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The Interconnection Ideas for Carbon Emissions Trading Market in Guangdong, Hong Kong, Macao and Greater Bay Area

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Abstract: Building the interconnection mechanism of carbon emission trading market in the Guangdong-Hong Kong-Macao Greater Bay Area is an innovative exploration to promote regional carbon emission reduction. This paper analyzes the feasibility of interconnecting carbon emission trading markets in the Bay Area from the perspectives of the difference between industrial structure and energy consumption, as well as the compatibility of carbon emission trading systems, by analyzing the operation status of carbon trading markets in Guangdong, Shenzhen, Hong Kong, and Macao, and the experience of Guangdong and Shenzhen as the Chinese carbon trading pilot. Based on the above discussion, this paper puts forward three adjustment ideas for the interconnection of the Bay Area Carbon Market: providing legal support, unifying the access to industry sectors and its quantities, and establishing a complete carbon emission monitoring, reporting and verification institution.

Keywords: Carbon Emission Market; Guangdong-Hong Kong-Macao Greater Bay Area; Interconnection.

1. Introduction

The origins of the international carbon emissions trading mechanism can be traced back to the 1990s, when the United States advocated for the inclusion of international carbon emissions trading in the United Nations Framework Convention on Climate Change, intending to reduce greenhouse gas emissions and mitigate global climate change. In December 1997, the Third Conference of the Parties to the United Nations Framework Convention on Climate Change adopted the Kyoto Protocol, which for the first-time recognized greenhouse gas emissions rights as a valuable resource and acknowledged their scarcity, thus endowing them with the characteristics of a tradable commodity. The Kyoto Protocol officially came into effect on February 16, 2005, enabling developed countries to engage in emissions trading, allowing countries that struggled to meet their greenhouse gas emission reduction targets to purchase excess emission allowances from other countries in exchange. This marked the beginning of the international carbon emissions trading system.

From a global perspective, the carbon emissions trading market reached a scale of 229 billion euros in 2020, representing an 18% year-on-year increase. The total volume of carbon trading also reached a record high of 10.3 billion tons. The European Union Emissions Trading System (EU ETS), established in 2005, is not only the earliest but also the largest carbon trading market in the world. According to a study conducted by Refinitiv, the EU's market accounts for nearly 74% of the global total.

As a responsible developing nation, China has firmly implemented a national strategy to actively address climate change, guided by Xi Jinping's ecological civilization ideology. China wants to encourage and direct the development of a just, sensible, and beneficial global climate governance framework. In 2011, China initiated the exploration of carbon emissions trading mechanisms and markets by issuing the "Notice on Pilot Work for Carbon Emissions Trading." Pilot projects for carbon emissions trading were first conducted in the provinces of Guangdong and Hubei, as well as in the cities of Beijing, Tianjin, Shanghai, Chongqing, and Shenzhen. This marked the initial phase of China's exploration into carbon trading. After three years of exploration, the "Interim Measures for the Management of Carbon Emissions Trading" were issued by the central government in December 2014, which established the basic framework for a unified Chinese carbon trading market. In 2017, the National Development and Reform Commission (NDRC) issued the "National Carbon Emissions Trading Market Construction Plan (Electricity Industry)," marking the end of the pilot phase and the completion of the design of China's carbon trading system. China officially entered the phase of carbon emission trading market construction. By the end of 2020, China's carbon market covered more than 20 industries, including electricity, cement, and steel, and included over 3,000 carbon emission control units. The trading volume of carbon allowance reached 43.4 million tons of carbon dioxide equivalent, representing a year-on-year growth of 40.85%. The trading value of carbon allowance reached 1.267 billion Chinayuan, showing an upward trend since 2018 and reaching a historical high. On July 16, 2021, the Chinese carbon trading market was officially launched, initiating online trading and entering the stage of a unified carbon trading market. The Chinese Carbon Trading Market Trading Center is located in Shanghai, and the carbon allowance registration system is based in Wuhan, playing a pivotal role in the national carbon trading system. The National Voluntary Greenhouse Gas Emission Reduction Management and Trading Center, constructed in Beijing, serves as an important supplement to the Chinese carbon trading market.

As an important component in the overall development strategy, the Guangdong-Hong Kong-Macao Greater Bay Area has consistently leveraged the comprehensive advantages of Guangdong, Hong Kong, and Macao, taking decisive action to lead the formation of a new pattern of

comprehensive openness in the new era. This is also true for the construction of carbon emission trading markets. In February 2019, the Communist Party of China Central Committee issued the "Development Outline of the Guangdong-Hong Kong-Macao Greater Bay Area", emphasizing the importance of "promoting ecological civilization construction" in the development of the Bay Area, emphasizing the need to innovate green and low-carbon development models, promoting the pilot experience of Guangdong's carbon policy, and advancing research and application demonstrations of the Bay Area. During the National People's Congress and the Chinese Political Consultative Conference (NPC & CPPCC) in the same year, Lu X, a member of the National Committee of CPPCC, mentioned supporting the development of carbon emission trading in the Bay Area, proposing to establish a carbon emission rights trading market in the Bay Area based on the successful experience of Guangdong's carbon emission rights trading so as to promote low-carbon development in the Bay Area. By September 2021, the People's Government of Guangdong issued the "Action Plan for Deepening the Market-oriented Allocation Reform of Capital Elements in Guangdong" which provided important instructions for the construction of the carbon trading market in the Bay Area: "Explore the establishment of an internationally interconnected carbon market. Based on the Guangdong carbon trading market, study and construct the Bay Area carbon emission rights trading market, promote the participation of Hong Kong and Macao investors in Guangdong's carbon market transactions, and establish a cross-border carbon emission rights trading mechanism."

Since the Hong Kong and Macau regions are primarily reliant on the financial services, trade, and tourism industries, the scale of carbon emissions reduction is limited, thus posing significant challenges in establishing an independent carbon trading market. Researching and constructing a mechanism for the interconnection and interoperability of the carbon trading markets in the Bay Area can better leverage the economies of scale in the region, enhancing overall efficiency and cost-effectiveness in carbon emissions reduction. Consequently, this endeavor can contribute to the achievement of the China's "dual carbon" target.

Regardless of the macro strategic perspective or the practical need to establish a unified carbon market, the imperative of interconnecting the carbon trading markets in the Bay Area cannot be ignored. Therefore, this paper combines the origins and current operation of carbon trading markets to expound on the feasibility of studying the mechanism for interconnectivity between carbon markets in the Bay Area. Additionally, this paper provides suggestions for adjusting the corresponding carbon market interconnection mechanism.

2. The Current Operation of Carbon Trading Market in the Bay Area

2.1. The Current Operation of Carbon Trading Market in the Nine Cities of the Pearl River Delta

In 2011, the NDRC issued the "Notice on Carrying out Pilot Work on Carbon Emission Trading" to implement the requirements of the "12th Five-Year Plan" for gradually establishing a domestic carbon trading market. Guangdong, Shenzhen and other five regions were designated as pilot regions for carbon trading. The carbon emission trading market was launched on June 18, 2013, marking the official start of the specialized process of promoting national green and low-carbon transformation through market-based means. Moreover, the carbon trading market in Guangdong was officially launched on December 30, 2013.

Shenzhen has not only taken the lead among the seven pilot markets but has also achieved several achievements in the early work. These include the first local regulation in China to establish carbon trading emission rights, titled "Regulations on Carbon Emission Management in Shenzhen" Additionally, Shenzhen has developed the first guiding technical documents on quantification, reporting, and verification of greenhouse gas emissions, titled "Guidelines for Quantification and Reporting of Greenhouse Gas Emissions by Organizations" and "Guidelines for Verification of Greenhouse Gas Emissions by Organizations." Furthermore, Shenzhen has pioneered the first allowance allocation mechanism in China, completing the allowance allocation for over 600 companies within one week. Lastly, Shenzhen has established and put into operation the first carbon trading public service electronic platform, composed of a registration system, greenhouse gas emission information management system, and trading system.

In terms of carbon allowance allocation methods, Guangdong has made breakthroughs by being the first in the country to implement a combination of free and paid allowance allocation. It serves as the most important experimental base for allowance auctions in the Chinese carbon trading market. Till the end of 2021, Guangdong has organized more than 19 paid allowance auctions, with cumulative auction revenues exceeding 800 million Chinayuan. In the first year of the Guangdong carbon trading pilot, regulated emitters were required to purchase 3% of paid allowance before obtaining the remaining 97% of free allowance. By 2014, the free allowance for power companies were further reduced to 95%. Based on the annual auction results, Guangdong has continuously adjusted the specific details of the paid auction allowance allocation method, established the majority of free allowance while also set a small portion of paid allowance. This approach allows companies to obtain free carbon assets while also bearing a certain emission reduction pressure, effectively enhancing their awareness of proactive carbon reduction.

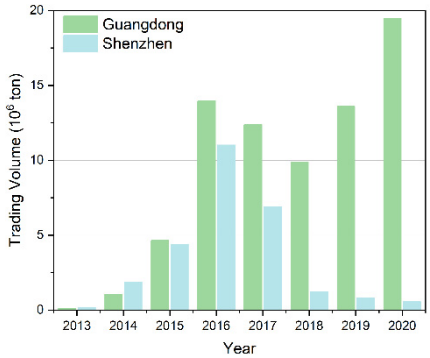

Figure 1. Annual trading volume of Guangzhou Shenzhen carbon emission trading market

Note: Data in Figure 1 are calculated by the Chinese carbon emission trading website.

With the exception of 2013 and 2014, Guangdong has had

a greater total amount of carbon trading than Shenzhen. The difference between the two has been growing yearly since 2016. The carbon market in Guangdong saw trading volume increase to 19.49 million tons of carbon allowance by 2020, placing it top among the seven pilot provinces and cities in terms of growth potential and making up almost 45% of the country's carbon market trading volume that year. Meanwhile, it is also the only carbon market among the pilot markets with a trading volume exceeding 15 million tons. The trading volume in Shenzhen's carbon market was only 551,300 tons of carbon allowance, with much lower trading activity compared to Guangdong.

When it comes to individual carbon markets, Guangdong's carbon market was in the early development stage from 2013 to 2015. After 2016, the trading activity in the market significantly increased, with annual trading volumes consistently exceeding 10 million tons of carbon allowances, reaching its peak in 2020. Shenzhen's carbon market, on the other hand, showed an overall trend of growth followed by a decline. Before 2017, the volume of carbon emission rights trading was considerable, with its peak occurring in 2016 at 11.02 million tons of carbon allowance, ranking second among the seven pilot regions, only behind Guangdong.

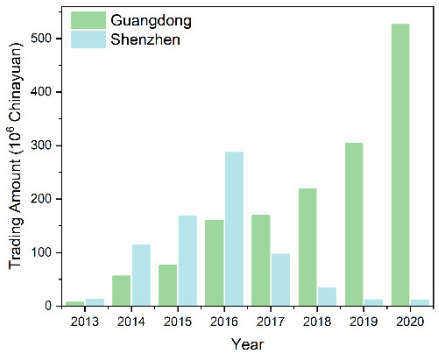

Figure 2. Annual trading amount of Guangzhou Shenzhen carbon emission trading market

Note: Data in Figure 2 are calculated by the Chinese carbon emission trading website.

Based on the trading amount in the carbon trading market, prior to 2016, the trading amount in Guangdong's carbon trading market was consistently lower than that in Shenzhen, with a difference of 5.2984 million in 2013, gradually widening to a staggering 127.39 million in 2016. However, in 2017, Shenzhen's carbon trading amount experienced a significant decline, with a decrease of 66.18%. While the trading amount in Guangdong's carbon market remained stable and surpassed that of Shenzhen since 2017 and subsequent years.

In terms of carbon market trading amount, Shenzhen's trading amount initially increased and then decreased, reaching a peak of 159.81 million Chinayuan in 2016 and a new low of 11.05 million Chinayuan in 2020, which is lower than the initial trading amount of 12.53 million Chinayuan in Shenzhen's carbon trading market. The trading amount of trading allowance in Guangdong, on the other hand, has gradually climbed from 7.23 million Chinayuan in 2013 to 526.38 million Chinayuan in 2020, indicating a significant growth rate.

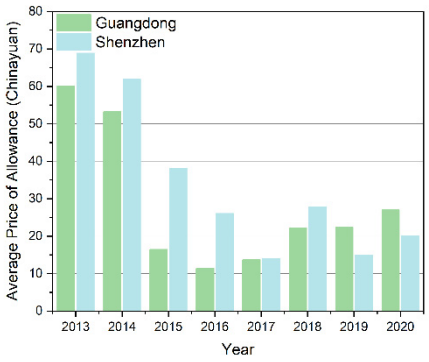

Figure 3. Annual average price of carbon allowance of Guangzhou and Shenzhen carbon emission trading market in each year

Note: Data in Figure 3 are calculated by the Chinese carbon emission trading website.

The average price of carbon allowance in the pilot carbon trading markets vary significantly between Guangdong and Shenzhen, mainly due to the different methods of determining the total carbon allowance and allocation schemes. Additionally, the inability of the two markets to engage in cross-regional trading further contributes to the disparity in carbon allowance price. As depicted in the Figure 3, the carbon allowance price was relatively high in 2013 and 2014 when the carbon trading platforms were just established. Both Shenzhen and Guangdong had average prices exceeding 50 Chinayuan per ton. However, from 2016 to 2020, the carbon allowance price remained relatively stable, fluctuating between 10 and 30 Chinayuan per ton. The mean carbon allowance price in Guangdong from 2013 to 2020 was 30.84 Chinayuan per ton, which is lower than the mean carbon allowance price of 37.66 Chinayuan per ton in Shenzhen. The variance of carbon allowance price in Guangdong was 301.49, slightly smaller than the variance of 408.81 in Shenzhen, indicating that Shenzhen experienced greater fluctuations in carbon allowance price over the past eight years.

2.2. The Current Operation Status of the Carbon Trading Markets in Hong Kong and Macau

As of now, Hong Kong and Macau have yet to be included in the nationwide carbon emissions trading market.

The Hong Kong Emissions Trading Platform officially commenced operations in 2014, jointly launched by the Hong Kong Carbon Exchange Limited and the Hong Kong Emissions Exchange. During the same period, Hong Kong also released its first carbon trading mobile application. Unlike the carbon allowance in the Guangdong and Shenzhen carbon markets, the products currently listed on the Hong Kong Carbon Exchange are limited to Chinese Certified Emission Reduction (CCER), Certified Emission Reductions (CER), and Voluntary Emission Reductions (VER), resulting in inadequate liquidity. In addition to enterprises, individuals can also request for allowance and trade carbon emissions rights through this platform.

As for Macau, its carbon emissions mainly come from local direct emissions and indirect emissions generated from imported electricity, with the former accounting for approximately 90% of Macau's total carbon emissions. Currently, Macau has not established a carbon emissions exchange. It aims to reduce local direct energy consumption

through the adoption of clean energy alternatives and electrification technologies. Furthermore, Macau promotes the active consumption of clean power, such as solar and wind energy, through economic measures, thereby reducing its carbon emissions.

3. Feasibility of Connecting the Carbon Trading Markets in the Bay Area

3.1. Differences in Industrial Structure and Energy Consumption

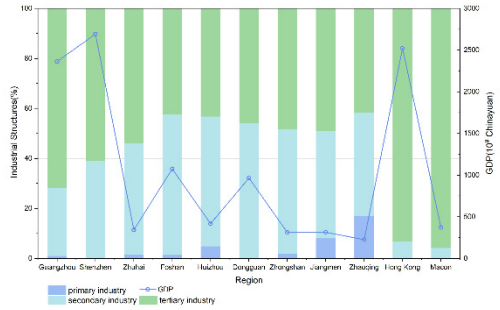

Figure 4. Economic Development of the Bay Area in 2019

Note: Data in Figure 4 are counted by Guangdong Statistical Yearbook issues 2019

Figure 4 provides a horizontal comparison of the gross domestic product (GDP) and industrial structures in the Bay Area in 2019. In terms of GDP, there is currently a tripartite confrontation situation, with Shenzhen, Hong Kong, and Guangzhou dominating the top three positions and ranking in the first tier, each with a GDP exceeding 2 trillion Chinayuan. Among them, Shenzhen firmly holds the top spot in the Bay Area with a GDP of 2.36 trillion Chinayuan. Foshan and Dongguan, two major manufacturing cities, are in the second tier. The remaining six cities have fluctuating GDP values ranging from 200 billion Chinayuan to 400 billion Chinayuan, with Macau leading the third tier with a GDP of 371.83 billion Chinayuan.

The industrial structure of each city in the Bay Area also exhibits differences. Western cities in the Bay Area, such as Jiangmen and Zhaoqing, are primarily focused on agriculture and equipment manufacturing, with Zhaoqing having the highest proportion of the primary industry among all cities, reaching 17.1%. Central cities in the Bay Area, such as Foshan and Dongguan, are dominated by secondary industry and have vigorously developed advanced manufacturing. Eastern cities in the Bay Area, such as Guangzhou and Shenzhen, are primarily focused on emerging industries and high-tech industries, with a low proportion of the primary industry and the tertiary industry accounting for about two-thirds of the total output value. Coastal cities in the Bay Area, namely Hong Kong and Macau, have highly developed tertiary industries, with the proportion exceeding 93% in both regions.

The energy consumption and energy intensity in eleven cities in 2019 reflects the inconsistency in energy consumption among regions. In terms of total energy consumption, Guangzhou had the highest consumption, reaching 62.942 million tons of standard coal equivalent, followed by Shenzhen and Dongguan. Zhaoqing, Zhuhai, and Macau ranked at the bottom with a consumption of less than 10 million tons of standard coal equivalent. However, the situation is different when it comes to energy intensity. Huizhou, with median energy consumption, had the highest energy intensity of 82.7 tons of standard coal equivalent per million Chinayuan of GDP. This means that for every Chinayuan increase in GDP, an average of 82.7 tons of standard coal equivalent is consumed. Zhaoqing, despite having a lower total energy consumption, is a typical city with high energy intensity. Guangzhou, Zhuhai, Foshan, and Dongguan have similar energy intensities, ranging from 40 to 42 tons of standard coal equivalent per million Chinayuan. Hong Kong and Macau, due to their industrial structure, have the lowest energy intensity, not exceeding 7 tons of standard coal equivalent per million Chinayuan.

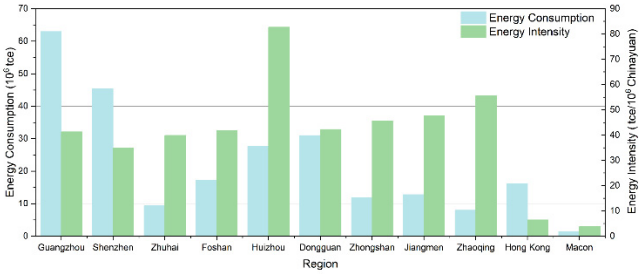

Figure 5. Energy consumption of the Bay Area in 2019

Note: Data in Figure 5 are counted by Guangdong Statistical Yearbook issues 2019.

Given the significant differences in industrial structure and energy consumption in the Bay Area, as well as variations in emission reduction costs and potentials, establishing interconnection between carbon emission trading markets in the Bay Area can better leverage the resource allocation role of the market. This can lower the transaction costs for covered participants in some cities and improve the revenue of covered participants in other cities. For the central cities of Guangzhou and Shenzhen, it is challenging to adjust their industrial structure to reduce energy consumption. The high energy consumption in these cities leads to higher costs for carbon emission control. By establishing a mechanism for interconnection between carbon trading markets in the Bay Area, covered participants in Guangzhou and Shenzhen can purchase carbon allowance from cities like Zhaoqing and Zhuhai at more favorable terms, reducing compliance costs and achieving a "win-win" situation for both parties.

3.2. Compatibility of Carbon Emission Trading Systems

Given that Hong Kong and Macau have not yet been incorporated into the national carbon emission trading market, it is crucial to establish an interconnected mechanism for carbon emission trading in the Bay Area. With the purpose of ensuring compatibility and facilitating interconnection, Hong Kong and Macau can achieve this by incorporating the current carbon emission trading systems in Guangdong and Shenzhen into the design of their own systems. Therefore, this paper primarily focuses on discussing the compatibility of the current carbon emission trading systems in Guangdong and Shenzhen.

Table 1. Comparison of Carbon Emission Trading Systems in Guangdong and Shenzhen

Entry	Guangdong	Shenzhen
Reduction Targets	CO2 emissions intensity per unit of GDP in 2020 down 20.5% from 2015.	CO2 emissions intensity per unit of GDP in 2020 down 23.0% from 2015.
Total Allowance	The total allowance for 2020 is 465 million tons, with 438 million tons allocated to installations and 27 million tons reserved.	The total allowance for 2020 is approximately 300 million tons, with around 290 million tons allocated to regulated enterprises and 10 million tons reserved.
Greenhouse Gas Emissions Reduction	Carbon Dioxide.	
Coverage	49.2% of carbon emissions in Guangdong, with 245 enterprises and 23 new enterprises covered.	40% of carbon emissions in Shenzhen, with 690 enterprises covered.
Coverage sectors	Electricity, cement, steel, petrochemical, papermaking, civil aviation.	Electricity, steel, petrochemical, papermaking, construction, transportation, civil aviation, services, manufacturing, water services.
Threshold of stationary emissions	Enterprises with total carbon emissions of 20 thousand (or 10 thousand) tons of standard coal equivalent or above in 2019 province-wide (excluding Shenzhen).	Enterprises with total carbon emissions of 3,000 tons of standard coal equivalent or above in 2019.
Allocation ratio of allowance	Free allocation and Auction Reserve Price (ARP), with the former making up 95% of the total.	Free allocation and Auction Reserve Price (ARP), with the former making up 97% of the total.
sector allowance allocation calculation	Grandfathering method for petrochemical, cement, steel, etc. Benchmarking method for electricity, cement, steel, papermaking, civil aviation.	Grandfathering method for petrochemical, cement, steel, etc. Benchmarking method for thermal power generation, manufacturing, services, etc.
Investor structure	Complying enterprises, investment institutions, other organizations, and individuals	Complying enterprises, brokerage institutions, investment institutions, individuals
Risk control	10% price fluctuation limit.	Not specified.
Market regulation mechanism	Government storage: Government reserves 5% of the surrender allowance. Auction price floor: 90% of the average price of the previous three months' allowance.	Government storage: Government reserves 2% of the surrender allowance. Market intervention: The government can repurchase carbon allowances (up to 10% of the total) when there are unusual price swings.
Storage mechanism	Not allowed.	
Offsetting by credits	Key installations are allowed to use CCER to offset the paid carbon emission allowance annually, with the offset ratio not exceeding 5% of the paid carbon emission allowance.	Installations are allowed to use CCER to offset the paid carbon emission allowance annually, with the offset ratio not exceeding10% of the annual carbon emission allowance. CCER generated within the boundary of carbon emissions verification in Shenzhen cannot be used to offset. The eligible certified emission reductions include the following types: (1) Chinese Certified Emission Reduction (CCER) (2) Guangdong Certification Emission Reduction (PHCER) (3) Other certified emission reductions approved by the competent authorities.
Penalty Mechanism	Make up and submit any allowances that are over the cap. The following year's carbon allowance will be decreased by an equivalent amount if the fine is not paid by the deadline. A fine of at least 20,000 and no more than 30,000 Chinayuan will be imposed.	Make up and submit any allowances that are over the cap. The following year's carbon allowance will be decreased by an equivalent amount if the fine is not paid by the deadline. At the same time, a fine shall be imposed, which is three times the average price of the allowance for the six consecutive months. Inclusion in credit records, cancellation of financial support and suspension of approval for filing of major fixed asset investment projects within five years.
Other Constraint Mechanisms	None.	The responsibility of carbon emission control will be included in the performance assessment and evaluation system of state-owned enterprises.
Compliance period	The performance period is stipulated as June 2, with the actual performance period being July 8.	The performance period is stipulated as June 2, with the actual performance period being June 3.

Note: Data in Table 1 are compiled by relevant policy documents from Guangdong and Shenzhen.

Table 1 shows that the carbon emissions trading systems in Guangdong and Shenzhen employ relative emission reduction targets with similar intensity. They both set the emission reduction gas as carbon dioxide and use a combination of free allowances and paid auctions to allocate allowance. The investor structures are also very close to similar and the storage mechanisms are the same. Both systems allow the use of CCER to offset carbon emissions allowance.

The coverage proportions of the emission trading systems are also relatively close, with Guangdong covering 49.2% of carbon emissions and Shenzhen covering 40% of carbon

emissions. In terms of coverage sectors, despite variances in the coverage of some industries, Guangdong and Shenzhen both mainly focus on the electricity, steel, and petrochemical industries. In addition, the market regulatory mechanisms in both areas are also quite similar. As for the compliance period, although there are cases of proactive extension in the carbon market, Guangdong and Shenzhen have consistent compliance periods.

By comparing Guangdong and Shenzhen's carbon emissions trading systems in 16 aspects, it can be concluded that the existing systems in both regions are generally compatible and possess key elements for interconnecting the carbon markets in the Bay Area.

3.3. Other Aspects

Average allowance price: From Figure 3, it can be seen that the average allowance price in the Guangdong and Shenzhen carbon trading markets in 2020 were 27.01 Chinayuan per ton and 20.05 Chinayuan per ton respectively, with the prices being relatively close. Interconnecting the Bay Area carbon market will not cause carbon leakage due to different carbon prices between regions.

Geographical location: Eleven cities in the Bay Area are all located in the Pearl River Delta, with urban areas distributed along coast. The Bay Area is enclosed by the Hong Kong-Zhuhai-Macao Bridge, Humen Bridge, and Shenzhen-Zhongshan Corridor, which have connected the east and west banks. The geographical proximity of cities in the Bay Area facilitates frequent trade between urban enterprises, which benefits the interconnection of the Bay Area's carbon trading markets and the handling of carbon emissions rights issues across administrative boundaries.

Previous cooperation: Some regions in the Bay Area have already carried out a series of cooperation in the field of green and low-carbon development, laying a solid foundation for the establishment of interconnection mechanisms for the carbon trading market in the Bay Area. For example, Guangdong Emissions Exchange, Hong Kong Emissions Exchange, and Guangzhou SaiBao Company Limitid have signed a strategic cooperation agreement to jointly promote the development of the carbon market in the Guangdong-Hong Kong region. Kaidi Ecological Environment Technology Company Limitid. and Hong Kong Emissions Trading Company Limited have also signed a strategic cooperation agreement to promote cooperation in carbon emission permits and carbon sinks.

4. Ideas to Connect the Carbon Trading Markets in the Bay Area

4.1. Providing Legal Support

This paper compares the carbon emission trading systems in Guangdong and Shenzhen and concludes that while there are some similarities, there are also some key disparities between the two systems. For example, there are significant differences in the carbon emission thresholds for enterprises in Guangdong and Shenzhen. Guangdong sets the threshold at 20,000 tons or more, while Shenzhen has a stricter threshold of 3,000 tons or more for participants to be included in control. In terms of other regulatory mechanisms, Shenzhen imposes harsher penalties on non-compliant participants and has stringent punishment measures on credit records and financial support, while Guangdong's penalties are relatively lenient.

Therefore, it is necessary to establish a legal mechanism for carbon emission trading in the Bay Area from the first place. This mechanism should provide unified regulations on the specific procedures of interconnection among regions and market divergences. For example, it could include mutual recognition of allowance and joint auctions to facilitate smooth transactions among multiple parties. In this field, the Bay Area can learn from the interconnecting measures taken by the European Union and Norway. Both parties have adjusted the architectural components of their carbon emission trading schemes and devised distinct legal frameworks for interconnecting. For instance, the EU and Norway's interconnection issue was resolved by mutual recognition of allowances under Article 25 of EU Directive 2003/87/EC. However, given the internationalization nature of the Hong Kong and Macao markets, it may be allowed to retain certain differentiated settings when setting the trading mechanisms in the Bay Area.

4.2. Unified the Access to Industry Sectors and its Quantities

From Table 1, although the main industries covered by Guangdong and Shenzhen have a similar structure, there are still some slight differences in terms of industry kinds. To further compare the access industries of the carbon market in the Bay Area, this paper conducts a horizontal analysis of the access industries and its quantities in the carbon trading market of the nine cities in the Pearl River Delta in 2020 (excluding Hong Kong and Macao), as shown in Table 2.

Table 2. Comparison of the access industries and its quantities in carbon trading market of the 2020 Pearl River Delta Nine-City in 2020

Admission Sectors	Steel	Electricity	Aviation	Petrochemical	Cement	Papermaking
Shenzhen	3	1	1	1	-	5
Guangzhou	3	11	3	2	3	1
Zhuhai	1	5	1	5	1	2
Foshan	5	1	-	1	2	2
Zhaoqing	-	-	-	-	5	5
Jiangmen	6	4	-	-	2	10
Huizhou	3	4	-	5	4	1
Dongguan	-	8	-	1	1	22
Zhongshan	1	5	-	-	-	2

Table 2. (continued): Comparison of the access industries and its Quantities in Carbon Trading Market of the 2020 Pearl River Delta Nine-City in 2020

Admission Sectors	Construction	Transport	Water Services	Services	Manufacturing	Total
Shen zhen	6	11	8	32	630	698
Guangzhou	-	-	-	-	-	23
Zhuhai	-	-	-	-	-	15
Foshan	-	-	-	-	-	11
Zhaoqing	-	-	-	-	-	10
Jiangmen	-	-	-	-	-	22
Huizhou	-	-	-	-	-	17
Dongguan	-	-	-	-	-	32
Zhongshan	-	-	-	-	-	8

Note: Data in Table 2 are compiled by relevant policy documents, including "the Implementation Plan for the Allocation of Carbon Emission Quota in Guangdong Province in 2020" and "the Notice of Shenzhen Ecological Environment Bureau on the Pilot Project of Carbon Emission Trading in 2020."

According to Table 2, there are considerable disparities in the admission industries and quantities across the nine cities. When compared to other cities, Shenzhen is far ahead in access industries and its quantities, covering the building, transportation, water, service, and manufacturing industries. This is due, in part, to varying carbon emission thresholds for sectors participating in the carbon trading market between Shenzhen and Guangdong, resulting in a variable number of admission industries. Another reason is that, in the construction of the carbon trading system, Shenzhen, with its dominant tertiary industry structure, has diversified its admission enterprise area.

To establish an interconnected carbon trading market in the Bay Area, adjustments need to be made to the industries and quantities admitted by each city, so that the admission industries of different cities are roughly the same. Without total uniformity, it can be changed within a short range by the regional industrial structure. This will prevent certain businesses from avoiding compliance expenses by relocating to places where the industry is not included in the access sectors, avoiding carbon leakage. Following the initial growth phase, the number of participants should be expanded so as to improve liquidity and boost market vitality in the Bay Area's carbon trading market.

4.3. Establishing a Complete Carbon Emission Monitoring, Reporting and Verification Institution

To ensure the normal trading of carbon emission rights, the construction of a carbon emission monitoring, reporting, and verification institution (MRV) should be considered in addition to fully evaluating the design of the carbon emission trading system. The MRV institution enables regulatory agencies to collect credible and authentic carbon emission information, ensuring the organizationally seamless implementation of carbon emission rights trading.

In terms of the enterprise reporting system do the two regions differ significantly. Guangdong is separated into three reporting levels: enterprise, emission unit, and emission equipment, and the degree of reporting changes based on the mechanism of allowance allocation. While Shenzhen has developed "Methods for Quantifying and Reporting Greenhouse Gas Emissions in the Electricity Industry" and "Methods for Quantifying and Reporting Greenhouse Gas Emissions in the Water Supply Industry" based on the unique characteristics of carbon emissions in the local electricity and water supply industries. Such distinctions will result in varying quality criteria for indicators in various carbon trading systems, resulting in varying levels of recognition for the carbon trading market.

To ensure the effectiveness of carbon emission data after the interconnection of the Bay Area, each region should promptly clarify relevant technical regulations for carbon emission verification, such as a unified list of third-party verification institutions and unified industry calculation guidelines, and strive to form unified MRV standards for the Bay Area.

Additionally, the Bay Area needs to actively promote its regional service industry relevant to the carbon trading market. With the increase in the number of admission enterprises in the interconnected carbon trading market of the Bay Area, there will be a strong demand for carbon verification, which cannot be met solely by existing third-party verification institutions and individuals. Each region should work together to support third-party verification institutions, develop expert talent, provide corresponding support for the construction of MRV institutions in the Bay Area, and promote the growth of the carbon trading market services sector.

5. Conclusion

Relying on the early experience of Guangdong and Shenzhen as carbon emission trading pilots, and drawing on the strengths of Hong Kong and Macau in financial and other fields, the interconnection mechanism of the Bay Area carbon emission trading market will not only play a scale effect by expanding the coverage and covering the total amount of emissions, reduce the total cost of emission reduction, avoid carbon leakage, but also deepen the practical cooperation between regions in the field of green low-carbon development, and provide new momentum for the development of Guangdong-Hong Kong-Macao carbon trading system. Moreover, its advanced achievements and experiences will provide a reference for the future construction of cross-regional carbon market both domestically and internationally.

Building a "Beautiful China" depends on the Guangdong-Hong Kong-Macao Greater Bay Area's green and low-carbon growth, which is also essential for mitigating and adjusting to climate change and maintaining the wellbeing of its

inhabitants. In the future, the governments of Guangdong, Hong Kong, and Macau should actively promote the interconnection of the Bay Area carbon emissions trading market and establish a highly centralized trading mechanism, providing strong support for China's goal of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060, and ultimately creating a livable, business-friendly, and tourist-friendly environment for the residents of the Bay Area.

Declarations

Conflict of interest the authors have no relevant financial or non-financial interests to disclose.

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