Evaluation of Sustainable Development Status and Driving Factors at the Municipal Scale in the Yellow River Basin: Postprint

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Abstract

Research on sustainable development status is an important basis for regional scientific decision-making and effective management. Following the systems interaction approach, we construct an evaluation framework for sustainable development status, employ an asset-liability method to assess the status and trends of sustainable development in the Yellow River Basin from 2006 to 2020, and identify its intrinsic dominant driving factors based on the Weaver-Thomas model. The results show that: (1) The sustainable development status of the Yellow River Basin is not optimistic. Although asset levels are developing positively, both liability and net asset levels exhibit a downward trend. (2) The spatial differentiation characteristics of asset, liability, and net asset levels are significant. Asset levels demonstrate latitudinally an evolution from an inverted U-shaped pattern to a gradual upward trend, and longitudinally a relatively stable spatial pattern of "lower in the north, higher in the south". Liability levels exhibit a concentric spatial structure that gradually decreases from north to south, while both high-value and low-value areas of net asset levels display temporal inertia and spatial agglomeration convergence characteristics. (3) Dominant driving factors vary among different types of cities. Low asset-low liability type cities have the most numerous and structurally complex dominant driving factors, with ecological efficiency being the primary influencing system; the remaining three types of cities are characterized by fewer factors and predominantly asset factor influences, but low asset-high liability type cities exhibit stronger liability driving forces. In the future, cities in the Yellow River Basin need to formulate development pathways tailored to their own development characteristics.

Full Text

Evaluation and Its Driving Factors of Sustainable Development States in the Cities of the Yellow River Basin

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Abstract: Research on sustainable development status is crucial for informed decision-making and effective regional management. Following the concept of system interaction, this study constructs an evaluation framework for sustainable development status. The asset-debt method is employed to assess the sustainable development status of the Yellow River Basin from 2006 to 2020, while the Weaver-Thomas model identifies the dominant internal driving factors. The results indicate: (1) The sustainable development status of the Yellow River Basin is not optimistic. Although asset levels show positive trends, both debt and net asset levels exhibit downward trajectories. (2) Spatial differentiation characteristics of asset, debt, and net asset levels are significant. Asset levels display an evolving pattern from an inverted "U" shape to a gradual climbing trend latitudinally, while maintaining a relatively stable "low north, high south" spatial pattern radially. Debt levels demonstrate a circular spatial structure that gradually decreases from north to south. Both high- and low-value areas of net assets exhibit temporal inertia and spatial agglomeration convergence. (3) Dominant driving factors vary across city types. Low asset-low debt cities exhibit the most numerous and structurally complex dominant driving factors, with ecological efficiency as the primary influencing system. The remaining three city types show less intense driving dynamics, primarily influenced by asset factors, though low asset-high debt cities face relatively greater debt-driven pressures. Future development in the Yellow River Basin requires tailored development pathways based on local characteristics.

Keywords: system interaction; assets; debts; Weaver-Thomas model; Yellow River Basin

1.1 Study Area Overview

Due to historical river course changes and the absence of national-level strategic planning, a unified definition of the Yellow River Basin's boundaries has not yet been established. Referencing relevant literature and considering data availability, this study includes all municipal units in Shandong, Shanxi, Henan, Shaanxi, Ningxia, and Gansu provinces, as well as municipalities in Inner Mongolia excluding Chifeng, Tongliao, Hinggan League, and Hulunbuir, plus Xining City in Qinghai, totaling 73 municipal units [Figure 1: see original paper]. The Yellow River Basin possesses unique geographical, climatic, and hydrological characteristics, serving as an ecological corridor connecting the Qinghai-Tibet Plateau, Loess Plateau, and North China Plain. It also represents a crucial link covering and radiating economic and social development across eastern, central, and western China, holding a pivotal strategic position in the national development landscape and socialist modernization. However, the basin faces prominent contradictions between economic development and environmental protection, with socio-economic development highly dependent on resources and the environment. The region confronts numerous challenges constraining sustainable development, including tightening resource constraints, environmental pollution, ecosystem degradation, insufficient momentum for industrial structure transformation and upgrading, low economic development efficiency, and imperfect regional coordinated development mechanisms, resulting in an overall state of unbalanced and inadequate development.

1.2 Data Sources

Data were obtained from the *China City Statistical Yearbook*, provincial and municipal statistical yearbooks, water resources bulletins, national economic and social development statistical bulletins, and the China Entrepreneur Investment Club for 2006–2020. Missing data for individual indicators were interpolated using the mean method, while price indices were converted to constant prices using 2006 as the base year.

1.3 Indicator System Construction

The relationships among economic, social, and ecological environmental systems can be abstracted into three models: parallel, interactive, and restrictive. Parallel relationships are represented by three non-intersecting circles of varying sizes or three independent pillars. Interactive relationships are depicted as circles of varying sizes with intersecting areas or triangles formed by centers. Restrictive relationships are shown as nested circles of varying sizes. Since China's sustainable development strategy emphasizes interactive relationships, this study constructs an evaluation framework based on system interaction [Figure 2: see original paper].

The interactive relationship between social and economic systems (Region A) emphasizes the welfare level generated by economic development and the so-

cial resources required to support it, focusing on the equitable distribution of social benefits and social production efficiency. This is characterized by social distribution, specifically selecting indicators for equitable distribution of economic growth and social input efficiency. The interactive relationship between economic and ecological environmental systems (Region B) emphasizes avoiding economic growth at the expense of ecological environment. To balance economic development and ecological environmental protection in their 博弈 relationship, attention must be paid to the economic efficiency of material scale and natural capital input for economic growth. This requires developing production methods with low resource consumption and low pollution emissions, characterized by ecological efficiency, specifically selecting indicators for resource productivity and environmental productivity. The interactive relationship between social and ecological environmental systems (Region C) emphasizes that the ecological environment possesses not only ecological value but also social value. However, irrational resource utilization and distribution have led to prominent environmental justice issues. Social structural inequality also threatens the stable operation of ecosystems and interferes with ecological environmental protection. To address this situation, emphasis must be placed on the equality of material consumption and environmental space occupation, requiring resource-saving and environment-friendly lifestyles, characterized by ecological footprint, specifically selecting indicators for ecological use fairness and social development sufficiency .

1.4.1 Sustainable Development Status Measurement

Since the indicators in TABLE:1 contain 30 elements with some information redundancy among them, and the asset-debt method based on the principle of "comparative advantage" is a ranking-based analytical approach that can reduce information redundancy, this method is adopted for measurement. Within the spatial distribution of each indicator, the top 10 ranking positions are selected to form the "assets" of sustainable development status. The optimal indicator rank set is defined as j = 1,2,…,30, with corresponding scores of 1, 0.97,…, 0.03. The asset level (xi) of each research unit i for support system i is calculated as:

$$x_i = \sum_{j=1}^{n_i} \left(1 + 0.97 \times \frac{1}{j}\right) \times \text{rank}_{ij}$$

where n_i represents the number of asset indicators in support system i, and rank_{ij} represents the rank of indicator j in support system i for unit i.

Similarly, the bottom 10 ranking positions in each indicator's spatial distribution are selected to form the "debt" of sustainable development status. The worst indicator rank set is defined as j = 1,2,…,30, with corresponding scores of -1, -0.97,…, -0.03. The debt level (yi) of each research unit i for support system i is calculated using the same approach. The sum of "assets" and "debt" for

each region i's support system represents the net assets (A_i) of that system. Summing A_i across all subsystems yields the region's net assets (A).

1.4.2 Identification of Dominant Driving Factors for Sustainable Development Status

The Weaver-Thomas model is employed to identify internal dominant driving factors. This model seeks the optimal fit between actual and hypothetical combination ratios within multi-element systems. Calculation steps follow relevant literature.

2.1 Spatiotemporal Analysis of Asset Levels

Asset levels showed an overall upward trend from 2006 to 2020 [Figure 3: see original paper]. The mean asset level increased from 20.23% in 2006 to 25.30% in 2020, primarily due to rising levels in medium-high grade areas and significant improvement in low-value areas. Cities experiencing grade changes accounted for 59.52% of the total, with more cities showing grade increases than decreases. Among cities without grade transformation, 35.29% remained consistently high-grade. Spatially, asset levels evolved from an inverted "U" pattern in 2006 to a gradual climbing trend latitudinally, while maintaining a "low north, high south" characteristic radially. Longitudinally, asset levels displayed a "midstream 突起, downstream and upstream 凹陷" distribution in 2006, though this trend moderated by 2020. The midstream region, rich in resources, gradually internalized wealth accumulation through technology-oriented, green, and intelligent development of traditional high-energy-consuming industries, though further improvement potential is narrowing. The "upstream 凹陷" spatial pattern reflects the staged leapfrog development achieved in downstream areas, with competitive advantages gradually highlighted through spatial coordination within the Central Plains and Shandong Peninsula urban agglomerations. Overall, most northern cities evolved from low-level equilibrium to medium-level equilibrium, though significant gaps with southern cities persist, indirectly reflecting the "clustering" spatial characteristics of low asset levels.

2.2 Spatiotemporal Analysis of Debt Levels

Debt levels exhibited an overall upward trend from 2006 to 2020, with widespread rank adjustments signaling rising development pressure [Figure 4: see original paper]. The debt level displayed a circular spatial structure gradually decreasing from north to south, with Inner Mongolia and Ningxia as high-value centers gradually declining westward and southward. Inner Mongolia, as a minority-concentrated underdeveloped region with diverse resource-environment advantages, faces difficulties escaping the 困境 of fragile ecological environment and limited environmental capacity due to strong traditional development path dependence. In contrast, most cities in Shaanxi, Henan, and Shandong are low-level areas, with central-southern Shaanxi forming a debt "basin" and Henan and Shandong forming debt "marginal

zones." Most Henan cities remained medium-low level throughout 2006–2020, indicating that improvements in location, population, industry, and resources have gradually reduced development shortcomings and constraints.

2.3 Spatiotemporal Analysis of Net Asset Levels

Net asset levels showed a downward trend from 2006 to 2020, with relatively stable spatial patterns characterized by "high south, low north" [Figure 5: see original paper]. The number of cities with upward grade shifts was fewer than those with downward shifts, primarily distributed in Shanxi and Shandong. Cities without positive-negative conversion accounted for 73.49%, with 48.81% showing no grade conversion throughout the period. High-value areas are concentrated in Henan, Guanzhong Plain, while low-value areas are located in Inner Mongolia and Ningxia, indicating path dependence in both vertical and horizontal dimensions. Convergent regional development backgrounds and models have strengthened temporal inertia and spatial "agglomeration convergence" effects.

2.4 Analysis of Dominant Driving Factors

The actual development levels of various indicators constitute internal factors forming spatiotemporal differences in sustainable development status. Since different city types exhibit distinct sustainable development characteristics requiring categorical discussion, this analysis examines dominant driving factors for sustainable development favorable zones, attention zones, and improvement zones.

2.4.1 Sustainable Development Favorable Zone High asset-low debt cities demonstrate prominent development advantages, characterized by numerous dominant driving factors primarily driven by asset factors, with environmental production efficiency and ecological use fairness as main dimensions [Figure 6: see original paper]. The number of dominant driving factors ranges between 5–7, with asset factor proportions between 65.34%–82.85%. Diversified development paths reflect these cities' flexibility and adaptability, while also showing their ability to leverage development advantages. Key dominant factors include economic contribution coefficient, economic output per unit energy consumption, green burden coefficient, employment population per unit water consumption, and employment population per unit energy consumption, primarily distributed in environmental production efficiency and ecological use fairness dimensions. This reflects these cities' emphasis on balancing resource-environment carrying capacity and development potential, focusing on unified ecological, production, and living benefits. Sound ecological environments provide strong support for comprehensive benefits of high-quality, efficient economic and social development.

2.4.2 Sustainable Development Attention Zone High asset-high debt cities exhibit strong agglomeration and transformation capabilities for advan-

tageous resources, with fewer but asset-driven dominant factors, primarily in economic growth equitable distribution and resource productivity dimensions [Figure 7: see original paper]. The number of dominant driving factors ranges between 3–4, concentrated between 3–5, with asset factor proportions between 72.99%–85.03%. These cities clearly understand their strengths and weaknesses, focusing on leveraging advantages and strengthening core competitiveness. Key factors include economic output per unit labor input, economic output per unit technology input, employment population per unit water consumption, income level of economic growth, economic output per unit fixed asset investment, medical level of economic growth, and education level of economic growth, primarily in economic growth equitable distribution and resource productivity dimensions. This indicates these cities are in a state of partial gains, focusing on building fair and just social environments while seeking input-output efficiency at the economic system factor input 端.

Low asset-low debt cities lack prominent development advantages, exhibiting the most numerous and structurally complex dominant driving factors, with ecological efficiency as the primary driving system [Figure 8: see original paper]. Except for Pingdingshan City in 2015, all other cities show diversified driving patterns, with 5–7 dominant factors exhibiting joint effects of asset, debt, and non-asset/debt factors. Asset factors maintain strong influence but gradually decrease, while non-asset/non-debt factors' dominant positions gradually rise, reflecting these cities' active mobilization of limited resources for development without comprehensive development planning. These cities face unclear development goals, positioning, and pathways, unable to achieve coordinated development and resource optimization, severely constraining sustainable development and efficiency improvement. Medical level of economic growth, economic output per unit labor input, employment population per unit water consumption, economic output per unit technology input, economic output per unit land area input, economic output per unit water consumption, and education level of economic growth are primary asset-driven factors. Medical level of economic growth, economic output per unit labor input, employment population per unit water consumption, and economic output per unit energy consumption are primary debt-driven factors, mainly distributed in economic growth equitable distribution and social input efficiency dimensions. This is primarily because most of these cities are located in ecologically fragile central-western regions facing multiple constraints including backward infrastructure, separated technology and talent, low investment and trade facilitation levels, and unformed characteristic advantageous industrial systems. Nevertheless, they still emphasize optimizing social resource allocation and improving social welfare while seeking symbiotic development between economic and social systems.

2.4.3 Sustainable Development Improvement Zone Low asset-high debt cities exhibit the worst development status, with fewer dominant driving factors primarily driven by asset factors but also experiencing relatively high debt-driven forces, mainly in economic growth equitable distribution and social input

efficiency dimensions [Figure 9: see original paper]. Dominant driving factors are scattered but generally fewer in number. These cities are primarily located in ecologically fragile central-western regions facing multiple constraints. Despite low development levels, they emphasize optimizing social resource allocation and improving social welfare, seeking symbiotic development between economic and social systems. They actively adapt to scientific development models constrained by resource carrying capacity and ecological environmental capacity, reducing ecological environmental damage and impact on the basis of comprehensive conservation and efficient resource utilization, promoting mutual promotion and coordinated development between ecological environment and economic systems, and collaboratively improving resource and environmental production efficiency.

3 Discussion

The evaluation results differ from studies showing significant improvement in the Yellow River Basin's sustainable development index, primarily due to differences in research perspectives, indicators, and methods. Establishing measurement indicator systems is key to implementing sustainable development assessments. Unlike previous studies that isolated ecological, economic, and social systems, this study follows system interaction thinking to construct a comprehensive sustainable development status evaluation indicator system, providing new ideas for improving sustainable development evaluation systems. Empirical results objectively reflect the sustainable development status of the Yellow River Basin, facilitating policy recommendations from a system interaction perspective. Precisely identifying driving factors of urban sustainable development is crucial for policy regulation, yet current research offers weak analysis of dominant driving factors for different city types. This study reveals that low asset-low debt cities exhibit debt factor-driven phenomena, even as dominant driving factors, possibly because when a city's certain indicator lacks comparative advantage in the basin, it remains a local development advantage. The study finds the Yellow River Basin's sustainable development status is not optimistic, differing from some existing research.

4 Conclusions and Recommendations

4.1 Conclusions

(1) The sustainable development status of the Yellow River Basin is not optimistic, with debt levels playing an important role. Although asset levels have improved, both debt and net asset levels show downward trends. Therefore, identifying debt factors, assessing and reducing debt levels constitute the main opportunities and challenges facing the Yellow River Basin.

(2) Asset, debt, and net asset levels all exhibit agglomerated and non-equilibrium spatial characteristics. Asset levels maintain stable "low

north, high south" patterns. Debt levels show circular spatial structures gradually decreasing from north to south. Net asset levels exhibit "high south, low north" characteristics with temporal inertia and spatial "agglomeration convergence" effects.

(3) Dominant driving factors differ across city types but are dominated by asset factors. Low asset-low debt cities lack comprehensive development planning, with the most numerous and structurally complex dominant driving factors, where non-asset/non-debt driving factors' status gradually rises, and environmental and resource production efficiency are dominant dimensions. High asset-high debt cities focus on leveraging strengths and avoiding weaknesses, with the fewest dominant driving factors but primarily asset-driven, focusing on economic growth equitable distribution and resource productivity dimensions. Both high asset-low debt and low asset-high debt cities are primarily driven by asset factors, with the former showing diversified development paths concentrated in environmental production efficiency and ecological use fairness dimensions, while the latter shows limited development paths concentrated in economic growth equitable distribution and social input efficiency dimensions, constrained by non-prominent comparative advantages and relatively high debt-driven forces.

4.2 Recommendations Categorized policy implementation is a major strategy to address unbalanced and inadequate sustainable development in the Yellow River Basin. Differentiated regulation recommendations are as follows:

High asset-low debt cities should consolidate multi-point supporting "cornerstones" by tapping asset factor potential. First, establish and improve equalization guarantee mechanisms for basic public services, appropriately expand basic public service coverage, and improve service standards to ensure all groups share economic development achievements. Second, focus on interactions between economic and ecological environmental systems, promote energy conservation and resource-environmental protection, strengthen investment in energy-saving technologies, accelerate technological and institutional innovation, and emphasize promotion and application of advanced technologies to improve resource production efficiency. Third, further tap development potential of asset factors.

High asset-high debt cities should emphasize the social value of resource environments based on regional comparative advantages. First, continue improving interaction levels between ecological environment and social systems, fully utilize asset development advantages, pursue decoupled development between ecological environment consumption and social welfare, establish fair and just social group welfare distribution mechanisms, and tap ecological use fairness potential. Second, emphasize integration of economic and environmental systems, strengthen environmental regulations, enhance fee-based and investment-based environmental regulations, and improve environmental production efficiency levels.

Low asset-low debt cities should optimize driving structures and integrate driving forces. Starting from strengthening economic and social system interactions, continue optimizing production methods and improving ecological efficiency while tapping potential of non-asset/non-debt factor levels, appropriately avoiding debt-driven factors, and enhancing comprehensive urban development strength.

Low asset-high debt cities should prioritize strengthening integrated development of economic and social systems. First, emphasize the material foundation role of economic growth in improving medical care, education, and income levels, and the promoting effect of the latter on the former, forming a virtuous cycle under sustained economic growth. Second, focus on the scale and structure relationship between economic development input factors, seek optimal investment benefits, consolidate dominant driving positions of social input efficiency dimensions. Finally, emphasize asset factor driving effects, strengthen overall planning and categorical guidance, scientifically assess local development conditions, and explore suitable development models and pathways.

(4) Merely emphasizing system interaction relationships is insufficient to form lasting momentum for overall development. When formulating sustainable development pathways, cities must clarify the complexity, systematicity, and coordination of relationships among indicators, systems, and spaces, avoid goal conflicts, and promote overall improvement in development scale, efficiency, and levels in the Yellow River Basin through holistic approaches.

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Note: Figure translations are in progress. See original paper for figures.