Analysis models for China's carbon trading market: comparison and outlook

Chener Duan1, *, a, †, Yiran Mi2, *, b, †, Ziye Lan3, *, b, †

1University of Southampton, UK,
2North China Electric Power University, China,
3Queen’s University of Belfast, UK
*Corresponding author. Email: acd2m18@soton.ac.uk, b myr0204160527@163.com,
zlan01@qub.ac.uk
†These authors contributed equally.

Abstract—At the national and international levels, human-induced climate change has become a significant political concern, with the large rise in carbon dioxide concentration being a pressing issue that must be addressed. Carbon trading has shown to be one of the most successful strategies to accomplish energy saving and emission reduction as a flexible tool for dealing with climate change. As the nation with the highest carbon emissions today, China’s research on its carbon trading market has a guiding significance to the globe. The study findings of different models focusing on carbon trading markets are presented from three aspects: carbon emission reduction efficiency, carbon market efficiency, and internal information change trends in the carbon market. The results show that the efficiency of China’s pilot carbon market is currently poor, with just a mediocre efficiency attained. The existing carbon market’s key issues are its low transaction volume and weak market liquidity. Based on the comprehensive review of and comparison among existing models studying the carbon trading market, we proposed plausible suggestions for future research directions and development methods of the carbon trading market, including the utilization of carbon tax, improved market transparency, and government oversight.

1. Introduction
The substantial increase in CO₂ concentrations has resulted in global climate change. Climate change caused by humans has become a major political concern at both the national and international levels, prompting the search for legislative “solutions” [1,2]. The Kyoto Protocol, which was signed in 1997, reintroduced the notion of carbon trading as a flexible instrument for dealing with climate change. Since then, the carbon market has evolved into a new institutional arrangement to address climate change, and it has proven to be one of the most effective methods for achieving energy conservation and emission reduction [3], with the potential to become one of the world’s major commodities markets soon [3].

Carbon markets have the potential to become the greatest strategy to avert climate change [1]. According to Cameron Hepburn [4], the current carbon market is still new and immature. In addition, emission trading can potentially have negative moral and psychological consequences and to suffocate voluntary actions, diverting focus away from the critical need to alter human behavior, institutions, and the infrastructure. Therefore, the global carbon-trading sector has plenty of room to grow. Calel [4] projected the global carbon market might reach an increase of $175 billion annually. Calel [4] researched new data and compared it to past emission-trading experiences to identify how carbon markets work...
and fail. According to Lederer [5], only governments and international agreements can regulate carbon markets. Market participants, non-government organizations (NGOs), and public-private partnerships (PPPs) lack the political power to develop, manage, or capture nascent market systems. Researchers are looking mostly at the Clean Development Mechanism (CDM) and how to set up a carbon trading market in China [1].

Since China produces more CO₂ than any other country, China must balance its economic growth with protecting the environment [2]. Climate change mitigation efforts throughout the world will be hindered if China’s greenhouse gas (GHG) emissions continue to rise [1]. China’s carbon trading market has gone a long way in the last few years. Introducing carbon market principles and practices into China via the Clean Development Mechanism (CDM) has been a success. The CDM was accepted by China in 2004 and its “Measures on the Operation and Management of Clean Development Mechanism Projects” were released in 2005. With a share of carbon credits sold worldwide of 43.52%, China has swiftly ascended to the top of the CDM market. Many opportunities exist for lowering China’s greenhouse gas emissions throughout the country’s energy industry in general. China’s unique government administrative structure and other features make the carbon trading market a good choice for the country.

Carbon trading has focused mostly on Europe because of the maturity and growth of the European carbon market. In the carbon market in China, there is a dearth of research and analysis. Chinese researchers are particularly interested in the potential impact of carbon trading on energy efficiency and emissions reductions, both of which are the key focuses of the country’s carbon trading market studies. In this study, we overviewed and evaluated the development history of China’s policies on its carbon trading market, providing insights on the key success factors of effective policy measures. More importantly, we reviewed, analyzed, and compared prevailing models used to study China’s carbon market. Based on the combination of findings of existing models, the institutional framework and development of carbon trading in China are further examined. In addition, we proposed future research directions and predicted future carbon market development trends after synthesizing existing studies.

2. The development of the Carbon Trading System (CTS)

2.1. Conceptualization

According to Pigou [8], forcing firms to bear the costs of their pollution would have significant social benefits. Coase [7] supplied the conceptual foundations for carbon trading by demonstrating that spreading property rights and facilitating trade may result in efficient outcomes. Not until 1968 did Dales make the first direct link between the model and environmental contamination, according to the journal Science [8]. “Cap and trade” schemes are often used to give businesses with a restricted number of permits, or licences, from the federal government. Because they assist in meeting a need that does not exist, it is vital to have allowances in place. Corporate emissions should be reduced when doing so is less costly than acquiring permits, according to the EPA. With its market-based approach, carbon trading seeks to reduce the negative effects of climate change on the environment [9].

2.2. Global Policy Development

Furthermore, the notion of emissions trading is not a new one in the realm of business. In the 1990s, the United States began exporting sulphur dioxide (SO₂) and nitrogen oxides (NOX) to other countries on the worldwide market [10]. Initial reactions were scepticism, but it is now universally acknowledged to be an enormous success. Nonetheless, despite the fact that the European Union Emission Trading System (EUETS) is now the world’s largest programme, it is by no means the only one of its sorts in existence. Because it focuses just on carbon dioxide emissions from permanent industrial sites in Europe, it leaves room for various policy methods to be used to address the other five major greenhouse gases as well as emissions from other industries. Many nations, like the United Kingdom in 2002 and the Australian state of New South Wales in 2003, had already created carbon pricing programmes before the European Union's Emissions Trading Scheme came into being in 2007. When the Kyoto Protocol
was originally implemented, it allowed for carbon trading via three “flexible alternatives”, which were available from 2008 to 2012. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was implemented from 2008 to 2012.

2.3. China’s policy development
As the world’s greatest producer of greenhouse gases, China is under tremendous pressure to cut its carbon dioxide emissions [1&3]. China has made significant progress in the development of a carbon trading system (Figure 1). To introduce carbon trading to China, the Clean Development Mechanism has proven a useful conduit. “Measures on Operation and Management of Clean Development Mechanism Projects” was published in 2005 by China after it embraced the CDM in 2004[1]. With 43.52 percent of all CDM carbon credits exported, China has been the world’s greatest exporter since then. In order to create a carbon trading market, environmental exchanges were set up in a number of Chinese towns in 2008. China’s NDRC permitted seven administrative districts with varied levels of economic growth and industrial structure to experiment with and construct carbon trading systems before pushing it nationally. Hubei, Guangdong, Guangxi, and Chongqing provinces are included in this list [1]. High energy users and emitters are the primary customers of carbon dioxide, which is sold on a global scale. The Chinese government pledged in 2009 to reduce GDP-based carbon emissions by 40–45 percent. Since China’s new five-year plan was announced in March 2011, the country has been moving from voluntary emission reductions to mandated ones as part of the “Twelfth Five-Year Plan.”

![Figure 1: The Development of China’s CTS Policy](image)

2.4. China’s Current Carbon Trading Situation
To test the feasibility of carbon trading in China, in October 2011 the National Development and Reform Commission (NDRC) chose four cities (Beijing, Chongqing, Shanghai, and Tianjin), two provinces, and the Shenzhen Special Economic Zone (SEZ) [1]. A nationwide ETS would be tested in these seven pilots after 2016, it is expected. By the end of 2014, China’s largest cities, including Beijing, Shanghai, Shenzhen, Tianjin, Guangdong, Hubei, and Chongqing, had officially initiated carbon-emissions trading. Other states are anticipated to follow soon after. Seven ETSs are expected to regulate between 0.8 and 1.0 billion tons of CO₂ emissions over their operating lifespan. They may even exceed the EU ETS as the world’s second-largest cap and trade program if their trading systems are linked together. When it comes to the number of quotas available, Guangdong’s pilot zone is second only to the EU Emissions Trading System (EU ETS) in terms of the total amount of CO₂ released in 2013 [1].
3. The development of the Carbon Trading System (CTS)
A large number of researchers have developed a variety of models to investigate and analyse China’s carbon trading market as part of the process of developing the country’s carbon trading market. The majority of the study focuses on the advantages of carbon emission reduction as well as the market efficiency of the carbon market, which is among the most important.

3.1. The carbon trading market’s benefits for reducing carbon emissions
Domestic and foreign scholars have established various models to study the emission reduction efficiency of China’s carbon trading market. The author will make a comparison between the carbon trading emission reduction research based on the three-stage data envelopment analysis (DEA) model and the spatial difference-in-differences model and get the significance and reference value.

The three-stage DEA model has been widely used not only in the carbon market but also in other fields (such as industry, agriculture, construction, etc.). It is a relatively mature carbon emission reduction benefit research model [11, 12, 13]. Its biggest characteristic is that it can eliminate the influence of non-operational factors (external environmental factors and random factors) on efficiency, so that the efficiency value can reflect the internal management level of the DMU (decision-making unit) more truly. The spatial difference-in-differences model is an innovative model based on DID (difference-in-differences), which can explore the spatial interaction of emission reduction transmission paths innovatively. However, few scholars use this model to study the emission reduction characteristics of the carbon market.

Wang Yong and Zhao Han [14] evaluated and analyzed the carbon emission efficiency before and after the establishment of the carbon trading market based on the three-stage DEA model and compared the differences in carbon emission efficiency among provinces and regions in China according to the convergence principle. Their study pointed out that the launch of the carbon trading market had an improvement effect on carbon emission efficiency, and the carbon emission efficiency remained unchanged or increased in China’s pilot carbon trading areas. The biggest feature of the three-stage DEA model is that it can eliminate the influence of external environmental factors and random factors on efficiency, so that the efficiency value assessed can more truly reflect the internal management level of decision-making units. They not only introduced the four factors of industrialization degree, urbanization degree, technological progress, and energy consumption intensity into the model, but also conducted a comparative analysis before and after the establishment of the carbon trading market. In this model, GDP is selected as the output variable, and input variables are set as capital stock, labor force, and total carbon emissions. After using the three-stage DEA model for analysis, the researchers also used convergence analysis to analyze the correlation between the urbanization degrees of different provinces and the emission reduction benefits of the carbon trading market, and they put forward that the urbanization degree will widen the gap between provinces and regions, which is not conducive to the convergence of carbon emission efficiency. This study focuses on the comparison between the national emission reduction benefits and different regions of the country and concludes that the increase and decrease of emission reduction effects before and after the establishment of carbon trading markets in different regions, which intuitively reflects the improvement of emission reduction benefits after the establishment of carbon trading markets.

Based on the balanced panel data of 285 prefecture-level cities in China from 1999 to 2017, Li Ruonan, Yang Lijun, and Zhao Xiaoli [15] use the spatial difference-in-differences model to research and discuss the emission reduction effect and transmission mechanism of carbon trading pilot projects. Carbon trading can not only effectively promote local carbon dioxide emission reduction, but also drive the surrounding areas and produce emission reduction benefits. The study suggests that because of the increased cost of emissions, companies may reduce carbon dioxide emissions through technological innovation or production adjustment. At the same time, carbon trading brings positive economic benefits, and economic growth is often accompanied by carbon dioxide emissions. The main idea of this paper is to verify the emission reduction effect of the carbon trading market according to economic development benefits. This study selected seven factors as control variables, including regional GDP, the proportion...
of added value of different industries in GDP, total industrial output value, science and technology expenditure, the number of comprehensive scientific research employees, and the total population of the region at the end of the year. Based on the balanced panel data from 1999 to 2017 of 285 perfection-level cities, TA conducted an empirical study on the impact of carbon emission trading rights on carbon dioxide emission reduction in China by using the SDID model and studied the transmission mechanism by using the SAR model as the benchmark regression model. This study employs a number of model combinations to demonstrate how carbon trading can effectively promote local carbon dioxide emissions, drive the surrounding area, and generate emissions benefits, as well as how carbon trading can push pilot areas and the surrounding area into economic growth and the industrial scale carbon trading market, reducing carbon dioxide emissions and driving the surrounding area toward greater efficiency.

In conclusion, both models demonstrate that the carbon market is a good driver of emission reduction. The former demonstrates the development of different regions, and the emission reduction effect is more obvious in the two periods before and after the establishment of the carbon trading market. The second model demonstrates the effect of carbon trading from the perspective of economic and urbanization development, and also demonstrates the effect of the carbon trading market on emission reduction. Their results put forward the impact of urbanization scale and scientific research and technology development on the emission reduction effect of the carbon trading market.

3.2. Efficiency of carbon emission trading market
This part mainly focuses on introducing the model for studying the efficiency of the carbon emission trading market itself and analysing the significance and guiding role of the research on market efficiency for the future development of the carbon market. The advantages of DEA model have been mentioned above and will not be repeated here.

Xin-gang Zhao et al. [10] borrowed the basic model of “fair game” to establish a market efficiency model for China’s carbon trading pilots. They use running tests to test whether China’s carbon emission trading market has achieved a market state called weak efficiency market, and one of the main advantages of this method is that it can surmount the shortcomings of serial correlation tests that are susceptible to extreme values and whether there is limited variance. During the inspection, they collected carbon price data from four different carbon trading pilots, which have sufficient data. By using the model to analyse the data, they analysed the efficiency of China’s carbon emission trading market and verified the weak-form effectiveness of it. In the end, it is concluded that China’s carbon emission trading pilot has become a weak-form efficiency model, that is, Carbon prices only reflect all the information available from the transaction. However, it has not yet achieved semi-strong form efficiency or strong form efficiency. At the same time, the operating test results also demonstrate that China’s carbon emission trading market is ineffective if the market is in an emerging and immature state and is effective only when the market reaches a larger-scale mature state. It can be seen that the efficiency of China’s carbon emission trading pilot market is low, but if given time, the scale of China’s carbon emission market will be expanding, and meanwhile it is showing signs of restoring market efficiency.

In addition, in response to the low efficiency of the carbon emission trading pilot market, Zhao Xingang, Gui-wu Jiang, and others [3] conducted empirical research on the data of each pilot and calculated the market efficiency in four different aspects: carbon price, market transaction volume, the transparency of market information and market liquidity. It also examines the causes of low market efficiency from three perspectives: fundamental conditions, technology, the institutional system, and transaction participants. Finally, corresponding policy recommendations were put forward based on the status quo and reasons.

Han Jinyu and others [16] also tried to analyse the carbon market’s efficiency of China’s seven pilot projects. Through the establishment of a DEA model, the ratio of input to output is used to measure the operation of the carbon emission trading market, and the efficiency of each pilot is also measured. The results show that most of the pilots have been well evaluated and the carbon market is gradually maturing, but there is still a lot of room for exploration before the market is mature. At the same time, the article proposes that carbon trading market’s operating efficiency is generally measured by three aspects:
transaction scale, market liquidity, and price stability. One of the main problems in China’s current carbon trading market is insufficient market liquidity. Carbon trading volume cannot be substantially increased without the participation of risk management tools such as carbon futures in the market.

In general, the above-mentioned scholars’ analyses of the efficiency of China’s carbon emission trading market all show that the efficiency of China’s pilot carbon markets is relatively low at this stage, and only weak efficiency has been achieved. Small market trading volume and poor market liquidity are both major problems in the current carbon market.

3.3. Carbon price and carbon trading capacity forecast

In addition to the research on the two basic models previously mentioned, the study of the variables should also be taken into account. There are several factors to consider while developing environmental and energy conservation measures, including the volume of carbon trading and the price of carbon trading. Because China is the world’s largest emitter of carbon dioxide, the country’s carbon trading capacity, carbon price trend, and carbon market policy direction all have a significant global impact. Using six distinct machine learning models, Lu Hongfang and colleagues [17] were able to accurately estimate daily carbon prices and trade volumes in eight different carbon markets throughout China. Kernel-based nonlinear extension of the Arps descent model optimised by XGBoost, RF, and grey wolf optimizer (GWO-KNEA), support vector machine optimised by particle swarm optimizer and fruit fly optimizer, respectively. Optimized annealing method (SVM), radial basis function neural network (RBFNN), and other ways [17]. After comparing the prediction results of each model, a better model with increased prediction stability and accuracy is identified. RBFNN model based on a neural network, SVM-based model PSO model, SA model FFOA and semi-empirical GWO model are only a few examples of machine learning approaches [17].

It has been discovered via study that the improved RBFNN and GWO-KNEA models are the most accurate forecasters of carbon price and trading volume in the global carbon market [17]. The improved RBFNN model has an average prediction accuracy of 98.40 percent in the eight carbon pricing data sets studied, whereas the GWO-KNEA model has an average prediction accuracy of 97.89 percent in the same data sets [17]. To be clear, the highest level of forecast accuracy does not necessarily imply the highest level of consistency in the forecast. In terms of model importance, however, both are equally crucial since they determine whether or not the forecast will make significant errors at critical moments in time. As a result, even while the accuracy of the support vector machine is not always the highest, it is the steadiest, and as a result, its predictions still have a larger degree of significance.

| Authors | Model | Key Data | Main conclusion |
|---------|-------|----------|-----------------|
| Wang Yong and Zhao Han | Three-stage DEA model | GDP (output variable) Capital stock, Labour and total carbon emissions (Input variables) | The development of different regions, and the emission reduction effect is more obvious in the two periods before and after establishing the carbon trading market. |
| Li Ruonan, Yang Lijun, and Zhao Xiaoli | DID and SDID model | Regional GDP, proportion of added value of different industries in GDP, total industrial output value, science and technology expenditure, number of comprehensive scientific research employees and total population of the region | Looking at the role of carbon trading from the perspective of economic and urbanization development, it also demonstrates the role of the carbon trading market in reducing emissions. |
| Xin-gang Zhao and others | “Fair game” model | Carbon price form Beijing, Shenzhen Tianjin, and | Weak-form efficiency model for China’s carbon trading pilot |
Shanghai has been developed, which means that market prices may accurately represent historical data on carbon pricing [10].

Han Jinyu and others DEA model the ratio of input to output in the carbon market. Most of the pilots have been well evaluated and the carbon market is gradually maturing, but there is still a lot of room for exploration before the market is mature.

Lu Hongfang and others XGBoost, RF, GWO-KNEA, RBFNN, SA-FFOA-SVM, PSO-SVM. Carbon price and carbon trading volume. The best predictions are made using the enhanced RBFNN and GWO-KNEA models [17].

### 4. Potential future research directions

#### 4.1. Efficient reduction of carbon emissions

The current research on the carbon emission reduction benefits of the carbon emission trading market is sufficient, including the vertical comparison of the carbon emission reduction benefits before and after the development of the carbon trading market in each pilot and the horizontal comparison of the carbon emission intensity between the pilot and non-pilot. However, there is insufficient research on the reasons for the differences in carbon prices and volatility among the pilots. To implement the development of a nationwide carbon trading market in the future, the prediction, judgment, and analysis of the influencing factors of carbon emission reduction efficiency should be more fully studied. At the same time, due to China's vast territory, the differences caused by different regions should receive in-depth and detailed analysis.

#### 4.2. Market effectiveness

The above-mentioned related research shows that small market trading volume and poor market liquidity are the prominent problems in China's current carbon trading pilot market. Besides, adding risk hedging tools that match carbon market prices and risks and risk management tools such as carbon futures can effectively increase carbon market trading volume and enhance market liquidity. Therefore, future research can focus on the trend and degree of changes in market transaction volume and market efficiency after the addition of risk management and hedging tools.

### 5. Future development direction and suggestions

#### 5.1. The addition of the carbon tax

Combining the research results and suggestions of many scholars, the author believes that while technology updates and market policy adjustments promote the increase in carbon trading volume, the government's regulation of carbon prices and taxes will have a positive impact on carbon dioxide emissions reduction. For example, the establishment of a national carbon trading market will help promote the development of the carbon market and reduce the loss of regional carbon assets. However, at the same time, it is necessary to fully consider regional differences such as resource reserves, industrial structure, and actual economic development and give different provinces and cities flexible policy authority. Given that the carbon tax has the same effect on GDP, it has higher emission reduction efficiency and lower long-term emission reduction costs. When the domestic carbon trading market is established in advance, the coordinated management of carbon tax and carbon trading should be carried out. The carbon tax should start with a low tax rate and gradually increase.

#### 5.2. Transparency of information

In fact, if you want to ensure high market liquidity, the necessary condition is that the market has matching transaction capacity. The size of the market's carrying capacity depends on whether the
number of transaction participants is sufficient. In terms of how to grow the number of traders, it is unavoidable that an open and transparent market environment be maintained in order for the market to function effectively. In exchange, a market that is open and transparent might attract a variety of traders [3]. The carbon market's transparency as a policy market is determined by system design and information sharing. However, when it comes to the publication of carbon emission information, there is a significant deficiency in information. Inadequate transparency contributes to higher volatility in the carbon emission trading market, which has a negative impact on the excitement of market participants and has a negative impact on the size of the market.

First and foremost, it is vital to strengthen the carbon emission statistics and accounting system in order to increase openness in information sharing. In order to make timely decisions, decision makers must be fully informed on the unique system architecture and must disclose important projects or data at the appropriate time. To begin, increase the company's grasp of its market access criteria, fundamental rules, and verification processes. The comprehension of carbon emission trading cannot be limited to a linguistic interpretation. Furthermore, businesses must recognize the far-reaching significance of this form of trade in terms of encouraging energy conservation and emission reduction, improving the general structure of the industry, and increasing the overall competitiveness of associated businesses. Last but not least, the construction of a comprehensive public information sharing platform is the most crucial step forward. Other data, in addition to fundamental firm data, such as the carbon price and transaction volume, has been traceable in the last year or so.

5.3. Government control
The carbon market's scarcity is entirely set by the government, with great policy sensitivity, and alternative institutional designs will have an impact on the carbon market's market efficiency. As a result, the government's carbon emission cap and allowance allocation can have a direct impact on the carbon market's supply and demand. Therefore, the government must clearly refine the formulation of relevant systems and indicators and introduce a complete calculation and verification system to stabilize carbon prices and the enthusiasm of traders.

In addition, there is no clear reward and punishment mechanism in the current carbon market. Although there are rules governing reward and punishment mechanisms, their substance is ambiguous, and their application is very variable. When incentives and penalties do not meet expectations, transaction participants' excitement may be harmed. In this case, the carbon market's function will be impacted, the market's foundation will be shattered, and the impact of energy saving and emission reduction would be severely limited. Furthermore, ineffective penalties cannot effectively deter companies from entering the carbon trading market and meeting their compliance obligations. Therefore, the main responsibility of the government also includes perfecting the relevant laws and regulations on the reward and punishment mechanism so as to ensure the number of traders and the market efficiency of the carbon market.

6. Conclusion
In this study, we overviewed the development history of China's carbon trading market, and reviewed and analyzed the main models studying China's carbon market, from three different perspectives: the benefits of emission reduction, the efficiency of the market, and estimates of carbon prices. We summarized the main findings of existing research as well as provided recommendations for the evolution of the global carbon market in the foreseeable future.

Based on the common findings of different studies, the establishment of a carbon trading market can speed up the achievement of the 30% - 60% emission reduction goals. Furthermore, this study recommends that future research should focus on delving further into the elements that impact the efficiency of carbon emission reduction as well as the efficiency of the carbon trading market. The paper concludes with a discussion of potential future growth paths as well as optimization suggestions for the creation of a carbon market in China. Carbon tax policies, information openness, and government macro-control should all be prioritized for the future growth and extension of the carbon market to
achieve an increase in trading volume and market liquidity in the future.

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