*Pol. J. Environ. Stud. Vol. 34, No. 5 (2025), 6251-6262*
DOI: *10.15244/pjoes/191978* ONLINE PUBLICATION DATE: 2024-10-28

*Original Research*

# Green Finance, Green Technology Innovation, Green Tax, and Energy-Economy-Carbon Emissions - A China Provincial-Based Analysis

**Chao Li[1], Wenyueyang Deng[2]***

[1]Shanxi University, Taiyuan, China
[2]School of Economics and Management, University of Science and Technology Beijing, Beijing, China 100083

*Received: 8 May 2024*
*Accepted: 3 August 2024*

## Abstract

Green finance, green technology, and green tax systems are the necessary process and inevitable result of accelerating the construction of ecological civilization and realizing high-quality development; energy-economy-carbon emission (EEC) is related to the quality of economic and social development, which is of great significance to the green transformation of the development mode. This paper selects 30 provincial-level regions in China from 2013 to 2022 as samples to empirically test the separate impacts as well as the comprehensive impacts of green finance, green technology, and green tax system on EEC. The results show that: green finance, green technology, and green tax systems have a positive impact on EEC; the combination of green policies under the coupling degree of coordination affects EEC; based on the fuzzy set qualitative comparative analysis (fsQCA) group state analysis to get two paths of the impact of green policies on EEC, and to discuss the causal relationship between the green policies under the paths and the results of the concern, to provide the best solution for the provinces and municipalities to implement the green policies.

**Keywords:** green finance, green technology, green tax system, energy-economy-carbon emissions, policy combination

## List of Abbreviations

EEC: Energy-economy-carbon emissions
GF: Green finance
GTI: Green technology
GT: Green tax

## Introduction

Since the industrial era, the fossil-energy-heavy, high-carbon growth model has had dire consequences for the atmospheric environment on which human survival depends, and the major ecosystems and planetary climate systems on which human survival depends may no longer be reversible. Relevant data show that the world emits about 51 billion tonnes of greenhouse gases annually; in 2019 alone, carbon dioxide emissions amounted to a whopping 36.44 billion tonnes, accounting for 74% of total greenhouse gases.

*e-mail: dengwenyueyang66@163.com

The existing development model has long been thought of as unsustainable, and reducing carbon emissions to combat climate change has gradually become a global consensus.

In recent years, the Chinese government has attached great importance to the construction of ecological civilization and high-quality development and has actively promoted the development and implementation of green policies, such as green finance, green technology, and green taxation. On September 22, 2020, President Xi Jinping made a major declaration of "carbon peak, carbon neutral" at the 75th General Debate of the United Nations General Assembly, which aims to achieve green development by Guiding resources such as finance, technology, and taxation towards green industries, and promoting the optimization of the energy-economy-carbon emissions (EEC) structure, so as to achieve the goal of green development.

In the academic field, a number of studies have explored the impacts of green finance, green technology, and green tax on economic growth, environmental protection, and carbon emissions. Zhou et al. point out the positive effects of green finance on the development of environmental protection industries[1], while Lv et al. analyze the potential of green technology innovation in reducing carbon emissions. However, these studies mostly focus on the impact of a single policy and less on the combined effect of green policy combinations [2]. In addition, there needs to be a more in-depth discussion on the mechanism of how green policies promote green transformation by influencing EEC.

Therefore, this paper aims to empirically test the individual as well as combined impacts of green finance, green technology innovation, and green tax on EEC, providing a new perspective for a deeper understanding of the role of green policies in promoting green transformation. The paper selects 30 provincial-level regions in China as the research sample and utilizes data from 2013 to 2022 to explore the pathways and causal relationships of green policies on EEC using the fuzzy set qualitative comparative analysis (fsQCA) method.

The marginal contributions of this paper lie in, firstly, the multidimensional integrated analysis. It not only analyzes the impacts of green finance, green technology, and green tax systems on energy-economy-carbon (EEC) emissions individually, but also further explores the integrated impacts of these green policies under the degree of coordination. This multidimensional and comprehensive analytical framework provides a new perspective for understanding the integrated effects of green policies on EEC. Second, empirical research is based on Chinese provincial data. Studies based on a large amount of actual data can more accurately reflect the effects of green policy implementation in China and provide policymakers with a more reliable basis for decision-making. Third, the application of the fuzzy set qualitative comparative analysis (fsQCA) method. Through the fsQCA method, the article reveals the different paths of the impact of green policies on EEC and discusses in depth the causal relationship between green policies and the outcomes of concern under these paths. This kind of research, which combines theoretical analysis and practical application, provides strong support for policy formulation and implementation. Fourth, in-depth exploration of green transition development. The article's research not only focuses on the direct impact of green policies on EEC but also further explores the role of these policies in promoting green transition development. This in-depth exploration of green transition development is of great significance to the realization of sustainable economic and social development.

The subsequent sections of this paper are structured as follows: In Section 2, we delve into the relevant literature and formulate hypotheses. Section 3 provides an introduction to the methods and data employed. The presentation and discussion of results unfold in Sections 4 and 5. Ultimately, Section 6 encapsulates our concluding remarks and outlines the policy implications.

## Theoretical Analysis and Hypothesis Formulation

### Green Finance and EEC

The theory of environmental responsibility investment emphasizes that companies can enhance shareholder value by taking environmentally responsible practices, and also increase value for non-financial stakeholders [3]. This theory believes that a company's environmental responsibility behavior can indirectly promote sustainable economic development by improving its reputation, reducing operational risks, and attracting investors. Gilchrist conducted a systematic literature review on corporate environmental responsibility practices under the background of green bonds and green loans and found that these practices not only enhance shareholder value but also increase value for non-financial stakeholders [3]. Huang et al. further found that the green and low-carbon financing system has a promoting effect on the development of clean technologies, such as low-carbon technologies, and has a suppressive effect on carbon emissions. Green finance enhances corporate value by promoting corporate environmental responsibility practices, which is consistent with the ESG theory [4].

Based on the theory of financial development, the level of financial development has an important impact on environmental degradation by providing funds, risk management, and investment channels [5]. Financial development can promote the development of environmentally friendly technologies and industries, thereby reducing negative impacts on the environment. Afzal analyzed data from 40 European countries from 1990 to 2019 and found a negative correlation between financial development and environmental degradation, while foreign direct investment (FDI) and institutional

quality seem to exacerbate environmental degradation [5]. Khan quantified the role of green finance as "climate mitigation financing" and found that it reduced ecological footprints in 26 economic entities in Asia, showing environmentally friendly characteristics [6]. Pong argues that green finance attracts financial capital towards green industries through targeted regulation, promotes industrial and energy structure adjustments, and suggests focusing on green market development to improve energy efficiency and reduce energy intensity [7]. Wang believes that active mobilization of the capital market should be carried out, integrating the main board market, the small and medium-sized enterprises board market, and the off-exchange market to expand financing channels for large and small enterprises and lower financing thresholds. Meanwhile, efforts should be made to enrich green financial tools, such as green securities, green insurance, and carbon finance [8]. The negative correlation between financial development and environmental degradation indicates that financial development helps reduce environmental degradation, which is consistent with the theory of financial development.

The SDGs theory emphasizes the role of finance in achieving environmental and social goals. Green finance guides capital towards sustainable development projects and promotes coordinated economic, social, and environmental development. Lee explores the relationship between green finance and the SDGs, particularly in the case of China, showing how green finance supports the achievement of sustainable development goals [9]. Wang examines the causal relationship between green finance and sustainable development through empirical analysis, finding that green finance has had a positive impact on sustainable development globally [10]. As a tool to achieve the SDGs, green finance guides capital towards sustainable development projects and promotes coordinated economic, social, and environmental development.

Based on the above analysis, this paper proposes the following hypotheses H1: Green finance has a positive impact on EEC by promoting environmentally responsible practices, supporting financial development, and achieving the SDGs.

## Green Technology Innovation on EEC

The government behavior theory emphasizes the role of government in economic development, especially by setting growth targets to guide regional development. However, Wicki's research indicates that the growth targets set by the government and its top-down amplification effects have a significant inhibitory effect on green technology innovation, especially in cities with rapid economic growth and over-achievement of growth targets. Wicki found that the setting and amplification of growth targets have an inhibitory effect on green technology innovation, and this inhibitory effect is more pronounced in cities with rapid economic growth and over-achievement of targets [11]. Lv analyzed the efficiency of green technology innovation in 30 provinces of China using the DEA-SBM model and the GML index and found that there is a complex relationship between financial development and green technology innovation, with environmental regulation playing a positive moderating role in the relationship between financial structure and green technology innovation [2]. The government behavior theory suggests that economic growth targets may inhibit green technology innovation, but appropriate environmental regulation and financial support can promote the development of green technology. The financial development theory argues that the level of development of the financial system has an important impact on technological innovation. Feng's research further explores the role of digital finance in promoting green technology innovation, emphasizing the advantages of digital finance in reducing enterprise financing constraints and promoting industrial upgrading [12]. Wang used patent data to analyze the development of green technology innovation in China comprehensively, pointing out significant progress in water and wastewater treatment, solar photovoltaic energy, etc., from 1990 to 2015 in China [13]. Lv found that the financial structure is conducive to the development of green technology innovation, while the scale and efficiency of finance may have a negative impact on green technology innovation [2].

The theory of financial development emphasizes the support role of the financial system for technological innovation, and the development of digital finance provides new solutions for green technology innovation. The theory of environmental regulation focuses on the government's role in guiding economic activities through regulations and policies to reduce negative impacts on the environment. Du's research analyzed the heterogeneous impact of environmental regulation on green technology innovation and industrial structure upgrading through a partial linear function coefficient panel model [14]. Cvjetko Bubalo emphasized the importance of environmentally friendly and adjustable solvents in the development of green technology, especially in reducing the use of volatile and flammable organic solvents in industrial processes [15]. Du found that the impact of environmental regulation on green technology innovation and industrial structure upgrading varies at different levels of economic development, and the promotion of green technology innovation by environmental regulation becomes more significant as economic development levels increase [16]. Yang et al. and He also emphasized the positive role of green technological progress in improving energy efficiency and reducing carbon emissions [17, 18].

The theory of environmental regulation indicates that regulation can significantly promote green technological innovation and industrial upgrading.

Based on the above analysis, we propose the following hypothesis H2: Green technology has a positive impact on EEC. Green technologies exert

a positive impact on the energy-economy-carbon emissions system through appropriate government guidance, financial system support, and promotion by environmental regulation.

### Green Tax and EEC

Pollution tax theory in environmental economics suggests that by taxing polluting activities, environmental costs can be internalized, and firms and individuals can be incentivized to adopt more environmentally friendly behaviors. Rausch and Uddin provide insight into the design of green tax policy, including the level of tax rates, the trajectory of the rate of growth, and the way in which tax revenues can be reinvested [19]. Utilizing numerical dynamic general equilibrium modeling, Rausch examines the lifetime and intergenerational distributional effects of carbon tax exchanges on the U.S. economy, highlighting several fundamental choices in policy design [19]. Lifetime and intergenerational distributional effects of carbon tax exchanges on the U.S. economy, highlighting several fundamental choices in policy design. Uddin explores the impacts of green taxes and energy efficiency on sustainability in Bangladesh, finding that green tax incentives contribute to the achievement of environmental and climate change-related sustainability goals [20]. By internalizing environmental costs and incentivizing firms and individuals to adopt environmentally friendly behaviors, green tax policies promote the development and adoption of environmentally friendly technologies.

The theory of tax-neutral reform proposes that the potential benefits of tax policy can be realized by recycling tax revenues while reducing distortions to the economy. Oates discusses the role of green taxes in the tax system, emphasizing the importance of tax-neutral reforms and fairness [21]. Shafi examines the impacts of green tax incentives on environmental sustainability and climate change, with special reference to their prevalence in developing countries—situation, using data from the Swedish stock market for empirical analysis [22]. Fang explored the relationship between green tax policy and energy transition from the perspectives of energy consumption and production and found that the impact of green tax policy on energy transition is nonlinear [23]. The theory of tax-neutral reform emphasizes that, through the recycling of tax revenues, environmental goals can be achieved without increasing the overall tax burden, and the acceptability and effectiveness of tax policy can be improved.

The green economy transition theory suggests that through policy incentives, it is possible to promote the transition of the economy from high pollution and energy consumption to green and low carbon. Norouzi and Ahmad's study used game theory and ESG scoring methodology to analyze the role of green taxes in promoting the green transition of the economy [24]. Ahmad used environmental, social, and governance (ESG) scores to construct the dependent variable and investigated the effect of green tax incentives on firms' sustainable production methods [25]. The theory of green economic transition suggests that green tax policies can serve as an important tool to promote sustainable development by facilitating the transition of the economy in a green and low-carbon direction.

Based on the above analysis, we can put forward the following hypothesis H3: Green tax system has a positive impact on energy-economy-carbon emissions. The green tax system has a positive impact on the energy-economy-carbon emission system by optimizing the tax structure, incentivizing environmental protection behaviors, and promoting economic transformation.

### Green Policy Combination on EEC

Based on the multivariate experimental design, in terms of green finance, Peng studied the relationship between green finance development, R&D investment, and regional economic growth [26], and Yang et al. discussed the relationship between green finance, structural adjustment, and carbon emissions. In terms of green technology [27], He analyzed the relationship between energy constraints, green technology innovation, and sustainable growth [18], and Chen et al. discussed the impact of environmental regulation, green technology progress, and green economy. In terms of green taxation [28], Yu researched green taxation-economic environment synergy and green taxation-economic growth-industrial upgrading [29].

Looking at the research objectives and research results in this field, there is little comprehensive impact on energy, economy, and carbon emissions. From the separate assumptions of the impact of green finance, green technology, and green tax system on EEC, it is found that the correlation relationship may be positively correlated.

Based on the above analysis, this paper proposes the following hypothesis H4: Green finance, green technology, and green tax systems affect each other, and together they have a positive impact on EEC.

## Methods

### Variable Definition

As a key factor influencing green and low-carbon development under the "dual carbon" goal, there are few academic studies on the comprehensive relationship between energy, economy, and carbon emissions in China. In order to ensure that the research process and research results are always scientific and rigorous, this paper draws on the energy-economy-carbon emission coupling and coordinated development index system constructed by scholar Dong Volunteer, and assigns the weight coefficient results to each corresponding index to calculate the comprehensive score of EEC, that is,

Table 1. Energy, economy, and carbon emissions.

| Level 1 | Level 2 | Level 3 | Weight |
|---|---|---|---|
| Energy | Total amount of energy | Total energy production | 47.11% |
| | | Total energy consumption | 6.28% |
| | | Total electricity consumption | 23.31% |
| | Energy mix | Proportion of coal resource consumption | 13.10% |
| | Energy quality | Energy consumption per unit of GDP | 5.63% |
| | | Electricity consumption per unit of GDP | 4.57% |
| Economy | Economic scale | GDP | 14.23% |
| | | Total retail sales of consumer goods | 15.54% |
| | | Investment in fixed assets | 12.86% |
| | | Total imports and exports | 37.09% |
| | Economic structure | The secondary sector accounts for a share of GDP | 2.79% |
| | | The tertiary sector accounts for a proportion of GDP | 6.90% |
| | Economic quality | GDP per capita | 9.05% |
| | | GDP growth rate | 1.54% |
| Carbon emission | Carbon pollution | Total CO2 emissions | 8.16% |
| | | CO2 emissions per capita | 7.81% |
| | | CO2 emission intensity | 11.22% |
| | Carbon governance | Investment in carbon governance as a proportion of GDP | 72.82% |

the comprehensive index of EEC. Table 1 describes the specific indicators.

Green Finance (GF). Referring to the research of Fu, Shi, and other scholars [26, 30], this paper selects green credit, green securities, green insurance, and green investment as the components of green financial indicators, adopts the panel entropy method to calculate the weights of the indicators, and correspondingly assigns them to their standardized values, to obtain a comprehensive indicator for measuring the development of green finance. The definitions of the above relevant indicators are shown in Table 2.

Green Technology Innovation (GTI). This paper takes green patents as the entry point for research, selects green invention patents highlighting products, methods, and their improvement, and green utility model patents highlighting the shape and structure of products suitable for practical use, and calculates the sum of the authorized volume of the two types of green patents in

Table 2. Green finance.

| Level 1 | Level 2 | Meaning |
|---|---|---|
| Green credit | Percentage of green credit size | Interest expenditures of the six major energy-consuming industries/total interest expenditures of industrial industries |
| Green securities | Share of A-share value of environmental protection enterprises | The market capitalization of regional environmental protection enterprises/total A-share market capitalization |
| Green insurance | Percentage of green insurance size | Regional agricultural insurance expenditures/total regional insurance expenditures |
| Green investment | Percentage of fiscal expenditure on energy conservation and environmental protection | Total fiscal expenditure on energy conservation and environmental protection/total fiscal expenditure |
| | Percentage of investment in environmental pollution control | Investment in environmental pollution control/GDP |

Table 3. Green technology innovation.

| Level 1 | Level 2 | Meaning |
|---|---|---|
| Patents for green inventions | Inventive green technology innovation | Patents granted for green inventions |
| Green Utility Model Patent | Practical green technology innovation | Green utility model patents granted |

order to measure the green technological innovation indexes, and the specific indexes are defined in Table 3.

Green Tax (GT). Based on the connotation of green tax in a broad sense and referring to the explanation of green tax [31], this paper selects eight types of taxes, namely, resource tax, consumption tax, urban maintenance and construction tax, urban land use tax, cultivated land occupation tax, vehicle and vessel tax, vehicle purchase tax and environmental protection tax (sewage charge), and adds them together to get the total green tax revenue, and then uses the proportion of the total green tax revenue in the total tax revenue to measure the green tax system evaluation index. The proportion of the total green tax revenue to the total tax revenue measures the green tax system evaluation index.

Referring to the studies on the potential influencing factors of EEC [32, 33], this paper chooses the following factors as control variables: the degree of openness to the outside world (Op), industrial agglomeration (IA), the level of urbanization (Urb), and the population density of the region (Pop). The definitions of specific variables are summarized in Table 4.

## Modelling

$$EEC_{i,t} = \alpha_1 + \alpha_2 GF_{i,t} + \alpha_3 Op_{i,t} + \alpha_4 IA_{i,t} + \alpha_5 Urb_{i,t} + \alpha_6 Pop_{i,t} + \mu_1 \quad (1)$$

In model (1), i denotes each provincial area and t denotes the year. The main focus is on the coefficients, which, if positive, support hypothesis H1, indicating that green finance has a positive impact on EEC.

$$EEC_{i,t} = \beta_1 + \beta_2 GTI_{i,t} + \beta_3 Op_{i,t} + \beta_4 IA_{i,t} + \beta_5 Urb_{i,t} + \beta_6 Pop_{i,t} + \mu_2 \quad (2)$$

In model (2), the main focus is on the coefficients, which, if positive, support hypothesis H2, indicating that green technology has a positive impact on EEC.

$$EEC_{i,t} = \gamma_1 + \gamma_2 GT_{i,t} + \gamma_3 Op_{i,t} + \gamma_4 IA_{i.t} + \gamma_5 Urb_{i.t} + \gamma_6 Pop_{i.t} + \mu_3 \quad (3)$$

In model (3), the main focus is on the coefficients, which if positive support hypothesis H3, indicating that the green tax system has a positive impact on EEC.

## Sample Selection and Data Sources

In this paper, the panel data of 30 provincial-level regions in China (except Tibet and Hong Kong, Macao, and Taiwan due to incomplete data disclosure) from 2013-2022 are used as the research samples. The raw data of the explanatory variable energy-economy-carbon emission composite indicators come from the China Statistical Yearbook, CSMAR database, Wind database, and other official data statistics. The data of the explanatory variables green financial development indicators (green credit, green securities, green insurance, green investment) originated from China Statistical Yearbook, China Environmental Statistical Yearbook, China Insurance Yearbook, Wind database, RESSET database, and provincial and municipal statistical yearbooks; the data of the green technological innovation indicators (green invention

Table 4. Variable Definition Table.

| Variable type | Variable name | Variable symbol | Variable description |
|---|---|---|---|
| Explained variable | Energy-economy-carbon emission | EEC | Refer to the energy-economy-carbon emission coordinated development evaluation system. |
| Explanatory Variables | Green financial development indicator | GF | Calculated by panel entropy method |
| | Green technology innovation indicator | GTI | Sum of two types of green patent grants |
| | Green tax system evaluation indicator | GT | Total green tax revenue/total tax revenue |
| Control Variables | Degree of Openness to the outside world | Op | Amount of foreign investment actually used |
| | Industrial agglomeration | IA | Industrial employment/land area |
| | Urbanization level | Urb | Urban population/total population |
| | Regional population density | Pop | Population/land area in the region |

patents, green utility model patents) are obtained from the data statistics official by reference to the IPC code of the green patent list issued by the World Intellectual Property Organization (WIPO) and filtered from the international patent classification table of the State Intellectual Property Office (SIPO); the data of the green tax system evaluation indicators (green tax revenues from eight tax types, total tax revenues) are derived from the China Statistical Yearbook, China Tax Yearbook, and the National Bureau of Statistics (NBS). The data on the control variables of the degree of openness of the foreign economy, government economic intervention, and industrial agglomeration were obtained from the China Statistical Yearbook, of which the data on industrial agglomeration were also obtained from the China Population and Employment Statistical Yearbook; and the data on the level of urbanization and regional population density were obtained from the China Urban Statistical Yearbook.

## Empirical Results and Discussion

### Descriptive Statistics

Table 5 shows the descriptive statistics of the variables in this paper, the maximum value of the value of the explanatory variable EEC is -0.059, the minimum value is -1.004, and the average value is -0.585, which indicates that there is a difference in the level of coordinated development of the provinces in the sample in terms of EEC.

### Basic Regression

The basic regression of the two-way fixed-effects model of the integrated energy-economy-carbon emission indicator EEC with the explanatory variables GF, GTI, and GT respectively is carried out, and the regression results in Table 7 are obtained. As shown in Table 6, the correlation coefficient between EEC and the green financial development indicator GF is -0.122, and the coefficient is negative and significant at the level of 1%. Referring to the theory of Yang and Liao [27] on the study of the relationship between green finance and carbon emissions, because green finance has a significant role in reducing the level of the country's carbon emissions and with the development of green finance on the energy consumption, economic structural adjustment and carbon emission The inhibitory effect of negative indicators such as energy consumption, economic restructuring, and carbon emissions is more obvious, and may exceed the total of the promotional effect on other energy indicators and economic indicators, so the regression coefficient presents negative, but in the overall positive impact, so it can be interpreted that the hypothesis H1 is valid. The correlation coefficient of the EEC and the green technological innovation indicator GTI is 0.024, and the coefficient is positive and significant at the level of 5 percent, so it accepts the hypothesis H2. The correlation coefficient between EEC and green tax evaluation index GT regression is -0.089, the coefficient is negative and significant at 5% level, the same as hypothesis H1, the green tax system focuses on the reverse regulation of energy structure, economic structure, carbon emissions due to the specificity of the tax, and the regression coefficient is negative so that we accept hypothesis H3 that the green tax system has a positive impact on energy-economy-carbon emission.

### Robustness Tests

In order to further test the robustness and reliability of the research results of this paper, the method of lagging one period of the explanatory variables is used to process the data of the research sample variables. It is found that the coefficients of each variable and its sign and significance are not essentially changed from the empirical results of the previous article, so it is considered that the findings of this paper are robust.

The method of variable shrinkage processing is used to process the data of the research sample variables to obtain new sample data for regression analysis. It is observed that the coefficients of each variable and its sign and significance are not essentially changed from

Table 5. Descriptive Statistics.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| EEC | 300 | -0.585 | 0.206 | -1.004 | -0.059 |
| GF | 300 | 0.153 | 0.087 | 0.035 | 0.577 |
| GTI | 300 | 0.357 | 0.478 | 0.002 | 3.368 |
| GT | 300 | 0.276 | 0.149 | 0.062 | 0.886 |
| Op | 300 | 1.632 | 2.671 | 0.023 | 19.533 |
| IA | 300 | 0.791 | 1.297 | 0.009 | 7.607 |
| Urb | 300 | 0.576 | 0.126 | 0.356 | 0.895 |
| Pop | 300 | 0.471 | 0.703 | 0.008 | 3.916 |

Table 6. Basic regression.

| | (1) | (2) | (3) |
|---|---|---|---|
| | EEC | EEC | EEC |
| GF | -0.122*** | | |
| | [0.0413] | | |
| GTI | | 0.024** | |
| | | [0.0109] | |
| GT | | | -0.089** |
| | | | [0.0370] |
| Op | -0.001 | -0.003 | -0.001 |
| | [0.0013] | [0.0020] | [0.0014] |
| IA | -0.001 | -0.004 | 0.006 |
| | [0.0121] | [0.0123] | [0.0125] |
| Urb | 0.978*** | 0.999*** | 1.006*** |
| | [0.1094] | [0.1097] | [0.1094] |
| Pop | 0.223** | 0.173* | 0.207** |
| | [0.0891] | [0.0899] | [0.0893] |
| _cons | -1.307*** | -1.311*** | -1.297*** |
| | [0.0800] | [0.0807] | [0.0813] |
| N | 300 | 300 | 300 |
| $R^2$ | 0.903 | 0.902 | 0.902 |

Note: Standard errors in brackets,* p<0.1, ** p<0.05, *** p<0.01 (the data below is as above)

Table 7. Green policy combination on EEC based on coupled harmonization degree.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | EEC | EEC | EEC | EEC |
| oGFGTI | 0.097** | | | |
| | [0.0478] | | | |
| oGFGT | | -0.023 | | |
| | | [0.0347] | | |
| oGTIGT | | | 0.149** | |
| | | | [0.0729] | |
| oGFGTIGT | | | | 0.033 |
| | | | | [0.0614] |
| Controls | Yes | Yes | Yes | Yes |
| _cons | 0.125* | 0.134* | 0.127* | 0.127* |
| | [0.0753] | [0.0763] | [0.0753] | [0.0760] |
| N | 300 | 300 | 300 | 300 |
| $R^2$ | 0.548 | 0.542 | 0.548 | 0.541 |

Table 8. Necessity analysis of green policies based on fsQCA.

| conditional variable | consistency | coverage |
|---|---|---|
| cGF | 0.600 | 0.643 |
| ~cGF | 0.649 | 0.588 |
| cGTI | 0.786 | 0.916 |
| ~cGTI | 0.526 | 0.477 |
| cGT | 0.555 | 0.582 |
| ~cGT | 0.753 | 0.696 |

Note: "~" denotes "not" in logical operations.

the previous empirical results, so the results of this paper are considered to be robust.

## Green Policy Combination on EEC Based on Coupled Harmonization Degree

In this paper, the coupling coordination degree model is used for the coupling coordination of the three types of green policies GF, GTI, and GT two-by-two combinations as well as the interaction of the three common combinations. Table 7 shows the regression results of green policy combinations based on the coupling coordination degree. The coefficient of Column (1) oGFGTI is positive and significant at the 5% level, which indicates that the coordinated development of green finance and green technology can promote the integrated development of EEC. The coefficient of Column (2) oGFGT is negative and insignificant, which indicates that the combined policy of green finance and green tax has some substitution effect on energy-economy-carbon emission, and the positive effects of each other may cancel each other out. The coefficient of column (3) oGTIGT is positive and significant at the 5% level, which indicates that the coordinated development of green technology and green tax system can promote the integrated development of energy-economy-carbon emission. Column (4) oGFGTIGT has a positive but not significant coefficient, which indicates that there is some offsetting effect among the three types of green policy combinations and a good combination effect is not realized.

## Green Policy Combination on EEC Based on fsQCA

Fuzzy-Set Qualitative Comparative Analysis (fsQCA) is a social science research methodology that combines qualitative and quantitative analytical techniques for exploring causal relationships in complex social phenomena. fsQCA is particularly well suited for studies dealing with ambiguities, uncertainties, or non-linear relationships. This paper chooses to use fsQCA for the following reasons: the impact of green policies on energy-economy-carbon (EEC) emissions involves multiple factors, and there may be ambiguities and uncertainties among these factors. fsQCA is able to deal with such ambiguities and provide more accurate analytical results. The impact of green policies on EEC is a complex social phenomenon that involves the interaction of multiple factors. fsQCA is able to identify these complex causal relationships, providing in-depth understanding. By identifying policy combinations that lead to success or failure, fsQCA can provide targeted advice and guidance to policymakers. This is important for provincial governments to implement green policies and develop effective energy and climate policies.

In this paper, we take the average data of 30 provinces (cities and districts) from 2013 to 2022 as the research sample and select energy-economy-carbon emission EEC as the outcome variable, and green finance GF, green technology GTI, and green tax GT as the conditional variables. Drawing on Zhang [34] dynamic QCA analysis, the calibrated data cEEC, cGF, cGTI, and cGT were obtained by using the 95% quartile, 50% quartile, and 5% quartile as the calibration anchors through the direct calibration method to complete the calibration.

Regarding the analysis of necessary conditions, COVERAGE denotes the degree of coverage, and CONSISTENCY denotes the level of consistency, i.e., the percentage of successful cases that have a certain

Table 9. Truth table for fsQCA-based green policies.

| cGF | cGTI | cGT | number | cEEC | cases | raw consist. | PRI consist. | SYM consist. |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 3 | 1 | cases | 0.962 | 0.905 | 0.905 |
| 1 | 1 | 0 | 7 | 1 | cases | 0.915 | 0.844 | 0.871 |
| 1 | 1 | 1 | 2 | 1 | cases | 0.925 | 0.737 | 0.737 |
| 0 | 1 | 1 | 4 | 0 | cases | 0.924 | 0.658 | 0.684 |
| 0 | 0 | 1 | 5 | 0 | cases | 0.683 | 0.294 | 0.317 |
| 0 | 0 | 0 | 2 | 0 | cases | 0.673 | 0.239 | 0.239 |
| 1 | 0 | 0 | 3 | 0 | cases | 0.649 | 0.209 | 0.234 |
| 1 | 0 | 1 | 4 | 0 | cases | 0.609 | 0.183 | 0.183 |

Table 10. Grouping analysis results of fsQCA-based green policy.

| conditional variable | Configuration 1 | Configuration 2 |
|---|---|---|
| cGF | | ● |
| cGTI | ● | ● |
| cGT | U | |
| consistency | 0.934 | 0.915 |
| raw coverage | 0.672 | 0.541 |
| unique coverage | 0.196 | 0.065 |
| Overall solution consistency | 0.932 | |
| Overall solution coverage | 0.737 | |

Note: '●' and 'U' indicate the presence or absence of core. Blank indicates the presence or absence of both.

condition, and whether or not it is higher than 0.9 is used to judge the necessity of individual conditions. As shown in Table 8, the analysis finds that the aggregated consistency of the three types of green policies is less than 0.9, which fails the necessary conditions test, indicating that the three types of green policies are not necessary conditions for integrated energy-economy-carbon emission development.

In order to ensure the strength of the interpretation of the grouping, this paper sets the consistency threshold to 0.8, the frequency threshold to 1, and the PRI threshold to 0.7, and uses this as a reference to change the 0 and 1 values of the result column cEEC, and eventually there are no logical residual items, covering 30 cases, and constructing the truth table as shown in Table 9.

Due to the large differences in resource endowment as well as policy bias between provinces and municipalities in China, coupled with the exclusion of contradictory simplifying assumptions, it was found to be difficult to make a uniform judgment on the role of antecedent conditions on the results in the counterfactual analysis, and therefore, no directional presuppositions were made. Taking the intermediate solution as the main one and parsimonious solution as the supplementary one, according to the correlation between the presence or absence of conditions in the intermediate solution and parsimonious solution to judge them as core presence or core absence, edge presence or edge absence, two configurations of cGTI*~cGT and cGF*cGTI were obtained, and the results of the grouping analysis are shown in Table 10. The Overall solution consistency is 0.932, which is greater than the critical criterion of 0.8, and the Overall solution coverage is 0.737, which indicates that the overall consistency has better explanatory strength and that the two groupings derived can be a sufficient condition for the integrated development of energy-economy-carbon emission. From group stage 1, it is found that when the green tax system is absent, green technology, as a core condition, can promote the integrated development of energy-economy-carbon emission. In group 2, green finance and green technology linkage constitute a combination of sufficient conditions for the integrated coordination of EEC.

## Conclusions

This paper selects 30 provincial-level regions in China from 2013 to 2022 as samples to empirically test the separate impacts as well as the comprehensive impacts of green finance, green technology, and green tax system on EEC. The results show that: green finance, green technology, and green tax systems have a positive impact on EEC; the combination of green policies under the coupling degree of coordination affects EEC; based on the fuzzy set qualitative comparative analysis (fsQCA) group state analysis to get two paths of the impact of green policies on EEC, and to discuss the causal relationship between the green policies under the paths and the results of the concern, to provide the best solution for the provinces and municipalities to implement the green policies.

We put forward the following policy recommendations:

First, we deeply understand the positive effect of green finance in the optimization of energy structure, actively respond to the "double carbon" goal, and use more diversified green products to guide the flow of market financial resources to the green and low-carbon industries and promote the development of the green economy. And can be based on the actual situation of the domestic regions to develop effective green financial policies, and fully promote the construction and improvement of China's green financial system.

Second, in order to enhance the level of green technology in China, the primary goal is to vigorously develop green technology innovation capacity, the government needs to promulgate preferential support policies related to green technology, encourage enterprises to strengthen green technology research and development and innovation, especially for the total amount of energy, energy quality is low and other high energy-consuming enterprises, to improve the total factor green energy efficiency, from green investment to green consumption, towards a low-carbon economy.

Third, differentiate the implementation of the regional green tax system, coordinate the regional adaptability and coverage of green tax policy, standardize various types of green tax collection processes and mechanisms, implement green tax formulation for various types of enterprises, and promote green transformation and upgrading. Strictly control carbon emissions in a low-carbon-oriented manner, actively manage carbon pollution in order to realize the green goal of energy conservation and emission reduction, and improve the overall system of China's green tax system.

Fourthly, the government, enterprises, and society need to improve the attention to green policies, from the formulation and implementation to the implementation and publicity, each subject should actively participate in it, so as to promote the coordination of the three types of green policies, namely, green finance, green technology, and green taxation, and to truly empower the integrated development of energy-economy-carbon emission in each province.

Fifthly, policy coordination and harmonization should be strengthened, an information-sharing mechanism should be established, and policy evaluation and adjustment should be enhanced. The Government should strengthen coordination and cooperation among green finance, green technology, and green tax policies to form policy synergies and jointly promote green development. Establish an information-sharing mechanism among green finance, green technology, and green tax policies, strengthen communication and collaboration in the process of policy implementation, and improve the efficiency of policy implementation. Regularly evaluate and adjust green finance, green technology, and green tax policies, and make necessary adjustments and optimizations according to policy implementation and actual effects to ensure the realization of policy objectives.

Sixth, build a strategic framework for green development and promote the collaborative role of the Troika. A green development strategic framework centered on green finance, green technology, and green taxation should be actively constructed. First, enterprises should strengthen cooperation with financial institutions to provide financial support for green technology R&D and green projects through green financial financing tools, such as green bonds and green credit. At the same time, enterprises should increase their R&D investment in green technology and promote the greening of production processes through technological innovation to reduce energy consumption and carbon emissions. In addition, enterprises should actively respond to green tax policies and further reduce the cost of green development through tax exemptions and concessions. Through the collaborative effect of green finance, green technology, and green tax, enterprises can realize a win-win situation in terms of economic and environmental benefits.

Seventh, establish green supply chain management and promote the green development of the whole industry chain. Enterprises should actively establish a green supply chain management system and carry the concept of green development throughout the entire industrial chain. Enterprises should prioritize the selection of raw materials and products that meet environmental standards in the procurement process and promote the green transformation of upstream suppliers. In the production process, enterprises should adopt clean production technology to reduce pollution emissions in the production process. In the sales process, enterprises should actively promote green products and services and guide consumers to form green consumption habits. In addition, enterprises should strengthen communication and collaboration with partners to promote the green development of the whole industry chain jointly. By establishing a green supply chain management system, enterprises can realize the collaborative emission reduction of the whole industry chain and promote the virtuous cycle of green development.

## Acknowledgments

This research was funded by National key research projects of accounting (2023KJA3-12).

## Conflict of Interests

The authors declare no conflict of interest.

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