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A Configuration Analysis of the Impact of Multiple Systems on Regional Green Innovation Performance Based on QCA

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Abstract: In alignment with global “dual carbon” objectives, China is working to reach carbon peak and attain carbon neutrality, all while tackling pressing issues like resource shortages and environmental degradation. This study examines how formal and informal institutional factors affect regional green innovation, offering insights for policy formulation. Using the Qualitative Comparative Analysis (QCA) method and data from the China Statistical Yearbook—2022, it analyzes 31 provinces, incorporating six factors: environmental regulation, policy support, market input, environmental ethics, public attention, and media coverage. Findings highlight that environmental regulation, public attention, and media coverage are essential for high green innovation performance. Different institutional configurations—such as regulation and public resonance, regulation with market support, and ethics-driven approaches—enhance innovation, while certain combinations, like isolated regulation, may hinder progress. These insights support policymakers in promoting regional green innovation by leveraging various institutional factors.

1. Introduction

As global efforts toward "dual carbon" goals advance, countries face both challenges and opportunities. China, as the world’s largest energy consumer and carbon emitter, plays a critical role in global climate initiatives. Yet, its high-emission, resource-intensive development model no longer aligns with the sustainability required for high-quality growth. Beyond rapid economic expansion, China grapples with resource scarcity and environmental degradation. Transitioning to a sustainable, low-carbon industrial model and promoting green innovation have become crucial steps toward achieving carbon peak and neutrality goals.

At the regional level, green innovation performance is significantly influenced by institutional factors, especially provincial policies that create the essential frameworks for regional green innovation. Formal and informal institutions interact, jointly influencing regional green innovation. Traditional research methods, however, frequently fall short in capturing the complexity of these interactions, hindering a comprehensive understanding of their combined effects on green innovation.

Recent literature has increasingly focused on green innovation performance. Some scholars

emphasize the technological innovation perspective, suggesting that green innovation is driven primarily by firms' R&D investments and technological capabilities[1]. Others focus on market dynamics, pointing to market demand and competitive pressures as key drivers[2]. Although these studies contribute valuable insights into green innovation and its drivers, they often employ quantitative methods that assume linear relationships, thus failing to capture the complex interplay of multiple institutional factors[3]. Furthermore, much of the existing research examines individual institutional influences in isolation, lacking a holistic examination of how these factors interact to shape regional green innovation[4].

To overcome these limitations, this study utilizes Qualitative Comparative Analysis (QCA) to explore how institutional factors jointly influence regional green innovation across Chinese provinces. This approach provides a solid theoretical foundation and practical guidance for provincial governments in formulating scientifically grounded green innovation policies. By highlighting the interactions between formal and informal institutions, this paper transcends the constraints of traditional linear models, providing novel insights into effective institutional configurations that foster sustainable, low-carbon development at the regional level.

2. Research Design

2.1 Research Method

Regional green innovation performance arises from the complex interplay of formal and informal institutions rather than any single factor. Traditional quantitative methods frequently assume linear relationships and emphasize single-factor influences, limiting their capacity to capture the nuanced effects of institutional interactions. In contrast, Qualitative Comparative Analysis (QCA) adeptly addresses these complexities, enabling the simultaneous assessment of multiple conditional variables and uncovering how different factor combinations can yield similar outcomes. This approach uncovers the equifinality of institutional configurations—demonstrating that different factor combinations can produce the same result—which provides richer insights for policy formulation.

Accordingly, this study utilizes fuzzy-set QCA (fsQCA) to comprehensively examine how formal and informal institutions together shape regional green innovation. This approach transcends the limitations of linear assumptions, providing a deeper insight into institutional dynamics and offering policymakers valuable guidance in promoting sustainable, low-carbon development.

2.2 Model Construction

According to institutional theory, the institutional environment has a decisive influence on the behavior of individuals and organizations. Formal and informal institutions together form the institutional framework for green innovation, creating a mechanism that balances incentives and constraints, thereby fostering the positive development of green innovation. Configuration theory further suggests that regional green innovation performance results from the combined effects of multiple institutional factors. Configuration analysis, in contrast to traditional research methods, more effectively uncovers the complex interactions among these factors and identifies various institutional combinations that drive green innovation, offering a broader foundation for policy formulation.

Accordingly, this paper adopts an institutional environment perspective, selecting six factors to assess the influence of multiple institutions on regional green innovation. The research model is shown in Figure 1.

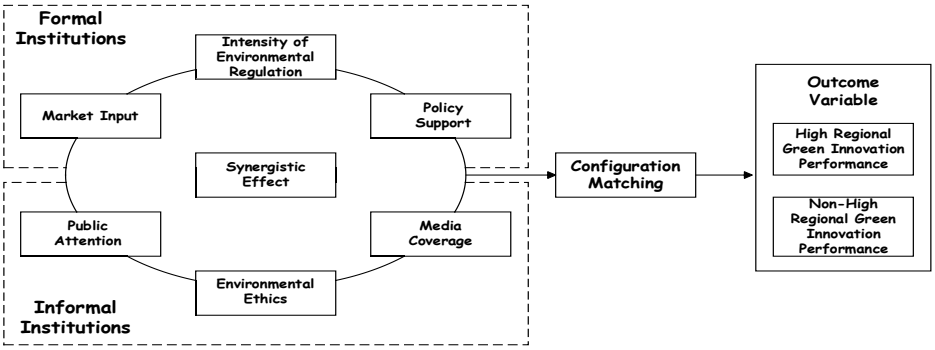

Figure 1: Research Model for Factors Influencing Regional Green Innovation Performance

2.3 Data Sources and Indicator Selection

This study takes China's provinces as the research objects and, following the principle of "sufficient sample size and data availability," selects 31 provinces, autonomous regions, and municipalities (excluding Hong Kong, Macao, and Taiwan) as research cases. The relevant data are sourced from *the China Statistical Yearbook—2022*, the National Intellectual Property Administration of China, Baidu Search Index, and Pkulaw. Drawing on the studies of Yuan Yijun et al.[5], Zhang Shengjie[6], and Wang Mingyue[7], the indicators for formal institutions include environmental regulation, policy support, and market input. Referring to the research by Jiang Yufeng et al.[8] and Y. R. Yang et al.[9], informal institutions are measured by environmental ethics, public attention, and media coverage.

In the fuzzy-set Qualitative Comparative Analysis (fsQCA) data processing, the six influencing factors are considered causal conditions, with regional green innovation performance serving as the outcome variable. The specific indicators are shown in Table 1.

Table 1: Variable Selection

Variables			Symbols	Explanation of Indicators
Outcome Variable		Regional Green Innovation Performance	RGIP	Total Green Innovation Patent Applications and Authorizations in 2022
Causal Conditions	Formal Institutions	Intensity of Environmental Regulation	ERI	Ratio of Environmental Fixed Investment to Urban GDP
		Policy Support	GS	Government Documents and Work Reports on Green Innovation in 2022
		Market Input	MI	The ratio of environmental pollution control investment to urban GDP
	Informal Institutions	Environmental Ethics	EE	The Mention of Environmental Ethics in Corporate Social Responsibility Reports and Government Documents
		Public Attention	ADSV	Using the Baidu Index to search for keywords such as "green," "innovation," "ecology," "carbon neutrality," "energy conservation and emission reduction," and "sustainable development," the average daily search volume can be obtained.
		Media Coverage	IA	By using the Baidu Index to search for keywords such as "green," "innovation," "ecology," "carbon neutrality," "energy conservation and emission reduction," and "sustainable development," the attention values (information interest levels) can be obtained.

3. Empirical Results and Analysis

3.1 Data Calibration

Fuzzy-set theory permits variable values to range continuously between 0 and 1, reflecting varying degrees of membership. In this study, a direct calibration method is employed to establish anchor points. Data for each variable is ranked in descending order, with thresholds for full membership (90%), the crossover point (50%), and full non-membership (10%) defined as anchor points. The raw data is subsequently transformed into fuzzy membership values within the 0 to 1 range. Following this calibration, Table 2 presents the fuzzy-set values for each variable.

Table 2: Data Calibration

Set	Fuzzy Set Calibration		
	Full Non-Membership (10%)	Crossover Point (50%)	Full Membership (90%)
ERI	0.0547	0.0577	0.0105
GS	3.05	14.05	33.05
MI	0.65	2.31	6.19
EE	254.05	495.05	841.05
ADSV	685.05	1271.5	2034.05
IA	18579.05	75654.05	223789.05
RGIP	1566.05	8766.05	37099.05

3.2 Necessary Condition Analysis

In the fsQCA approach, it is essential to first assess the necessity of individual conditions before examining configuration patterns—that is, to determine whether a single variable qualifies as a "necessary condition" for the outcome. Typically, the necessity consistency threshold is set at 0.9; if a condition's consistency exceeds this threshold, it is deemed necessary for the outcome variable. Table 3 shows the results of the necessity analysis for six condition variables in relation to high and non-high regional green innovation performance. The analysis reveals that environmental regulation intensity, public attention, and media coverage (with consistency > 0.9) are necessary conditions for high regional green innovation performance. Additionally, environmental regulation intensity is also a necessary condition for non-high regional green innovation performance.

Table 3: The necessity test for individual conditions in the fsQCA

Condition Variables	Outcome Variable			
	RGIP		~RGIP	
ERI	0.996	0.456	0.999	0.585
~ERI	0.093	0.984	0.071	0.953
GS	0.826	0.752	0.443	0.516
~GS	0.469	0.397	0.787	0.852
MI	0.540	0.542	0.553	0.709
~MI	0.711	0.554	0.643	0.641
EE	0.763	0.703	0.456	0.537
~EE	0.497	0.417	0.748	0.802
ADSV	0.967	0.848	0.401	0.449
~ADSV	0.373	0.327	0.865	0.971
IA	0.979	0.867	0.399	0.451
~IA	0.381	0.331	0.883	0.981

Note: The symbol "~" is a Boolean logic operator meaning "not", indicating the absence of a corresponding condition. For example, "~Policy Support" represents the absence or non-high level of policy support.

3.3 Configuration Analysis

Configuration analysis is the core of fsQCA (fuzzy-set Qualitative Comparative Analysis). The condition configuration refers to the combination of causal conditions that influence the outcome variable. The QCA solution includes three types: complex solution, intermediate solution, and parsimonious solution. Configuration pathways are built based on the intermediate solution, where conditions that appear in both the intermediate and parsimonious solutions are considered core conditions, while those only appearing in the intermediate solution are treated as peripheral conditions. The results of the configuration analysis are shown in Table 4. There are four different configurations that lead to high regional green innovation performance, and five different configurations that lead to non-high regional green innovation performance.

Table 4: Configuration Pathways for Regional Green Innovation Performance

Causal Conditions		Outcome Variable								
		RGIP				~RGIP				
		H1				NH1	NH2	NH3	NH4	NH5
		H_{1a}	H_{2b}	H_{3c}	H_{4d}					
Formal Institutions	ERI	●	●	●	●	●	●	●	●	●
	GS	⊗			●		●		⊗	●
	MI		●		⊗			●		⊗
Informal Institutions	EE			●	⊗	⊗				⊗
	ADSV	●	●	●	⊗	⊗	⊗	⊗	●	⊗
	IA	●	●	●	●	⊗	⊗	⊗	●	
Consistency		0.900	0.937	0.940	0.958	0.995	0.992	0.992	0.799	0.990
Raw Coverage		0.439	0.512	0.575	0.465	0.648	0.350	0.492	0.305	0.235
Unique Coverage		0.027	0.053	0.317	0.207	0.199	0.024	0.082	0.055	0.018
Overall Consistency		0.910				0.918				
Overall Coverage		0.922				0.886				

Note: ● indicates the presence of a core condition, ● indicates the presence of a peripheral condition, ⊗ indicates the absence of a core condition, ⊗ indicates the absence of a peripheral condition, and a blank space indicates that the condition variable may be present or absent.

When the core conditions are the same, they can form second-order equivalent configurations. For example, if the core conditions of H_{1a}, H_{2b}, H_{3c}, and H_{4d} are the same, these four configurations constitute one second-order equivalent configuration[10]. From this, four configuration pathways for high regional green innovation performance are summarized.

3.3.1 Configuration Analysis of High Regional Green Innovation Performance

(1)H_{1a}: ERI*~GS*ADSV*IA

This pathway, classified as "Regulation and Public Resonance", centers on high media coverage, with environmental regulation and public attention as peripheral conditions. Media raises environmental awareness and strengthens regulatory enforcement through public oversight. Public attention reflects societal expectations, and together with media, significantly enhances green innovation. Provinces like Hebei, Anhui, Liaoning, and Shaanxi exemplify this. For instance, in Hebei, public attention and media coverage create informal institutional pressure, prompting proactive measures that improve innovation performance.

(2)H_{2b}: ERI*MI*ADSV*IA

This "Regulation and Market-Driven" pathway relies on high media coverage as the core, with environmental regulation, market input, and public attention as peripheral conditions. Media swiftly disseminates green innovation content, driving market interest. Regulation provides a framework, while market input supplies resources, and public attention contributes to social oversight. Shanghai,

Zhejiang, Hubei, Hebei, Shandong, and Anhui follow this configuration. For example, Zhejiang's regulatory system and significant market input, combined with media promotion, drive businesses to engage in green innovation, enhancing performance.

(3)H_{3c}: ERI*EE*ADSV*IA

This pathway, known as "Ethics-Driven and Social Resonance," features high media coverage with environmental regulation, environmental ethics, and public attention as peripheral elements. Media emphasizes environmental ethics, raising public awareness and fostering green innovation. Regulation provides policy support, while ethics and public attention reflect values related to sustainability. Jiangsu, Guangdong, Shandong, Zhejiang, Henan, Anhui, Beijing, Sichuan, Hubei, and Liaoning exemplify this pathway. In Jiangsu, media coverage of green issues bolsters societal values, driving adherence to ethical norms in green innovation.

(4)H_{4d}: ERI*GS*~MI*~EE*~ADSV*IA

This "Regulation and Innovation Hindrance" pathway features high media coverage, with environmental regulation and policy support but lacks market input, ethics, and public attention, which stifles green innovation. While media raises awareness, the absence of these critical supports limits practical application. Chongqing exemplifies this pathway: despite regulatory and policy support, insufficient market input and public interest hinder green innovation, restraining performance improvements.

3.3.2 Configuration Analysis of Non-High Regional Green Innovation Performance

(1)NH1: ERI*~EE*~ADSV*~IA

This "Regulation-Isolated" model includes environmental regulations but lacks support from environmental ethics, public attention, and media coverage, resulting in limited social and market backing for green innovation. Examples include Hainan and Guizhou. In Hainan, despite strong regulations, the absence of ethics, public interest, and media support weakens the motivation for green innovation.

(2)NH2: ERI*GS*~ADSV*~IA

This "Policy Vacuum" type has environmental regulations and policy support but lacks media coverage and public attention, reducing the policies' reach and impact. Regions like Guizhou, Guangxi, Yunnan, and Shanxi exhibit this model. In Guizhou, policy initiatives exist but are underutilized due to low public awareness and limited media engagement.

(3)NH3: ERI*MI*~ADSV*~IA

In the "Market Indifference" type, environmental regulation and market input are present, but low public attention and media coverage lead to weak demand for green innovation. Ningxia, Gansu, and reflect this pattern. For instance, Ningxia has regulatory and market resources, but minimal public interest and media coverage limit green innovation progress.

(4)NH4: ERI*~GS*ADSV*IA

This "Internal Resource Deficiency" model includes regulation and public attention but lacks market input, environmental ethics, and adequate media coverage, hindering green innovation. Hebei, Anhui, and Shaanxi illustrate this pathway. In Hubei, strict regulations and public interest exist, but insufficient market investment limits innovation opportunities.

(5)NH5: ERI*GS*~MI*~EE*~ADSV

This "Comprehensive Innovation Obstruction" type has regulatory and policy support but lacks market input, ethics, public interest, and media coverage, creating significant barriers to green innovation. Chongqing and Shanxi follow this pattern. In Shanxi, basic regulatory support is present, yet limited market resources and low public interest impede green innovation.

4. Conclusions

This study reveals that environmental regulation, public attention, and media coverage alone do not constitute sufficient conditions for achieving high regional green innovation performance. Instead, four effective institutional configurations are identified: Regulation and Public Resonance, Regulation and Market-Driven, Ethics-Driven and Social Resonance, and Regulation and Innovation Hindrance. Conversely, five configurations hinder innovation: Regulation-Isolated, Policy Vacuum, Market Indifference, Internal Resource Deficiency, and Comprehensive Innovation Obstruction. These findings offer practical insights for policymakers on how to leverage institutional configurations to enhance green innovation. Future research could expand on these configurations, considering additional contextual factors to refine green innovation strategies and support sustainable, low-carbon development.

5. Recommendations

To fully leverage policy support and public engagement, regional policies should be tailored to specific needs, thereby promoting regulation and public participation-driven green innovation.

Policies should also cater to investment needs, optimizing market resource allocation to foster synergy between regulatory and market-driven green innovation.

To meet ethical needs, incorporate environmental ethics education across all levels, fostering an ethics-driven and socially resonant green innovation culture. This should include integrating environmental ethics into school curricula, professional training, and public campaigns, while encouraging businesses to embed these values into corporate strategies. By doing so, green innovation performance is enhanced, contributing to regional sustainable development.

Further, policies should address resource needs by increasing market investment and raising social awareness to overcome innovation bottlenecks. Expanded funding, human resources, and technology support will attract greater attention to green innovation. Concurrently, media campaigns and educational activities can heighten public focus on environmental issues, cultivating a positive social atmosphere and driving green innovation.

Incentive-based policies are crucial for cultivating a supportive social environment and rewarding proactive engagement in green innovation. Communication-focused policies can tackle the challenges of policy dissemination and execution.

Additionally, to overcome media limitations, increase support and incentives to stimulate interest in green innovation. Media can raise awareness, while financial incentives like tax breaks can drive market demand for green innovation, further enhancing regional performance.

Finally, prioritize coordination by unifying support measures and establishing a comprehensive coordination mechanism. This approach combines increased market input, environmental ethics education, public awareness, and media dissemination, ensuring that all efforts work synergistically to break through innovation barriers and advance regional green innovation.

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