Evaluation and Obstacle Factors for the Coordinated Development of Carbon Reduction, Pollution Control, Green Expansion and Economic Growth in Cangzhou City

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Abstract Taking Cangzhou City, a pilot city for heavy chemical industry in the Beijing – Tianjin – Hebei region, as the research object, time series data from 2010 to 2024 were selected. Based on the unique local resource endowment, a comprehensive evaluation system covering 15 indicators from four subsystems of carbon reduction, pollution control, green expansion, and economic growth was constructed. Entropy method, coupled coordination, and obstacle-degree model were used for quantitative calculation. The results showed that the comprehensive development level of Cangzhou City continued to improve during the research period, but the development pace of the four subsystems was unbalanced. The growth of green expansion relying on canal afforestation and saline-alkali tolerant wheat planting was the most prominent, and the carbon reduction link was the long-term core constraint for coordinated development. The coupling degree of the system continued to increase, but the coupling coordination was always below 0.5, and it was in a mild imbalance stage for a long time, showing the characteristics of "high coupling, low coordination". The progress of CCUS promotion, the scale of saline alkali land and canal greening, and the energy consumption per unit of GDP are the main limiting factors. Based on the shortcomings of local development, practical measures are proposed from three aspects: expanding carbon capture projects, improving the quality of characteristic ecological spaces, and perfecting diversified collaborative governance. This can provide empirical reference for similar heavy chemical industrial cities to coordinate ecological governance and industrial green transformation.

Key words Cangzhou City; Carbon reduction – pollution control – green expansion – economic growth; Coupling coordination; Obstacle-degree model

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The report of the 20[th] National Congress of the Communist Party of China clearly proposes to "promote carbon reduction, pollution control, green expansion, and economic growth in a coordinated manner", requiring the overall promotion of industrial restructuring, pollution control, ecological protection, and response to climate change. The 2024 Central Economic Work Conference further emphasized the need to accelerate the comprehensive green transformation of economic and social development. This strategic deployment marks a new stage of multi-objective coordinated development in China's ecological civilization construction.

In recent years, research on the coordinated development of carbon reduction, pollution control, green expansion, and economic growth has become increasingly abundant. Yin Bibo *et al.* [1] constructed an evaluation index system for the synergy level of pollution control and carbon reduction and the growth index of green expansion, and examined the spatiotemporal evolution characteristics and driving factors of the coupling coordination degree between the two. Ren Xiaosong *et al.* [2] used the panel dynamic QCA method based on the TOE framework to analyze the configuration path of provincial-level coupling and collaborative development in China. Cui Xinlei *et al.* [3] studied the dynamic evolution of coupling coordination and its influencing factors in the Yellow River basin. At the urban scale, Lv Jiaqi *et al.* [4] studied the characteristics and obstacles of coordinated development in typical cities in the Yangtze River Delta. Bao Zehang *et al.* [5] measured the coupling coordination of urban agglomerations in the Yangtze River Delta. However, existing research mostly focuses on the national, provincial, or urban-agglomeration scale, and refined research on individual typical industrial cities remains insufficient. As key spatial carriers for collaborative efficiency, cities vary in development stage, industrial structure and resource endowment, which may result in significant spatial heterogeneity of coordination mechanisms that cannot be easily uncovered by macro-level analysis.

Cangzhou City is a typical industrial city in the Beijing – Tianjin – Hebei region, mainly focusing on traditional heavy chemical industries. It has faced structural problems such as coal-dominated energy consumption and highway-oriented transportation for a long term. During the "14[th] Five-Year Plan" period, $PM_{2.5}$ concentration decreased by 21% compared with the end of the "13[th] Five-Year Plan" period, and the proportion of new energy installed capacity reached 62.14%. In 2024, Cangzhou was selected as a national pilot city for collaborative innovation in pollution control and carbon reduction, providing a typical sample for collaborative research at urban scale.

In this paper, Cangzhou was taken as the object to build a

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four-dimensional evaluation system of carbon reduction, pollution control, green expansion, and economic growth. Comprehensively using entropy method, coupled coordination, and obstacle-degree model, the level of coordination was calculated and the constraints were identified, providing empirical support for the green transformation of similar industrial cities.

1 Research framework and indicator system

1.1 Research methodology

1.1.1 Establishment of indicator system. Drawing on existing research results, this paper constructs an evaluation system covering four subsystems and a total of 15 indicators, based on the industrial characteristics and ecological background of Cangzhou City and following the principles of scientificity, comprehensiveness, typicality, and data availability.

The carbon reduction subsystem selects three indicators: greenhouse gas emissions, coal consumption proportion, and CCUS pilot approval, which comprehensively reflect the scale of carbon emissions, the degree of energy structure cleanliness, and policy driving forces. The pollution control subsystem characterizes the effectiveness of atmospheric and water environment treatment by the proportion of days with excellent air quality and the sewage treatment rate, respectively. After the positive transformation of three negative indicators of solid waste intensity, exhaust gas intensity, and wastewater intensity, the "comprehensive index of three wastes treatment" is synthesized, to comprehensively characterize the level of industrial pollution control. The green expansion subsystem incorporates two regional characteristic indicators, namely the green area of the Grand Canal corridor and the planting area of saline-alkali tolerant wheat, based on the conventional indicators of forest coverage and green space in built-up areas, to reflect the particularity of the green expansion work in Cangzhou. The economic growth subsystem selects five indicators, including per capita GDP, total green patent applications, energy consumption per unit of GDP, comprehensive utilization rate of general industrial solid waste, and per capita SO_2 emissions, to comprehensively examine the quality of economic growth and the effectiveness of green transformation.

1.1.2 Comprehensive evaluation model. To eliminate the influence of dimensionality, the original data were subjected to range normalization, and a 0.001 of translation correction was used for the standardized results. The comprehensive index of three wastes treatment was synthesized after positive transformation of three negative indicators: solid waste intensity, exhaust gas intensity, and wastewater intensity. Using the entropy method for objective weighting, the weight was determined based on the information entropy of indicators. The smaller the information entropy and the greater the degree of variation, the higher the weight. Then the comprehensive development index of each subsystem was calculated by weighting. The evaluation index system for carbon reduction – pollution control – green expansion – economic growth is shown in Table 1.

Table 1 Evaluation index system for carbon reduction – pollution control – green expansion – economic growth

Dimension	Indicator level	Direction	Unit	Coefficient of variation	Indicator weight
Carbon reduction	C_1: greenhouse gas emissions	Negative	10^4 t CO_2	0.177 2	0.073 6
	C_2: energy structure (proportion of coal consumption)	Negative	%	0.115 2	0.047 8
	C_3: CCUS pilot approved	Positive	–	0.592 8	0.246 3
Pollution control	P_1: proportion of days with good air quality	Positive	%	0.139 4	0.057 9
	P_2: comprehensive index of three wastes treatment	Positive	–	0.192 2	0.079 8
	P_3: sewage treatment rate	Positive	%	0.030 1	0.012 5
Green expansion	E_1: forest coverage rate	Positive	%	0.095 9	0.039 8
	E_2: green area of built-up area	Positive	hm^2	0.076 6	0.031 8
	E_3: green space in built-up areas	Positive	mu	0.160 9	0.066 9
	E_4: planting area of saline-alkali tolerant wheat	Positive	10^4 mu	0.305 7	0.127 0
Economic growth	G_1: GDP per capita	Positive	yuan/person	0.064 0	0.026 6
	G_2: total number of green patent applications	Positive	items	0.146 1	0.060 7
	G_3: energy consumption per unit of GDP	Negative	t standard coal /10^4 yuan	0.129 7	0.053 9
	G_4: comprehensive utilization rate of general industrial solid waste	Positive	%	0.049 8	0.020 7
	G_5: per capita SO_2 emissions	Negative	kg/person	0.131 6	0.054 7

Note: The CCUS pilot approved takes 2022 as the policy starting year, with a value of 0 before 2022 and a value of 1 including 2022 and afterwards; the total weight is 1, due to rounding-off, and there may be slight deviations in the sum of each weight.

The comprehensive development indexes of the four subsystems were calculated according to the formula (1), and the comprehensive development index was calculated according to the formula (2):

$$U_i = \sum_{j=1}^{k} w_j X_{ij} \quad (1)$$

$$T = W_1 U_1 + W U_2 + W_3 U_3 + W_4 U_4 \quad (2)$$

where U_i is the comprehensive development index of the i^{th} subsystem ($i = 1, 2, 3, 4$, corresponding to the subsystems of carbon reduction, pollution control, green expansion, and economic growth respectively); k is the number of indicators contained in this subsystem; X_{ij} is the standardized value of the k^{th} indicator of subsystem i after translation correction. The comprehensive development index U_i of each subsystem ranges from 0 to 1, with a higher value indicating a higher level of development for that subsystem. T is the comprehensive development index, and W_i is the weight of subsystem i in comprehensive development. Referring to the research of Ren Xiaosong *et al.* [2], it is believed that the four subsystems are equally important in collaborative development, so $W_1 = W_2 = W_3 = W_4 = 0.25$.

1.1.3 Coupling coordination model. The coupling coordination model was used to measure the collaborative development level of interactions and influences between multiple subsystems. Referring to the research of Wang Shujia *et al.* [6], a coupling coordination model for the four systems of carbon reduction, pollution control, green expansion, and economic growth was constructed. The specific calculation formulas for coupling degree and coupling coordination degree are as follows:

$$C = \left\{ \frac{U_1 \times U_2 \times U_3 \times U_4}{(U_1 + U_2 + U_3 + U_4)^4} \right\}^{1/4} \quad (3)$$

$$D = \sqrt{C \times T} \quad (4)$$

where U_1, U_2, U_3, and U_4 are the development indices of subsystems for carbon reduction, pollution control, green expansion, and economic growth, respectively. C is the coupling degree, and D is the coupling coordination, with both values ranging from 0 to 1. The larger the value of D, the higher the level of collaborative development among the four subsystems.

Using the classification standard of coupling coordination level defined by Guo Shanshan[7], the coupling coordination relationship is divided into 4 major categories and 10 levels (Table 2).

Table 2 Classification criteria for coupling coordination levels

Coupling stage	Coupling degree C	Coordination degree D	Coordination type
Low-level coupling stage (I)	(0 – 0.3)	(0 – 0.1)	Extreme imbalance (I – 1)
		[0.1 – 0.2)	Serious imbalance (I – 2)
		[0.2 – 0.3)	Moderate imbalance (I – 3)
Antagonistic stage (II)	[0.3 – 0.5)	[0.3 – 0.4)	Mild imbalance (II – 1)
		[0.4 – 0.5)	Near imbalance (II – 2)
Adaptive stage (III)	[0.5 – 0.8)	[0.5 – 0.6)	Reluctant coordination (III – 1)
		[0.6 – 0.7)	Junior coordination (III – 2)
		[0.7 – 0.8)	Intermediate coordination (III – 3)
High-level coupling stage (IV)	[0.8 – 1.0]	[0.8 – 0.9)	Good coordination (IV – 1)
		[0.9 – 1.0]	High-quality coordination (IV – 2)

1.1.4 Obstacle degree model. The objective obstacles that constrain the collaborative process of "carbon reduction, pollution control, green expansion, and economic growth" were quantified using an obstacle-degree model. The calculation formula is as follows:

$$F_{ij} = w_{ij} \times W_i \quad (5)$$

$$O_{ij} = \frac{F_{ij} \times (1 - X_{ij})}{\sum_{i=1}^{k} \sum_{j=1}^{n} F_{ij} \times (1 - X_{ij})} \times 100\% \quad (6)$$

$$V_i = \sum_j O_{ij} \quad (7)$$

where w_{ij} is the weight of the j^{th} indicator in subsystem i; F_{ij} is the contribution of indicator j to subsystem i; O_{ij} is the obstacle level of the indicator layer, reflecting the degree of constraint of a single indicator on collaborative development, and n is the number of indicators contained in subsystem i; V_i is the obstacle degree of subsystem layer, which is the sum of obstacle degrees of all indicators within the subsystem. The larger the values of O_{ij} and V_i, the stronger the constraining effect of the indicator or subsystem on the coordinated development of carbon reduction, pollution control, green expansion, and economic growth.

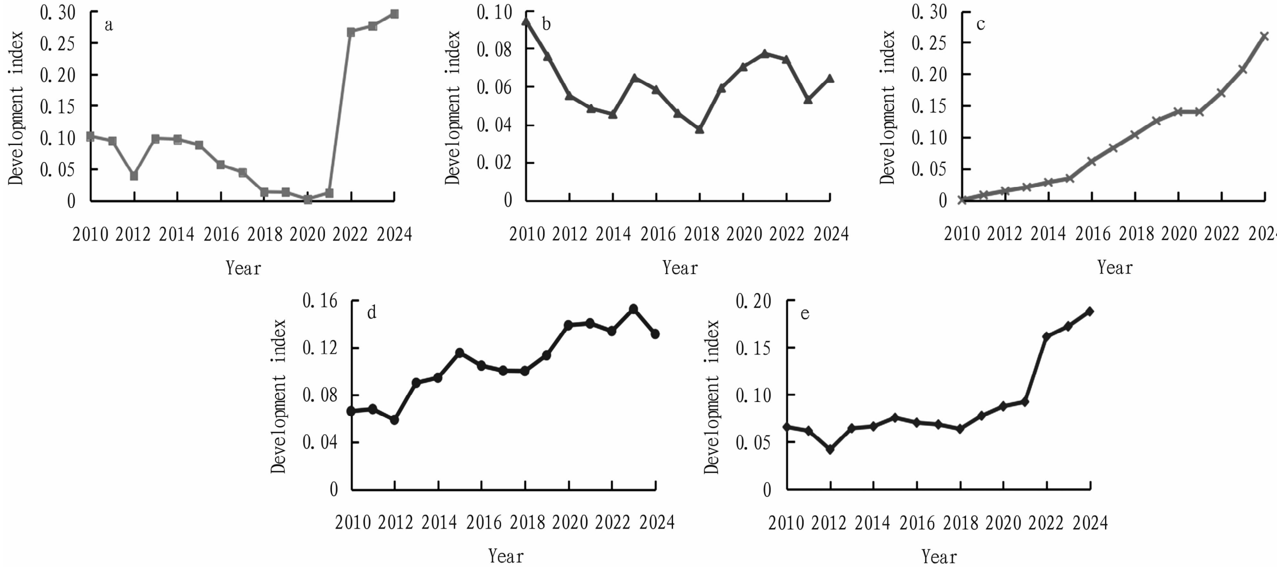
1.2 Data source In this paper, the period from 2010 to 2024 was selected. The data covered two types of indicators: socio-economy and resource-environment, and were taken from various statistics, environmental bulletins, and public information from multiple departments and industry associations in Cangzhou. Missing data were filled in using the interpolation method.

2 Results and analysis

2.1 Comprehensive development level The comprehensive coordination index of carbon reduction, pollution control, green expansion, and economic growth in Cangzhou from 2010 to 2024 overall fluctuated and increased significantly during the research period. Development can be divided into three stages: a low-level stable period from 2010 to 2014, steady growth from 2015 to 2020, a significant acceleration in the rate of improvement after 2021, with the overall synergy level continuously getting better.

There were significant differences in the development pace of the four subsystems. The carbon reduction index continued to decline in the early stage, but quickly rebounded after 2022 relying on CCUS policies. The pollution control index showed a U-shaped change, and the effectiveness of pollution control was gradually becoming apparent. The growth rate of the green expansion sector was far ahead, with canal greening and saline-alkali tolerant wheat planting being the core driving forces. The economic growth index was slowly increasing, and the transformation of traditional industries constrained the green growth rate of the economy (Fig. 1).

The development of various systems was uneven. The momentum of green expansion was strong, while the carbon-reduction and pollution-control subsystems experienced prominent fluctuations. There is still great potential for improvement in the overall coupling and coordination level of the region.



Note: a. Carbon reduction; b. Pollution control; c. Green expansion; d. Economic growth; e. Comprehensive coordination index.

Fig. 1 Change trends in the comprehensive development indexes of various subsystems and comprehensive coordination index from 2010 to 2024

2.2 Coupling coordination level From 2010 to 2024, the coupling degree and coupling coordination degree of the carbon reduction, pollution control, green expansion, and economic growth system in Cangzhou showed an overall fluctuating upward trend, with a coupling degree of 0.849 at the end of the period. The degree of correlation between various systems continued to deepen, with only a brief decline in 2020 due to the drag of the carbon reduction index. The final coupling coordination degree was 0.399 6, which has not crossed the critical value of 0.5, and it was still in the imbalance range overall.

The temporal changes can be divided into three stages (Table 3): from 2010 to 2015, the coordination level was slowly improved, from serious imbalance to moderate imbalance, and the rapidly expanding chemical industry dragged down the collaborative improvement. From 2016 to 2021, the development has been fluctuating and stagnant. The greening of the Grand Canal and the planting of saline-alkali tolerant wheat have continued to accelerate, but carbon emissions remained high, and the progress of carbon reduction lagged behind. The coordination status remained stable in the serious to moderate imbalance range. From 2022 to 2024, the coordinated level accelerated growth. Relying on CCUS carbon sequestration projects and the large-scale layout of new energy, the carbon reduction shortcomings were alleviated, and the coordination degree approached the critical range, gradually approaching the coordination stage.

Over the past fifteen years, the collaboration level has only progressed from "serious to moderate to mild imbalance", without entering the stage of adaptation and coordination, showing characteristics of high coupling and low coordination. The four major systems were closely interconnected, but the speed of green expansion far exceeded that of carbon reduction and pollution control. The development of various sectors was unbalanced and has been in a low-level constraint state for a long time. In the future, it is necessary to continue to deepen CCUS demonstration, strictly control energy consumption intensity, consolidate pollution control achievements, and promote the synchronous and balanced development of the four systems.

Table 3 Changes in coupled coordination degree of carbon reduction, pollution control, green expansion, and economic growth

Year	Coupling degree (C)	Coupling coordination degree (D)	Coordination type
2010	0.173 8	0.106 7	Serious imbalance (I-2)
2011	0.719 1	0.210 3	Serious imbalance (I-2)
2012	0.876 2	0.191 3	Serious imbalance (I-2)
2013	0.844 3	0.232 8	Moderate imbalance (II-1)
2014	0.882 5	0.241 7	Moderate imbalance (II-1)
2015	0.911 7	0.262 4	Moderate imbalance (II-1)
2016	0.966 2	0.260 4	Moderate imbalance (II-1)
2017	0.939 0	0.253 3	Moderate imbalance (II-1)
2018	0.746 1	0.217 7	Moderate imbalance (II-1)
2019	0.731 9	0.238 4	Moderate imbalance (II-1)
2020	0.431 5	0.194 5	Serious imbalance (I-2)
2021	0.699 8	0.254 1	Moderate imbalance (II-1)
2022	0.903 1	0.381 8	Mild imbalance (II-2)
2023	0.851 3	0.383 1	Mild imbalance (II-2)
2024	0.849 3	0.399 6	Mild imbalance (II-2)

2.3 Obstacle factors From the perspective of subsystem obstacles, carbon reduction was the primary factor restricting the coordinated development of Cangzhou. The continuous increase in obstacles was rooted in the high proportion of local heavy chemical industries and the incomplete transformation of high energy consuming industrial structures. The degree of obstacles to green expansion has significantly decreased, and afforestation in the canal and planting of saline-alkali tolerant wheat have continued to advance, resulting in outstanding achievements in ecological construction. The degree of obstacles to economic growth first increased and then decreased, while the degree of obstacles to pollution control was the lowest over a long term, and the foundation was stable (Fig. 2). The effectiveness of atmospheric governance and corporate environmental protection transformation was stable.

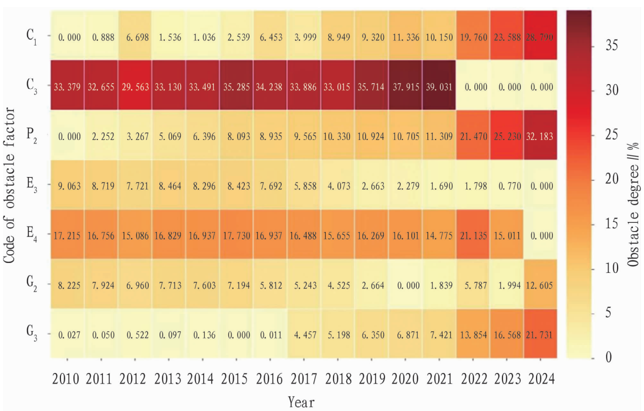


Fig. 2 Thermal map of obstacle factor and obstacle degree

Among various indicators, CCUS implementation, saline-alkali tolerant wheat, canal greening, energy consumption per unit of GDP, and coal proportion were the five core limiting factors (Table 4). After the CCUS project was put into operation, the constraint effect was significantly weakened, and the effect of carbon sequestration and emission reduction was obvious. The degree of constraint on indicators related to canals and saline alkali land continued to increase, and the progress of ecological construction lagged behind overall development. The constraint on energy consumption per unit of GDP has been increasing year by year, making it more difficult to save energy. The constraints on coal consumption have been significantly alleviated, and the popularization of new energy has promoted the continuous optimization of the energy structure.

Table 4 Main obstacle factors and their average obstacle degree

No.	Main obstacle factors	Average obstacle degree // %
1	C_3: CCUS pilot approved	19.77
2	E_4: planting area of saline-alkali tolerant wheat	17.81
3	E_3: green space in built-up areas	12.09
4	G_3: energy consumption per unit of GDP	9.81
5	C_2: energy structure (proportion of coal consumption)	7.97
6	G_5: per capita SO_2 emissions	7.57
7	P_2: comprehensive index of three wastes treatment	5.32
8	G_2: total number of green patent applications	4.50

In the future, CCUS demonstration applications should be continuously expanded, energy consumption levels should be strictly controlled, and the ecological expansion of canals and saline-alkali land should be accelerated, to address the shortcomings of each subsystem.

3 Conclusions and suggestions

3.1 Conclusions Taking Cangzhou City as the research object, this paper constructs a four-dimensional evaluation system of "carbon reduction – pollution control – green expansion – economic growth" by adopting the comprehensive evaluation method, coupling coordination degree model, obstacle-degree model, and structural equation model (SEM), and systematically measures the collaborative development level of Cangzhou City from 2010 to 2024. The main conclusions are as follows:

(1) From 2010 to 2024, the comprehensive development index of Cangzhou City increased from 0.065 6 to 0.188 0, with a growth rate of 186.6%. The proportion of green expansion subsystem has jumped from less than 0.1% to 43.5%, there were significant fluctuations in carbon reduction and pollution control, and economic growth was steady. The asynchronous development of the four systems was prominent.

(2) The coupling coordination degree has increased from 0.106 7 to 0.399 6, and it has gone through "serious imbalance – moderate imbalance – mild imbalance". However, it has long shown the characteristics of "high coupling degree and low coordination degree", and there was still a significant gap from the stage of coordinated development.

(3) The carbon reduction subsystem was the primary obstacle, with an average obstacle level of nearly 40%. The top five obstacle factors in the indicator layer were CCUS pilot approved, area of saline-alkali tolerant wheat, greening area of Grand Canal, energy consumption per unit of GDP, and energy structure. The ecological expansion speed lagged behind, and the pressure of energy consumption control continued to increase.

3.2 Suggestions

3.2.1 Undertaking large-scale carbon capture projects, and promoting energy conservation and consumption reduction in industrial enterprises. Based on the existing CCUS demonstration base in Huabei Oilfield, it should expand the construction scale, continuously improve the supporting infrastructure for carbon dioxide capture and transportation, establish special support funds, provide corresponding financial subsidies for carbon sequestration equipment of park enterprises, and regularly arrange professional teams to provide technical guidance to Bohai New Area and Lingang Power Enterprises. It should comprehensively review the energy consumption status of local high energy consuming industries such as coking and pipeline equipment, dynamically control the energy consumption of enterprises based on the city-level online monitoring system, urge high energy consuming enterprises to support energy-saving facilities such as waste heat recovery and distributed

(To page 91)

petitive advantage as the "potato capital of China", it is necessary to improve water-saving facilities, establish meteorological disaster prevention systems, select excellent varieties, and improve field management to fill the gaps in climate. This will enable the construction of a modern potato industry system that is adapted to climate characteristics, promote stable and increased income in regional characteristic agriculture, and assist in rural revitalization and high-quality sustainable development of agricultural economy.

References

[1] JIN LX, LI YP, LI D, *et al*. Suitability analysis of key potato growth stages in Inner Mongolia under climate change[J]. Chinese Journal of Eco-Agriculture, 2018(1): 38–48.

[2] WANG YP, YIN XX, WU NE, *et al*. Climatic suitability model for potato in Wulanchabu[J]. Chinese Agricultural Science Bulletin, 2018(13): 126–130.

[3] WANG YL, HOU Q, MIAO BL, *et al*. Potato in Inner Mongolia: Risk regionalization of drought disaster at seedling stage[J]. Chinese Agricultural Science Bulletin, 2018(12): 118–124.

[4] SUN MY, LIU JH, ZHAO BP, *et al*. Impact of ridging with full plastic-film mulching on soil water, enzymatic activities and yield of rain-fed potato[J]. Journal of Irrigation and Drainage, 2017(4): 1–8.

(From page 87)

photovoltaics, and replace and eliminate inefficient coal-fired equipment in batches. It should fully tap the coastal mudflat space of Huanghua Port, make overall arrangements for new energy projects of wind and light, steadily improve the scale of regional clean energy supply, continue to optimize the local energy structure, and alleviate the pressure of carbon reduction brought by heavy chemical industry.

3.2.2 Revitalizing saline-alkali land resources along the Grand Canal, and expanding urban and rural green spaces. It should systemically promote the construction of ecological corridors along the Grand Canal, continuously add waterfront forest protection and artificial wetlands, implement land transfer and seedling support policies for village collectives participating in afforestation, synchronously lay out ecological tourism sites along the Grand Canal, and simultaneously release ecological and cultural tourism benefits. Based on the local research platform for saline alkali land, it should promote the large-scale planting of saline-alkali tolerant wheat, provide free high-quality seeds and standardized field technical services to planting subjects, cultivate local leading enterprises in grain processing, and extend the characteristic industrial chain of saline alkali planting. It should simultaneously promote the green spaces transformation of idle urban land and corners of rivers, plan supporting ecological isolation zones for various chemical industrial parks, steadily expand the green space of the entire area, and narrow the development gap of the four major systems.

3.2.3 Encouraging public supervision, and improving supporting mechanisms for green development. It should establish an integrated online and offline environmental supervision channel, implement an incentive mechanism for reporting environmental issues, regularly publicize the progress of CCUS, canal greening, and saline alkali land renovation projects to the public, regularly carry out grassroots environmental protection science popularization propaganda, and consolidate the bottom-up supervision power of the masses. Local financial institutions should be guided to optimize credit allocation, new energy, green agriculture in saline alkali land, and low-carbon technological transformation in chemical industry should be listed as key support areas, and credit supply should be moderately tightened for high energy consuming foreign trade enterprises. It should incorporate development indicators related to carbon reduction and green expansion into the annual assessments of various districts, counties, and parks, stabilize financial investment in environmental protection and green technology research and development, link Beijing and Tianjin scientific research resources to carry out low-carbon and saline alkali improvement technology research and development, promote the landing of green technologies adapted to local industries, and form a multi-party collaborative governance system.

References

[1] YIN BB, KUANG P, OUYANG XT, *et al*. Spatio-temporal characteristics and driving factors of the coupling coordination degree between the pollution-carbon reduction, and the green expansion and economic growth in China[J]. Economic Geography, 2024, 44(11): 122–131.

[2] REN XS, LI JH. Analysis of the configuration path of the coupled coordinated development of carbon reduction, pollution reduction, green expansion, and economic growth in China[J]. Environmental Science, 2026, 47(3): 1609–1622.

[3] CUI XL, WANG YR, MA YR. Dynamic evolution of carbon reduction–pollution reduction–green expansion–economic growth coupling coordination and its influencing factors in the Yellow River basin[J]. Research of Soil and Water Conservation, 2024, 31(4): 275–287.

[4] LV JQ, LIU HC, LIU MM, *et al*. Research on the coupling synergy of carbon reduction, pollution control, green expansion, and economic growth in representative cities of the Yangtze River Delta[J]. Environmental Pollution & Control,2026, 48(6): 1–9.

[5] BAO ZH, CHENG SS, TU HL. Synergy measurement and coupling coordination degree of carbon reduction, pollution control, green expansion, and economic growth in urban agglomeration of the Yangtze River Delta[J]. Low Carbon World,2024,14(1): 175–177.

[6] WANG SJ, KONG W, REN L, *et al*. Research on misuses and modification of coupling coordination degree model in China[J]. Journal of Natural Resources, 2021, 36(3): 793–810.

[7] GUO SS. Coupling and coordination of ecosystem health and urbanization in the Yellow River basin[D]. Xuzhou: China University of Mining and Technology, 2022.