International Business & Economics Studies
ISSN 2640-9852 (Print) ISSN 2640-9860 (Online)
Vol. 8, No. 2, 2026
www.scholink.org/ojs/index.php/ibes

Original Paper

Configurational Paths and Dynamic Mechanisms of "Quantitative-Qualitative Synergistic Improvement" in Low-Carbon Innovation in Energy-Rich Regions from the Perspective of Carbon Neutrality

Lin Chen[1] & Changheng Wang[1]

[1] School of Management, Shandong University of Technology, Zibo 255012, China

Received: April 26, 2026 Accepted: May 17, 2026 Online Published: June 3, 2026
doi:10.22158/ibes.v8n2p241 URL: http://dx.doi.org/10.22158/ibes.v8n2p241

Abstract

Driven by the global carbon neutrality agenda and China's high-quality development strategy, energy-rich regions, as the main body of national energy security supply and key areas of carbon emission control, are facing severe challenges and strategic opportunities for low-carbon transition. Resolving the theoretical dilemma and practical bottleneck of the uncoordinated evolution between "quantitative expansion" and "qualitative improvement" in low-carbon innovation activities in such regions has become a critical scientific issue urgently to be addressed. Following the logical paradigm of "Motivation→Behavior→ Countermeasures", this study integrates configurational theory and system dynamics thinking to construct an integrated analytical framework for "quantitative-qualitative synergistic improvement" in low-carbon innovation in energy-rich regions. By combining content analysis, expert surveys and group fuzzy decision-making trial and evaluation laboratory method, this study identifies multi-dimensional key factors driving "quantitative-qualitative synergistic improvement" in low-carbon innovation; furthermore, fuzzy-set qualitative comparative analysis is employed to reveal multiple equivalent configurational paths driving high patent output, high economic benefits and high comprehensive innovation quality. The findings show that a single factor is not a necessary condition for success, while the non-linear complex coupling of multi-dimensional factors such as technology, institution and environment constitutes the core dynamic mechanism. The conclusions clarify the realization logic of "quantitative-qualitative synergistic improvement" from dynamic and global perspectives, and provide theoretical basis and practical guidance for energy-rich regions to formulate differentiated low-carbon innovation strategies according to local conditions and achieve sustainable *development under the goal of carbon neutrality.*

Keywords

energy-rich regions, low-carbon innovation, quantitative-qualitative synergistic improvement, configurational analysis, dynamic mechanism

1. Introduction

Against the profound reshaping of the global climate governance pattern and the solemn commitment of China's "dual carbon" goal, promoting the comprehensive green transformation of economic and social development has evolved from an "optional question" to a "must-answer question" (Wu Chuanqing et al., 2023). Energy-rich regions, as the core production areas of national strategic fossil energy and clean energy, have long shouldered the important mission of ensuring energy supply, but have simultaneously formed a heavy chemical industrial structure characterized by high carbon emissions. Such regions generally face practical dilemmas including sharp contradictions between economic growth and environmental protection, weak sustainable development capacity, and enormous pressure of low-carbon transition (Song Yongyong et al., 2024). Therefore, systematically exploring how energy-rich regions break through the "high-carbon lock-in" effect and realize "quantitative-qualitative synergistic improvement" of low-carbon innovation—that is, while expanding the innovation scale of green technology patents, low-carbon products and so on, significantly improving the contribution of innovation to core goals such as carbon emission reduction performance and high-quality economic development—has become a core topic with both theoretical frontier and practical urgency.

Existing studies have laid an important foundation for understanding low-carbon innovation. Scholars have conducted extensive exploration from the dimensions of connotation definition, development measurement (Liang Wenqun et al., 2019; Zhang Liao et al., 2020) and influencing factors (Zhou Zhifang et al., 2019; Hou Jian et al., 2024) of low-carbon innovation, and gradually realized that the importance of innovation quality has increasingly surpassed simple innovation quantity (Yu Liping et al., 2020; Zhang Hong et al., 2025). In view of the particularity of energy-rich regions, some studies have begun to focus on their economic resilience (Tang Yu et al., 2022), industrial transformation (Jiang Haining et al., 2020) and environmental regulation effect (Lai Xiaodong et al., 2023). However, systematically reviewing the existing achievements, three major theoretical gaps can be found: first, most studies tend to adopt the net effect thinking to explore the linear impact of a single factor, which is difficult to reveal the complex complementary, substitution or inhibitory relationships among multiple factors, resulting in insufficient analysis of the complex dynamic mechanism of "quantitative-qualitative synergistic improvement" in low-carbon innovation. Second, the research methods are dominated by static panel data analysis, lacking forward-looking simulation and verification of realization paths from the perspective of dynamic evolution and system simulation. Third, existing studies mostly focus on the national, provincial or general urban levels, and the refined and systematic research on energy-rich regions with strong uniqueness in resource endowment, industrial structure and ecological constraints is still scarce.

To bridge the above theoretical gaps, this study proposes the following core research questions: What are the key factors driving “quantitative-qualitative synergistic improvement” in low-carbon innovation in energy-rich regions? How do these factors form different dynamic configurations through complex non-linear coupling? How do different configurational paths guide differentiated implementation strategies? To this end, this study will follow the overall idea of “theoretical analysis → factor identification → configurational analysis → path interpretation”, and comprehensively use content analysis method, Delphi expert survey method and fuzzy-set qualitative comparative analysis to construct an integrated analytical framework. This study aims to reveal the “different paths leading to the same goal” of “quantitative-qualitative synergistic improvement” in low-carbon innovation in energy-rich regions from a configurational perspective, provide precise decision-making references beyond the “one-size-fits-all” model for policymakers and enterprise managers, and help energy-rich regions achieve high-quality development in the carbon neutrality era.

2. Theoretical Basis and Analytical Framework

2.1 Connotation Definition of “Quantitative-Qualitative Synergistic Improvement” in Low-Carbon Innovation in Energy-Rich Regions

Low-carbon innovation is not a single technological breakthrough, but a systematic process of the co-evolution of technological paradigm, institutional structure and industrial ecology, whose core purpose is to achieve substantial decoupling between economic development and carbon emissions (Wu Chuanqing et al., 2023). For energy-rich regions, this concept has specific situational connotations. Firstly, the “quantity” of innovation reflects the scale and breadth of innovation activities directly related to low-carbon transition, such as the number of low-carbon technology patent applications, total R&D investment in green technologies, and the number of clean energy projects. Secondly, the “quality” of innovation refers to the actual contribution efficiency of innovation activities to regional sustainable development, specifically characterized by: first, the improvement of carbon emission reduction performance, that is, a significant decline in carbon emission intensity per unit GDP; second, the simultaneous growth of economic benefits to avoid economic stall caused by “campaign-style” carbon reduction; third, the embeddedness and autonomy of the technological system, that is, the formation of low-carbon technology clusters with core competitiveness deeply integrated with the local industrial foundation.

Therefore, “quantitative-qualitative synergistic improvement” of low-carbon innovation in energy-rich regions specifically refers to the synchronous, coordinated and mutual promotion of scale expansion and efficiency improvement in their low-carbon innovation activities in the process of moving towards the carbon neutrality goal, effectively avoiding the “patent bubble” of “quantity without quality” or shrinking emission reduction of “sluggish growth”, and finally leading to a new paradigm of green high-quality development with more resilience and inclusiveness.

2.2 Theoretical Basis: Integration of Configurational Perspective and System Dynamics

Traditional regression analysis based on net effect is based on the assumption that each influencing factor is independent and acts on the outcome variable linearly superposed. However, the low-carbon innovation system in energy-rich regions is a typical complex socio-technical system intertwined with multiple factors and non-linear interactions. The effect of a certain factor often highly depends on the existence of other factors. To solve this complex causal problem, this study introduces configurational theory. The theory holds that the outcome at the phenomenal level is often not driven by a single condition, but equivalently caused by a variety of "configurations" composed of multiple interdependent and combined conditions. This provides a powerful theoretical lens for explaining the practical phenomenon that different energy-rich regions can achieve "quantitative-qualitative synergistic improvement" even if they adopt different strategies and rely on different advantages.

Furthermore, to make up for the lack of static configurational analysis in explaining the process dynamics, this study integrates system dynamics thinking. System dynamics is good at describing the causal feedback loops, time delays and non-linear dynamic behaviors among multi-variables in complex systems. The combination of the two means that firstly, fsQCA is used to identify the key conditional configurations leading to "quantitative-qualitative synergistic improvement" from cross-sectional data, and then system dynamics model is used to simulate and deduce the strategic paths represented by these configurations, observing the evolution trajectory and long-term effects of internal and external factors at different time scales, so as to realize the methodological leap from "factor combination" to "process simulation".

2.3 Construction of "Motivation → Behavior → Countermeasures" Integrated Analytical Framework

Based on the above theoretical integration, this study constructs a three-level progressive logical framework (Figure 1, conceptual diagram). The first level is motivation analysis: aiming to systematically identify the key internal driving factors of "quantitative-qualitative synergistic improvement" in low-carbon innovation in energy-rich regions, such as enterprise digital capability and R&D talent agglomeration, and external situational factors, such as government subsidy intensity and carbon trading market maturity. The second level is behavior analysis: as the core of the analysis, configurational thinking and dynamic simulation are used to explore how these key factors trigger and continuously promote the system behavior of "quantitative-qualitative synergistic improvement" in different combinations. Different configurations represent different "behavior patterns" or "strategic formulas" to achieve the same goal. The third level is countermeasure analysis: based on the identified configurational paths and simulation results, refine situational matching and differentiated policy toolkits and management countermeasures to provide precise path navigation for different types of energy-rich regions.

The framework follows the logical chain of "Motivation → Configurational Behavior and Dynamic Path → Differentiated Countermeasures", aiming to systematically open the theoretical black box of the complex process of "quantitative-qualitative synergistic improvement" in low-carbon innovation in energy-rich regions.

3. Research Design and Methods

3.1 Research Methodology System

To achieve the research objectives, this study adopts a diversified combination of methods to form triangulation. Firstly, content analysis method is used to code 263 high-quality literatures on "low-carbon innovation" and "energy-rich regions" in CNKI and Web of Science Core Collection to preliminarily outline the driving factors. Secondly, two rounds of Delphi expert surveys are conducted. Twenty-five experts from universities, government think tanks and energy enterprises are invited to evaluate the importance of 22 initially selected factors, and the core factor set is streamlined by calculating the expert coordination coefficient (Kendall's W) and coefficient of variation. Thirdly, group fuzzy decision-making trial and evaluation laboratory method is adopted to analyze the causal hierarchy and correlation strength among core factors by constructing a direct influence matrix, and identify causal factors and result factors. Finally, based on the panel data of 15 typical energy-rich prefecture-level cities in China, such as Yulin, Ordos, Datong and Liupanshui from 2015 to 2022, fuzzy-set qualitative comparative analysis is used to solve and deconstruct the conditional configurations leading to a high degree of "quantitative-qualitative synergistic improvement".

3.2 Variable Measurement and Calibration

(1) Outcome variable: comprehensive index of "quantitative-qualitative synergistic improvement" in low-carbon innovation. To avoid the one-sidedness of a single index, this study constructs a two-dimensional comprehensive evaluation system. The dimension of "quantity" is measured by the number of green patent applications per unit GDP. The dimension of "quality" integrates: (a) cited frequency of green patents; (b) industrial added value per unit carbon emission; (c) diffusion breadth of low-carbon technologies in local non-energy industries. The final comprehensive index is synthesized by weighting the above indicators through the entropy weight method. Cities with high annual growth rate and high absolute value of the comprehensive index are defined as achieving "quantitative-qualitative synergistic improvement".

(2) Condition variables. Based on literature review and expert survey, 6 key antecedent conditions are finally included: internal factors include (a) digital infrastructure level, (b) human capital reserve, (c) traditional industrial technology lock-in effect; external factors include (d) government environmental regulation intensity, (e) marketization degree, (f) carbon market policy dummy variable.

(3) Data calibration. Before fsQCA analysis, all variables need to be converted into fuzzy set membership scores between 0 and 1. This study adopts the direct calibration method and sets three qualitative anchors: full membership, crossover point and full non-membership. For the reverse indicator of "traditional industrial technology lock-in effect", reverse calibration is carried out.

4. Configurational Paths and Dynamic Mechanism Analysis

4.1 Necessity Analysis of a Single Condition

Firstly, this paper tests whether there is a necessary condition leading to “quantitative-qualitative synergistic improvement” in low-carbon innovation in energy-rich regions. The analysis results show that the consistency level of all single conditions (including their negation sets) is lower than the critical threshold of 0.9. This indicates that there is no single indispensable “killer” factor. In other words, neither high-intensity environmental regulation nor superior digital foundation can alone guarantee the realization of “quantitative-qualitative synergistic improvement”. This finding strongly supports the necessity of adopting the configurational perspective in this study.

4.2 *Sufficiency Analysis of Conditional Configurations*

By constructing a truth table, setting the frequency threshold as 1 and the original consistency threshold as 0.8, standardized analysis is conducted on the configurations leading to a high degree of “quantitative-qualitative synergistic improvement”. The analysis results reveal three equivalent paths with significant explanatory power. The consistency of the overall solution is 0.91 and the coverage is 0.67, indicating that these configurations have strong explanatory power for the outcome. The three core paths can be summarized as follows:

Path 1: Technology-Institution Dual-Wheel Drive Type. The core condition combination of this path is: high digital infrastructure level + high human capital reserve + strong environmental regulation. This configuration shows that for energy-rich regions with good digital foundation and abundant talent reserves, the implementation of high-intensity environmental regulation can produce a strong “Porter effect”, forcing enterprises to use existing digital and technological advantages to carry out high-quality low-carbon innovation. In this scenario, the existence of marketization degree and carbon market policy is not decisive.

Path 2: Market-Policy Collaborative Innovation Type. The characteristic conditions of this path are: high marketization degree + included in carbon trading pilot policy + weak traditional industrial lock-in. This path is applicable to regions where although the initial digital and talent advantages are not prominent, the market vitality is abundant and they have been included in the national carbon market control. The stable price signal and quota constraint formed by the carbon market, together with the high marketization degree, can effectively hedge the path dependence of traditional high-carbon industries, guide capital and talents to independently flow to low-carbon innovation fields, and realize the synchronous growth of “quality” and “quantity”.

Path 3: Endogenous Capacity Compensation Type. This path is manifested as: high human capital reserve + weak traditional industrial lock-in + strong environmental regulation. This configuration reveals an important phenomenon: in energy-rich regions where the external market environment and digital infrastructure are not perfect, by concentrating resources to cultivate high-skilled human capital and cooperating with strong environmental regulation to break the old technological lock-in, low-carbon innovation can be directly empowered. Under this path, the driving force of innovation mostly comes from internal knowledge accumulation and direct guidance of government policies, rather than completely relying on the spontaneous order of the market.

4.3 Configurational Interpretation of Dynamic Mechanism

The above findings profoundly reveal the non-linear, equivalent and complementary dynamic mechanism of "quantitative-qualitative synergistic improvement" in low-carbon innovation in energy-rich regions. Firstly, the non-linearity of the mechanism lies in that high marketization degree is a necessary condition in Path 2, but not a core condition in Path 1, and its importance fluctuates with the situation. Secondly, the equivalence of the mechanism lies in that the three paths start from three distinct logical starting points of "technology-institution", "market-policy" and "human power-regulation", and lead to the same ideal result by different paths. Finally, the complementarity of the mechanism is reflected among various factors: for example, in Path 1, strong digital infrastructure compensates for the lack of market signals; in Path 3, strict environmental regulation compensates for the lack of market-oriented environment. This complex coupling relationship shows that the effectiveness of any single policy is highly dependent on its supporting combination, and policy formulation must shift from the "best practice" thinking to the "situational adaptation" thinking.

5. Conclusion and Countermeasures

5.1 Main Conclusions

Based on configurational theory and system dynamics thinking, this study constructs and empirically tests an integrated analytical framework for "quantitative-qualitative synergistic improvement" in low-carbon innovation in energy-rich regions, and draws the following core conclusions: First, the "quantitative-qualitative synergistic improvement" of low-carbon innovation in energy-rich regions is a process driven by the complex coupling of multi-dimensional factors such as technology, human resources, institution, market and policy, and there is no single path, which is essentially the non-linear system emergence result of multiple factor combinations. Second, three equivalent and realizable configurational paths are identified: "technology-institution dual-wheel drive", "market-policy collaborative innovation" and "endogenous capacity compensation", confirming multiple "formulas" to achieve the same strategic goal. Third, the "net effect" of a single factor is highly situation-dependent, and its action direction and intensity are determined by the conditional configuration it is in, which explains why similar policies implemented in different energy-rich regions produce different effects.

5.2 Theoretical Contributions and Practical Implications

This study goes beyond the traditional net effect linear thinking, introduces configurational theory into the research of low-carbon innovation in energy-rich regions, and provides a causal explanation framework closer to the real complexity. Secondly, it constructs and verifies the integrated logic of "Motivation → Behavior → Countermeasures", systematically responds to the core theoretical problem of "how quantity and quality coordinate" in low-carbon innovation, and enriches the regional innovation management theory under the background of carbon neutrality. Finally, by revealing multiple groups of equivalent paths, it provides a new perspective and theoretical evidence for resolving the paradoxical relationship between “resource curse” and “innovation-driven”.

Practical Implications: First, abandon the “copy-paste” policy transplantation. Governments of all energy-rich regions should select the development path that best matches their own resource endowment based on the accurate diagnosis of local digital foundation, human capital stock, marketization degree and industrial lock-in characteristics. For example, regions with abundant scientific and educational resources such as Xi’an and Xuzhou can focus on Path 1, while regions such as Ordos that have been included in the carbon market can prioritize Path 2. Second, build a coordinated policy package. Policy design should shift from a single tool to a combination punch. While implementing the carbon trading policy, it is necessary to support the construction of local talent training system and intermediary service platforms to promote technology diffusion. While strengthening environmental regulation, it is necessary to supplement investment in digital infrastructure to help enterprises reduce compliance and innovation costs. Third, dynamic monitoring and adaptive adjustment. In view of the dynamics of the system, the region’s development stage and configuration conditions should be reviewed regularly, and the policy combination should be adjusted predictively to ensure that the selected path can continue to produce positive effects, and finally help energy-rich regions successfully move towards a green, prosperous and sustainable carbon-neutral future while ensuring national energy security.

References

Cao, X., Hayyat, M., & Henry, J. (2025). Green energy investment and technology innovation for carbon reduction: Strategies for achieving SDGs in the G7 countries. *International Journal of Hydrogen Energy*, *114*, 209-220.

He, R., Wan, P., & Yang, M. (2024). The resource curse in energy-rich regions: Evidence from China’s ultra-high voltage transmission. *Energy*, *304*, 132153.

Hou, J., & Kang, W. (2024). Intelligence, industrial transformation and upgrading, and low-carbon technology innovation. *Journal of Management Review*, *36*(9), 96-106.

Jin, J., Chen, T. L., Zhao, Y. T. et al. (2025). Collaborative digital and green transformation of industries empowering new quality productivity: Logic and approach. *R&D Management*, (1), 74-84.

Lai, X. D., & Zhan, W. L. (2023). Impact of energy-saving and emission reduction policy of 10,000 enterprises on green technology innovation of enterprises and its internal mechanism. *China Population, Resources and Environment*, *33*(4), 104-114.

Li, X. H., & Tao, Y. T. (2023). Measurement, regional differences and cause identification of China’s green low-carbon innovation development under the “dual carbon” goal. *China Population, Resources and Environment*, *33*(1), 124-136.

Liang, W. Q., Qin, T. R., & Liang, P. (2019). Classification measurement and comparison of regional green low-carbon innovation efficiency in China. *Journal of Arid Land Resources and*

Environment, *33*(11), 9-16.

Liu, J., Zhang, J., Ma, X. et al. (2024). The road to sustainable development: Can the new energy demonstration city policy promote the industrial structure transformation?. *Renewable Energy*, *237*(PB), 121721.

Lyu, Y., Bai, Y., & Zhang, J. (2024). Digital transformation and enterprise low-carbon innovation: A new perspective from innovation motivation. *Journal of Environmental Management*, *365*, 121663.

Tang, X., Feng, J., Mao, X. et al. (2024). Will technological innovation uncertainty affect the distribution of benefits from low-carbon innovation activities in industrial clusters?—A study based on gray Shapley values. *Managerial and Decision Economics*, *45*(4), 1743-1755.

Meng, X., & Zhu, P. F. (2025). Research on the effect and mechanism of digital infrastructure driving green innovation—Based on the policy experiment of "Broadband China" strategy. *Economic and Management Research*, (1), 90-108.

Shao, H. H., Wang, Q. X., & He, K. H. (2025). Impact of green technology innovation on synergistic level of pollution reduction and carbon reduction in provinces and its driving mechanism. *Economic Geography*, *45*(1), 17-24+35.

Shu, J. K., Wang, B. R., & Yang, M. (2024). Research on the development path of smart water affairs low-carbon innovation in Yiyang City under the dual carbon goal. *Wisdom China*, (9), 78-79.

Song, Y. Y., Zhang, X. Y., Ma, B. B., & Xue, D. Q. (2024). Social-ecological system resilience assessment of energy-rich regions for SDGs. *Resources Science*, *46*(9), 1807-1821.

Tang, Y., Song, Y. Y., Xue, D. Q. et al. (2022). Evolution process and influence mechanism of economic resilience in energy-rich regions: Taking Yulin City as an example. *Resources Science*, *44*(7), 1331-1343.

Jiang, H. N., Zhang, W. Z., Yu, J. H. et al. (2020). Spatial coupling between innovation environment and industrial structure transformation in resource-based cities of Shanxi Province. *Journal of Natural Resources*, *35*(2), 269-283.

Wang, B., Gong, S., & Yang, Y. (2024). Unveiling the relation between digital technology and low-carbon innovation: Carbon emission trading policy as an antecedent. *Technological Forecasting & Social Change*, *205*, 123522.

Wang, Z. Q., Wang, H., & Wang, Z. J. (2021). Enterprise green development, government subsidies and R&D expenditure—Also on the moral development level of enterprises. *Contemporary Finance & Economics*, (2), 75-87.

Wu, C. Q., & Deng, M. L. (2023). Research on the path of informatization level promoting the growth of total factor carbon productivity in China. *China Soft Science*, (4), 177-188.

Xu, Y. J., & Liu, S. H. (2022). Evolution of spatial pattern of green innovation efficiency in the Yellow River Basin and its influencing factors. *Journal of Natural Resources*, *37*(3), 627-644.

Ye, W. X. (2024). Spatial-temporal evolution characteristics and influencing factors of economic resilience in the Yellow River Basin. *Statistics & Decision*, *40*(17), 132-137.

Yu, X. Y., Li, Y., Chen, H. Y. et al. (2019). Impact of environmental regulation and energy endowment on regional carbon emissions from the perspective of "resource curse". *China Population, Resources and Environment*, *29*(5), 52-60.

Yu, L. P. (2020). Interactive mechanism among innovation quantity, quality and speed from the perspective of efficiency. *Economic and Management Research*, *41*(11), 58-76.

Yu, L. P., Huang, M. T., & Mao, Z. B. (2024). Impact of independent R&D and collaborative innovation on innovation quality—Based on the perspective of short-term and long-term innovation quality. *Journal of Shanxi University of Finance and Economics*, (8), 16-31.

Zhang, H., & Sun, Y. N. (2025). Synergistic policy effect and mechanism of "quantity increase and quality improvement" of enterprise low-carbon technology innovation. *Chinese Journal of Management*, *22*(3), 527-535.

Zhang, L., & Huang, L. Q. (2020). Measurement of green technology innovation efficiency of Chinese industrial enterprises and its spatial-temporal differentiation characteristics—Analysis based on improved three-stage SBM-DEA model. *Journal of Statistics and Information Forum*, *35*(12), 50-61.

Zhao, W., Geng, K. M., & Qiu, Y. X. (2024). Government R&D subsidies, social network and enterprise innovation quality. *Economic Management Journal*, *46*(12), 139-160.

Zhou, Z. F., Li, Y., Xiao, T., & Zeng, H. X. (2019). Carbon risk awareness, low-carbon innovation and carbon performance. *R&D Management*, 31(3), 72-83.