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Original Research

Institutional Configuration Study of Urban Green Economic Efficiency – Analysis Based on fsQCA and NCA

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Abstract

Since there is a lot of discussion and attention focused on green economic efficiency, the central government has prioritized the sustainable development of the urban economy. Utilizing the fuzzy set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) methodologies based on sample data from 276 Chinese cities in 2021, this study examines the institutional configurations that influence urban green economic efficiency. The findings show that environmental regulations, environmental subsidies, green credit, the green equity market, and the level of enterprise intelligence cannot individually constitute the required conditions for determining urban green economic efficiency. However, they form four institutional configurations that enable cities to attain high levels of green economic efficiency. The study provides useful insights for sustainable development by thoroughly revealing the intricate causal links between numerous institutional aspects and urban green economic efficiency.

Keywords: green economic efficiency, fsQCA, NCA, sustainable development, urban economy

Introduction

With the rise in global population and escalating industrialization, many countries continue to rely on fossil fuels for production and transportation. However, the dependence on such patterns of economic development poses severe challenges, including resource wastage, environmental pollution, and inefficient economic growth [1]. This reliance escalates damage to the global ecological environment, making the transition from brown to green economic models an urgent priority [2]. The green economy, marked by an environmentally oriented development approach, has gained global recognition and become a major emblem of the new era's economic model, gradually proliferating worldwide. In contrast to the traditional brown economy, the green economy emphasizes the concurrent advancement of the economy and the environment. It demands that the economy maintain a certain pace of economic growth while achieving resource conservation, environmental improvement, and increased growth efficiency, paving the way for a green and sustainable development path [3]. In this context, investigating how to enhance green economic efficiency by fostering a low-carbon

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circular economy is of utmost importance for achieving sustainable development.

The rising frequency of global climate disasters and the growing recognition of environmental preservation have gradually redirected the focus of various sectors towards green economic efficiency (GEE). Existing research predominantly focuses on measurement and the influencing factors of GEE. In terms of the measurement model, scholars commonly use SBM-related models for calculation. Among these, many scholars use the DEA-SBM model as the measurement model for national, regional, or corporate green economic efficiency [4]. However, some scholars also use the SBM-DDF model for calculations [5]. Scholars select input indicators from material capital, human capital, and energy consumption, with GDP as the expected output indicator and carbon dioxide and other industrial pollutant emissions as the undesired outputs [6].

In terms of influencing factors, plenty of studies show that the emergence of smart enterprises can reduce the production costs of companies and city economic activities [7]. Simultaneously, digitization can promote industrial integration in city clusters [8], collaboratively enhancing the energy utilization efficiency of low-productivity sectors [9]. This positively promotes the enhancement of urban GEE [10]. Besides, green credit can increase the level of environmental concern among corporate entities [11], reduce the level of financial constraints on enterprises [12], and effectively enhance innovation levels by lowering the financial risks associated with innovation in business operations [13]. This, in turn, improves the efficiency of using high-pollution energy sources such as fossil fuels, promoting the sustainability of the economy [14]. Moreover, the government plays a crucial role in promoting green economic development. It possesses significant policy authority, strategic vision, and execution capabilities [15], being able to impose constraints on the development of economic entities such as companies or cities by implementing measures like harmless waste treatment or penalties for pollution emissions [16]. This contributes to promoting the economic development of regions or countries [17].

Existing literature provides reliable insights into the study of urban green economic efficiency (GEE). However, most literature focuses on the specific effects of certain factors on GEE [18], overlooking the interactions among these factors. The improvement of GEE results from the combined effects of multiple factors involving complex causal relationships. If traditional univariate research approaches are followed, significantly different research conclusions may emerge in situations where multiple variables coexist. Therefore, exploring the compound effect of different institutional configurations on urban GEE helps to overcome the narrow perspectives of previous research. A comprehensive study of the enhancement path of GEE from the perspective of institutional configurations is useful.

As a result, this study's contribution is probably as follows: First, considering the complexity and multiple causalities of urban green economic development, this study uses a research method that combines fsQCA with NCA, replacing the traditional single-factor regression methods employed in previous literature. On the one hand, this approach overcomes potential issues of neglecting different types of mutually non-exclusive influencing factors in the study, discussing the sufficiency and necessity of the factor configuration from a holistic perspective [19]. It shows the necessary conditions for improving GEE. On the other hand, by applying the NCA method, it avoids the limitation of fsQCA in determining only the existence of necessary conditions and quantifying the necessity of factors. This makes the research results more comprehensive, persuasive, and responds to the academic suggestions that combining fsQCA with NCA can give greater value [20]. Second, starting from a multi-factor institutional configuration perspective, this paper examines how urban green economic development is achieved via the lens of government, market, and companies. It analyzes the feasibility of urban green sustainable development in detail based on a combination of different institutional elements, providing more comprehensive and reliable policy recommendations for enhancing urban GEE and achieving sustainable development.

Theoretical Framework

Government Intervention and Green Economic Efficiency

The 2018 World Investment Report signals that implementation of development policies combining subsidies and regulations has become a common practice in 101 countries globally over the past decade [21]. Considering the public nature of the ecological environment and economic externalities [22], coupled with the externalities of knowledge spillover from green innovation [23], economic entities lack intrinsic motivation for proactive green innovation. Therefore, government intervention is needed for green economic development, playing the roles of enforcer and incentivizer. This is achieved by environmental regulations and environmental subsidies to address the issue of intrinsic motivation, directly influencing urban green economic efficiency [24].

From an enforcer's perspective, environmental management costs are a vital concern for businesses and relevant departments [25]. As a result, the government has ample reason and motivation to formulate a series of punitive environmental regulatory policies. Through such measures, individual pollution behavior is regulated, the motivation for green innovation is enhanced, and the economy's sustainable development level has been improved. Well-formulated and effectively implemented environmental regulations remarkably increase the cost of pollution emissions. This compels businesses and relevant departments to participate in technological innovation, enhance the level of green transformation, and popularize environmental awareness [26]. It also promotes the coordinated improvement of industry productivity and the degree of sustainable economic development [27]. Moreover, the implementation of environmental regulations imposes external pressures on businesses, such as legal obligations, taxes, and fines, compelling them to abandon pollution-intensive activities [28].

From an incentivizer's perspective, government subsidies have become an effective means to stimulate green innovation and achieve sustainable development [29]. Environmental subsidies can offset the financial investment required for green innovation, alleviate the research and development pressure, and mitigate associated financial risks, thereby enhancing the enthusiasm of businesses and relevant departments for innovation [30]. On the other hand, government environmental subsidies can prevent economic entities, such as businesses, from engaging in opportunistic behaviors. These subsidies focus on areas such as clean transformation, efficient utilization of clean energy and water resources, and regional environmental optimization [31]. As the green transformation in these areas often has a low input-output ratio and a long return period, requiring substantial funding, the participation of government subsidies helps to alleviate the insufficient environmental governance investment in these domains [32].

Market Support and Green Economic Efficiency

The market, as the primary forum for economic activities, is vital for urban green economic development due to its distinct resource allocation mechanism. Financial institutions act as "lubricants" and "boosters" in the operation of a market economy. The allocation of green credit resources by financial institutions can promote green industries in the region and remarkably restrain the emissions of carbon dioxide and other pollutants, preventing environmental degradation and promoting economic growth. In addition, with the establishment of the National Green Equity Trading Center by the Chinese government in May 2013, green equity markets, such as carbon emission rights, energy usage rights, and emission rights, have become very prominent.

Green credit has arisen as a form of indirect financing where environmental factors are included in the credit evaluation criteria of commercial institutions [33]. Green credit is a sustainable credit financing method that, through the government guidance of financial institutions, facilitates financing for green projects by businesses and relevant departments, thereby steering the economy towards a green transformation [34]. The issue of low internal financing demand for environmental governance by businesses and relevant departments and generally high external financing demand is addressed by green credit, which is an essential source of funding for environmental pollution governance, the optimization of industrial energy conservation, and environmental protection levels [35]. It has improved the market competition environment, gradually shifting business orientation from a focus solely on increasing output and improving financial performance in the brown economy era to a balanced emphasis on financial performance and green performance.

The trading of green equity, such as carbon emission rights and emission rights, by businesses or relevant departments is referred to as green equity trading. When the green equity trading policy has an exogenous impact on energy prices, different types of market entities will weigh the cost-benefit of green patent research and development, the purchase and sale of emission rights, and other green equity, and choose the optimal decision. If choosing to engage in green patent research and development, it will need to bear the research and development costs, but under the conditions of successful innovation, it can also generate considerable profit. There are obstacles to traditional government-mandated environmental regulatory policies in the context of the green development concept. Environmental equity trading markets use market incentives to commercialize environmental rights and enforce businesses' primary obligation to cut pollution and carbon emissions. This increases the operating costs of medium and high-pollution businesses, breaks through the bottleneck of command-type environmental regulation, pushes businesses to innovate green technologies, and boosts energy efficiency [36].

Innovation and Entrepreneurship in Green Economic Efficiency

Enterprise intelligence and urban entrepreneurial activity significantly enhance the sustainable growth of the urban economy [37]. On the one hand, enterprises can optimize their existing production and operation methods, streamline supply-chain networks and product sales channels, and decrease the costs of market supply and demand research and management. This stimulates green technological innovation, reduces dependence on highly polluting resources, and promotes urban green economic efficiency through digital technology [38]. The self-learning ability, high adaptability, and high automation level of artificial intelligence accelerate the development of new energy technologies [39]. It enables enterprises to decompose the complexity and comprehensiveness of their production activities using artificial intelligence and reconstruct services and production processes [40]. Through intelligent monitoring of pollution sources and real-time identification of production processes using dynamic perception capabilities and intelligent decision-making capabilities, pollution can be treated point-to-point, reducing energy consumption and enhancing overall green production efficiency. At the urban economic level, artificial intelligence has the characteristics of diffusion-type innovation, contributing to the spillover effects of green technological innovation, assisting in driving green innovation in industry clusters, and promoting the overall green development of the industry, aligning with the direction of urban green development [41].

On the other hand, entrepreneurial activities are a strong driving force for sustainable economic development. It is an essential support for a major component in promoting the construction of a green and innovative country. Entrepreneurial vitality reflects a country's commitment to and emphasis on green economic development. By stimulating entrepreneurial vitality, sustainable economic development is guided, ensuring the vitality of socio-economic development and the fluidity of the enterprise ecosystem and promoting a more healthy and higher-quality economic development. Entrepreneurial activities accelerate the research and commercialization of new technological achievements, the birth of new enterprises, and the emergence of new industries, fostering industry competition [42]. This compels the companies to participate in green technological innovation and product research and development, strengthening their competitive advantages and increasing the market visibility of their products. By accelerating the generation of new services, thoughts, technologies, and models, entrepreneurial activities drive the transformation of technological and managerial innovations into green outcomes, providing strong support for the improvement of GEE.

Experimental Procedures

Methodology

Compared with traditional research methods, the QCA method enables the analysis of complex relationships between cases, and fsQCA adopts a configurational perspective based on the combination of multiple factors. It handles issues of degree variation and partial membership through Boolean operations and set relationships, where the selection of cases directly influences the results of configurational analysis. The NCA approach, proposed by Vis and Dul in 2016 [20], is used to examine the necessary but not sufficient conditions in case analysis and explore to what extent antecedent conditions can produce the outcome variable. The combination of fsQCA and NCA methods effectively addresses the limitation of fsQCA in only determining the necessity of variables, explores the interaction and synergy effects of multi-factor combinations in cases, and enhances the persuasiveness and completeness of research conclusions.

First, the urban green economic efficiency (GEE) is influenced by the synergistic and collaborative effects of multiple factors in the internal economic environment of the city. Traditional linear regression makes it challenging to simultaneously test the effect of more than three influencing factors on the outcome variable. However, fsQCA can analyze the interactions among multiple factors affecting green economic efficiency, studying non-linear ties between different combinations of influencing factors and urban green economic efficiency, along with their coverage range [43]. In addition, fsQCA combines the strengths of qualitative and quantitative research, making it applicable to a wide range of data sizes, including small samples (below 15), medium samples (15 to 50), and large samples (above 100). The case study of 276 cities selected in this paper falls into the category of large samples, aligning with the applicability of fsQCA. Furthermore, the use of NCA accurately identifies the percentage of factors required for cities to achieve high-level GEE, aiding in a deeper understanding of the contribution of each factor to GEE. This facilitates the summarization of generalizable development strategies for achieving high-level green GEE in cities.

Data

During the process of selecting case cities, this study focused on cities in mainland China. Considering the disclosure year of data, sample availability, and completeness, this study chose sample data from 276 cities in 2021 for the research. The sample data were sourced from the China Statistical Yearbook and statistical yearbooks compiled by various city governments. In cases of individual missing values, they were supplemented through manual inquiries and interpolation methods.

Variables

Dependent Variable

This study employs green economic efficiency (GEE) as the dependent variable. Following existing research [44], this study selects DEA-SBM for measurement. Considering the detailed model settings for DEA-SBM in the referenced literature, this paper does not elaborate on the specific model here.

The input-output indicators for GEE are defined as follows: (1) Asset Input: measured by total fixed asset investment recorded under the sustainable inventory method; (2) Labor Input: measured by the number of employees at the end of the year per city; (3) Resource Input: measured by annual electricity consumption per city; (4) Expected Output: measured by the real gross domestic product (GDP) of the city converted based on the 2005 benchmark; (5) Non-Expected Output: measured by the emission of industrial wastewater, sulfur dioxide, and particulate matter to assess pollutant emissions.

Conditional Variables

The control variables are: (1) Environmental Regulation: used to describe governmental control over environmental protection and pollution emissions. It is measured by artificially collecting and analyzing the frequency of green environmental protection-related terms in government work reports; (2) Environmental Subsidies: used to describe the extent of government support for environmental protection projects. It is measured by the proportion of investment in environmental pollution control to GDP; (3) Green Credit: used to describe the development level of the green credit market. It is measured by the proportion of the total amount of credit for environmental projects to the total credit. (4) Green Equity Market: used to describe the depth of transactions in the green equity market. It is measured by the proportion of carbon trading, energy use rights trading, and emission rights trading to the total equity market transactions; (5) Smart Enterprise Level: used to measure the level of enterprises' use of artificial intelligence. It is measured by the number of artificial intelligence enterprises in the current year; (6) Entrepreneurial Vitality: used to measure the entrepreneurial vitality of a city. It is measured by the number of new entrepreneurial enterprises per hundred people.

Results and Discussion

Empirical Analysis

Variable Calibration

By employing the direct calibration method to calibrate each variable, calibration points are set at Fully In (95%), Crossover (50%), and Fully Out (5%) as per the approach. Table 1 presents the quantiles for each variable.

Table 1 shows the calibration anchor points for result variables and conditional variables at 5%, 50%, and 95%, as well as the average values of each data point. According to the comparison results between the calibration anchor and the sample mean, the average values of GEE, Regulation, Smartenterprise, and Entrepreneurial indicators are significantly higher than the 50% calibration anchor. This indicates that the distribution deviation of various indicators in the sample cities is large, and the differences between cities are significant. Some cities have higher levels of green economic efficiency, environmental regulation, number of smart enterprises, and entrepreneurial vitality, which drives the overall mean to rise. The mean and 50% calibration anchor of the Support, Greencredit, and Equitymarket indicators are almost the same, indicating that the government support, green credit support, and equity market development levels of the sample cities are evenly distributed, with similar numbers of high-level and low-level cities. On the other hand, there is a significant difference in the distribution of Smartenterprise indicators, indicating a significant difference in the number of smart enterprises in Chinese cities. There is a difference of nearly 134 times in the number of smart enterprises between cities, with significant differences in the distribution of smart enterprises and low coordination of the level of intelligence between cities.

Necessity Analysis

fsQCA Analysis

The necessity of conditional variables was examined through fsQCA. Table 2 presents the results, which show the consistency of each conditional variable is less than 0.9. As a result, it is preliminarily concluded that there are no necessary conditions.

NCA Analysis

The NCA technique necessitates the simultaneous satisfaction of at least two requirements to determine necessary conditions: an effect size not less than 0.1 and results from a Monte Carlo simulation permutation test that indicate the importance of the effect size [20]. This

Table 1. Variable calibration results.

Types	Variables	Calibration anchors			Mean
		Fully in (95%)	Crossover (50%)	Fully out (5%)	
Outcome variable	GEE	1.113	0.371	0.199	0.452
Conditional variable	Regulation	6.523	3.193	1.521	3.477
	Support	0.017	0.008	0.002	0.008
	Greencredit	0.088	0.055	0.019	0.056
	Equitymarket	0.050	0.027	0.010	0.028
	Smartenterprise	13376.850	476.500	99.250	2281.518
	Entrepreneurship	5.929	1.481	0.771	2.102

Table 2. fsQCA Analysis results.

Variables	GEE		~GEE	
	Consistency	Coverage	Consistency	Coverage
Regulation	0.658	0.611	0.662	0.754
~Regulation	0.735	0.639	0.658	0.703
Support	0.690	0.646	0.610	0.702
~Support	0.681	0.587	0.692	0.733
Greencredit	0.743	0.634	0.653	0.685
~Greencredit	0.631	0.597	0.651	0.757
Equitymarket	0.699	0.643	0.611	0.690
~Equitymarket	0.663	0.581	0.684	0.736
Smartenterprise	0.695	0.780	0.495	0.682
~Smartenterprise	0.717	0.536	0.840	0.772
Entrepreneurship	0.708	0.717	0.546	0.679
~Entrepreneurship	0.683	0.550	0.772	0.765

Note: ~ indicates absence of or a low level.

Table 3. NCA Analysis results.

Variables	Method	Ceiling zone	Effect size	C-accuracy	P-value
Regulation	CE_FDH	0.010	0.010	100%	0.376
	CR_FDH	0.026	0.027	97.1%	0.182
Support	CE_FDH	0.003	0.003	100%	0.880
	CR_FDH	0.001	0.001	100%	0.897
Greencredit	CE_FDH	0.028	0.029	100%	0.058
	CR_FDH	0.129	0.138	94.9%	0.006*
Equitymarket	CE_FDH	0.012	0.013	100%	0.258
	CR_FDH	0.008	0.009	98.9%	0.526
Smartenterprise	CE_FDH	0.026	0.028	100%	0.000*
	CR_FDH	0.103	0.110	92.0%	0.000*
Entrepreneurship	CE_FDH	0.019	0.020	100%	0.041*
	CR_FDH	0.038	0.040	97.8%	0.073

study employs two different estimation methods, namely Upper Limit Regression Analysis (CR) and Upper Limit Envelope Analysis (CE), to analyze the effect sizes of the five antecedent conditions, as in Table 3.

Table 3 shows that Greencredit and Smartenterprise are statistically significant with impact sizes larger than 0.1 when using the CR approach. For these variables, the C-accuracy values are both less than 0.5. According to the criteria for determining necessary conditions in the NCA method, they cannot be considered necessary conditions. To conclude, none of the six antecedent conditions are deemed necessary for achieving high-level green economic efficiency.

Bottleneck analysis can explain the necessary levels of antecedent conditions required to achieve different levels of the dependent variable. Therefore, we used Upper Limit Regression Analysis (CR) for examination. Table 4 presents the results, indicating that to achieve 100% green innovation efficiency, 32.1% environmental regulation, 13.4% environmental subsidies, 61.6% green credit market, 79.6% green equity market, 84.1% smart enterprise level, and 52.9% entrepreneurial vitality are required. On the one hand, the importance of Greencredit, Equitymarket, Smartenterprise, and Entrepreneurship related to corporate activities is relatively high, all exceeding 50%. This may be because,

Table 4. Bottleneck analysis results.

GEE	Regulation	Support	Greencredit	Equitymarket	Smartenterprise	Entrepreneurship
0~50%	NN	NN	NN	NN	NN	NN
60%	NN	NN	6.4	NN	NN	NN
70%	NN	NN	20.2	NN	NN	NN
80%	NN	NN	34.0	NN	19.7	NN
90%	13.2	NN	47.8	NN	51.9	18.1
100%	32.1	13.4	61.6	79.6	84.1	52.9

Note: NN means unimportant.

Table 5. Sufficiency Analysis results.

Model	S1	S2	S3	S4
Regulation		●		●
Support			●	●
Greencredit	●	●	●	
Equitymarket	⊗	•		●
Smartenterprise	●	●	●	●
Entrepreneurship	●		●	•
Raw coverage	0.375	0.378	0.451	0.313
Unique coverage	0.013	0.015	0.057	0.007
Consistency	0.898	0.893	0.868	0.899
Solution coverage	0.512			
Solution consistency	0.869			

as the main body of market activities, enterprises are indispensable for improving the overall green economic efficiency of the city. They are able to make independent decisions to a certain extent and have the ability to take different measures to meet the requirements of urban green development. On the other hand, the importance of "Regulation" and "Support" is relatively low, which may be because in the context of green development, the government may provide more support for institutional environment and market mechanisms rather than direct intervention. Therefore, as a necessary condition, its importance is relatively low.

Sufficiency Analysis

This study utilized the fsQCA method for configurational analysis with a configuration consistency threshold of 0.8, a case frequency threshold of 1, and a PRI consistency level of 0.6 [43]. When a solution simultaneously appears in both parsimonious and intermediate solutions, it is classified as a core condition, while if it only appears in intermediate solutions, it is called a marginal condition. In simpler terms, there is a strong causal relationship between the core condition and the outcome variable, while the causal relationship between the marginal condition and the outcome variable is weak. In different combinations, only when the prerequisite conditions for the existence or absence of the core condition are met can this combination be further discussed. Table 5 presents the specific results. In the table, '●' indicates the presence of a core condition, '•' indicates the presence of a marginal condition, '⊗' indicates the absence of a core condition, and a blank cell indicates a condition that can either be present or absent. The results show a consistency of 0.869, surpassing the 0.8 threshold, indicating the overall effectiveness of these solutions. Furthermore, the coverage rate of the solutions is 0.512, exceeding 0.5, signifying that these solutions can cover 51.2% of the sampled cities.

As per Table 5, S1 to S4 depict the configurational conditions for green economic efficiency in four case cities, representing four equivalent pathways to achieve high levels of green economic efficiency

(GEE). This illustrates the feature of several convergent and simultaneous routes towards urban GEE. Based on the results in Table 5, the configurational types for GEE in the case cities are categorized into four types (where '*' denotes 'and').

Credit * Smart * Entrepreneurship-Driven Configuration. According to configuration H1, cities can attain high levels of green economic efficiency provided they meet certain fundamental requirements, including high enterprise intelligence, high levels of green credit assistance, high levels of entrepreneurial vitality, and a non-high green equity trading market.

This suggests that in cities where the development level of the green equity trading market is not high, the government can achieve high levels of GEE by supporting financial institutions in green credit business while encouraging the intelligent transformation of enterprises and stimulating entrepreneurial vitality. This may be because in regions where the green equity trading market is not yet widespread, businesses lack positive incentives from green equity trading. Therefore, on the one hand, support from financial institutions in the green credit business is required to alleviate operational and financial risks brought about by green innovation. On the other hand, starting from the business side, while stimulating intelligent transformation and promoting entrepreneurial spirit, it is imperative to accelerate the renewal of zombie enterprises, increase market competitiveness, and drive enterprises towards green transformation, thereby enhancing green economic efficiency.

Regulation * Credit * Smart-Driven Configuration. Configuration H2 suggests that, under the core conditions of high environmental regulation, high green credit support, and high enterprise intelligence, along with the green equity trading market as a marginal condition, cities can achieve high levels of green economic efficiency. Cities with such configuration elements often have strong government intervention in the economy. Regardless of the development of the green equity trading market, local government can always constrain enterprises to participate in green production through environmental regulation policies, reducing environmental pollution. Even if the depth of the green equity trading market falls short of expectations, businesses will still face strong external constraints. In addition, cities with high levels of enterprise intelligence enable the promotion of big data platform construction and supply-chain transformation, allowing less intelligent enterprises to share cashless green production technologies. This facilitates intelligent and green transformation, reduces production energy consumption, and ultimately achieves the overall green development of the city's economy.

Subsidy * Credit * Smart * Entrepreneurship-Driven Configuration. Configuration H3 indicates that cities with high levels of environmental protection subsidies, high green credit support, high enterprise intelligence, and high entrepreneurial vitality as core conditions can achieve high green economic efficiency. In such cities, the government tends to invest in environmental protection for enterprises and various production sectors. Businesses that get government funding for environmental conservation frequently update the financial market with good news, showing that they are pursuing green innovation and garnering significant government interest for further growth. Therefore, with the support of the well-established green credit support system of financial institutions, these enterprises not only receive government environmental protection subsidies but also assistance from financial institutions in the financial market. They work together to coordinate the green transformation of regional firms through the external spillover effects of green innovation. Moreover, high levels of intelligence and entrepreneurial vitality in the market imply intense competition. Businesses frequently speed up digitization and greening to attract investors. This increases their competitiveness, stabilizes their market share, and steadily raises the city's economy's overall green efficiency.

Regulation * Subsidy * Equity * Smart-Driven Configuration. Configuration H4 indicates that cities with high levels of environmental regulation, high protection subsidies, high green equity trading market development, and high enterprise intelligence, supplemented by high entrepreneurial vitality as a marginal condition, can achieve high levels of GEE. In such cities, the government plays the dual role of punisher and motivator, providing environmental protection subsidies to enterprises and relevant departments that comply with green production while penalizing producers in highly polluting industries. In addition, enterprise behavior in the equities trading market can also be restrained by the highly developed green equity trading market and government intervention in economic operations, avoiding the emergence of irregular equity trading behavior under the self-operation of the market economy. The high intelligence of enterprises in the city raises the level of digital technology, and under the multiple drives of punitive measures in environmental regulation, environmental protection subsidies, and trading benefits in the equity market, enterprises will increase awareness of using big data platform information-sharing functions, improve consciousness of digital and green transformation, consciously reduce carbon emissions, and achieve high levels of GEE in the city's development.

Robustness Analysis

First, drawing on previous research [45], this study adjusted the configurational consistency threshold from 0.8 to 0.749 and re-implemented the tests. The results indicated a solution coverage of 0.512 and a solution consistency of 0.869. Second, this study adjusted the PRI consistency threshold to 0.5, as suggested by Greckhamer et al. [46]. The tests yielded a solution coverage of 0.628 and a solution consistency of 0.822. To avoid duplication and save space, no additional table is added. To summarize, the research conclusions remain robust through heterogeneity tests.

Conclusions

This study, based on the perspective of green economic efficiency (GEE), utilized 276 Chinese cities as case studies. It used a mixed method of fsQCA and NCA to examine the intricate causal linkages between urban six condition variables and green economic efficiency: environmental regulation, environmental subsidies, green finance, green equity market, corporate intelligence level, and entrepreneurial vitality.

The conclusions drawn are as follows: First, those six condition variables and urban GEE are highly correlated. To achieve a 100% level of urban green economic efficiency, cities need to reach at least 32.1% in environmental regulation, 13.4% in environmental subsidies, 61.6% in the green credit market, 79.6% in the green equity market, 84.1% in corporate intelligence, and 52.9% in entrepreneurial vitality.

Second, the combination of several elements in the urban economic environment leads to high-level green economic efficiency in cities. There are four paths to achieving this: credit * smart * entrepreneurship-driven, regulation * credit * smart-driven, subsidy * credit * smart * entrepreneurship-driven, and regulation * subsidy * equity * smart-driven. These paths reflect diverse implementation methods of urban green economic efficiency in different locations and development conditions.

Lastly, while no single factor is a necessary condition for achieving high urban green economic efficiency, corporate intelligence level is a core condition on all four paths. This shows the importance of digitization in the green transformation of urban production, highlighting the strong universality of constructing a high-quality digital innovation environment for GEE.

Policy Recommendations

On the one hand, the urban green economy should focus on the improvement of the green finance system. The government should actively motivate market entities to participate in green development and innovation. This can be achieved by further designing policy reward mechanisms, incentivizing financial institutions to develop diverse green finance products, and investing in enterprise green technological innovation. Positive incentives, like different reserve ratios and low-interest refinancing, should be given to financial institutions that perform very well at the end of the year. Through incentive mechanisms, this method seeks to increase the urban GEE. On the other hand, the urban green economy should pay attention to digital transformation. Enterprises should attach great importance to the driving role of digital transformation in their green transformation and enhanced market competitiveness, actively promoting the establishment of a reward mechanism for digital innovation achievements. This will encourage the emergence of digital innovation achievements among internal employees, which play a positive role in achieving enterprise digital transformation. At the same time, the government should accelerate the popularization and promotion of digital information technology, ensuring that everyone, from top management to every departmental employee, possesses a relatively comprehensive knowledge of internet information.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. FAROOQ M.U., SHAHZAD U., SARWAR S., LI Z.J. The impact of carbon emission and forest activities on health outcomes: empirical evidence from China. Environmental Science and Pollution Research. **26** (13), 12894, **2019**.
2. HE B., YU X.X., HO S.E., ZHANG X.Y., XU D. Does China's Two-Way FDI Coordination Improve Its Green Total Factor Productivity? Polish Journal of Environmental Studies. **33** (1), 173, **2024**.
3. Shao Q.L. Paving ways for a sustainable future: a literature review. Environmental Science and Pollution Research. **27**, 13032, **2020**.
4. LUO K., LIU Y., CHEN P.F., ZENG M. Assessing the impact of digital economy on green development efficiency in the Yangtze River Economic Belt. Energy Economics. **112**, 106127, **2022**.
5. FUKUYAMA H., WEBER W.L. A directional slacks-based measure of technical inefficiency. Socio-Economic Planning Sciences. **43** (4), 274, **2009**.
6. ZHANG J. Estimation of China's provincial capital stock (1952-2004) with applications. Journal of Chinese Economic and Business Studies. **6** (2), 177, **2008**.
7. REZA-GHAREHBAGH R., HAFEZALKOTOB A., MAKUI A., SAYADI M.K. Financing green technology development and role of digital platforms: Insourcing vs. outsourcing. Technology in Society. **69**, 101967, **2022**.
8. JIANG Q., LI J., SI H., SU Y. The Impact of the Digital Economy on Agricultural Green Development: Evidence from China. Agriculture. **12** (8), 1107, **2022**.
9. ISHIDA H. The effect of ICT development on economic growth and energy consumption in Japan. Telematics and Informatics. **32** (1), 79, **2015**.

10. GUAITA MARTÍNEZ J.M., PUERTAS R., MARTÍN MARTÍN J.M., RIBEIRO-SORIANO D. Digitalization, innovation and environmental policies aimed at achieving sustainable production. Sustainable Production and Consumption. **32**, 92, **2022**.
11. LV C., FAN J., LEE C.C. Can green credit policies improve corporate green production efficiency? Journal of Cleaner Production. **397**, 136573, **2023**.
12. WANG Y., LEI X., LONG R., ZHAO J. Green Credit, Financial Constraint, and Capital Investment: Evidence from China's Energy-intensive Enterprises. Environmental Management. **66** (6), 1059, **2020**.
13. SU X., PAN C., ZHOU S., ZHONG X. Threshold effect of green credit on firms' green technology innovation: Is environmental information disclosure important? Journal of Cleaner Production. **380**, 134945, **2022**.
14. ZHANG M., LI X., PAI C.H., DING H., ZHANG X. Green credit and fossil fuel resource efficiency: Advancing sustainability in Asia. Resources Policy. **86**, 104204, **2023**.
15. KONG F., WANG Y. How to understand carbon neutrality in the context of climate change? With special reference to China. Sustainable Environment. **8** (1), **2022**.
16. KURNIAWAN T.A., LIANG X., O'CALLAGHAN E., GOH H., OTHMAN M.H.D., AVTAR R., KUSWORO T.D. Transformation of Solid Waste Management in China: Moving towards Sustainability through Digitalization-Based Circular Economy. Sustainability. **14** (4), 2374, **2022**.
17. JIANG Y., NI H., NI Y., GUO X. Assessing environmental, social, and governance performance and natural resource management policies in China's dual carbon era for a green economy. Resources Policy. **85**, 104050, **2023**.
18. XIONG W., JIANG M., TASHKHODJAEV M., PASHAYEV Z. Greening the economic recovery: Natural resource market efficiency as a key driver. Resources Policy. **86**, 104268, **2023**.
19. SCHNEIDER C.Q., WAGEMANN C. Set-Theoretic Methods for the Social Sciences. Cambridge University Press. **2012**.
20. VIS B., DUL J. Analyzing Relationships of Necessity Not Just in Kind But Also in Degree. Sociological Methods & Research. **47** (4), 872, **2016**.
21. World Investment Report 2018. UNCTAD. **2018**.
22. ZHENG Y., LI C., LIU Y. Impact of environmental regulations on the innovation of SMEs: Evidence from China. Environmental Technology & Innovation. **22**, 101515, **2021**.
23. SHAO Y., CHEN Z. Can government subsidies promote the green technology innovation transformation? Evidence from Chinese listed companies. Economic Analysis and Policy. **74**, 716, **2022**.
24. DONG Z., HE Y., WANG H., WANG L. Is there a ripple effect in environmental regulation in China? – Evidence from the local-neighborhood green technology innovation perspective. Ecological Indicators. **118**, 106773, **2020**.
25. SHUAI S., FAN Z. Modeling the role of environmental regulations in regional green economy efficiency of China: Empirical evidence from super efficiency DEA-Tobit model. Journal of Environmental Management. **261**, 110227, **2020**.
26. PORTER M.E. Essay. Scientific American. **264** (4), 168, **1991**.
27. AMBEC S., COHEN M.A., ELGIE S., LANOIE P. The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? Review of Environmental Economics and Policy. **7** (1), 2, **2013**.
28. FAROOQ U., WEN J., TABASH M.I., FADOUL M. Environmental regulations and capital investment: Does green innovation allow to grow? International Review of Economics & Finance. **89**, 878, **2024**.
29. HUANG Z., LIAO G., LI Z. Loaning scale and government subsidy for promoting green innovation. Technological Forecasting and Social Change. **144**, 148, **2019**.
30. PLANK J., DOBLINGER C. The firm-level innovation impact of public R&D funding: Evidence from the German renewable energy sector. Energy Policy. **113**, 430, **2018**.
31. SHAO Y., CHEN Z. Can government subsidies promote the green technology innovation transformation? Evidence from Chinese listed companies. Economic Analysis and Policy. **74**, 716, **2022**.
32. DUQUE-GRISALES E., AGUILERA-CARACUEL J., GUERRERO-VILLEGAS J., GARCÍA-SÁNCHEZ E. Does green innovation affect the financial performance of Multilatinas? The moderating role of ISO 14001 and R&D investment. Business Strategy and the Environment. **29** (8), 3286, **2020**.
33. THOMPSON P., COWTON C.J. Bringing the environment into bank lending: implications for environmental reporting. The British Accounting Review. **36** (2), 197, **2004**.
34. JEUCKEN M. Sustainable Finance and Banking: The Financial Sector and the Future of the planet. Earthscan Publications Ltd. London **2001**.
35. HE L., ZHANG L., ZHONG Z., WANG D., WANG F. Green credit, renewable energy investment and green economy development: Empirical analysis based on 150 listed companies of China. Journal of Cleaner Production. **208**, 363, **2019**.
36. HARIHARAN D., REDDY D. Impact of Waste Management Policies and Use of Green Energy Sources to Reduce Environmental Pollution in the Global Business Market Atmosphere. Technoarete Transactions on Renewable Energy, Green Energy and Sustainability. **2** (2), **2022**.
37. HOPENHAYN H. Firms, Misallocation, and Aggregate Productivity: A Review. Annual Review of Economics. **6** (1), 735, **2014**.
38. NAMBISAN S., LYYTINEN K., MAJCHRZAK A., SONG M. Digital Innovation Management: Reinventing Innovation Management Research in a Digital World. MIS Quarterly. **41** (1), 223, **2017**.
39. LYU W., LIU J. Artificial Intelligence and emerging digital technologies in the energy sector. Applied Energy. **303**, 117615, **2021**.
40. HUTCHINSON P. Reinventing Innovation Management: The Impact of Self-Innovating Artificial Intelligence. IEEE Transactions on Engineering Management. **68** (2), 628, **2021**.
41. POPKOVA E.G., INSHAKOVA A.O., BOGOVIZ A.V., LOBOVA S.V. Energy Efficiency and Pollution Control Through ICTs for Sustainable Development. Frontiers in Energy Research. **9**, **2021**.
42. NOSELEIT F. Entrepreneurship, structural change, and economic growth. Journal of Evolutionary Economics. **23** (4), 735, **2012**.
43. FISS P.C. Building Better Causal Theories: A Fuzzy Set Approach to Typologies in Organization Research. Academy of Management Journal. **54** (2), 393, **2011**.

44. TONE K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research. **130** (3), 498, **2001**.
45. CRILLY D., ZOLLO M., HANSEN M.T. Faking It or Muddling Through? Understanding Decoupling in Response to Stakeholder Pressures. Academy of Management Journal. **55** (6), 1429, **2012**.
46. GRECKHAMER T., FURNARI S., FISS P.C., AGUILERA R.V. Studying configurations with qualitative comparative analysis: Best practices in strategy and organization research. Strategic Organization. **16** (4), 482, **2018**.