# Analysis of the Relationship between Regional Carbon Financial Market Development and Industrial Structure Upgrading: A Grey Relational Model Approach

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**Abstract.** Carbon finance, recognized globally as one of the effective solutions to combat global warming, is poised to inject fresh vitality into economic and societal production as it develops. Based on data from 13 cities in the Beijing-Tianjin-Hebei region, this study explores how the development of the carbon finance market affects industrial structure upgrading from the perspectives of carbon finance market development level and industrial structure upgrading. Firstly, by constructing an evaluation indicator system, a comprehensive comparative analysis of the carbon finance market development and industrial structure upgrading of these cities is conducted. Secondly, the study uses the grey relational model to delve into the degree of correlation between the development level of the carbon finance market and the upgrading of the industrial structure. The result shows significant regional disparities among these cities in terms of the development of the carbon finance market and the upgrading of industrial structure. Beijing and Tianjin lead in terms of carbon finance market development. Through the analysis using the grey relational model, it is found that there is a moderate to strong correlation between the level of development of the carbon finance market and industrial structure optimization, indicating the importance of all factors in influencing industrial structure upgrading. Empirical results demonstrate that, on a holistic scale, the development of carbon finance has a significantly positive impact on industrial structure advancement and rationalization. However, disparities exist among different cities, primarily attributed to varying levels of economic development, policy orientation, and developmental stages.

**Keywords:** Carbon finance market; Industrial structure upgrading; Comprehensive evaluation; Grey relational analysis.

## 1. Introduction

Carbon finance plays a vital function in facilitating the transition towards a sustainable economy and the attainment of goals related to carbon peaking and carbon neutrality [1]. The continuous development and optimization of industrial upgrading are closely related to the improvement of regional production capacity and economic development level. Starting from 2011, China's economic growth rate began to slow down, entering a phase of speed shift. Studying the development trajectories of various countries reveals that achieving industrial structure upgrading is an indispensable and challenging process [2]. Therefore, researching the correlation between carbon finance and industrial structure upgrading is of paramount importance.

In relation to the research concerning the correlation between carbon financial markets and industrial structure, some scholars have analyzed and elucidated the mechanisms of their impact. Concerning the development of carbon finance, it has become a global trend, and its significance lies in enhancing the role of the market in optimizing the allocation of environmental resources and further improving China's energy-saving and emission-reduction financing system [3]. Regarding industrial structure upgrading, the future direction is to vigorously promote the continuous and rapid development of modern agriculture, the service industry, technological innovation, and energy conservation and environmental protection [4]. Regarding the research on the relationship between carbon finance and industrial structure upgrading, regions with higher levels of carbon finance development also tend to have higher levels of industrial structure upgrading [5]. To promote industrial structure upgrading, from the point of carbon financial market development, the most effective approach is for the government to enact relevant policies and systems [6].

Most studies focus on individual provinces or city clusters as research objects, with limited literature examining multiple cities within a single region. This study focuses on the Beijing-Tianjin-Hebei region because it is an industrially developed area with a high level of urbanization, prominent air pollution, and structural pollution, with carbon dioxide emissions ranking among the highest in the country. Therefore, using the 11 cities in the Beijing-Tianjin-Hebei region as research objects to investigate the impact of carbon finance on industrial upgrading in the region, which serves as a model for promoting regional industrial green transformation and domestic industrial upgrading. From a regional perspective, the development of the carbon financial market in the Beijing-Tianjin-Hebei region was evaluated using the entropy weight method. Subsequently, quantitative analysis of the relationship between the two was conducted using the Grey Relational Model analysis, elucidating the influence of carbon finance development on the optimization of industrial structure [7].

## 2. Mechanisms of Carbon Finance in Industrial Upgrading

### 2.1. Analysis from the Perspective of the Carbon Financial Environment

China's domestic practices in green finance started relatively late. Currently, carbon finance primarily operates through the green credit business of banks, which considers ecological resource protection and pollution prevention and control of the ecological environment when granting loans. Specifically, it can be divided into two aspects: First, actively complying with relevant national environmental economic policies, providing loans to enterprises engaged in low-carbon environmental protection, environmental conservation, and green economy, thereby assisting them in development. Second, restricting credit financing for enterprises with high energy consumption, high emissions, and high pollution, thereby curbing their highly polluting production activities and prompting them to undergo industrial adjustments. This can play a crucial role in the process of carbon finance influencing industrial structure.

### 2.2. Analysis Based on the Carbon Financial Trading Mechanism

The carbon trading mechanism in the carbon financial market involves the government allocating total carbon emissions for a country or region to different enterprises or sectors [8]. These emissions allowances are referred to as emission quotas or permits, essentially treating carbon emissions as a tradable commodity with a price in the market. Enterprises with emissions below their quotas can sell their surplus allowances to enterprises with higher emissions. On the other hand, enterprises exceeding their quotas must purchase additional allowances to compensate for their excess emissions. This trading mechanism encourages companies to seek cost-effectiveness under carbon emission constraints, directs resource allocation to areas with the lowest emission reduction costs, and fosters innovation in green technologies, thereby promoting industrial upgrading from an energy efficiency perspective.

### 2.3. Analysis Based on Carbon Financial Market Policies

Under international cooperation frameworks and based on historical emission levels, specific carbon reduction targets are formulated, such as reducing a specific percentage of carbon emissions. In situations where carbon market quotas are limited, carbon financial markets integrate carbon trading price signals and other market factors to allocate more emission quotas to environmentally friendly, low-carbon enterprises that demonstrate greater capabilities. The allocation of carbon emission quotas can be guided by these targets or indicators to ensure that enterprises or sectors receive appropriate support in achieving national objectives. Increasing the allocation of green enterprise stocks in the market and implementing a series of related policies, such as setting up carbon funds and providing tax incentives, can be effective. Through mechanisms that stimulate economic incentives, cost-effectiveness, and technological innovation, businesses can be encouraged to reduce carbon emissions, contributing to the development goals of a low-carbon economy.

# 3. Empirical Analysis

## 3.1. Indicator Selection and Data Sources

### 3.1.1. Measuring the Level of Carbon Finance Development

To measure the level of carbon finance development, there is no specific standard. This study drew upon prior research on the measurement of regional carbon finance development levels in China and constructed an evaluation indicator system for the level of carbon financial market development, as illustrated in Table 1. This system evaluates the level of carbon finance development in each of the cities using six assessment indicators from four aspects: economic development, energy efficiency, financial environment, and scientific technology. These indicators include carbon intensity, financial sector value-added, carbon emissions loan intensity, financial contribution rate, the optimization of the tertiary industry structure, and the proportion of R&D expenditures [9].

**Table 1.** Evaluation Indicator System for Carbon Finance Market Development.

| Target layer | Criterion layer | Indicator Layer | Indicator Description | Index Number |
|---|---|---|---|---|
| Carbon Financial Market Development Level | Energy Efficiency Indicator | Scientific Research Indicator | Carbon Emissions/GDP | X1 |
| | | Financial Industry Value Added | Financial Industry Value Added | X2 |
| | | Carbon Loan Intensity | Carbon Emissions/Outstanding Loans | X3 |
| | Financial Environment Indicator | Financial Contribution Ratio | Total Loans/GDP | X4 |
| | Economic Development Indicator | Third Industry Structure Optimization | Third Industry Value Added/GDP | X5 |
| | Scientific Research Indicator | Research and Development Expenditure Ratio | Regional Science and Technology Expenditure/GDP | X6 |

Source: The National Bureau of Statistics of China, Statistical yearbooks and China carbon accounting database.

### 3.1.2. Measurement of Industrial Structure Upgrading Level

Currently, there are various methods in academia for measuring industrial structure upgrading, primarily focusing on rationalization and advancement. Some scholars also use an industrial upgrading index. To better represent the level of industrial structure upgrading, this study selects the Theil index, industrial upgrading index for advancement, and the proportion of the three major industries in GDP as indicators. The Theil index reflects the relative differences between different industrial sectors, indicating the degree of imbalance in the industrial structure. If the Theil index gradually decreases over time, it suggests that industrial structure upgrading may be occurring. The industrial upgrading index represents the relative superiority or inferiority of different industrial sectors in terms of technology level and value chain position. If the index of high-value-added industries gradually increases over time while that of traditional industries relatively decreases, it may indicate that industrial structure upgrading is taking place. The proportion of each industry's output value in GDP is a commonly used method for measuring the structure of the three industries. By comparing the proportion of output value of each industry in GDP, it can be revealed that the current

stage of economic development and measure changes in the economic structure [10]. The evaluation index of industrial structure upgrading is set up in Table 2. The data required for calculation of GDP, industrial structure coefficient, output value of each industry, technological innovation input, etc. are obtained from the National Bureau of Statistics of China.

**Table 2.** Evaluation Indicator System for Industrial Structure Upgrading.

| Target layer | Criterion layer | Indicator Layer |
|---|---|---|
| Industrial Structure Upgrade | Sophistication | Theil Index |
| | | Industrial Upgrade Index |
| | Rationalization | Primary Industry/GDP |
| | | Secondary Industry/GDP |
| | | Tertiary Industry/GDP |

Source: The National Bureau of Statistics of China

### 3.2. Comparative Calculation Based on Entropy Weighting Method

#### 3.2.1. Carbon Finance Market Development Level and Ranking

Using the entropy Weight-TOPSIS method, weights are assigned to each indicator and calculate the scores for the level of carbon finance market development in each city. The scores and rankings for the years 2017 to 2019 are shown in Table 3.

**Table 3.** Carbon Finance Market Development Level and Ranking for Various Regions in 2010, 2015, and 2020.

| Region | 2010 | Ranking | Region | 2015 | Ranking | Region | 2020 | Ranking |
|---|---|---|---|---|---|---|---|---|
| Beijing | 0.464 | 1 | Beijing | 0.439 | 1 | Beijing | 0.438 | 1 |
| Tianjin | 0.184 | 2 | Tianjin | 0.214 | 2 | Tianjin | 0.155 | 2 |
| Baoding | 0.028 | 8 | Baoding | 0.023 | 12 | Baoding | 0.023 | 12 |
| Qinhuangdao | 0.048 | 4 | Qinhuangdao | 0.043 | 4 | Qinhuangdao | 0.034 | 8 |
| Langfang | 0.023 | 11 | Langfang | 0.030 | 8 | Langfang | 0.039 | 6 |
| Cangzhou | 0.026 | 10 | Cangzhou | 0.028 | 9 | Cangzhou | 0.030 | 10 |
| Shijiazhuang | 0.060 | 3 | Shijiazhuang | 0.039 | 6 | Shijiazhuang | 0.047 | 5 |
| Zhangjiakou | 0.034 | 7 | Zhangjiakou | 0.044 | 3 | Zhangjiakou | 0.033 | 9 |
| Chengde | 0.027 | 9 | Chengde | 0.023 | 10 | Chengde | 0.035 | 7 |
| Handan | 0.037 | 6 | Handan | 0.037 | 7 | Handan | 0.048 | 4 |
| Xingtai | 0.021 | 12 | Xingtai | 0.023 | 11 | Xingtai | 0.030 | 11 |
| Hengshui | 0.009 | 13 | Hengshui | 0.018 | 13 | Hengshui | 0.021 | 13 |
| Tangshan | 0.039 | 5 | Tangshan | 0.041 | 5 | Tangshan | 0.068 | 3 |

Source: The National Bureau of Statistics of China, Statistical yearbooks and China carbon accounting database.

From the rankings, it can be observed that Beijing and Tianjin consistently hold the top two positions from 2010 to 2020. In terms of energy efficiency, Beijing, Tianjin, and Hengshui have the highest impact, indicating that these regions have relatively high carbon emissions per unit of economic output. This reflects the prominence of carbon emissions issues during their industrialization and urbanization processes. Moreover, carbon finance market development in these regions may face environmental pressures. The influence of financial sector value-added is highest in Xingtai, Handan, and Cangzhou, suggesting that the financial sector plays a significant role in these cities' economies. The impact of R&D expenditure ratio is greatest in Xingtai, Zhangjiakou, and Hengshui, indicating that high levels of research investment contribute to the development of these cities' industries. Lastly, the influence of carbon emissions loan intensity is highest in Hengshui, Beijing, and Baoding, reflecting the strong emphasis on carbon reduction and green development in these regions.

### 3.2.2. Industrial Structure Upgrading Level and Ranking

Using the entropy weight-TOPSIS method, weights are assigned to each indicator and calculate the scores for the level of industrial structure upgrading in each province. The scores and rankings for the years 2017 to 2019 are shown in Fig.1.




**Fig 1.** Industrial Structure Upgrading Level and Ranking for Various Regions in 2010, 2015, and 2020.

Source: The National Bureau of Statistics of China, Statistical yearbooks and China carbon accounting database

From the rankings, it is obvious that Beijing and Tianjin consistently hold the top two positions in terms of industrial structure upgrading. This suggests that these regions have made significant advancements in their industries, particularly in terms of technological innovation and the development of emerging industries. Conversely, cities such as Baoding, Tangshan, Langfang, Cangzhou, Zhangjiakou, Chengde, Shijiazhuang, Handan, Xingtai, and Hengshui, located in Hebei Province, face challenges in industrial structure upgrading due to their strong dependence on traditional high-carbon industries. These cities may require more time and investment to transition to more environmentally friendly and high-value-added industries. Additionally, their relatively lower technological levels and limited innovation capacity may hinder industrial upgrading.

### 3.3. Analysis of Results Using the Grey Relational Model

The Grey Relational Model is apt for conducting a more in-depth analysis of the interrelationships between carbon finance market development and industrial structure upgrading. Industrial structure upgrading is considered as the reference sequence, while the carbon finance market development level is treated as the comparative sequence. The results of the grey relational model calculations are presented in Table 4.

**Table 4.** Grey Relational Degrees between Carbon Finance Market Development Level and Industrial Structure Upgrading.

| Region | Energy Efficiency | Financial Environment | | | Economic Development | R&D |
|---|---|---|---|---|---|---|
| | X1 | X2 | X3 | X4 | X5 | X6 |
| Beijing | 0.5 | 0.733 | 0.64 | 0.196 | 0.215 | 0.396 |
| Tianjin | 0.394 | 0.888 | 0.564 | 0.223 | 0.261 | 0.48 |
| Qinhuangdao | 0.327 | 0.981 | 0.49 | 0.274 | 0.281 | 0.538 |
| Baoding | 0.351 | 0.98 | 0.509 | 0.281 | 0.29 | 0.538 |
| Tangshan | 0.331 | 0.981 | 0.498 | 0.273 | 0.285 | 0.558 |
| Langfang | 0.306 | 0.983 | 0.491 | 0.193 | 0.207 | 0.591 |
| Cangzhou | 0.218 | 0.985 | 0.403 | 0.241 | 0.233 | 0.612 |
| Shijiazhuang | 0.214 | 0.984 | 0.435 | 0.112 | 0.231 | 0.608 |
| Zhangjiakou | 0.196 | 0.991 | 0.363 | 0.153 | 0.284 | 0.665 |
| Chengde | 0.235 | 0.99 | 0.315 | 0.158 | 0.338 | 0.557 |
| Handan | 0.291 | 0.988 | 0.362 | 0.198 | 0.317 | 0.576 |
| Xingtai | 0.378 | 0.989 | 0.538 | 0.128 | 0.245 | 0.696 |
| Hengshui | 0.66 | 0.99 | 0.748 | 0.218 | 0.178 | 0.64 |

Source: The National Bureau of Statistics of China, Statistical yearbooks and China carbon accounting database

The grey relational model results indicate that there is a moderate to strong correlation between carbon finance market development level and industrial structure upgrading, suggesting that all factors are important in influencing industrial structure upgrading. The cities most influenced by carbon emissions intensity are Hengshui, Beijing, and Tianjin. This indicates that these cities have relatively high carbon emissions per unit of economic output, reflecting environmental pressures in their industrial and urban development. To promote industrial structure upgrading, governments can consider reducing carbon emission quotas accordingly, thereby lowering carbon emissions.

Influence from financial sector value-added is most prominent in Xingtai, Handan, and Cangzhou, possibly indicating that the financial sector plays a significant role in the economies of these cities. As a supportive industry, the financial sector can provide financing, investment, and risk management services to other industries, thereby facilitating the upgrading of the industrial structure.

The impact of R&D expenditure ratio is highest in Xingtai, Zhangjiakou, and Hengshui, reflecting their high research investment levels and innovation capacity. High levels of research investment contribute to innovation competitiveness and, subsequently, promoting the optimization and upgrading of industrial structure.

The influence of carbon emissions loan intensity is most significant in Hengshui, Beijing, and Baoding, suggesting that these regions prioritize carbon reduction and green development. They provide financial support, such as carbon loans, to encourage the development of green industries, contributing to their good performance in terms of carbon emissions loan intensity.

Among the four subsystems influencing carbon finance market development, the financial environment has the highest correlation with industrial structure upgrading, while energy efficiency has the lowest correlation. This indicates that carbon finance market development mainly relies on the influence of government policies and financial environments, requiring financial support such as investment, financing, and financial innovation. The lower correlation with energy efficiency may be due to the fact that improving energy efficiency typically involves technical and engineering innovations, which may depend more on a company's own technological investment and management improvements. In this process, the role of the financial market may be relatively limited.

## 4. Conclusion

This study, focusing on the factors influencing the rationalization and advancement of industrial structure upgrading, explored the mechanism through which the development level of the carbon finance market affects industrial structure upgrading. It empirically analyzed data from 13 cities in the Beijing-Tianjin-Hebei region for the years 2003 to 2020. The study employed the entropy weight-TOPSIS method to construct evaluation indicator systems for both carbon finance market development level and industrial structure upgrading. Comparative analyses of the development status of these 13 cities were conducted. Furthermore, the grey relational model was used to analyze the degree of correlation between industrial structure upgrading and carbon finance market development level. The following conclusions were drawn.

Based on the comprehensive evaluation, regional differences were found in the carbon finance market development level and industrial structure upgrading among the 13 cities. Beijing and Tianjin are at the forefront of carbon finance market development in the country, while Xingtai, Hengshui, and Cangzhou are relatively lagging behind. Beijing and Tianjin also exhibit relatively good levels of industrial structure development, while the industrial structure upgrading in cities like Chengde, Baoding, and Xingtai is less favorable.

According to the results of the grey relational model, there is a moderate to strong correlation between the carbon finance market development level and industrial structure upgrading, indicating that all the considered factors are important in influencing industrial structure upgrading. When assessing the impact of individual indicators, the order of influence on industrial structure upgrading

from high to low is as follows: financial sector value-added, R&D expenditure ratio, carbon emissions loan intensity, carbon intensity, optimizing the structure of tertiary industry, and financial contribution rate.

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