Postprint: Coupling Interaction between New-type Urbanization and Low-carbon Development in the Ningxia Yellow River Basin Urban Agglomeration

Authors: Zhou Tao, Wang Yajuan, Liu Xiaopeng

Date: 2025-09-01T11:34:35+00:00

Abstract

This study investigates the coupling and interactive relationship between new urbanization and low-carbon development to provide support for realizing the transformation of new urbanization, promoting 'carbon emission reduction,' and facilitating regional high-quality development. Based on panel data from 2012–2022 for the Yellow River urban agglomeration in Ningxia, and employing a modified coupling coordination model, panel vector autoregression (PVAR) model, and Tobit model, this paper examines the spatio-temporal evolution of coupling coordination, interactive response relationships, and influencing factors of new urbanization and low-carbon development in the Yellow River urban agglomeration of Ningxia. The results indicate: (1) The coupling coordination degree between new urbanization and low-carbon development in cities of the Yellow River urban agglomeration of Ningxia demonstrates a sustained positive trend, gradually forming a spatial pattern characterized by 'one pole with multiple cores.' (2) A long-term equilibrium relationship exists between new urbanization and low-carbon development, yet the degree of interaction remains relatively low, with the promoting effect of new urbanization on low-carbon development exceeding that of low-carbon development on new urbanization. (3) Factors such as urbanization level and environmental governance contribute to improving the coupling coordination between new urbanization and low-carbon development, whereas industrialization level emerges as a key factor impeding their benign coordinated development.

Full Text

Coupling Interaction Study of New-type Urbanization and Low-carbon Development in Ningxia Urban Agglomeration along the Yellow River

ZHOU Tao[1], WANG Yajuan[1], LIU Xiaopeng[2],[3]

[1]School of Economics and Management, Ningxia University, Yinchuan 750021, Ningxia, China
[2]Undergraduate School, Ningxia University, Yinchuan 750021, Ningxia, China
[3]School of Geography and Planning, Ningxia University, Yinchuan 750021, Ningxia, China

Abstract: This study aims to examine the coupling and interactive relationship between new-type urbanization and low-carbon development to support the transformation of new urbanization, promote carbon emission reduction, and facilitate regional high-quality development. Based on panel data from the Ningxia urban agglomeration along the Yellow River from 2012 to 2022, this paper employs a modified coupling coordination model, a panel vector autoregression (PVAR) model, and a Tobit model to investigate the spatiotemporal evolution of coupling coordination, interactive response relationships, and influencing factors between new-type urbanization and low-carbon development in this region. The results show that: (1) The coupling coordination degree between new-type urbanization and low-carbon development in cities of the Ningxia urban agglomeration along the Yellow River continues to improve, gradually forming a spatial pattern characterized by "one pole with multiple cores." (2) A long-term equilibrium relationship exists between new-type urbanization and low-carbon development, though the degree of interaction remains relatively low. The promoting effect of new-type urbanization on low-carbon development is stronger than that of low-carbon development on new-type urbanization. (3) Factors such as urbanization level and environmental governance contribute to improving the coupling coordination degree, while industrialization level emerges as a key obstacle to their coordinated development.

Keywords: new-type urbanization; low-carbon development; coupling coordination; interactive response; Ningxia urban agglomeration along the Yellow River

Introduction

As China's urbanization accelerates, increased energy consumption from urban population growth, infrastructure expansion, and energy-intensive industrial development has led to substantial carbon emissions. The contradiction between rapid urbanization and carbon reduction goals has become increasingly prominent. Urbanization is an essential path to modernization, and urban agglomerations serve as the primary spatial carriers for new-type urbanization. The National New-type Urbanization Plan (2014–2020) emphasizes the need to promote economically vibrant, high-quality, and ecologically beautiful urban agglomerations. During the 14th Five-Year Plan period, China has issued a series of documents including the National New-type Urbanization Report (2020–2021) and the 14th Five-Year Plan Implementation Plan for New-type Urbanization, which stress the continued focus on urban agglomerations as the main form and the effort to build efficient, clean, and low-carbon green cities.

New-type urbanization, as a high-quality urbanization model characterized by people-oriented development, industry-city integration, resource conservation, and ecological livability, provides crucial support for low-carbon development. By improving public service systems and constructing ecological spatial networks, it enhances resource allocation efficiency and environmental quality while promoting residents' well-being. It drives industrial restructuring, facilitates the specialized upgrading of service industries and clean transformation of manufacturing, and accelerates improvements in energy utilization efficiency. Through rational planning, it creates high-tech, low-energy industrial spaces, high-quality living spaces for residents, and urban ecological carbon sink spaces, significantly enhancing urban ecological carrying capacity and sustainable development levels. Meanwhile, low-carbon development propels new-type urbanization. Green economic growth injects economic vitality and technological momentum into urbanization, while resource and environmental constraints compel enterprises to optimize energy consumption patterns, pushing urbanization toward intensive, efficient, and green transformation. Under the guidance of ecological concepts and policy demonstrations, low-carbon development guides industrial upgrading and spatial layout optimization, facilitating high-quality new-type urbanization. Moreover, low-carbon development emphasizes the goal of "prosperous living and sound ecology," which aligns highly with the people-oriented, ecologically livable concept of new-type urbanization, providing value orientation and practical foundations for their coupling interaction.

The successful realization of high-quality new-type urbanization in urban agglomerations is inseparable from low-carbon development models, as the two complement each other. Therefore, exploring the coupling interaction between new-type urbanization and low-carbon development in urban agglomerations is significant for achieving new-type urbanization, realizing "dual carbon" goals, and building high-quality urban agglomerations.

Current research on new-type urbanization and low-carbon development mainly focuses on three aspects. First, studies on the relationship between urbanization and carbon emissions have built quantitative analysis models to verify their correlation and examine how related factors affect carbon emissions during urbanization. Second, research on specific pathways for low-carbon urbanization development has proposed suggestions from perspectives such as planning system optimization, institutional innovation, and governance mechanism improvement. Third, studies on coupling coordination between new-type urbanization and low-carbon development have applied coupling coordination models for empirical analysis. For instance, Zong et al. analyzed the spatiotemporal coupling relationship between new-type urbanization and low-carbon development at the provincial scale from 2005 to 2016.

Overall, existing research on urbanization and low-carbon development is rich and provides important references for clarifying their relationship and achieving high-quality urban development. However, from the perspective of research content, previous studies have focused more on the unidirectional impact of urbanization on carbon emissions and specific pathways, with insufficient interpretation of the internal mechanisms of coupling interaction between the two systems and limited research on influencing and constraining factors for their coordinated development. Methodologically, coupling coordination models have been primarily used to explore coordination relationships, with less attention paid to dynamic relationships and temporal characteristics. In terms of research perspective, existing literature has mainly focused on eastern coastal regions and economically developed urban agglomerations, while relatively less attention has been paid to economically lagging and ecologically fragile urban agglomerations. These urban agglomerations face multiple pressures from economic development, resource and environmental constraints, and carbon emission reduction during urbanization, making coordinated development between new-type urbanization and low-carbon development a key challenge.

The Ningxia urban agglomeration along the Yellow River, as a typical underdeveloped urban agglomeration in northwestern China, constitutes an important component of the national "two vertical and three horizontal" urbanization strategic pattern. Its urbanization construction faces challenges such as insufficient scale of basic public services, relatively low levels of county-level service facilities, inadequate integrated development of the urban agglomeration, and the need for improved ecological construction and protection. Resource-based cities also face challenges of heavy industrial structure and path dependence in green and low-carbon transformation. Against this backdrop, the collaborative advancement of new-type urbanization and low-carbon development presents regional complexity and interactivity, necessitating analysis from a systematic perspective.

This study takes ten cities in the Ningxia urban agglomeration along the Yellow River as research objects to explore their coupling coordination relationship and spatiotemporal evolution characteristics, clarify the interactive response relationship between the two systems, and identify influencing factors of their coupling coordination degree, aiming to provide references for low-carbon urbanization construction in this region and similar areas.

1 Data and Methods

1.1 Study Area Overview

The Ningxia urban agglomeration along the Yellow River is located in the middle and upper reaches of the Yellow River, geographically positioned between 36°66 – 39°58 N and 104°28 –106°89 E, with terrain gradually transitioning from hills to plains from south to north. Specifically, it includes Yinchuan City, Shizuishan City, Wuzhong City (Litong District), Shapotou District, Qingtongxia City, Lingwu City, Zhongning County, Yongning County, Helan County, and Pingluo County—ten cities in total. This region covers approximately 40% of the province's land area but carries 80% of its urban population, with highly concentrated economic activities. A preliminary urban agglomeration pattern has formed, representing the core area of Ningxia's economy, culture, and ecology, and occupying an important position in national and autonomous region development strategies.

1.2 Indicator System and Data Sources

Drawing on existing research, this study constructs an indicator system for new-type urbanization and low-carbon development in the Ningxia urban agglomeration along the Yellow River from five dimensions: economic, social, population, ecological, and land (Table 1). The DPSIR model is adopted to build a low-carbon development indicator system from five aspects: low-carbon driving forces, pressure, state, impact, and response. The entropy method is used to calculate indicator weights.

Socioeconomic data primarily come from the Ningxia Statistical Yearbook (2013–2022), China Urban and County Construction Statistical Yearbook (2013–2022), and statistical yearbooks of each city, with some data obtained through secondary calculations. Carbon emission data are derived from the EDGAR v6.0 grid data provided by the Global Atmosphere Research Emission Database for 2012–2020. PM2.5 data come from grid data provided by the Atmospheric Composition Group at Washington University in St. Louis. Data on energy conservation and emission reduction-related word frequencies in government work reports are extracted from government work reports of the Ningxia urban agglomeration along the Yellow River, quantifying relevant word frequency indicators using text measurement methods. Missing data are supplemented by consulting national economic and social development statistical annual reports and government work reports, as well as using linear interpolation.

1.3 Methods

1.3.1 Modified Coupling Coordination Degree Model The coupling coordination model can reflect the strength of interaction relationships between subsystems or sub-elements and the overall development degree of the system. Due to issues such as low validity and simplified calculations in traditional coupling coordination models, this study adopts a modified model to measure the coupling coordination relationship between new-type urbanization and low-carbon development. The calculation formulas are as follows:

$$C = \left\{ \frac{\prod_{i=1}^{n} U_i}{\left[\prod_{i=1}^{n} U_i\right] \times \left[\frac{\sum_{i=1}^{n} U_i}{n}\right]^{n-1}} \right\}^k$$

$$T = \sum_{i=1}^{n} \alpha_i U_i, \quad \sum_{i=1}^{n} \alpha_i = 1$$

$$D = \sqrt{C \times T}$$

where:
- C is the coupling degree, with larger values indicating stronger interconnections between subsystems;
- T is the coordination degree, representing the contribution of subsystems to coordination;
- D is the coupling coordination degree;
- U_i and U_j are the comprehensive evaluation indices of systems i and j;
- n is the number of subsystems;
- α_i are coefficients to be determined, representing the contribution share of subsystems. This study has two subsystems, with $\alpha_1 = \alpha_2 = 0.5$, indicating equal importance.

Referring to existing literature, the coupling coordination degree between new-type urbanization and low-carbon development is classified as shown in Table 2.

1.3.2 Relative Development Model To clarify the relationship between the two subsystems, this study introduces a relative development model to judge the synchronous development status of new-type urbanization and low-carbon development in the Ningxia urban agglomeration along the Yellow River. The formula is:

$$E = \frac{U_{\text{new}}}{U_{\text{low}}}$$

where E is the relative development degree; U_{new} and U_{low} are the comprehensive evaluation indices of new-type urbanization and low-carbon development, respectively. Based on existing research, when $E > 1.2$, new-type urbanization leads low-carbon development; when $0.8 < E \leq 1.2$, new-type urbanization and low-carbon development develop synchronously; when $E \leq 0.8$, low-carbon development lags behind new-type urbanization.

1.3.3 PVAR Model This study establishes a Panel Vector Autoregression (PVAR) model and employs impulse response and variance decomposition to analyze the dynamic interactive response relationship between the two systems. The model is specified as:

$$Y_{it} = \theta_0 + \sum_{j=1}^{p} \theta_j Y_{i,t-j} + \eta_i + \mu_t + \varepsilon_{it}$$

where Y_{it} represents the comprehensive evaluation indices of new-type urbanization and low-carbon development; i and t denote region and year, respectively; θ_0 is the intercept term; θ_j is the parameter matrix; j is the lag order; η_i and μ_t are individual and time effects; ε_{it} is the random disturbance term.

2 Results

2.1 Temporal Evolution Characteristics of New-type Urbanization and Low-carbon Development Levels

Using the entropy method, we calculated the comprehensive evaluation indices of new-type urbanization and low-carbon development in the Ningxia urban agglomeration along the Yellow River (Figure 2). Overall, new-type urbanization levels steadily increased from 2012 to 2022, with the mean comprehensive evaluation index rising from 0.213 to 0.322, representing a 51.21% increase. Yinchuan City and Shizuishan City ranked at the forefront, with their evaluation indices exceeding 0.4 in 2022 and maintaining continuous growth. In contrast, Helan County started from a lower baseline of 0.102 in 2012 but significantly improved its new-type urbanization level during the 12th and 13th Five-Year Plan periods through infrastructure strengthening and industrial upgrading, reaching 0.212 in 2022—a 107.73% increase, the fastest growth among all cities. These findings indicate an overall positive trend in new-type urbanization across the urban agglomeration, though significant inter-city differences exist in progress speed and effectiveness.

Low-carbon development levels showed a fluctuating upward trend, with the mean comprehensive evaluation index increasing from 0.268 to 0.363. Yinchuan City stood out in low-carbon development, with its evaluation index reaching 0.559 in 2022, ranking first and maintaining a leading position. Lingwu City lagged in low-carbon development, with its index consistently ranking lowest at 0.178 in 2012 and only increasing to 0.245 in 2022, indicating significant challenges in low-carbon transformation. This is because Lingwu City, as an energy production base, relies heavily on fossil energy and has a high proportion of secondary industry, which constrains low-carbon development speed. Overall, gaps between cities narrowed during the study period, but differences in resource endowments and industrial structures led to varying progress in urban low-carbon development pathways.

2.2 Coupling Coordination Development Analysis

Based on formula (1), we calculated the coupling coordination degree of new-type urbanization and low-carbon development for each city from 2012 to 2022 (Figure 3). Temporally, the coupling coordination interval evolved from "transitional development" to "coordinated development," with the mean value increasing from 0.481 to 0.522, showing a slight upward trend. Significant inter-city differences exist in coordinated development.

In 2012, only Yinchuan City (0.493) and Zhongning County (0.494) were in the brink-of-disorder stage, while other cities were in the barely-coordinated stage. By 2016, Wuzhong City (0.522), Qingtongxia City (0.516), Shapotou District (0.511), and Lingwu City (0.506) entered the primary coordination stage, while Helan County (0.497) entered the barely-coordinated stage. By 2022, Yinchuan City (0.578) took the lead in reaching intermediate coordination, while Pingluo County (0.539) entered the primary coordination stage. Although inter-city gaps narrowed, coordination levels in southern regions remained relatively low. Overall, the spatiotemporal evolution of coupling coordination exhibits certain radiation effects, with cities like Yinchuan and Shizuishan leveraging economic, technological, and industrial advantages to drive coordinated development in surrounding cities through regional cooperation, demonstration, and resource flow.

Spatially, the spatial pattern evolved from "high in the north, low in the south" to "one pole with many nuclei" (Figure 4). In 2012, Yinchuan City had the highest coupling coordination degree, while most central and southern cities had lower coordination, presenting a "high in the north, low in the south" pattern. Subsequently, Shizuishan City, Shapotou District, and other cities significantly improved their coupling coordination, gradually forming a "one pole with many nuclei" pattern. Helan County and Zhongning County, due to weak new-type urbanization foundations, remained in brink-of-disorder or barely-coordination states for some time, lagging behind other cities. By 2022, all cities in the urban agglomeration had coupling coordination degrees above 0.5, entering the primary coordination stage and achieving significant progress in high-quality development and low-carbon urbanization transformation.

The mean relative development degree of the Ningxia urban agglomeration along the Yellow River was below 0.8, with overall characteristics of new-type urbanization lagging behind low-carbon development (Table 3). Low-carbon development led new-type urbanization in all ten cities, with no cities achieving synchronous development. This may be because new-type urbanization progressed relatively slowly due to weak infrastructure, large urban-rural gaps, and insufficient public service supply, with long-term planning and capital investment needs further increasing development pressure. In contrast, low-carbon development advanced relatively faster, benefiting from policy support and resource advantages. Documents such as the Ningxia Hui Autonomous Region Climate Change Action Plan provided institutional guarantees and policy foundations for low-carbon construction, with low-carbon pilot cities like Yinchuan, Shizuishan, and Wuzhong playing demonstration roles in driving regional low-carbon development. Lingwu City experienced persistent low-carbon development lag from 2012 to 2022 due to high dependence on resource-based industries, facing significant challenges in industrial transformation.

2.3 Interactive Response Relationship between New-type Urbanization and Low-carbon Development

Using the PVAR model with a 2-period lag and Monte Carlo simulation with 500 iterations, we obtained impulse response functions between new-type urbanization and low-carbon development to explore their interactive effects (Figure 5). When new-type urbanization faces a one-unit shock from itself, it shows strong positive effects, peaking in the current period and slowly declining thereafter, remaining unconverged by period 6, indicating strong dynamic cumulative effects and path dependence. When low-carbon development faces a one-unit shock from new-type urbanization, the response is strong in period 1, then begins to decline but remains positive, indicating that industrial structure upgrading and green infrastructure construction have stable and lasting effects on low-carbon development. This positive effect does not appear immediately but shows a lag due to factors such as industrial adaptation, residents' concept transformation, and policy implementation. When new-type urbanization faces a one-unit shock from low-carbon development, the effect intensity increases continuously from period 1 to period 3, then declines and stabilizes, indicating that capital investment, resource and environmental constraints, and technological innovation effectively promote urbanization transformation toward intensive, efficient, and green directions.

Variance decomposition reveals that new-type urbanization's contribution to itself remains stable at over 90%, showing strong self-driving mechanisms. Low-carbon development's contribution to new-type urbanization increased from 2.103% to 9.167%, indicating that low-carbon transformation drives new-type urbanization, though its significant improvement still relies mainly on its own development inertia. Low-carbon development's variance decomposition shows that its contribution to itself was 100% in period 1, but declined rapidly to 66.738% by period 6, indicating significant short-term effects but requiring external momentum for long-term sustainability. New-type urbanization's contribution to low-carbon development was 33.262% in period 1, continuously increasing to 38.847% by period 6, indicating that new-type urbanization provides long-term support for low-carbon development, with their positive interaction continuously strengthening. Horizontally, new-type urbanization's contribution rate to low-carbon development is consistently higher than low-carbon development's contribution to new-type urbanization, indicating that new-type urbanization's promoting effect on low-carbon development is more significant.

2.4 Analysis of Influencing Factors of Coupling Coordination Degree

Drawing on existing research, this study constructs a panel Tobit model with coupling coordination degree between new-type urbanization and low-carbon development as the dependent variable and economic development level, urbanization level, industrialization level, government capacity, city size, and environmental governance level as explanatory variables. The model is specified as:

$$D_{it} = \beta_0 + \beta_1 \text{Gdp}_{it} + \beta_2 \text{Urit} + \beta_3 \text{Ind}_{it} + \beta_4 \text{Gov}_{it} + \beta_5 \text{Ucl}_{it} + \beta_6 \text{Env}_{it} + u_{it}$$

where D_{it} is the coupling coordination degree; Gdp_{it} is economic development level (per capita GDP); Urit is urbanization level (urban population proportion); Ind_{it} is industrialization level (secondary industry share); Gov_{it} is government capacity (per capita fiscal expenditure); Ucl_{it} is city size (construction land area proportion); Env_{it} is environmental governance (harmless treatment rate of household waste); β_0–β_6 are coefficients; and u_{it} is the random disturbance term.

The regression results (Table 5) show that economic development level, urbanization level, government capacity, city size, and environmental governance have positive effects on coupling coordination, with effect magnitudes ranked as: urbanization level (0.007) > environmental governance (0.006) > economic development level (0.003). Industrialization level has a negative effect (−0.008).

Economic development level shows a positive impact at the 1% significance level, though the coefficient is small. While economic growth drives infrastructure improvement, it fails to simultaneously enhance urban functional quality and low-carbon development levels. The urban agglomeration's economic growth quality and structure still need optimization. In 2022, the operating revenue of high-tech industries in Ningxia accounted for only 14.0% of GDP, with the industrial structure still dominated by resource-based and traditional manufacturing industries, where capital, technology, and other factor agglomeration effects have not been fully realized.

Urbanization level has a significant positive effect at the 1% level. Holding other variables constant, each unit increase in urbanization level increases coupling coordination by 0.007 units. Urbanization reduces production costs and enhances inter-firm collaboration and communication through population, industry, and resource agglomeration, generating technology spillover effects that improve resource utilization efficiency and accelerate low-carbon technology diffusion, thereby promoting coordinated development.

The industrialization level coefficient is negative, indicating that increased secondary industry proportion negatively affects coupling coordination. Holding other variables constant, each unit increase reduces coupling coordination by

0.008 units. In 2022, the secondary industry share in the Ningxia urban agglomeration reached 47.6%, significantly higher than the national average of 39.9%. The resource-intensive industrial system has high energy consumption, constraining coordinated development. Although cities are promoting energy conservation, carbon reduction, and green industry development in traditional industries, technological path dependence, insufficient environmental investment, and weak supervision mechanisms still cannot effectively support low-carbon urbanization processes. This echoes the variance decomposition results showing weak feedback from low-carbon development to new-type urbanization.

Government capacity has a positive but non-significant effect on coupling coordination, possibly because current fiscal expenditures in Ningxia prioritize basic needs like social security and employment over low-carbon urbanization support. As low-carbon policies advance, increased fiscal support for urban function optimization and low-carbon technology research may enhance government capacity's promoting effect.

City size positively affects coupling coordination at the 1% significance level. Holding other variables constant, each unit increase raises coupling coordination by 0.005 units. This supports compact city theory, where high-density and multi-functional land development effectively curbs urban sprawl, promotes resource-intensive utilization, and reduces carbon emissions while improving urbanization levels.

Environmental governance positively affects coupling coordination. Holding other variables constant, each unit improvement increases coupling coordination by 0.006 units. Strengthened environmental governance improves urban carrying capacity and ecological environmental quality, thereby promoting coupling coordination between new-type urbanization and low-carbon development.

3 Discussion and Conclusion

3.1 Discussion

Studying the coupling interaction and influencing factors between new-type urbanization and low-carbon development is crucial for improving new-type urbanization levels, promoting regional high-quality development, and achieving "dual carbon" goals in the Ningxia urban agglomeration along the Yellow River. The findings show that the coupling coordination degree continues to increase, consistent with research conclusions on urbanization and ecological protection coupling coordination in the Yellow River Basin. This study reveals the phenomenon of low coupling coordination in upstream Yellow River Basin urban agglomerations from a smaller micro-scale. The PVAR model further demonstrates the relationship from another dimension. Impulse response graphs show a long-term equilibrium relationship with mutual promotion in early stages but low interaction degree, gradually stabilizing later. Variance decomposition results indicate that both systems mainly rely on their own development inertia, with new-type urbanization having a stronger promoting effect on low-carbon development.

Overall, the Ningxia urban agglomeration along the Yellow River has achieved certain progress in economic, social, and ecological development, but achieving "dual carbon" goals and promoting new-type urbanization still requires multi-level and multi-faceted efforts. First, build differentiated low-carbon development pathways. As the central city, Yinchuan should fully play its leading role in promoting the integration of scientific and technological innovation and "Internet+" in low-carbon scenarios. Resource-based cities like Shizuishan should optimize energy structure and explore green industry alternatives. Lingwu City should strengthen collaborative development with the Ningdong Base and promote green upgrading of the coal industry. Each city should develop industries according to local conditions, building a complementary industrial system to promote regional collaborative development and green low-carbon transformation. Second, improve county-level urbanization quality. Counties like Helan and Zhongning should accelerate infrastructure and public service improvements, building functional complementary and industrially coordinated satellite town systems to enhance county-level urban carrying and agglomeration capacity. Third, strengthen regional 联动 development. As an important component of the Yellow River "Ji" character bend metropolitan circle, the urban agglomeration should leverage its location advantages to deepen industrial cooperation and ecological co-governance with surrounding urban agglomerations, enhancing its own development resilience and competitiveness.

This study provides references for low-carbon urbanization transformation and "dual carbon" goal achievement in the Ningxia urban agglomeration along the Yellow River and differentiated development of cities within the region. However, limitations remain. Considering that different urban agglomerations have varying economic structures and resource endowments, research conclusions may differ by regional characteristics. Future research could expand perspectives to conduct comparative studies on urban agglomerations with different development models and resource endowments to deeply reveal regional differences and mechanisms of low-carbon urbanization.

3.2 Conclusion

1) During the study period, the comprehensive evaluation index of new-type urbanization in the Ningxia urban agglomeration along the Yellow River showed a steady upward trend, while the low-carbon development comprehensive evaluation index showed a fluctuating upward trend, with differences in new-type urbanization and low-carbon development levels across cities.

2) The coupling coordination interval of new-type urbanization and low-carbon development evolved from "transitional development" to "coordinated development," showing a slight upward trend. The spatial

pattern evolved from "high in the north, low in the south" to "one pole with many nuclei." Most cities experienced new-type urbanization lagging behind low-carbon development.

3) There exists a long-term equilibrium relationship between new-type urbanization and low-carbon development, with mutual promotion in early stages but low interaction degree, gradually stabilizing later. Variance decomposition results show that both systems mainly rely on their own development inertia, with new-type urbanization having a stronger promoting effect on low-carbon development.
4) Economic development level, urbanization level, city size, and environmental governance all help promote coupling coordination development between new-type urbanization and low-carbon development in the Ningxia urban agglomeration along the Yellow River, while industrialization level is a key obstacle to their coordinated development.

References

[1] Huo T, Li X, Cai W G, et al. Exploring the impact of urbanization on urban building carbon emissions in China: Evidence from a provincial panel data model[J]. Sustainable Cities and Society, 2020, 56: 102068, doi: 10.1016/j.scs.2020.102068.

[2] Sun W, Huang C. How does urbanization affect carbon emission efficiency? Evidence from China[J]. Journal of Cleaner Production, 2020, 272: 122828, doi: 10.1016/j.jclepro.2020.122828.

[3] Central Committee of the Communist Party of China, State Council. National New-type Urbanization Plan (2014—2020)[M]. Beijing: People's Publishing House, 2014.

[4] National Development and Reform Commission of the People's Republic of China. 14th Five-Year Plan Implementation Plan for New-type Urbanization[EB/OL]. [2022-07-28]. https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202207/t20220728_{1332050}.html.

[5] National Development and Reform Commission. National New-type Urbanization Report. 2020—2021[M]. Beijing: People's Publishing House, 2022.

[6] Qi Ye, Cai Qin. Innovations in urban governance in the context of carbon neutrality[J]. Governance Studies, 2021, 37(6): 88-98.

[7] Tao Changqi, Peng Yongzhang. Population agglomeration, greening level and environmental pollution: An analysis of spatial heterogeneity based on urban data[J]. Journal of Jiangxi University of Finance and Economics, 2017(6): 21-31.

[8] Zong Xin, Yang Hao. Analysis on the spatio-temporal coupling relationship and driving forces of new urbanization and urban low-carbon development[J]. Ecological Economy, 2021, 37(4): 80-87.

[9] Li Huiyan. Research on new urbanization coordinated development of Beijing-Tianjin-Hebei city cluster based on the concept of production-living-ecological space[J]. Ecological Economy, 2021, 37(5): 92-98.

[10] Shen Zhongjian, Wang Jinyan, Yang Keyang, et al. Research on the coupling and coordination of new urbanization and low-carbon development in Shandong Province[J]. Urban Problems, 2022(11): 94-103.

[11] Wang Yujuan, Jiang Chengtao, Jiang Changliu. Can new-type urbanization and low-carbon economy be pushed coordinately? Empirical research based on 284 prefecture-level cities[J]. Finance and Trade Research, 2021, 32(9): 32-46.

[12] Gao Honggui, He Meixuan. Theoretical logic, connotative characteristics and practical direction of ecological priority green and low-carbon development[J]. Ecological Economy, 2023, 39(8): 13-18.

[13] Zhang Tengfei, Yang Jun, Sheng Pengfei. The impacts and channels of urbanization on carbon dioxide emissions in China[J]. China Population, Resources and Environment, 2016, 26(2): 47-57.

[14] Ma Caihong, An Siwen, Hua Yuqi, et al. Evolution and driving mechanism of ecological land use along the Yellow Economic Belt in Ningxia[J]. Economic Geography, 2022, 42(6): 179-187.

[15] Xu Wenfeng, Jiang Jing, Huang Xin, et al. Study on the coupling relationship between new urbanization and land use carbon emission safety in Gansu[J]. Natural Resources Information, 2023(4): 57-64.

[16] Feng Dong, Li Jian. Impacts of urbanization on carbon dioxide emissions in the three urban agglomerations of China[J]. Resources and Environment in the Yangtze Basin, 2018, 27(10): 2194-2200.

[17] Jiang Jikun, Zhu Shenglai, Cao Jichang, et al. Analysis of coupling coordination between new urbanization and carbon emission level: A case study of Shandong Province[J]. Ecological Economy, 2023, 39(3): 76-82.

[18] Zhang Lijun, Li Ning, Qin Yaochen, et al. The low-carbon city evaluation and its spatial differentiation based on the DPSIR model[J]. World Regional Studies, 2019, 28(3): 85-94.

[19] Wang Kai. Green transformation and development of China's urbanization[J]. City Planning Review, 2021, 45(12): 9-16, 66.

[20] Zheng Shiming, He Yujie, Zou Ke. Climate policy synergy: Mechanism and effect[J]. China Population, Resources and Environment, 2021, 31(8): 1-12.

[21] Hou Caixia, Zhang Yuzhou, Yang Jianping. Coupling coordination and obstacle factors of water-society-ecosystem in the Guanzhong Plain urban agglomeration[J]. Arid Land Geography, 2025, 48(4): 717-727.

[22] Wang Shujia, Kong Wei, Ren Liang, et al. Research on misuses and modification of coupling coordination degree model in China[J]. Journal of Natural

Resources, 2021, 36(3): 793-810.

[23] Zhao Jianji, Liu Yan, Zhu Yakun, et al. Spatiotemporal differentiation and influencing factors of the coupling and coordinated development of new urbanization and ecological environment in the Yellow River Basin[J]. Resources Science, 2020, 42(1): 159-171.

[24] Wang Jiankang, Han Qian. Temporal pattern of the coupling coordination of urban economy-society-environment in China[J]. Economic Geography, 2021, 41(5): 193-203.

[25] Sun Bin, Xu Wei, Xue Jianchun, et al. Analysis on the coupling coordination development of urbanization and eco-environment of urban agglomerations of the Yellow River Basin[J]. Yellow River, 2022, 44(6): 16-21.

[26] Han Yan, Zhang Yuting. Coupling and coordination development between urbanization and eco-environment in Gansu Province[J]. Research of Soil and Water Conservation, 2021, 28(3): 256-263.

[27] Li Jing, Zhang Yi. Coupling coordination and driving factors of new urbanization and ecological efficiency in Yangtze River Delta region[J]. Ecological Economy, 2022, 38(3): 109-114, 141.

[28] Deng Zongbing, Zong Shuwei, Su Congwen, et al. Research on coupling coordination development between ecological civilization construction and new urbanization and its driving forces in the Yangtze River Economic Zone[J]. Economic Geography, 2019, 39(10): 78-86.

[29] Liu Miaomiao, Wu Weidong. Empirical study of the coupling of new urbanization and rural revitalization in Shaanxi Province[J]. Arid Land Geography, 2024, 47(8): 1420-1430.

[30] Shao Jia, Leng Jing. Types and spatial pattern of coupling coordination between the new-type urbanization and eco-environment in Wuling mountainous area of Hunan[J]. Economic Geography, 2022, 42(9): 87-95.

[31] Cao Jialin, Liu Yanfang, Zhao Jinmei, et al. Coupling and coordination of economical and intensive utilization of urban construction land and high-quality development in Ningxia[J]. Arid Land Geography, 2024, 47(5): 872-884.

[32] Lin Meishun. CO_2 emission reduction under China's urbanization process: The economic cost and the strategies of emission reduction[J]. Quantitative & Technological Economics, 2016, 33(3): 59-77.

[33] Qian Zhiquan, Han Jiayin. Coupling process and mechanism of new-type urbanization and low-carbon development in Yangtze River Delta urban agglomeration[J]. Resources and Environment in the Yangtze Basin, 2023, 32(11): 2285-2297.

[34] Feng Junhua, Zhang Lulu. Coordination degree between new urbanization and ecological environment in Shaanxi Province[J]. Acta Ecologica Sinica, 2022, 42(11): 4617-4629.