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A Study on Initial Carbon Emission Quota Allocation Schemes in the Yangtze River Delta Region

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Abstract

Global climate change has become a pressing global challenge, and the scientific allocation of carbon emission rights is crucial for achieving regional emission reduction targets and promoting low-carbon transformation. As a core region of my country's economic development, the Yangtze River Delta region accounts for a high proportion of the country's total carbon emissions. The three provinces and one municipality of Shanghai, Jiangsu, Zhejiang, and Anhui exhibit significant differences in economic development levels, industrial structures, and carbon emission intensity. These differences reflect regional development imbalances and pose practical difficulties for the fair and efficient allocation of carbon emission rights. This paper takes the three provinces and one municipality of the Yangtze River Delta as the research object, and, focusing on the 2030 carbon peak target, designs and analyzes three initial carbon emission quota allocation schemes: fairness-oriented, efficiency-oriented, and a hybrid scheme balancing fairness and efficiency. By comparing the implementation effects of each scheme, its advantages and disadvantages are identified, providing theoretical support and practical reference for the construction of the carbon market in the Yangtze River Delta region, and also offering a reference for carbon quota allocation in other regions of China.

Keywords

Yangtze River Delta Region; Carbon Emission Rights; Initial Quota Allocation; Fairness And Efficiency; Carbon Peaking

1. Introduction

1.1. Research Background

Global climate change is a major challenge facing all mankind. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) clearly points out that the world has entered the era of carbon neutrality, and countries and regions need to work together to promote climate governance and share local governance

experiences^{(1)}. As the world's largest developing country, my country has taken the initiative to assume its responsibilities as a major power and has clearly proposed the dual carbon goals of achieving carbon peaking before 2030 and carbon neutrality before 2060. This goal will drive extensive and profound systemic changes in my country's economy and society. Carbon emission rights allocation, as the core link in the construction of the carbon market, is directly related to the implementation effect of emission reduction targets and also affects the coordinated development of regional economies.

The Yangtze River Delta region, encompassing Shanghai, Jiangsu, Zhejiang, and Anhui provinces and municipalities, is the core engine of my country's economic development and a key area for carbon emissions. This region accounts for only 3.7% of the national land area and about 16% of the national population, yet its GDP accounts for over 24% of the national total, and its carbon emissions account for over 20% of the national total, making it a key area for my country's low-carbon transformation. At the same time, the Yangtze River Delta region faces significant development imbalances: Shanghai, as an international metropolis, has a high level of economic development, with industries mainly focused on services and high-tech industries, resulting in relatively low carbon emission intensity; Jiangsu and Zhejiang have strong industrial bases and developed manufacturing sectors, leading to large total carbon emissions; Anhui, as a less developed region in the Yangtze River Delta's economic development, is in a stage of rapid industrialization and urbanization, with industries mainly focused on energy-intensive sectors, resulting in persistently high carbon emission intensity.

1.2. Research Significance

This research has significant theoretical and practical value. At the theoretical level, focusing on the Yangtze River Delta region as a typical example, this study designs three initial quota allocation schemes—fairness, efficiency, and a hybrid approach—enriching the theoretical system of regional carbon emission rights allocation. In particular, by considering the carbon inequity landscape and multi-dimensional development goals, it improves the allocation method that balances fairness and efficiency, providing a new perspective for regional carbon quota allocation research. Simultaneously, through empirical analysis comparing the effects of different schemes, it deepens the understanding of the coupling relationship between carbon emission rights allocation and regional economic development and low-carbon transformation, providing a reference for related research.

At the practical level, the research findings can provide specific guidance for the construction of the carbon market in the Yangtze River Delta region, clarifying the applicable scenarios and improvement directions for different allocation schemes, helping local governments formulate scientific and reasonable carbon emission rights allocation policies, coordinating the emission reduction responsibilities of the

three provinces and one municipality, and promoting regional coordinated low-carbon transformation. Furthermore, the practical experience of the Yangtze River Delta region can also provide a reference for carbon quota allocation in other regions such as the Pearl River Delta and the Beijing-Tianjin-Hebei region, contributing to the achievement of the national dual-carbon goals.

1.3. Current Status of Domestic and International Research

1.3.1. Current Status of International Research

International research on the initial allocation of carbon emission rights started earlier and has formed a relatively mature theoretical system and practical experience. From the perspective of allocation principles, the principles of fairness and efficiency are the core principles generally recognized by the academic community. The principle of fairness includes dimensions such as historical responsibility fairness, per capita fairness, and payment capacity fairness, while the principle of efficiency emphasizes optimizing resource allocation to minimize emission reduction costs.

In recent years, international research has gradually focused on the synergy between fairness and efficiency, proposing various hybrid allocation methods to achieve a balance by combining the advantages of different allocation principles. At the same time, the spatial transfer effect of carbon emissions and the problem of carbon unfairness have also become research hotspots. The academic community emphasizes considering the implicit carbon transfer in inter-regional trade during the allocation process to avoid unfair allocation of governance responsibilities^{(1)}.

1.3.2. Current Status of Domestic Research

Domestic research on the initial allocation of carbon emission rights started later, but with the introduction of dual-carbon targets, related research has increased rapidly. Domestic research mainly focuses on the national and regional levels, with regional research focusing on economically developed regions such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta. In the study of carbon quota allocation in the Yangtze River Delta region, scholars have proposed various allocation schemes from different perspectives: some scholars, based on the principle of fairness, have adopted the grandfather method, per capita allocation method, etc., emphasizing fairness between regions and focusing on historical carbon emission responsibility and regional development gaps; some scholars, based on the principle of efficiency, have used DEA models, zero-sum game models, etc., focusing on improving emission reduction efficiency and promoting the flow of carbon emission rights to high-efficiency regions^{(5)}; and some scholars have attempted to combine entropy methods, analytic hierarchy process, etc., to construct a hybrid allocation scheme, comprehensively considering fairness and

efficiency factors to optimize the quota allocation results.

1.4. Research Content and Methods

1.4.1. Research Content

This paper takes the three provinces and one municipality of Shanghai, Jiangsu, Zhejiang, and Anhui in the Yangtze River Delta region as the research object, and focuses on the initial carbon emission quota allocation scheme. Specific contents include:

First, reviewing the relevant theories and principles of initial carbon emission quota allocation, clarifying the core positions of fairness and efficiency in quota allocation;

Second, analyzing the current status and regional differences of carbon emissions in the Yangtze River Delta region, including total carbon emissions, carbon emission intensity, and the relationship between industrial structure and carbon emissions, providing a realistic basis for scheme construction;

Third, designing three allocation schemes: fairness-oriented, efficiency-oriented, and a hybrid scheme that balances fairness and efficiency, clarifying the ideas and calculation methods of each scheme;

Fourth, conducting empirical analysis of the three schemes, comparing their quota allocation results, fairness, efficiency, and emission reduction effects;

Fifth, summarizing the advantages and disadvantages of each scheme, and proposing optimization suggestions and future research directions for the initial carbon emission quota allocation in the Yangtze River Delta region.

1.4.2. Research Methods

The main research methods used in this paper are:

(1) Literature Review: A systematic review of domestic and international literature, policy documents, and research findings on the initial allocation of carbon emission rights was conducted to clarify the theoretical basis, current status, and shortcomings of the research, providing theoretical support and insights for future research.

(2) Statistical Analysis: Relevant data on GDP, population, total carbon emissions, and industrial structure of the three provinces and one municipality in the Yangtze River Delta region from 2010 to 2022 were collected. Statistical analysis was used to analyze the current status and differences in regional carbon emissions, providing data support for scheme construction and empirical analysis.

(3) Model Construction: An improved grandfather method model was constructed based on the principle of fairness; a zero-sum game model was constructed based on the principle of efficiency; and a hybrid allocation model was constructed based on the principle of synergy between fairness and efficiency, combined with the entropy method, to achieve quota allocation with different orientations.

(4) Empirical Analysis: The initial carbon emission rights of the three provinces and

one municipality in the Yangtze River Delta region were calculated using the three models. The implementation effects of each scheme were compared and analyzed using indicators such as the Gini coefficient, emission reduction costs, and technical efficiency to verify the rationality and feasibility of the schemes.

1.5. Research Innovations

The main innovations of this paper are twofold: First, it fully considers the regional differences and carbon unfairness in the Yangtze River Delta region, introduces the principle of transfer responsibility into the fairness-oriented scheme, takes into account both historical carbon emission responsibility and the spatial transfer effect of carbon emissions, and makes up for the shortcomings of insufficient attention to carbon transfer in existing research^{(1)}; Second, it uses the entropy method to construct a hybrid allocation scheme, determines the weight by calculating the information entropy of each indicator, avoids subjective weighting bias, and achieves synergistic optimization of fairness and efficiency. At the same time, it quantifies the emission reduction costs and efficiency of each scheme through empirical analysis, providing a scientific basis for scheme selection.

2. Relevant Theoretical Basis and Allocation Principles

2.1. Relevant Theoretical Basis

2.1.1. Environmental Justice Theory

Environmental justice theory is one of the core theoretical foundations of carbon emission rights allocation. Its core view is that all members of society enjoy equal environmental rights and should also bear equal environmental responsibilities, avoiding unfair distribution of environmental damage. In carbon emission rights allocation, environmental justice theory requires balancing intragenerational and intergenerational equity. Intragenerational equity emphasizes the fair allocation of carbon emission rights among different regions and groups within the same era, while intergenerational equity emphasizes the fair allocation between present and future generations, avoiding excessive consumption of carbon resources by the present generation and harming the development rights of future generations.

For the Yangtze River Delta region, environmental justice theory requires that quota allocation fully consider the development gaps among the three provinces and one municipality. It must guarantee low-carbon transition space for economically developed areas while reserving reasonable development rights for less developed areas, avoiding exacerbating regional development disparities due to unfair quota allocation and achieving coordinated regional development.

2.1.2. Resource Optimal Allocation Theory

Resource optimal allocation theory is the theoretical foundation of

efficiency-oriented carbon emission rights allocation. Its core idea is that, under conditions of resource scarcity, maximizing resource utilization efficiency and reducing total social costs through rational resource allocation. As a scarce environmental resource, the optimal allocation of carbon emission rights requires allocating them to regions or enterprises with the lowest emission reduction costs and highest emission reduction efficiency, minimizing overall emission reduction costs and promoting efficient low-carbon transition.

In the allocation of carbon quotas in the Yangtze River Delta region, the theory of optimal resource allocation requires full consideration of the emission reduction efficiency and cost of each region, guiding the flow of carbon emission rights to high-efficiency regions through market-based means, optimizing regional resource allocation, improving overall emission reduction efficiency, and achieving a win-win situation for economic development and low-carbon transformation.

2.1.3. Game Theory Theory

Game theory provides a new analytical perspective for carbon emission rights allocation. Its core premise is that different stakeholders have conflicting interests, and equilibrium is achieved through game theory, resulting in a reasonable distribution of benefits. The three provinces and one municipality of the Yangtze River Delta, as different stakeholders, engage in a game of interests in carbon emission rights allocation—economically developed regions hope to obtain more quotas to ensure economic development, while less developed regions hope to obtain reasonable quotas to support their own development and bear reasonable emission reduction responsibilities.

Based on game theory, this paper introduces the concept of zero-sum game in the efficiency-oriented scheme and takes into account the interests of each region in the hybrid scheme. Through collaborative game theory, it achieves a balance between fairness and efficiency, promoting a collaborative emission reduction pattern in the Yangtze River Delta region^{(1)}.

2.2. Principles for Initial Carbon Emission Rights Allocation

Combining relevant theories and the actual situation in the Yangtze River Delta region, this paper determines that the core principles for initial carbon emission rights allocation are the principles of fairness, efficiency, and sustainable development. These three principles are interconnected and mutually restrictive, constituting the basic principle system for quota allocation.

2.2.1. Fairness Principle

Fairness is the primary principle in the initial allocation of carbon emission allowances and the foundation for achieving coordinated regional development. Fairness, as referred to in this paper, includes three dimensions: first, historical

responsibility fairness, meaning that each region bears corresponding emission reduction responsibilities based on its past carbon emissions; the greater the historical total carbon emissions, the heavier the emission reduction task, and the smaller the allowance allocated; second, transfer responsibility fairness, meaning that considering the spatial transfer effect of carbon emissions, regions that transfer carbon emissions through trade must bear corresponding transfer responsibilities to avoid exacerbating the carbon inequality.

2.2.2. Efficiency Principle

The efficiency principle is the core principle in the initial allocation of carbon emission allowances, aiming to achieve optimal allocation of emission reduction resources and reduce overall emission reduction costs. The efficiency principle requires that allowances be tilted towards regions with high emission reduction efficiency and low costs, encouraging all regions to improve their emission reduction technologies and energy utilization efficiency.

2.2.3. Sustainable Development Principle

The sustainable development principle requires that the initial allocation of carbon emission allowances take into account both economic development and low-carbon transformation, meeting current emission reduction targets while ensuring the long-term sustainable development of the regional economy. For the Yangtze River Delta region, this principle requires that quota allocation schemes be combined with regional industrial structure upgrading and energy structure optimization, promoting the transformation and upgrading of high-energy-consuming industries, cultivating low-carbon industries, and achieving coordinated progress in economic development and low-carbon transformation. This avoids a one-size-fits-all approach to quota allocation and ensures that emission reduction targets are achievable and sustainable.

3. Current Status and Regional Differences in Carbon Emissions in the Yangtze River Delta Region

3.1. Overall Status of Carbon Emissions in the Yangtze River Delta Region

As one of the most economically developed regions in my country, the Yangtze River Delta region is also a key area for carbon emissions. Statistics show that in 2022, the total carbon emissions in the Yangtze River Delta region were approximately 850 million tons, accounting for 20.3% of the national total. The carbon emission intensity (carbon emissions per unit of GDP) was 0.58 tons/10,000 yuan, lower than the national average (0.65 tons/10,000 yuan), but still higher than that of developed countries, indicating that the task of low-carbon transformation remains arduous.

In terms of industry distribution, carbon emissions in the Yangtze River Delta region

are mainly concentrated in industry, energy, and transportation. Industry accounts for over 65% of carbon emissions, primarily from energy-intensive industries such as steel, chemicals, and building materials. The energy sector accounts for approximately 18%, mainly from coal and electricity consumption. Transportation accounts for about 12%, and its carbon emissions are showing a year-on-year upward trend due to regional urbanization and increased vehicle ownership. Other sectors, including agriculture and services, account for less than 5% of total carbon emissions.

From a temporal perspective, the total carbon emissions in the Yangtze River Delta region from 2010 to 2022 showed a trend of first rising and then stabilizing: From 2010 to 2018, with rapid regional economic development and the advancement of industrialization and urbanization, total carbon emissions increased year by year, with an average annual growth rate of 3.2%; after 2018, driven by dual-carbon targets and low-carbon transformation policies, the Yangtze River Delta region intensified its emission reduction efforts, and the growth rate of total carbon emissions slowed down and tended to stabilize, remaining basically between 840-850 million tons from 2020 to 2022, showing a steady decline, laying a good foundation for reaching peak carbon emissions in 2030.

3.2. Analysis of Regional Differences in Carbon Emissions in the Yangtze River Delta Region

The three provinces and one municipality in the Yangtze River Delta region have significant differences in economic development level, industrial structure, and energy structure, resulting in obvious regional differences in their current carbon emission status, mainly reflected in three aspects: total carbon emissions, carbon emission intensity, and industrial carbon emission structure.

3.2.1. Differences in Total Carbon Emissions

In terms of total carbon emissions, the pattern among the three provinces and one municipality in the Yangtze River Delta region is Jiangsu > Anhui > Zhejiang > Shanghai. In 2022, Jiangsu Province's total carbon emissions reached 320 million tons, accounting for 37.6% of the total emissions in the Yangtze River Delta region, making it the province with the highest total carbon emissions in the region. This is mainly due to Jiangsu's strong industrial base, with a concentration of energy-intensive industries such as steel and chemicals, resulting in high energy consumption. Anhui Province's total carbon emissions were 230 million tons, accounting for 27.1%. Although its economic development level is lower than that of Jiangsu, Zhejiang, and Shanghai, its industries are mainly energy-intensive, and it is in a stage of rapid industrialization, resulting in a large total carbon emissions. Zhejiang Province's total carbon emissions were 180 million tons, accounting for 21.2%. Benefiting from the optimization of its industrial structure, with a high

proportion of high-tech industries and services, its total carbon emissions were relatively low. Shanghai's total carbon emissions were 120 million tons, accounting for 14.1%. As an international metropolis, its industries are mainly service-oriented, with a relatively low proportion of industry, resulting in the lowest total carbon emissions.

3.2.2. Differences in Carbon Emission Intensity

In terms of carbon emission intensity, the pattern among the three provinces and one municipality of the Yangtze River Delta is Anhui > Jiangsu > Zhejiang > Shanghai, showing a negative correlation with economic development level. In 2022, Anhui Province's carbon emission intensity was 0.82 tons/10,000 yuan, far higher than the average level of the Yangtze River Delta. This is mainly due to Anhui's lower industrial structure, a high proportion of energy-intensive industries, and low energy efficiency. Jiangsu Province's carbon emission intensity was 0.61 tons/10,000 yuan, slightly higher than the average level. Although its industry is developed, its energy efficiency is relatively high, resulting in a lower carbon emission intensity than Anhui. Zhejiang Province's carbon emission intensity was 0.52 tons/10,000 yuan, lower than the average level, benefiting from industrial structure optimization and the application of low-carbon technologies. Shanghai's carbon emission intensity was 0.38 tons/10,000 yuan, the lowest among cities in the Yangtze River Delta. Its industries are mainly service and high-tech industries, with high energy efficiency and significant achievements in low-carbon transformation.

3.2.3. Differences in Industrial Carbon Emission Structure

In terms of industrial carbon emission structure, the differences among the three provinces and one municipality of the Yangtze River Delta are also quite significant. Shanghai's industrial carbon emissions account for only 45%, while its service sector accounts for 40%, making it the city with the lowest industrial carbon emissions and the highest service sector carbon emissions in the Yangtze River Delta, indicating the most optimized industrial structure. Zhejiang Province's industrial carbon emissions account for 58%, and its service sector for 35%, placing its industrial structure between Shanghai and Jiangsu. Its high-tech and green industries are developing rapidly. Jiangsu Province's industrial carbon emissions account for 70%, the highest among provinces in the Yangtze River Delta, with energy-intensive industries such as steel and chemicals being its main sources of carbon emissions. Anhui Province's industrial carbon emissions account for 72%, similar to Jiangsu, with a high proportion of energy-intensive industries, indicating a need for further industrial structure optimization.

3.3. Impact of Regional Differences on Carbon Emission Rights Allocation

Regional differences in carbon emissions in the Yangtze River Delta region have a dual impact on the initial allocation of carbon emission rights quotas: On the one hand, regional differences dictate that quota allocation must balance fairness and efficiency. It must consider the development needs of less developed regions like Anhui, avoiding excessively tight quotas that hinder their economic development, while also recognizing the low-carbon transformation achievements of developed regions like Shanghai and encouraging them to further improve emission reduction efficiency. On the other hand, regional differences also provide room for optimization in quota allocation. Through scientific allocation, carbon emission rights can be guided to flow to high-efficiency regions, optimizing regional resource allocation and achieving coordinated emission reduction.

Meanwhile, the unfair carbon landscape between regions also places higher demands on quota allocation^{(1)}. Shanghai, as a crucial node in the input and output of carbon-intensive products, maintains close economic and carbon transfer ties with Zhejiang. Jiangsu and Anhui have large internal carbon transfer volumes, but Jiangsu has a stronger capacity for external economic transfer. This carbon transfer pattern leads to a mismatch between carbon emission responsibilities and economic benefits in different regions, requiring full consideration of transfer responsibilities in quota allocation to ensure fair allocation. Ignoring regional differences and carbon inequity could lead to a Matthew effect, where developed regions receive more quotas while less developed regions receive insufficient quotas. This would not only exacerbate regional development disparities but also hinder the achievement of overall emission reduction targets. Therefore, constructing a scientifically sound quota allocation scheme must fully consider the regional differences and carbon inequity within the Yangtze River Delta region, achieving a synergy between fairness and efficiency.

4. Conclusions and Recommendations

4.1. Research Conclusions

This paper takes Shanghai, Jiangsu, Zhejiang, and Anhui provinces and municipalities in the Yangtze River Delta region as the research object. Focusing on the 2030 carbon peak target, it constructs three initial carbon emission quota allocation schemes. Through empirical analysis and comparison of implementation effects, the following conclusions are drawn:

First, the Yangtze River Delta region accounts for a high proportion of the national total carbon emissions. Significant differences in carbon emissions exist within the region, exhibiting a total emission pattern of Jiangsu > Anhui > Zhejiang > Shanghai and an intensity pattern of Anhui > Jiangsu > Zhejiang > Shanghai. Simultaneously, a clear carbon inequity exists, with close carbon transfer links between Shanghai and Zhejiang, and significant internal carbon transfer within Jiangsu and Anhui. These differences and carbon inequity pose real challenges to quota allocation.

Second, each of the three schemes has its advantages and disadvantages: the fairness-oriented scheme is highly fair, can improve the carbon inequality landscape, and protect the development rights of underdeveloped regions, but has low emission reduction efficiency; the efficiency-oriented scheme has high emission reduction efficiency and good results, but lacks fairness and faces the risk of the Matthew effect; the hybrid scheme balances fairness and efficiency, can balance the interests of various regions, improve the carbon inequality landscape, and has ideal emission reduction efficiency and results, making it more in line with the realities of the Yangtze River Delta and the 2030 carbon peak target.

Third, the hybrid scheme, which balances fairness and efficiency, is the optimal choice for the initial allocation of carbon emission quotas in the Yangtze River Delta region. This scheme uses the entropy method to integrate the weights of fairness and efficiency, avoids subjective weighting biases, and achieves synergistic optimization of fairness and efficiency. It can both ensure the achievement of the overall regional emission reduction target and promote regional coordinated development, providing a scientific solution for the construction of the Yangtze River Delta carbon market.

4.2. Policy Recommendations

Based on the research findings and the actual situation in the Yangtze River Delta region, the following recommendations are proposed to optimize the initial allocation of carbon emission allowances, promote regional coordinated low-carbon transformation, and achieve the 2030 carbon peak target:

4.2.1 Prioritize Mixed Allocation Schemes and Optimize the Quota Allocation Mechanism

The Yangtze River Delta region should prioritize the adoption of mixed allocation schemes that balance fairness and efficiency. Weight settings should be optimized based on the actual conditions of each region, fully considering carbon transfer effects and regional development disparities to ensure fairness and efficiency in allocation. Simultaneously, a dynamic quota adjustment mechanism should be established, regularly adjusting quotas based on regional economic development levels, carbon emission intensity, and emission reduction effects to adapt to the dynamic needs of low-carbon transformation; data sharing should be strengthened by establishing a Yangtze River Delta carbon emission data sharing platform and improving the statistical accounting system to ensure data accuracy and completeness.

4.2.2 Taking into account regional differences, implement differentiated emission reduction policies. In response to regional differences in the Yangtze River Delta, implement differentiated emission reduction policies: For economically developed and efficient regions such as Shanghai and Zhejiang, encourage them to further improve emission reduction technologies, expand the scale of low-carbon industries,

assume more emission reduction responsibilities, receive more policy support, and create demonstration and leading areas for low-carbon transformation; for industrially developed and large-scale regions such as Jiangsu, increase efforts to transform and upgrade high-energy-consuming industries, optimize energy structure, reduce carbon emission intensity, and gradually reduce total emissions; for less developed and high-intensity regions such as Anhui, provide more quota allocations and policy support, and encourage the introduction of low-carbon technologies and industries.

4.2.3 Improve the carbon market system and promote the market-based flow of carbon emission rights. Accelerate the integrated construction of the Yangtze River Delta carbon market, break down regional barriers, and promote the free flow of carbon emission rights among the three provinces and one municipality to achieve optimal resource allocation. Improve carbon trading rules, establish a sound price formation mechanism, give full play to the decisive role of the market in allocation, encourage efficient regions to sell surplus quotas to regions under greater pressure, and minimize emission reduction costs; strengthen market supervision, regulate trading behavior, prevent risks, and ensure the healthy and orderly development of the carbon market.

4.2.4 Strengthen regional collaboration and build a multi-level emission reduction incentive system. Establish a collaborative mechanism for the allocation of carbon emission rights in the Yangtze River Delta, strengthen communication and cooperation among the three provinces and one municipality, coordinate the allocation of quotas and emission reduction work, and form a collaborative emission reduction pattern. Simultaneously, a multi-tiered incentive system should be constructed by integrating policy tools such as carbon tariffs and green finance with the quota allocation mechanism: regions exceeding their emission reduction targets will receive financial subsidies and tax breaks; regions failing to meet their targets will be subject to penalties to force them to increase their emission reduction efforts; financial institutions will be encouraged to launch green credit and green bond products to support enterprises' low-carbon transformation and provide financial guarantees for quota allocation and emission reduction.

4.3. Future Research Directions

This study provides theoretical and practical support for the initial allocation of carbon emission rights in the Yangtze River Delta region, but there are still shortcomings. Future research can be deepened in the following aspects:

First, further explore the coupling relationship between carbon quota allocation and regional economic growth and industrial structure upgrading, quantify the long-term impact of different schemes on regional economic and industrial optimization, and improve scheme design.

Second, conduct in-depth research on the connection path between policy tools such

as carbon tariffs and green finance and the quota allocation mechanism, construct a multi-tiered and comprehensive emission reduction incentive system, and improve the implementation effect of the scheme.

Third, expand the research scope to include quota allocation at the industry and enterprise levels, construct a three-tiered allocation system of region-industry-enterprise, and improve the level of allocation refinement; at the same time, consider inter-period dynamic allocation and construct a long-term dynamic model.

Fourth, combine with global carbon governance trends to explore the connection path between carbon quota allocation in the Yangtze River Delta and the international carbon market, enhance the Yangtze River Delta's voice in global carbon governance, and promote low-carbon transformation and international integration.

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