Spatial Coupling Analysis on Carbon Emission, Industrial Structure and Ecological Benefits Coordination System: Performance of the Yellow River Basin

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Abstract. The contradiction between economic development and ecological protection in the Yellow River Basin has been serious for a long time. This paper bases on the Yellow River Basin and takes 9 provinces (autonomous regions) along the line to establish the measurement index of carbon emission, industrial structure and ecological benefit, and analyses the trend of temporal and spatial changes. Then, it builds the model of coupling coordination degree and studies the coordinating situation and dynamic interaction relationship of each part of the Yellow River basin by empirical research. The study shows that the carbon intensity of the Yellow River Basin was in a decreasing trend from north to south and improved noticeably from 2011 to 2017, especially in Ningxia Province. It can be concluded that the carbon emission, industrial structure and ecological benefit of the Yellow River Basin was generally in a moderately coupled state during the study period. The downstream region’s coupling degree was higher than that of the middle and upstream. Shandong Province took the lead, while Henan Province has improved most significantly in recent years. It is advised to take advantage of regional differentiation, accelerate industrial transformation, and improve environmental governance to facilitate coordinating development of all regions along the Yellow River Basin.

1. Introduction
After the beginning of the 21st century, climate changes and other issues have prompted countries to deal with the increasingly severe ecological problems and promote the green and low carbon development of the world industry. In September 2019, General Secretary Xi Jinping stressed at the Symposium on Ecological Protection and High-quality Development of the Yellow River Basin: Protecting the Yellow River is a profound plan for the great revitalization and sustainable development of the Chinese nation, and we must adhere to the concept of ecological priority and green development. The Yellow River basin is short of water resources and has crucial environmental problems. Among them, coal chemical companies account for 80% of the country's total. The above situation has led to a large proportion of traditional industries and a low level of industrial structure. In addition, agricultural production together with energy based economic development are not compatible with the environmental condition and capacity, which restrict its economic development prospect. Therefore, it is of great practical significance and urgency to study the industrial structure and ecological benefits of the Yellow River Basin.
Brannlund R [1] found that the adjustment of industrial structure is the key measure to reduce carbon emissions. Hatzigeorgiou [2] Vinuya, etc [3] used LMDI methods to analyze different countries and found that industrial structure, population and energy intensity had a significant impact on carbon emissions. Cheng Ye Qing [4] and Sun Zuoren [5] empirically analyzed the trend and characteristics of carbon emission intensity in energy consumption of China, and the driving factors of industrial carbon emission. Talukdar D [6] and Zhang Wei [7] found that the efficiency of energy use is mainly affected by the secondary industry. Such scholars as Ho Huishuang [8] established the model from drawing lessons from Kuznets model, and find that environmental regulation will promote the optimization of industrial structure, and the utility of environmental regulation policy to the optimization of industrial structure in different regions varies significantly. Yang Xiai [9] calculated the total economic volume and carbon emissions of various departments, and found that the optimization of industrial structure can reduce carbon emissions and promote economic development at the same time. Jin Fengjun [10] and Dong Zhanfeng [11] suggested that the fragile ecological environment and high load of resources and environment are the basic situation of the Yellow River Basin, and the establishment of ecological compensation mechanism in the Yellow River Basin is an effective means to promote its environmental protection and management and spur the high quality development of the economy. Chen Yao [12] puts forward the “Yellow River strategy”, that is, to promote the ecological protection and management of watersheds as a whole, to guide the planning of economic development and to regulate the overall interests of the linked watersheds. Such scholars as Tian Ze [13] have found that the coupling coordination degree of carbon emissions, industrial structure and regional innovation among provinces and cities in the Yangtze economic belt is basically consistent with the distribution of regional economic development level and innovation development ability in China. Such scholars as Zeng Fanqing [14] have found that China's financial system and industrial structure are in a high level of coupling stage for a long time.

It can be seen that the upgrading of industrial structure and the improvement of ecological benefits can reduce carbon emissions, and the carbon emission policy also has positive effects on it. At present, more attention is paid to the interaction between two elements, but little on research of the coupling and the interaction relationship of three elements. This paper combines the above three elements in order to carry out more comprehensive research and promote the low-carbon and high-quality development of the regional economy. Finally, we analyze the coupling coordination system and explore the optimizing path of coordinated development.

2. Another section of your paper

2.1. Measurement of Carbon Emission Indicators

Using the IPCC default emission factor calculation method, the carbon dioxide emissions from the 9 provinces of the Yellow River Basin are calculated. Take the default carbon content of the various fuels provided in the IPCC inventory guidelines and the default emission factors for each fuel into account, and calculate the carbon emissions from regional energy consumption activities from the energy consumption terminals (excluding carbon emissions from non-intentionally lost energy sources such as processing conversion, transport and distribution), the formula is as follows [15]:

$$C = \sum_{i=1}^{8} E_i \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12}$$

In formula (1), C denotes the total amount of carbon emissions produced for energy consumption; Ei, NCVi, and COFi represent the ith fossil fuel consumption, low calorific value, carbon content and carbon oxidation coefficient respectively. The i represents the energy type, which is raw coal, coke, crude oil and other 8 kinds of energy sources. 44/12 means the rate of conversion ratio between CO2 and C [15].
2.2. Measurement of Industrial Structure
This paper uses the index of industrial structure height to measure the level of industrial structure in various provinces. Industry and service industry are used to measure the development of regional industries. This project uses the second and third industry GDP ratio index of each region to measure the level of the industrial structure, the formula is as follows:

\[ K_i = \frac{X_i + Y_i}{G_i} \]  

(2)

Among them, \( K_i \) denotes the degree of the level of industrial structure; \( X_i \), \( Y_i \) denote the added value of the secondary and tertiary industries of the \( i \)th province while \( G_i \) represents the \( i \)th province’s GDP.

2.3. Two-stage Calculation of Ecological Benefits
The measurement of ecological benefit selects indicators related to pollution discharge and pollution control from the perspective of ecological pollution. Referring to the method of relevant scholars [16], the indicators and formulas are as follows:

\[ ECO_i = \frac{I'^u}{P'^u} \]  

(3)

\[ I'^u = \frac{I^u}{T_i} \]  

(4)

\[ P'^u = \sum_{j=1}^{u} P^w_j = \sum_{j=1}^{u} \frac{P^w_j}{P^g_j} \]  

(5)

Among them, \( ECO_i \) refers to \( t \)th year ecological benefit coefficient of the \( i \)th province; \( I'^u \) denotes the dimensionless value of the annual pollution control investment of the province; \( I^u \) denotes the total annual pollution control investment of the province; \( T_i \) denotes the average annual pollution control investment of each province; \( P'^u \) represents the sum of the dimensionless values of \( t \) year pollutant emissions of \( i \) provinces, including wastewater, solid waste, \( SO_2 \), nitrogen oxides and smoke dust, a total of five indicators; \( P^w \) Represents the \( t \)th year discharge of pollutants in \( i \) provinces; \( P^g \) denotes the average annual discharge of pollutants in provinces.

2.4. The Coupling Effect of the Interaction
Coupling refers to the phenomenon that two or more systems interact with each other and are often used in the economic field to judge whether the development of variables is orderly. In this study, the model of coupling degree and coupling coordination degree was constructed by referring to the research methods of Liao Chongbin [17], Lu Jin [18]. The steps are as follows:

(1) Constructing the coupling degree model of carbon emission, industrial structure and ecological benefit:

\[ C = \left( \frac{U_1 U_2 U_3}{(U_1 + U_2 + U_3)/3} \right)^{1/3} \]  

(6)

\( C \) is the coupling degree, and \( U_1, U_2, U_3 \) denote the carbon emission, industrial structure and ecological benefit index of each province respectively. Among them, the carbon emission index is selected as carbon emissions, the industrial structure index is selected as advanced degree, and ecological benefit coefficient is used to measure the ecological benefits. \( C \)’s value range is between 0~1, the larger the value is, the higher the coupling degree between systems is and vice versa.

(2) Build a model of coupling coordination:

In order to comprehensively reflect the degree of coordinated development between regional carbon emissions, industrial structure and ecological benefits, the coupling coordination degree model is further constructed on the basis of the coupling degree model. The formulas are as follows:
In the formulas above, $D$ indicates the coupling coordination degree, $C$ denotes coupling degree, $T$ denotes the coordination index of the three kinds of systems, and the $\alpha$, $\beta$, $\gamma$ are the system weight of them respectively. We consider that the three parameters are the same in the system, so we appoint $\alpha = \beta = \gamma = 1/3$.

According to the conclusion of relevant scholars [19], the coupling degree and coordination degree between carbon emission, industrial structure and ecological benefit are divided into 4 stages in Table 1 according to the output results:

| Coupling C | Level of coordination | Coupling coordination D | Level of coordination |
|------------|-----------------------|-------------------------|----------------------|
| $0 \leq C < 0.3$ | Separation phase | $0 < D \leq 0.3$ | Low coordination |
| $0.3 \leq C < 0.6$ | Antagonistic stage | $0.3 < D \leq 0.6$ | Moderate coordination |
| $0.6 \leq C < 0.8$ | Running-in phase | $0.6 < D \leq 0.8$ | Highly coordinated |
| $0.8 \leq C < 1.0$ | Coupling phase | $0.8 < D \leq 1.0$ | Extreme coordination |

Through the construction and analysis of the dual indicators of coupling degree and coupling coordination degree, it is possible to visually display the internal interaction of carbon emissions, industrial structure and ecological benefits of the Yellow River Basin. Then implement further analysis and research depending on the differences and changing trends of coordination degrees in various regions.

2.5. Data Sources

Based on the panel data of 9 provinces in the Yellow River Basin from 2011 to 2017, energy data are derived from the 2011~2017 China Energy Statistical Yearbook and provincial statistical yearbooks. The industrial structure data are obtained from the Statistical Yearbook of China with amendments to the original data. Relevant statistics of the ecological benefit index are taken from the China Environmental Statistical Yearbook. The related index is processed into dimensionless by the min-max deviation method. The specific conversion function is as follows: $x_1, x_2, \ldots, x_n$. Transform the sequence:

$$y_i = \frac{x_i - \min_{j \in [1,n]} \{x_j\}}{\max_{j \in [1,n]} \{x_j\} - \min_{j \in [1,n]} \{x_j\}}$$  \hspace{1cm} (9)

$y_1, y_2, \ldots, y_n \in [0,1]$ and the new sequence is dimensionless.

3. Empirical Analysis

3.1. Analysis of Selected Indicators

3.1.1. Evolution of Carbon Emissions. Carbon intensity refers to $CO_2$ emissions per unit of GDP, which has gradually become an important indicator for the assessment of the construction of ecological civilization.
Figure 1. Spatial distribution of carbon intensity in 2011 and 2017

It can be seen from Figure 1. that the distribution of carbon intensity in the provinces of the Yellow River Basin has apparent provincial differences, and shows an overall gradual increase from south to north. In 2011, the carbon intensity of Ningxia was significantly higher than that of other neighboring provinces, because petrochemicals, metallurgy, etc. are their pillar industries, the industrial structure is simplistic, and the heavy industry has a large proportion. For similar reasons, Inner Mongolia's carbon intensity in 2011 is second only to Ningxia. In 2017, the Yellow River Basin provinces witnessed varying degrees of carbon intensity decline. The four southern provinces: Sichuan, Henan, Shandong, and Shaanxi have successively declined in carbon intensity. The central provinces also declined, but the decline was not obvious in Ningxia, Inner Mongolia, and Shanxi. From the perspective of carbon intensity index, the effect of industrial adjustment on pollution control is remarkable. However, in Ningxia, Inner Mongolia, Shanxi and other regions with strong dependence on heavy industry still need to strengthen governance and stimulate industrial transformation.

3.1.2. Analysis of Industrial Structure Development. Figure 2. reflects the distribution of industrial structures of the provinces in the Yellow River Basin from 2011 to 2017.

Figure 2. Provincial distribution of industrial structure

Overall, proportion of the output value of the secondary and tertiary industries in various provinces has increased year by year, with Shanxi being the highest, followed by Shandong and Ningxia. Henan Province has maintained a high growth rate, and owned the largest total increase. Since Shanxi and Ningxia have a relatively high proportion of heavy industry and a low proportion of agriculture, they rank relatively high. Besides, Henan is a province majoring in agriculture. In the early period, the
proportion of its primary industry was relatively large. After several years of development, the proportion of GDP in the secondary and tertiary industries rose rapidly.

3.1.3. Ecological Benefit Analysis. Figure 3. shows the changes of ecological benefit intensity in the upper, middle and lower reaches of the Yellow River Basin from 2011 to 2017. It can be noticed that the distribution of the basin decreases from downstream to upstream significantly. The provinces in the upper reaches are deeply inland. Their economic development and industrial structure is relatively lagging behind, and there are certain disadvantages in the development of industrial industry. In addition, in 2017, the pressure of pollution discharge in the upper reaches of the Yellow River Basin increased while the investment in pollution control decreased, and the intensity value reached the bottom of 0.10, which is worthy of the attention of relevant departments. It is unacceptable to develop industry at the expense of environmental benefits. The middle reaches are Shanxi, Shanxi and Henan, among which Shanxi and Shaanxi take heavy industry as the industrial pillar. During the study period, the ecological benefits declined, but they are generally better than the upper reaches. The industrial structure model in the middle reaches is relatively fixed and inertial. It will take a certain period of time for transformation to make the economic development model a smooth transition. The lower reaches of the Yellow River are mainly Shandong, and its ecological benefit intensity fluctuates greatly from 2012 to 2014, which may be mainly due to industrial transfer. Shandong has achieved remarkable results in pollution control recently, with various indicators at the forefront. In the future, it is still imperative to continuously enrich the connotation of the industrial structure and improve industrial efficiency on the premise of ensuring environmental benefits.

![Figure 3. Ecological benefit intensity of upper, middle and lower reaches](image)

### Table 2. Coupling coordination degree of provinces in the Yellow River Basin from 2011 to 2017

| Provinces | 2011    | 2012    | 2013    | 2014    | 2015    | 2016    | 2017    |
|-----------|---------|---------|---------|---------|---------|---------|---------|
| Shanxi    | 0.494   | 0.515   | 0.517   | 0.442   | 0.466   | 0.458   | 0.535   |
| Mongolia  | 0.566   | 0.516   | 0.580   | 0.588   | 0.575   | 0.543   | 0.560   |
| Shandong  | 0.656   | 0.672   | 0.613   | 0.662   | 0.682   | 0.666   | 0.669   |
| Henan     | 0.481   | 0.442   | 0.464   | 0.487   | 0.482   | 0.548   | 0.543   |
| Sichuan   | 0.416   | 0.387   | 0.390   | 0.387   | 0.371   | 0.336   | 0.349   |
| Shaanxi   | 0.467   | 0.484   | 0.473   | 0.436   | 0.467   | 0.418   | 0.411   |
| Gansu     | 0.387   | 0.463   | 0.396   | 0.376   | 0.307   | 0.356   | 0.334   |
| Qinghai   | 0.255   | 0.250   | 0.241   | 0.278   | 0.280   | 0.305   | 0.222   |
| Ningxia   | 0.344   | 0.385   | 0.418   | 0.460   | 0.410   | 0.455   | 0.383   |
Table 2 shows the specific distribution of coupling coordination degree in the Yellow River Basin from 2011 to 2017. In terms of time series, the distribution of coupling in each province is relatively stable, and most provinces are in a moderate coordination. The coupling coordination degree of Shandong Province has always been in a high coordination stage, with an average of 0.660 in recent years. Inner Mongolia coupling coordination degree is also relatively high, close to the highly coupled state. Shaanxi and Ningxia are in the moderate coupling stage, and the index fluctuates in a certain range. The coupling degree of Henan has increased the most, from 0.481 in 2011 to 0.543 in 2017, mainly due to its rapid industrial structure adjustment and significant benefits in recent years. However, the coupling coordination level of Gansu and Sichuan has experienced a downward trend. It is needed to boost resource investment in industrial structure optimization and pollution control system, which is a necessity to promote coordinated green development. Due to its special geographical location, Qinghai is basically at the stage of low coordination. The relevant departments should carry out a more suitable industrial transformation on the precondition of protecting the ecological environment of Sanjiangyuan Area and combining the geographical characteristics of high altitude and less plain.

4. Conclusion

4.1. Continue to Develop A Low-carbon Model, Taking Advantage of Regional Differences
Regardless of total carbon emissions or carbon intensity, the differences among regions in the Yellow River Basin are quite significant. The provinces with weaker economic development conditions in the upstream areas should guide the transformation of energy consumption, promote clean energy consumption, and give full play to their geographical advantages. The central and western regions have resource advantages, more funds should be invested in the construction of energy base stations to promote the transition of energy supply in the western region to low-carbon, and then feed back the higher energy demand in the eastern part of the Yellow River Basin; Compared with the upper and middle reaches, the downstream region should actively develop and apply carbon reduction technology, and spread to the other reaches in order to boost cross-basin technology sharing, which forms a virtuous circle interaction. In addition, the carbon emission monitoring and evaluation system should be optimized to establish a sound carbon trading market.

4.2. Accelerating Industrial Transformation and Promoting Balanced Economic Development
In the above analysis of the industrial structure of each province, it can be seen that the industrial structure of Shanxi and Ningxia is relatively high when the environmental ecological index is behind, which indicates that the industrial development of many provinces in the middle reaches of the Yellow River Basin is unbalanced. Therefore, while making the most of the advantages of regional resources and the industrial agglomeration effects, provinces should also seek the diversification of resource allocation and industrial structure. Otherwise, relying on the advantages of resources for a long time, especially industries with high energy consumption and high emissions will inevitably hinder the development of other industries and limit the prospects of regional development.

Under the market economy, the industrial structure is prone to being lagging, especially for industries that consume fossil energy as a driving force. Therefore, the government needs to actively intervene to mobilize the low-carbon transformation of industries and promote sustainable development. Under the background of “the Belt and Road Initiative”, appropriate introduction of foreign investment will stimulate the vitality of industrial transformation, promote economic cooperation between regions and spur industrial upgrading.

4.3. Intensify the Management of Ecological Environment
The Yellow River basin occupies quite a crucial position in the ecological environment of China. According to the results of the study, the effectiveness of eco-efficiency governance weakened from downstream to upstream. All provinces should make reasonable investment and policy guidance based on actual conditions, such as the current industrial structure distribution and pollution control priorities.
The central and eastern regions of the Yellow River Basin should focus on the development of a green circular economy, and the central and western regions should emphasize ecological protection and green energy utilization.

The ecological environment protection of the Yellow River Basin should be carried out from multiple perspectives, including the management and supervision of industrial enterprise pollution, the full use of resources, urban greening, and the construction of shelter forests. At present, the ecological construction of the Yellow River Basin has entered a pivotal period, relevant plans should continue to be implemented to accelerate the realization of the "Beautiful China" goal.

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References
[1] R. Brannlund, T. Lundgren, P. Marklund, Carbon intensity in production and the effects of climate policy-evidence from Swedish industry, Energy Policy, 67(2): 844-857, 2014.
[2] E. Hatzigeorgioue, H. Polatidish, D. Haralambopoulosd, CO₂ emissions in Greece for 1990—2002: A decomposition analysis and comparison of results using the arithmetic mean divisia index and logarithmic mean divisia index techniques, Energy, 33(3): 492-499, 2007.
[3] F. Vinuya, F. Difurio, E. Sandoval, A decomposition analysis of CO₂ emissions in the United States, Applied Economics Letters, 17(10): 925-931, 2010.
[4] Y. Cheng, C. Wang, S. Zhang, X. Ye, H. Jiang, A spatial measurement of carbon emission intensity and its influencing factors in China's energy consumption, Journal of Geography, 68(10): 1418-1431, 2013.
[5] Z. Sun, D. Zhou, P. Zhou, Research on driving factors of industrial carbon emission: A new method for production decomposition analysis, The Journal of Quantitative and Technical Economics, 29(5): 63-74+133, 2012.
[6] D. Talukdar, C. Meisner, Does the private sector help or hurt the environment? Evidence from carbon dioxide pollution in developing countries, World Development, 29(5): 827-840, 2001.
[7] W. Zhang, Q. Zhu, H. Gao, Industrial structure upgrading, energy structure optimization and low carbon development of industrial system, Economic Research, 51(12): 62-75, 2016.
[8] H. He, The empirical analysis of environmental quality, environmental regulation and industrial structure optimization-based on panel data of east, middle and west China, Regional Research and Development, 34(01): 105-110, 2015.
[9] X. Yang, S. Cui, J. Lin, et al., The comparison of CO₂ emission accounting methods for energy use and mitigation strategy: a case study of China, Acta Ecologica Sinica, 32(22): 7135-7145, 2012.
[10] F. Jin, Coordinated promotion strategy of ecological protection and high-quality development in the Yellow River Basin, Reform, (11): 33-39, 2019.
[11] Z. Dong, C. Hao, A. Li, et al., Ideas and key points of ecological compensation mechanism construction in the Yellow River Basin, Ecological Economy, 36(02): 196-201, 2020.
[12] Y. Chen, K. Zhang, X. Chen, et al., Ecological protection and high quality development in the Yellow River Basin, Regional Economic Review, (01): 8-22, 2020.
[13] Z. Tian, X. Jing, Q. Xiao, Carbon emission-industrial structure-regional innovation coupling and temporal and spatial evolution in the Yangtze Economic Belt, East China Economic Management, 34(02): 10-17, 2020.
[14] F. Zeng, D. Ye, The analysis of the coupling coordination degree between financial system and industrial structure-based on the perspective of new structural economics, Economic Review, (03): 134-147, 2017.
[15] X. Ma, R. Chen, et al., Factors decomposition and decoupling of China's industrial carbon emissions, China Environmental Science, 39(08): 3549-3557, 2019.
[16] Q. Pang, W. Zhou, T. Yang, Impact mechanism of carbon emission, industrial structure and environmental regulation in the Yangtze River Economic Belt, Industrial Technology Economics, 39(02): 141-150, 2020.

[17] Z. Liao, Quantitative evaluation and classification system of coordinated development of environment and economy: A case study of urban agglomeration in the Pearl River Delta, Tropical Geography, (02): 76-82, 1999.

[18] J. Lu, H. Zhou, Empirical analysis on the coupling relationship between human capital and economic growth in China, Journal of Quantitative and Technical Economics, 30(09): 3-19, 2013.

[19] W. Wu, S. Niu, Evolitional analysis of coupling between population, resources and environment in Gansu Province, Chinese Journal of Popolation Science, (2): 81-86, 2006.