Open Journal of Social Sciences, 2025, 13(5), 538-558
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Recent Progress in Research on China's Carbon Emission Trading Policy: An Overview

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How to cite this paper: Zhang, T. (2025). Recent Progress in Research on China's Carbon Emission Trading Policy: An Overview. *Open Journal of Social Sciences, 13,* 538-558.
https://doi.org/10.4236/jss.2025.135030

Received: April 22, 2025
Accepted: May 26, 2025
Published: May 29, 2025

Abstract

China's major national development goals and policies prioritize the implementation of initiatives to conserve energy and reduce emissions under the challenges of climate change. The carbon trading market has become a significant tool for energy conservation and emission reduction under the Kyoto Protocol framework. China initiated seven emissions trading scheme (ETS) pilots in 2011 and established a nationwide ETS by the end of 2017 to decrease its greenhouse gas emissions and facilitate its substantial energy transformation economically. Over the past over ten years, an increasing number of researches have focused on analyzing the designs, developments, impacts, challenges, and prospects of China's ETS pilots. This paper aims to provide an overview on recent progress in the study of China's ETS pilots. It first gives a brief introduction to the history and current status of China's ETS markets. Then the policy effects of ETS, including the carbon emission reduction effects, economic development effects, technology and energy efficiency effects, as well as other spillover effects, are discussed, followed by an overview on the comparison and coordination between ETS and other relevant climate policies. It further presents an overview of the studies that elaborate on the construction and optimization of China's carbon trading markets, including carbon market mechanisms, market efficiency, coordination and linking between different carbon markets, and market regulation. It is envisioned this progress review could provide useful implications and guidelines for developing China's carbon trading markets.

Keywords

Carbon Neutrality, Emission Trading Scheme (ETS), Carbon Market, Carbon Tax, Carbon Price

1. Introduction

Global climate change has caused problems such as rising sea levels and deterioration of the ecological environment, which have seriously affected economic development and the quality of human life. Reducing emissions and developing a low-carbon economy has become the consensus of countries around the world. To achieve this goal, the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol (1997) introduced the concept of carbon trading as an effective means of mitigating climate change (Gupta, 2010). In March 2021, the Outline of the People's Republic of China 14th Five-Year Plan for Economic and Social Development and Long-Range Objectives through the Year 2035 mentioned the need to promote market-based trading of carbon emission rights. Using the carbon emission trading scheme (ETS) to achieve carbon emission reduction in a flexible and low-cost manner is an important strategy to actively respond to climate change, as well as an important policy tool to implement China's carbon peaking and carbon neutrality goals ("dual carbon goals") (Liu, Chen, Zhao, & Zhao, 2015; Zhou, Lu, & Qiu, 2023).

The carbon trading market encourages companies and individuals to adopt energy-saving and emission reduction measures through price signals, promotes the low-carbon transformation of industries, thereby effectively reducing global climate change risks and providing new opportunities for green and low-carbon economic development (Perdan & Azapagic, 2011). Currently, China is constantly exploring ways to establish and develop a carbon trading market, ensuring the smooth operation of the carbon trading market by establishing and improving relevant laws and regulations and improving the carbon trading system, so as to promote the realization of "dual carbon goals".

This paper aims to provide an overview on recent progress in the study of China's ETS pilots. Firstly, a brief introduction to the history and current status of China's ETS markets is given. Then the policy effects of ETS, including the carbon emission reduction effects, economic development effects, and technology and energy efficiency effects, are discussed, followed by an overview on the comparison and coordination between ETS and other relevant climate policies. An overview on the studies that elaborate on the construction and optimization of China's carbon trading markets are also presented. It is envisioned this progress review could provide useful implications and guidelines for developing China's carbon trading markets.

2. Current Status of China's Carbon Emission Trading Scheme

China's involvement with carbon markets began with the implementation of the Clean Development Mechanism (CDM). In 2005, a law allowing participation in the CDM was established with the endorsement of the National Development and Reform Committee (NDRC), Ministry of Science and Technology (MOST), Ministry of Foreign Affairs (MFA), and Ministry of Finance (MOF). In April 2012, China held a prominent position in the CDM sector, accounting for 51% of all registered CDM projects (Maraseni, 2013). The CDM raised awareness among Chinese government officials, enterprises, and third-party verifiers about market-based processes by promoting the documentation of greenhouse gases (GHG) savings and their conversion into Certified Emission Reductions (CERs) for sale on international emissions exchanges. Recently, consistently low prices in the EU-ETS have reduced the appeal of participating in the CDM for project developers. The CDM has also set up other essential components of a national carbon market (Zhang, Karplus, Cassisa, & Zhang, 2014).

After the launch of a carbon emissions market pilot in Shenzhen in 2013, seven similar initiatives have been initiated in Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing, and Fujian. The seven pilot projects aim to address regional development disparities and industrial structure imbalances by focusing on China's eastern, central, and western regions, each with unique economic development levels and geographical characteristics (Zhang et al., 2014). Following the introduction of all pilot carbon markets, China's pilot carbon markets have now entered a significant stage of development.

Regarding the situations of carbon market operation, the cumulative trading volume of China's carbon trading pilots operating until June 2021 exceeded 400 million tons, with a cumulative trading volume of nearly 10 billion Chinese Yuan (CNY) (Wang, Sun, & Wang, 2024). Among these pilot markets, Guangdong has the most active trading volume. As of December 2020, the cumulative trading volume was 728.66 billion tons, accounting for 31.96% of the total. In addition, Hubei has the highest carbon trading turnover, with a 1.592 billion RMB accumulative total, accounting for 28.30% of the total. In contrast, the trading in Chongqing and Tianjin ETS is almost stagnant, with the lowest volume, 8.2446 million tons, and the smallest turnover, 52 million RMB, separately (Wu, 2022). Therefore, there is an obvious imbalance in the development of these carbon trading pilot markets, showing a significant regional heterogeneity. When considering carbon trading prices, the trading price trend of the pilot carbon market has changed significantly since the launch of the pilot carbon market. At the same time, the carbon quota trading prices in the pilot markets also vary greatly. Beijing's carbon price is the highest in the country, followed by Guangdong, Fujian and Chongqing are the lowest (Wu, 2022).

On July 16, 2021, China's national carbon market launched officially. The Chinese carbon market is the largest in the world. The cumulative trading volume of China's carbon quota exceeds 584 million tons, with a cumulative transaction amount of over 38.834 billion yuan, as of December 10, 2024. In terms of coverage, the national carbon market covers only the power industry, with a high degree of homogeneity (Lin & Jia, 2020). Starting from June 2023, China has successively carried out special research work on incorporating petrochemical, building materials and other industries into the national carbon market. Currently, the type of GHG covered by the global carbon market is carbon dioxide. China's national ETS market now uses a bottom-up strategy where all eligible enterprises are allocated their emission allowances for free. This allocation is determined using a national benchmarking method, which calculates the average carbon intensity of key sectors and products and compares it with that of individual emitters. Each emitter will receive allowances equivalent to its verified emissions (Li, Qi, Yan, & Zhang, 2022). China's national ETS does not yet function as a cap-and-trade system under this method. The current overall operation of the national carbon market is relatively stable and orderly, with trading prices rising steadily. Carbon quota trading prices fluctuate within the range of 40 yuan to 100 yuan per ton, and there are no very sharp rises or falls.

3. Policy Effects of ETS

Since China's ETS policy has brought some positive effects, including carbon emission reduction effects, economic development effects, technology and energy efficiency effects, and other spillover effects (Wu, 2023), it is critical to understand the complicated impacts and their interplay of different consequences of the policy. This section aims to provide a systematic overview on recent progress in the policy effects of ETS.

3.1. Carbon Emission Reduction Effects

As a market-oriented means of carbon emission reduction, many researchers have confirmed that the ETS can promote carbon emission reduction (Wang, Huang, & Liu, 2022). According to Zhang et al (Zhang, Duan, & Deng, 2019), after the opening of the carbon trading pilot program in Shenzhen, nearly 635 industrial enterprises included in the carbon market achieved their emission reduction goals. Feng et al (Feng, Zhao, & Yan, 2024) conducted a quasi-nature experiment by using the data of 272 prefecture-level cities in China from 2007 to 2019. The propensity score matching (PSM) and difference-in-difference (DID) methods were employed, which have quantitatively shown that the implementation of ETS can promote the reduction of carbon emission significantly. It was also demonstrated the emission reduction effect varies significantly among cities of different geographical locations, showing major heterogeneities.

The mechanisms of emission reduction are also extensively discussed. In fact, from a regional or macro perspective, many works have conducted empirical research from the perspective of environmental emission reduction and regional economic development effects, and discussed their action paths. As a marketbased environmental regulation tool, ETS brings economic effects mainly based on the Pollution Haven Hypothesis (Bashir, 2022) and the Porter hypothesis (Brännlund & Lundgren, 2009). The former hypothesis indicates that highly emitting industries can escape to regions with less strict environmental regulations, thus reducing emission in the pilot region. In other words, the term of "pollution havens" means that enterprises respond to the impact of carbon rights trading policies in a negative way, which may cause industries to escape to places with relatively loose environmental regulations, resulting in pollution transfer (Bashir, 2022). The Porter Hypothesis indicates that enterprises deal with the cost increase caused by carbon emission trading policies in a proactive way, namely, promoting more investment in innovative research and development, and fundamentally reducing costs (Brännlund & Lundgren, 2009).

The Porter effect and emission reduction effect of ETS were analyzed from the overall and local viewpoints by Ren et al. (Ren & Liu, 2023) utilizing China's province panel data from 2006 to 2020 using a multi-phase DID technique. They found that the study may infer the carbon mitigation effect and Porter effect (economic and green innovation effects), whose intensity varies over time. Local effects showed significant variation among the eight pilot provinces and cities. This study indicated that only the Chongqing carbon market can achieve both the Porter effect and the emission reduction effect, while the other seven pilot markets failed to promote economic, environmental, and green innovation simultaneously. Developed regions have stronger environmental and green innovation effects, while less developed regions have stronger economic development effects and no green innovation effects. Energy structure optimization reduces emissions and boosts economic growth, according to action path analysis. It was also shown that as a result of the carbon rebound effect, enhancing green innovation can only boost economic growth while increasing carbon emissions (Zhu & Lan, 2023).

Based on panel data from 281 Chinese prefecture-level cities from 2007 to 2017, Liu et al. (Liu, Cai, & Zhang, 2023) found that the ETS can coordinately control carbon dioxide and air pollution. This cooperation is achieved by increasing green production, reducing regional industrial output, and accelerating industrial structure upgrading. This coordinated control has regional variation, with synergistic emission reduction effects being greater in eastern and central cities that are more developed. Positive spatial spillover effects were identified on pilot cities' surrounding cities. Interestingly, it was also found that Pollution Haven effects may increase pollution in locations distant from the pilot areas.

Some researchers have found that ETS reduces carbon emissions by inhibiting economic growth. Zhang et al. (Zhang et al., 2019) calculated the direct and indirect carbon emissions of 37 industrial sub-sectors in each of China's 26 provinces from 2005 to 2015 and used a DID model to identify action paths. They found that while China's pilot ETSs reduced carbon emissions, they did so at the expense of industrial sub-sectors' outputs.

The regional spillover effects of emission reduction are also examined. Pollution transmission and industrial connection generate frequent carbon transfer and leakage, making it increasingly vital to understand regional carbon emissions' geographical correlation and coordinate prevention and control in regional environmental governance. ETS may reduce emissions through knowledge and technology spillovers, but it may also expedite the movement of high-polluting sectors to nearby regions and worsen high carbon emission scenarios. There is a complex interaction and rivalry between positive and negative spillover effects that needs further study. Li and Wang (Li & Wang, 2022) conducted a quasinatural experiment with the DID method and spatial DURBIN model (SDM) and found that ETS has reduced carbon emissions in pilots since 2013 and in neighboring regions, proving that ETS has a net-positive spatial spillover effect that decreases with distance.

3.2. Economic Development Effects

It is crucial to balance the emission reduction impacts of climate policy with the need for economic development. Zhang and Liu (Zhang & Liu, 2022) examined the impact of China's ETS on economic growth. Significant reductions in carbon emissions and emission intensity were observed in the trial ETS districts of Tianjin, Hubei, and Chongqing, alongside some economic growth. The results indicated a favorable relationship between emission reduction and economic development objectives. However, other experts confirmed ETS's negative economic development impacts. If area economic development is poor, ETS will hurt economic growth and won't help until it reaches a specific level. Li et al. (Li, Zhang, & Lu, 2018) used a dynamic computable general equilibrium (CGE) model with carbon trading blocks to examine power industry impacts beyond creating the national carbon trading market. Results revealed ETS would hurt the economy. Real GDP will fall 0.08% - 0.52% in 2030.

The second economic effect is the cost-saving effects. ETS has a regionally heterogeneous character on economic development. It depends on resource endowments, economic development, marketization, and government-market relations. Carbon emission trading has a greater impact in eastern regions, where financial development, opening up, and industrialization are significant, than in central and western regions. Wang et al. (Wang, cheng Dai, yan Ren, qing Zhao, & Masui, 2015) used a two-region dynamic CGE model to study the economic effects of ETS regulation on four energy-intensive sectors in Guangdong province. They found ETS might drastically lower economy-wide mitigation costs, and Guangdong province's GDP would rise 2.6 billion USD.

Although it has been widely agreed by the academia that China's carbon trading mechanism has reduced carbon emissions and intensity (Zhang, Zhang, & Yu, 2019), but there is no consensus on whether it did so by encouraging green technology innovation or just pollution transfer (Yan, Zhang, Zhang, & Li, 2020). Hu et al. (Hu, Ren, Wang, & Chen, 2020) believed that the improvement of technical efficiency due to ETS reduces carbon emissions, while Li et al. (Li, Wang, Liao, & Wen, 2021) claimed that carbon transfer to non-pilot areas reduces carbon emissions in pilot areas. Hence assessing an area, industry, or enterprise's total factor carbon efficiency (TFCE) is regarded as more meaningful than quantifying carbon emissions or intensity.

3.3. Technology and Energy Efficiency Effects

ETS policy has overall promoted technological innovation in pilot areas and emission control industries, such as green innovation and clean technology innovation. The impact on innovation mainly comes from several aspects, including the increase in operating costs, encouragement for companies to develop new products and technologies, and the signal-expectation mechanism of policies (Hu, Qi, & Chen, 2023a). However, the innovation effects brought about by it have differences between regions and industries, as well as spatial agglomeration effects and spillover effect. For instance, Zhao et al. (Zhao et al., 2023) examined how China's ETS affected power industry green innovation using provincial industrial data. Green innovation is exclusively pushed in Beijing and Guangdong power industries, rather than in other pilots, showing regional heterogeneity. Analysis showed that Beijing and Guangdong's carbon market and power industry success is due to their refined quota accounting mechanism, paid quota allocation, larger enterprise scale, and more R&D investments.

ETS policy also boosts low-carbon trade competitiveness and regional green total factor productivity. Zhang et al. (Zhang, Liu, Choi, Yang, & Li, 2022) dynamically assessed China's pilot ETS's technological advancement using a biannual Malmquist-Luenberger productivity indicator and a multi-period DID model. In industrial subsectors, the pilot ETS increased GTFP by 8.5%. The technology change index rose 17.5%, which is crucial to enhancing GTFP. This improved technique is through innovation channel, they revealed. This study showed that green technology innovation could help carbon neutrality.

Based on the theory of constraints, the ETS policy reduces the green environmental protection investment of heavily polluting enterprises. Its crowding out effect with productive investment is not conducive to the realization of longterm value of enterprises (Yu, Hao, & Sun, 2023). However, it is still rather complicated and unclear that how ETS affects firm's innovation (Guo & Zhang, 2024).

Research on the impact of environmental regulation on regional innovation efficiency has not reached a unified conclusion: some studies believe that there is a U-shaped nonlinear relationship between the two, with a local-neighbor linkage effect. Yang et al. (Yang, Li, & Zhang, 2016) conducted a nationwide online questionnaire survey in seven carbon trading pilots from May to November 2015 to determine what factors affect companies' ETS awareness and attitudes. The results showed that government rules and policy, public relations management, and expected economic gain favorably affect companies' ETS attitudes. Public relations management is the most important, while anticipated economic gain is a weak predictor. Although tested companies are motivated to conserve energy and reduce emissions, their environmental and energy strategies do not affect their ETS selection. Company opinions about the ETS are inverted U-shaped by mitigating technology levels. Carbon prices don't motivate enterprises to enhance mitigating technologies. Most corporations join the ETS to improve relations with governments and get a positive social reputation, not to reduce greenhouse gas emissions. Certain state-owned firms were found to participate in the carbon trading market to strengthen government relations and social prestige, not to upgrade emission reduction methods.

Few literature discuss the role of ETS from the perspective of energy efficiency. On the basis of promoting regional technological innovation, the implementation of ETS policy has promoted regional industrial optimization and upgrading and industrial agglomeration, and improved energy utilization efficiency, and the improvement effect has also increased over time (Zhang, Cheng, Liu, & Zhu, 2023). Ultimately, it enhances regional economic efficiency and plays a positive role in promoting high-quality regional economic growth. Song et al. (Song, Zheng, & Shen, 2023) showed that carbon trading enhances energy efficiency in static and dynamic effect analysis using a quasi-natural experiment using the DID model. The impact mechanism study demonstrated that energy structure adjustments and green technology innovation boost energy efficiency. In the fields with strong environmental law enforcement and environmental quality, the ETS can have a greater effect on improving the energy efficiency improvement. However, the argument that ETS can improve the energy efficiency is also controversial in some sectors and enterprises subject to specific situations like coal-fired power plants (Cao, Ho, Ma, & Teng, 2021).

4. Comparison and Coordination between Different Policies

It has been pointed out that the carbon emission trading policy cannot single-handedly solve all the practical problems of stabilizing the economy and promoting emission reductions in China (Chang & Wang, 2010). Hence the design of ETS should also address the compatibility with other policies so as to facilitate the coordinated application of different measures. Based on this, some researchers have carried out theoretical analysis on the advantages and disadvantages of carbon trading and carbon tax policies, or conducted model construction analysis on whether to choose carbon trading or carbon tax policies (Wang, Li, & Bu, 2023), which will be introduced in this section.

4.1. Carbon Tax

It has been suggested that China should take into account the respective advantages of carbon trading and carbon taxes (Chang & Wang, 2010). On the basis of carbon trading, carbon tax measures should be supplemented, and attention should be paid to the coordination between the two policies. Wang et al (Wang et al., 2023) used experimental economics to study the effects of cap and trade, carbon tax, and carbon tax-carbon trading policies on social economy and emission reduction, as well as carbon market average prices. Under the carbon tax-carbon trading policy, carbon emissions cannot be reduced, but manufacturers' profits will be reduced, especially high-consumption manufacturers, resulting in a lower average carbon market price than under the cap and trade policy. Le and Azhgaliyeva (Le & Azhgaliyeva, 2023) compared carbon tax and ETS on enterprises' national and sub-national (province) GHG emissions in three East Asia countries (China, Japan, the Republic of Korea (ROK)). Jia and Lin (Jia & Lin, 2020) used the CEEEA (China Environmental-Energy-Economy Analysis) model to compare carbon tax and carbon trading. They examined the effects of carbon tax mechanism and ETS on the environment, energy, and economy using GDP as an exogenous variable. Both ETS and carbon tax have considerable emission reduction capacity given a constant GDP effect, but carbon tax is more efficient. Additionally, this advantage increased over time. They found that ETS hurts the energy industry and other energy intensive industries. After evaluating the invisible costs of building a new carbon trading market, they suggested China directly charge energy firms or boost fossil fuel production taxes to minimize carbon dioxide emissions. In this sense, the commodity market can provide pricing incentives to reduce emissions.

4.2. Carbon Tax

There are relatively fewer studies on comparative and synergistic effects between carbon sinks and the two mostly discussed policies, namely, carbon trading and carbon tax (Xia, Li, Dong, & Zhang, 2021). Compared with the limited emission space that carbon rights continue to reduce, carbon sinks can increase space. The carbon emission rights allocation model based on carbon sinks is regarded as more effective in realizing carbon emission reductions (Guo, Yang, & Zhong, 2023). While improving emission reduction efficiency, it also takes into account the issue of equity in regional development and satisfies the Polluter-Pays Principle (Guo et al., 2023). Therefore, sufficient attention and exploration should be given to carbon sinks in the future.

Forest carbon sinks in carbon trading can help bridge the finance gap for carbon emission reduction and achieve carbon sequestration and neutrality. Song et al. (Song & Wu, 2023) developed an efficient carbon credit trading model for forest firms and industries using forest carbon sinks. Stochastic differential game technique determines carbon sink forest size and trade price. Forest carbon sequestration and economic development are coordinated by reasonable emission reduction duties. Farsighted forest companies are more likely to trade carbon credits when forest carbon sequestration is low, while shortsighted forest companies are more likely to trade carbon credits when forest carbon sequestration is high. Low emission reduction responsibility in carbon credit exchange increases forest carbon sequestration and encourages shortsighted forest companies to participate, showing the mechanism’s superiority. With minimal emission reduction commitments, the forest firm can win economically and environmentally.

4.3. Other Schemes

In addition, there are also some literature that conduct comparative studies on the respective characteristics of carbon emission rights trading policies and energy use rights trading, energy saving trading, pollution emission rights trading and green credit policies, and compare the differences in environmental efficiency when each policy is used in combination, in order to find the connection between different policy systems to achieve the optimal synergistic effect of multiple policies.

An example is the establishment of a combined trading mechanism for green certificate trading and carbon emission trading (Zhang et al., 2023), as well as a joint performance mechanism for carbon emission rights trading and energy use rights trading (Wang, Su, & Wang, 2023). A study demonstrated that implementing a policy that combines carbon emission trading and energyconsumption permit trading at both supply and demand sides can lead to economic benefits while also addressing the issue of unequal distribution of regional economic development rights (Zhang, Wei, Gao, Shi, & Zhou, 2022). Lin et al. (Lin et al., 2016) stated that feed-in tariffs (FITs) play a beneficial role in enhancing the ETS's motivation for renewable energy initiatives. They suggested that combining ETS with FITs might be a cost-effective climate strategy for China. Hu et al. (2023b) examined how Renewable Portfolio Standards (RPS) and China's ETS affect power users when combined.

5. Construction and Optimization of Carbon Trading Market

5.1. Carbon Market Mechanisms

The carbon emissions trading market mechanism can manage resources and create market incentives for environmental and economic benefits. In this section, an overview of literature investigating specific market mechanisms is provided, from the aspects of carbon emission quota allocation, carbon price, and risk identification and management.

5.1.1. Carbon Emission Quota Allocation

The carbon emission trading market's principal product is carbon quotas, which are public and private environmental products. The "tragedy of the commons" will result from improper allocation and regulation of negative externalities (Libecap, 2009). Thus, limiting the entire amount of carbon emission rights and rationally allocating them by regulation authorities can increase resource usage efficiency to Pareto optimality (Wang, Wang, Dang, & Wang, 2014). How to objectively set the total carbon emission rights, enhance the original allocation system, and evaluate allocation methods (grandfathering or baseline) is a significant research topic.

Unlike the model of cap-and-trade rules used by EU and other carbon markets, China's carbon trading pilot does not cap total emissions and allows pilots to manage their emissions. China's carbon trading pilots have designed effective allocation and distribution rules based on historical emissions with some benchmarking, a free allowance distribution arrangement with auction, and pre-determined quotas with ex-post allowance adjustments (Xiong, Shen, Qi, Price, & Ye, 2017). Allowance mechanism design has several problems. These include an overabundance of allowances, enterprises not obtaining credits for early abatement activities, double-counting of allowance, an excessive emphasis on historical emissions, and unclear administrative laws managing allowance distribution and allocation

(Xiong et al., 2017; Li & Jia, 2016).

China's pilot EST markets have five allowance components, including allowances for initial distribution, allowances for adjustments, allowance for new entrants, allowances for auctioning and allowances remained for price stability allowances (Zhang, 2015). For allowance allocation, every pilot considers early abatement steps to varying degrees, in order to reduce the impact of "whipping the fast ox" (Zhang, 2015). Pilot programs also treat existing and new emission sources differently. Historical emissions, emissions intensities, or sector-specific benchmarking determine allocations to existing emission sources. New entrants receive allowances based on benchmarking, like the EU ETS4. Allbusinesses in a sector receive these advanced-level allowances. Additionally, the pilots allow mandatory organizations to request allowance changes in the event of a large allowance shortfall (Zhang, 2015).

When allocating carbon quotas, it is necessary to consider the specific actual situations, such as the technical level of different industries, the development levels of different regions, and administrative coordination, so as to unify regional and individual efficiency and fairness, and reduce information asymmetry. In a number of studies, the question of how to rationally decompose China's national capital into provinces has been investigated. Gao et al. (Gao, Chen, & Yang, 2015) used Shanghai as a case study to develop and implement equal historical cumulative emissions per capita for carbon emission allocation. Wang et al. (Wang, Zhang, Wei, & Yu, 2013) proposed an enhanced zero sum gains data envelopment analysis optimization model for constant resource allocation. Using this model, and various scenarios of China's economic growth, CO_2 emissions, and energy consumption, a new efficient provincial emission allowance allocation mechanism for 2020 was proposed. The allocation showed that different provinces must mitigate the intensity of emissions, the intensity of energy, and increase the share of non-fossil fuels differently.

5.1.2. Carbon Price

The carbon price is a product of the interplay between market forces and total quota control (Xu, Tan, He, & Liu, 2019; Hintermann, 2010). There is currently no standardization of national carbon emissions and carbon trading data. Information asymmetry will occur, total quota setting will differ from real market demand, and the price mechanism will fail if central and local government agencies and emission companies do not have enough or accurate emission data (Benz & Trück, 2009; Creti, Jouvet, & Mignon, 2012). The effects of varying energy prices are unpredictable and subject to change over time (Fan & Todorova, 2017). Current researches mainly focus on the signaling role, fluctuation characteristics and influencing factors of carbon price (Xu et al., 2019; Hintermann, 2010). After the launch of China's pilot policy, researchers have paid attention to the price fluctuations in China's pilot areas based on the carbon price rate of return, and found that it has the characteristics of fluctuation aggregation and regional heterogeneities (Cui, Wang, Zhang, & Zheng, 2021). Although the carbon trading mechanism of two-way tiered pricing can control costs while achieving emission reductions, but different pricing ranges bring different transaction costs and carbon emission reduction degrees. Some researches further studied the factors that affect carbon prices, such as economic development level, policies and regulations, energy prices, market supply and demand, and climate (Aatola, Ollikainen, & Toppinen, 2013; Ji, Zhang, & Geng, 2018; Kanamura, 2016). Regarding price determination mechanism, Lin et al. (Lin & Jia, 2019b) used the CGE model to determine how industry coverage, the annual decline factor, and the free allowance rate affect the emission trading price. Fewer industries, a higher annual decrease factor, and a higher free allowance rate will raise ETS prices. They also found unexpected ETS prices when the market mechanism is not fully established. Impacts of carbon price are also comprehensively studied (Lin & Jia, 2019a).

5.1.3. Risk Identification and Management

In the first stage, the carbon finance market is at least faced with mechanism design risks, market supply risks and compliance risks (Wang & Wang, 2016). More detailed market risks include carbon price fluctuations and volatility, high transaction costs, credit and moral risks from information asymmetry, legal system risks and economic environment risks from compliance, etc. (DENG & ZHANG, 2019). Uncertain fluctuations in economic policies will also have an adverse impact on the carbon emission trading market (Fu, Chen, Xia, & Miao, 2022). Existing literature on the risks of carbon emission trading markets mainly focuses on the identification of risks (Chen, Wang, Miao, & Zhou, 2022), the effective measurements of risks (Dong, Huo, & Wang, 2023) and their spillover effects (Hwang et al., 2023), in order to find ways to manage risks. At the same time, under the development trend of financialization of the carbon emission rights trading market, sufficient attention must be paid to financial risks (Luo, Zhuo, & Xu, 2024). Wang and Yan (Wang & Yan, 2022) measured China's carbon market's integrated risk using Copula-EVTVaR. The copula and EVT-VaR models were used to capture the dependence between carbon price volatility and macroeconomic fluctuation and explore risk value. The empirical results showed that the conventional VaR, which focuses on a single carbon price volatility risk factor, overestimates risk. Assessing carbon market integration risk using the copula function, which accounts for risk component interdependence, is more successful than other methods.

5.2. Market Efficiency

Based on the efficient market hypothesis and the fractal market hypothesis (Montagnoli & de Vries, 2010), some scholars began to consider the effectiveness and liquidity of the carbon emission trading market in terms of transaction volume and transaction speed, and found that some pilot areas in China have reached weak-form efficiency (such as Shanghai), and some areas showing fluctuations accumulation have not reached weak-form efficiency (such as Hubei) (Zhang, Li, Li, & Guo, 2020). Overall, the effectiveness of China's ETS markets is not high. However, due to differences in selected data, methods and other exogenous factors, a unified conclusion has not yet been reached on whether China's carbon trading markets in pilot areas is effective.

It has been found by several studies that the effectiveness of market operations can be improved by increasing the participation of small businesses (expanding coverage), formulating clear and reasonable allocation plans (reducing free allocation), and increasing the types of carbon products (carrying out carbon finance pilots) (Yu, Peng, Li, & Guo, 2023; Wang, Su, Lobont, Li, & Nicoleta-Claudia, 2022). However, most literature focuses on the discussion of pilot carbon markets. In the context of building a national or even an international carbon trading market, research on the market efficiency needs further exploration.

5.3. Coordination and Linking between Different Markets

Since there are inherent connections between markets, changes in one market parameter will drive changes in one or more other markets, and multiple markets will influence and interact with each other, that is, linkage (Baker, 1990). When analyzing the correlation between different types of markets or multiple carbon emission trading markets, it was found that there are linkages between China's carbon emission trading markets (Liu et al., 2013), and that China's carbon emission trading market has links with the stock market (Wen, Zhao, He, & Yang, 2020), energy market (Ma, Wang, & Zhang, 2020), industrial market (Chang et al., 2023) and foreign carbon emission trading markets (e.g., EU ETS) (Zeng, Weishaar, & Vedder, 2018).

Connecting carbon emission trading markets increases coverage, reduces carbon leakage, and coordinates regional management. Dai and Masui (Dai & Masui, 2012) and Zhou et al. (Zhou, Zhang, Zhou, & Xia, 2013) examined inter-provincial carbon trading in China using numerical models. Both studies found that linking inter-provincial ETS markets could significantly reduce China's carbon reduction costs. While connecting markets, a reasonable offset mechanism is needed to avoid market inefficiencies caused by offsets exceeding carbon rights trading volume. Wang et al. (Wang, Shi, He, & Dong, 2022) examined domestic-international carbon emission trading market information flow and relationship using the DCC-GARCH model. The study found that carbon market spillovers are volatile and exchange is minimal. Feng et al. (Feng, Howes, Liu, Zhang, & Yang, 2018) simulated Hubei and Guangdong ETS integration using a CGE model. Simulations showed that integrating regions would lead to a trade-off between efficiency and equity. Guangdong may profit, while Hubei may lose. Poorer Chinese provinces are more emissionsintensive and should see higher carbon prices. Trade may only partially reduce costs if allowed. They found that linkage could reduce welfare by reducing fairness and efficiency. Thus, emissions-intensive and underdeveloped areas should have higher emission caps.

5.4. Regulation of Carbon Market

The institutional underpinning of an ETS consists of legislation, supervision and management, MRV (Measurement, Reporting, and Verification), and emission compliance systems. The infrastructure needed to operate the scheme includes registry, trade, and information management (RTI) systems. Furthermore, there are substantial connections and interactions between these systems, as MRV offers data support for emission compliance via the RTI system. Hence, the designs of the aforementioned systems must be closely interconnected. It is argued by many studies that to ensure the healthy and effective operation of China's ETS market, the support of some supervision and guarantee mechanisms is needed (Chen & Wu, 2023). This not only requires strong policy support, but also requires higher technical foundations. However, at present, the corresponding laws and policies are far from complete, and the negative externalities caused by the gas diffusion characteristics of carbon emissions are difficult to measure, which poses considerable challenges to the supervision of the entire process.

Zhang and Xu (Zhang & Xu, 2017) examined the effectiveness of "trial and error" regulation design for China's emission-trading pilot programs. Locally created and managed pilots evaluate regulatory design and implementation to develop a nationwide program. They argued that trial-and-error design of Chinese emission reduction pilot programs allows for local adaptation. Local regulations, organizational capabilities, and development goals are involved. Trial and error falls short in balancing the conflicts among environmental sustainability, business viability, financial integrity, and political legitimacy.

6. Conclusion

This paper provides an overview on recent progress in the study of China's ETS pilots. We first give a brief introduction to the history and current status of China's ETS markets. Then the policy effects of ETS, including the carbon emission reduction effects, economic development effects, technology and energy efficiency effects, as well as other spillover effects, are discussed, followed by an overview on the comparison and coordination between ETS and other relevant climate policies. A summary of the studies that elaborate on the construction and optimization of China's carbon trading markets is also presented, including carbon market mechanisms, market efficiency, coordination and linking between different carbon markets, and market regulation. There are still many challenges that China's ETS is confronted with, including low levels of liquidity of the ETS market, the lack of a strong price discovery function of the carbon market, incomplete regulation and legislation system, the insufficiency of carbon market financialization. Policy recommendations of the development of China's ETS may include, for instance, improving the carbon market operating mechanism, establishing a flexible carbon pricing mechanism, improving the construction of carbon market-related institutional systems, and promoting the development of carbon finance. It is envisioned this progress review could provide useful implications and guidelines for developing China's carbon trading markets.

Acknowledgements

The author gratefully acknowledges the support of University Youth Teacher Training Funding Program of Shanghai (ZZSZF21004) and Young Faculty Startup Fund of Shanghai University of Political Science and Law (Q-06-19-007-13).

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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