order to

Table 6. Variable design and calibration.

Variable type	Variable name	Full non-affiliation	Crossover point	Full affiliation
Outcome variable	*MCPI*	0.249	0.425	1.120
Antecedent variable	*Ft*	27.000	38.869	50.501
	Aud	0.446	0.532	0.593
	Deb	0.027	0.057	0.104
Antecedent variable	*Fis*	0.018	0.028	0.046
	Gov	0.180	0.286	0.716
	Inv	4.867	6.394	7.002
	Debt	6.174	8.307	9.755

Table 7. Necessary condition detection.

Conditional variable	Consistency	Coverage
Ft	0.697	0.681
~Ft	0.727	0.637
Aud	0.779	0.676
~Aud	0.668	0.660
Deb	0.600	0.579
~Deb	0.782	0.693
Fis	0.627	0.568
~Fis	0.789	0.744
Gov	0.892	0.831
~Gov	0.628	0.576
Inv	0.734	0.638
~Inv	0.665	0.656
Debt	0.867	0.739
~Debt	0.576	0.582

Note: "~" means "not" for logical operations.

have an impact on improving regional carbon emission performance, and the influence of any single factor is relatively weak. Therefore, it is essential to analyze the different combinations of antecedent variables to identify the multifaceted paths of influence on regional carbon emission levels.

Configuration Analysis

Since the sample size N is small in this paper, the frequency threshold is set to 1, the consistency threshold is set to 0.8, and the PRI consistency threshold is set to 0.7. The fsQCA 3.0 software is used to construct a truth table with 2k rows, where k represents the number of antecedent and dependent variables. The complex, intermediate, and parsimonious solutions are obtained, with the intermediate solution positioned between the complex and parsimonious solutions. It is generally considered to offer better interpretability and generalizability. The core and edge conditions of each solution are identified. Those that appear in both the intermediate and parsimonious solutions are considered core conditions, while those that appear only in the intermediate solution are regarded as edge conditions.

Table 8 reports the grouping of conditions that drive regional carbon performance, where • or ● indicates that the condition exists, ⊗ and ⊗ indicate that the condition is missing. ● or ⊗ indicates that the condition is a core condition. • or ⊗ indicates that the condition is a peripheral condition, and a blank space indicates that the condition may or may not exist.

It can be seen that there are four paths for the influence of the generalized government accounting function on regional carbon emission performance, with an overall coverage of 54.1% and an overall consistency of 94.3%, which is much higher than the consistency threshold of 0.8. The four paths can be sufficient conditions for regional carbon emission. Since the proxy variable selected for the government budget management function is budget deviation, which is a negative indicator, low budget deviation (*Deb*) corresponds to a high government budget management function when analyzed below, i.e., when Deb is the missing condition ⊗ or ⊗, it indicates a high government budget management function.

The following is an analysis of the specific configuration:

(1) Government Financial Accounting Function - Debt Function Driven

Configuration 1 points out that a high government financial accounting function (*Ft*), a high government debt function (*Debt*), and a low government auditing function (*~Aud*) are the core conditions, and a high government budget management function (*~Deb*), a low government cost management function (*~Fis*), and a high government performance management function (*Gov*) are the peripheral conditions that can promote the development of regional carbon emission performance.

Table 8. Grouping of conditions to facilitate the development of regional carbon performance.

Conditional variable	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Ft	●	⊗	⊗	●
Aud	⊗	⊗	⊗	•
Deb	⊗	•	⊗	⊗
Fis	⊗	●	•	●
Gov	•	⊗	●	●
Inv		⊗	⊗	•
Debt	●	⊗	⊗	•
Original coverage	0.275	0.307	0.236	0.279
Unique coverage	0.082	0.107	0.017	0.075
Consistency	0.978	0.928	0.942	0.948
Overall solution coverage	0.541			
Overall solution consistency	0.943			

Note: ● indicates that the core condition exists, • indicates that the marginal condition exists, ⊗ indicates that the core condition is missing, ⊗ indicates that the marginal condition is missing, and blank indicates that the condition is present or absent.

First, a comparative analysis of Configuration 1 from the perspective of government functions. 1. The dynamic balance mechanism of financial accounting, debt, and auditing. Configuration 1 indicates that in regions where government auditing functions are not yet fully developed (*~Aud*), improving fiscal transparency (*Ft*) and optimizing debt management (*Debt*) can still enhance regional carbon emission performance. This suggests that different governance mechanisms exhibit substitutability – when auditing functions are weak, transparency-based fiscal management can serve as a compensatory mechanism. This result challenges the conventional view that strong auditing capabilities are always essential for environmental governance, demonstrating that fiscal transparency and debt management may play a more direct role in promoting low-carbon development in certain contexts. 2. Budget management and performance governance: optimizing limited resources. Despite the weaker environmental cost management function (*~Fis*), strong budget management (*~Deb*) and performance management (*Gov*) functions can still improve regional carbon emission performance. This indicates that efficient budget management can mitigate inefficiencies in environmental expenditures, ensuring the optimal allocation of limited fiscal resources. Furthermore, a performance-oriented governance mechanism can enhance policy implementation efficiency, allowing governments to prioritize high-impact carbon reduction projects even under financial constraints. This configuration supports the perspective that fiscal discipline is not merely about reducing expenditures but rather optimizing fund allocation to achieve the greatest environmental impact.

Second, causal mechanisms and evolutionary perspective analysis of Configuration 1. The research findings indicate that the pathways to improving carbon emission performance mainly involve the following aspects: 1. Reducing information asymmetry between the government and enterprises, improving fiscal transparency, and ensuring that public funds are effectively directed toward low-carbon projects. 2. Maintaining a moderate level of government debt to provide long-term fiscal support while avoiding the fiscal risks associated with excessive debt. 3. Strengthening governance efficiency through budget management and performance management to ensure that fiscal expenditures are prioritized for high-performance environmental policies. This study challenges traditional environmental governance models and demonstrates that fiscal transparency and performance management can serve as new pillars for environmental governance. In some regions, they may be even more effective than traditional auditing and oversight mechanisms. With appropriate management, government debt can become a key resource for promoting low-carbon development, providing stable financial support for long-term environmental investments rather than merely being viewed as a fiscal burden.

(2) Government Cost Management Function Driven

In Configuration 2, the core conditions are a high government cost management function (*Fis*), a low government debt function (*Debt*), a low government financial accounting function (*Ft*), and a low government performance management function (*Gov*). The edge conditions are a low government audit function (*~Aud*), a low government budget management function (*Deb*), and a low government investment function (*~Inv*).

First, we look at a comparative analysis of different configurations. Initially, comparisons were made using high financial accounting and auditing functions. Traditional research generally regards strong financial accounting and auditing functions as key factors in enhancing environmental governance effectiveness. However, Configuration 2 demonstrates that even in cases where these functions are relatively weak, the government can still significantly improve regional carbon emission performance by strengthening cost management functions and controlling debt levels. This finding enriches conventional theories by illustrating that under specific conditions, management accounting functions can compensate for the deficiencies of financial accounting functions in environmental governance. Comparisons were then made using the high debt function. High debt levels typically impose significant repayment pressure on local governments, potentially compelling them to alleviate fiscal stress by increasing tax rates or relaxing environmental regulations – both of which could negatively impact low-carbon development. In contrast, Configuration 2, characterized by the low debt function, effectively mitigates this risk. By ensuring greater fiscal flexibility, low debt levels allow local governments to focus on environmental governance and low-carbon transitions rather than resorting to environmentally detrimental fiscal strategies.

From a longitudinal perspective, Configuration 2 highlights two key mechanisms in environmental governance. First is the role of management accounting functions. While traditional research has paid limited attention to the role of management accounting in environmental governance, Configuration 2 reveals that a strong cost management function can directly drive regional green transformation. This is achieved through optimized fiscal resource allocation and directing social capital toward low-carbon industries, thereby fostering sustainability in economic development. Second, the environmental governance mechanism of the low debt function. A low debt function not only alleviates the fiscal burden on local governments but also prevents environmentally harmful behaviors induced by repayment pressure, such as relaxing environmental regulations. This underscores the intrinsic link between fiscal and environmental sustainability, providing a theoretical foundation for formulating green fiscal policies that balance economic growth with ecological responsibility.

(3) Government Budget Management Function - Performance Management Function Driven

In configuration 3, when high government budget management function (~*Deb*), high government performance management function (*Gov*), and low government debt function (~*Debt*) are the core conditions, and high government cost management function (*Fis*), low government financial accounting function (~*Ft*), low government auditing function (~*Aud*), and low government investment function (~*Inv*) are the peripheral conditions, it helps to improve regional carbon emission performance.

First, compared to other configurations, Configuration 3 is distinct in its reliance on high-budget management and high-performance management functions while maintaining low debt levels to drive low-carbon development. This starkly contrasts configurations that depend on financial accounting or auditing functions. Unlike those emphasizing financial accounting and auditing, Configuration 3 suggests that these functions are not essential for achieving low-carbon development. Instead, by strengthening budget and performance management functions, low-carbon development goals can still be realized, even without financial transparency and governance capabilities. Moreover, the low-debt characteristic of Configuration 3 indicates reduced fiscal pressure on local governments, eliminating the need to raise taxes or relax environmental regulations to service debt. This, in turn, creates a stable fiscal environment for long-term green investments.

Second, from a longitudinal perspective, Configuration 3 offers significant theoretical and practical contributions. Theoretically, a high-budget management function ensures scientific budgeting and execution, reducing budget deviations and enhancing local enterprises' confidence in future development. This, in turn, encourages investment in green technologies and facilitates a transition to low-carbon development. High government performance management reflects a robust internal governance system capable of effectively implementing policies and allocating resources. Even when the auditing function is weak, strong performance management can still ensure the correct execution of policies and the rational distribution of funds, fostering a favorable environment for low-carbon development.

(4) Generalized government accounting function integrated and driven

Grouping 4 shows the integrated mechanism of the government accounting function on the regional carbon emission performance level. The core conditions are the high government financial accounting function (*Ft*), the high government budget management function (~*Deb*), the high government cost management function (*Fis*), and the high government performance management function (*Gov*). The edge conditions are the high government auditing function (*Aud*), the high government investment function (*Inv*), and the high government debt function (*Debt*).

First, compared to other configurations, Configuration 4 emphasizes the integration of multiple government accounting functions. Unlike other configurations that rely on only partial government functions, Configuration 4 demonstrates that the synergy of high financial accounting, auditing, and management accounting functions can create a strong governance framework. Although high debt and high investment

functions are marginal conditions, they are managed within a robust financial oversight and governance framework. This contrasts with configurations where high debt levels may lead to fiscal instability, highlighting the importance of balancing investment and debt management under strong accounting and governance mechanisms.

Second, from a longitudinal perspective, Configuration 4 offers significant theoretical and practical contributions. Theoretically, high financial accounting and auditing functions reduce information asymmetry and corruption, creating a transparent environment that encourages local enterprises to adopt green and low-carbon practices. In line with agency theory, transparency reduces opportunistic behavior and promotes sustainable development. Practically, the management accounting function plays a crucial role in resource optimization. High functions in budget management, cost management, and performance management reflect an enhancement in government management accounting capabilities, ensuring the scientific allocation and effective use of fiscal expenditures. This fosters a virtuous cycle of income and expenditure, supporting long-term green development.

Conclusions and Recommendations

Conclusions

This paper presents an innovative exploration of the intersection between regional carbon emissions and government accounting functions. We advance the understanding of their combined impact by systematically reviewing existing literature and constructing an integrated system of regional carbon emission measurement indicators and government accounting functions. Using the entropy value method and fsQCA approach, we empirically analyze the relationship between government accounting functions and regional carbon emissions, uncovering new insights. The key findings are as follows. 1. The study reveals a significant inhibitory effect of integrated government accounting functions on regional carbon emissions. Specifically, stronger integration of government accounting functions correlates with reduced per capita carbon emissions, lower carbon intensity, and improved regional carbon performance. This finding challenges conventional approaches that often view financial and environmental management as separate, underlining the potential for accounting systems to directly influence sustainability outcomes. 2. Through fsQCA, four critical paths to enhancing regional carbon emission performance were identified:

Path 1: Government financial accounting function leading to government debt function enhancement.

Path 2: Strengthening government cost management functions.

Path 3: Synergistic improvement of government budget management and performance management functions.

Path 4: Comprehensive integration of generalized government accounting functions.

Among these, the most influential path involves the synergy between government financial accounting and government debt functions, presenting a novel finding that underscores the potential of integrated financial management to foster low-carbon outcomes.

Policy Recommendations

Based on the findings of this paper, the following recommendations are put forward:

(1) Continuously promoting transparency in government financial operations, using modern network platforms to facilitate public access to financial data, is critical. This will strengthen social oversight and encourage public participation in decision-making processes, improving the predictability and openness of fiscal policies. By fostering an environment of public scrutiny, governments can enhance their accountability in managing carbon emissions and green development initiatives.

(2) Local government auditing authorities should adopt a green development framework in their audit practices, focusing on early detection and management of risks related to low-carbon development. This proactive auditing approach will not only improve risk management but also promote early intervention to keep regions on track toward sustainable and green development goals.

(3) Establishing a more scientific and standardized budget system is essential for increasing financial investment in environmental protection. Additionally, local governments should tailor cost management strategies to their unique economic and energy profiles, optimizing the use of environmental funds. A stronger emphasis on performance management will help improve governance capacity and create a more supportive framework for sustainable, low-carbon growth.

(4) Governments should align their investment plans with green development objectives and encourage private sector participation through incentives such as preferential loans or subsidies for green investments. It is also imperative that debt management remain within sustainable levels, with local governments strictly adhering to debt regulations. Establishing long-term mechanisms for debt oversight can prevent fiscal instability and ensure the continued flow of funds toward low-carbon projects.

(5) Local governments should acknowledge the interconnectedness of various government accounting functions and work to integrate these functions more effectively. This systemic approach will facilitate better coordination and enhance the collective capacity of accounting functions to support regional green and low-carbon development.

Limitations and Future Research Directions

Despite the valuable insights provided by this study, several limitations exist. First, the sample data is restricted due to challenges accessing recent Chinese government data, particularly regarding budget expenditure deviations and the Government Fiscal Transparency Index. Future research could address this limitation by incorporating more recent and comprehensive datasets. Additionally, this paper primarily focuses on provincial-level data from China, which may limit the generalizability of the findings. Future studies could expand the scope to include international comparisons, enriching the understanding of how government accounting systems interact with regional carbon emissions across different governance structures and development stages.

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Conflict of Interest

The authors declare no conflict of interest.

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