Global NEST Journal, Vol 23, No X, pp 1-7

Study of Chinese carbon emission trading market mechanism based on the game theory

Dai J.[1,2]***, Yan J.**[1] **and Gao H.**[3]
[1]School of Business, Sichuan University, Chengdu 610041, China
[2]Chengdu Qizhi Innovation Patent Agency, Chengdu 610096, China
[3]Science and Technology on Vacuum Technology and Physics Laboratory, Lanzhou Institute of Physics, Lanzhou 730000, China
Received: 04/09/2021, Accepted: 21/12/2021, Available online: 23/12/2021
*to whom all correspondence should be addressed: e-mail: daijw2010@163.com
https://doi.org/10.30955/gnj.003942

Graphical abstract

Abstract

In order to provide corresponding suggestions for the establishment and development of China's carbon trading market mechanism, the three-party game model of the competent government departments, carbon emission enterprises and third-party verification institution in the initial allocation of carbon emission rights and the rotation bargaining game model in the secondary carbon trading market are solved and analyzed in this paper. The results show that the competent government departments should improve the review efficiency effectively to reduce cost by outsourcing the review work to universities, research institutes and other scientific research units and increasing punishment for the collusion behavior between the carbon emission enterprises and third-party verification institution. At the same time, the competent government departments should adopt the regular regulatory policies to deal with collusion behavior and reduce the sampling proportion to cut cost of government review. The trading center should directly determine transaction price in combination with the forces of buyers and sellers, and make matchmaking trading directly by selecting the qualified buyers and sellers at the secondary carbon trading market in process of bilateral open bidding.

Keywords: game theory; carbon emission rights; carbon trading market mechanism; collusion behavior; match-making trading

1. Introduction

According to the report on the global climate state released by the World Meteorological Organization, the global concentration of major greenhouse gases continued to rise in the half year of 2020, and the global average temperature was about 1.2°C higher than the pre-industrial level. The last period of 2015 to 2020 was the six warmest years for the world since the meteorological records began (Tan *et al.*, 2020; Gong and Zhou, 2019). In order to deal with the climate change, the international community reached the Paris Climate Agreement in 2015, which put forward to control the global temperature rise less than 2°C and strive for the goal of 1.5°C compared with the industrial revolution. The countries around the world unanimously reached a consensus at the climate summit allowing the implementation of Paris Climate Agreement into the trot stage (Fang *et al.*, 2018; Jin *et al.*, 2019; Woo *et al.*, 2017). Every country has put forward its own carbon emission reduction targets according to its own national conditions. Among them, the United States proposed a new emission reduction target that the greenhouse gas emissions in 2030 reduce about 50%~52% compared with the 2005 (Huang *et al.*, 2020). The Japan has put forward that the reducing carbon emissions reached about 46% in 2030 compared with 2013 levels, which is 20% higher than its previous commitment of 26% reducing carbon emissions plan (Kanchinadham and Kalyanaraman, 2017). Canada proposes to reduce greenhouse gas emissions by 40%~45% in 2030 compared with 2005 (Nath *et al*., 2015). Brazil has pledged to cut its carbon emissions by 50% in 2030 and become carbon neutral in 2050, which has 10 years ahead of schedule (Wang *et al.*, 2017). Although the China and United States are the two largest carbon emission countries in the world, the emission reduction of greenhouse gases is not a matter of one single country. It involves the whole world trade rules and the carbon emission trading must be carried out in cooperation around the world that has been reached a consensus in the climate arena (Guo *et al.*, 2018; Li *et al.*, 2019; Weng and Xu, 2018; Liu and Cui, 2018). The most important aspect of the carbon emission trading market is the carbon price, which has not yet formed a free market pricing (Li and Lei, 2018). Previously, the Obama administration estimated the carbon price at $ 42 per ton, while the Trump administration put it only about $7. There are still differences in understanding of the carbon price within a country, it is necessary to explore in practice to reach a consensus on carbon price around the world. It need to develop the concrete solutions to a series of problems such as carbon pricing and carbon tariffs in practice (Li *et al.*, 2016; Wang and Wu, 2018; Yang *et al.*, 2019).

In 2020, China announced the goal of carbon emission to the world that strive to achieve the carbon peak in 2030 and achieve the carbon neutrality in 2060 (Chen *et al.*, 2015; Wang *et al.*, 2019). The so-called peak carbon dioxide emissions means that the annual carbon dioxide emissions of a region or industry reach the highest value in history, then go through a plateau period and enter a continuous decline process, which is the historical inflection point of carbon dioxide emissions from increase to decline (Zhu *et al.*, 2020; Zheng *et al.*, 2021). The carbon neutrality means that the carbon dioxide content emitted directly and indirectly by human activities and absorbed through afforestation and other ways cancel each other out in a certain area, offsets the carbon dioxide, and the final effect of nearly zero carbon dioxide emission realized (Shan *et al.*, 2021; Zhu *et al.*, 2020). China is the largest industrial nation in the world at present, emitting about 10 billion tons of carbon every year that is twice as much as the United States and three times as much as the European Union. China is responsible for about a quarter of the global carbon emissions at the present stage, which means that the carbon peak and carbon neutral achieving have the greatest impact on the China's economic development (Han *et al.*, 2017). China management needs to take all factors into full consideration when formulating the carbon emission trading mechanism and make great adjustments and changes, so as to be more conducive to the harmonious development between the national economic development and natural environment. The official opening of the world's largest carbon trading market in China's Hubei Province in 2021 is bound to accelerate the process of developing international carbon trading standards (Pan *et al.*, 2019; Xia and Tang, 2017). In order to meet the Paris Agreement's emissions reduction target of limiting temperature rise within 1.5°C, it is estimated that the proportion of non-fossil energy in China's primary energy consumption will reach about 25% to 28% in 2030. It is expected that the share of new energy in primary energy will rise from current 17 % to about 80 %, while the proportion of coal and oil will drop from current 75 % to about 10 % by 2060 (Chen *et al.*, 2019). This goal will surely lead to a low-carbon transition in China's traditional energy and manufacturing industry, which will have the greatest impact.

The development of carbon emissions trading market mechanisms, especially the carbon financial, will help to promote the social capital to flow into the low carbon field, conducive to stimulating the enterprise to develop the low carbon technology and use of the low carbon products, and make the pattern of enterprise production and business changed, that improving the market competitiveness of enterprises and providing the power for the cultivation and innovation in low carbon economy development (Wang *et al.*, 2018; Yu *et al.*, 2018). The explosive green industry is bound to give rise to green finance. At present, the carbon emission trading market launched at the end of June is only limited to the spot market. The explosive development of green industry will inevitably accelerate the birth of green finance industry, and there will be a lot of financial derivatives around carbon emissions in the future (Qu *et al.*, 2018). China's carbon peak and carbon neutrality plan will certainly prompt big changes in traditional industries direction of the energy-rich provinces, such as Inner Mongolia and Shanxi province. The tax revenue proportion of the mining and power industries in the Shanxi and Inner Mongolia province is more than 40 % and 30 %, respectively, that is related to employment, various public welfare and people's well-being behind the taxes (Zhang *et al.*, 2017). The transition from fossil energy to clean energy will put the large impact on these regions, which requires the provinces to prioritize their own advantages to complete the transformation of the energy industry (Hu *et al.*, 2017; Zhou *et al.*, 2017). For example, The Shanxi province can focus on carbon capture technology, and then use them as raw materials to develop high performance of carbon materials, carbon fiber, graphite and other strategic emerging industry. In the past we have adopted the extensive development model that emitting all of these carbon into the air directly and they are going to back to use and make it valuable in the future (Munnings *et al.*, 2016). The Inner Mongolia province can also develop clean energy, not just be restricted to the carbon capture technology, but also use of their own advantages and continuously enlarge the area of grassland, forests, wetlands which are considered the natural carbon dioxide absorption device. Then they can carry out the carbon sinks trade of forest, wetland and grassland or directly sell them to compensate their energy-intensive industries (Tan and Wang, 2017). This solves the problem we started with about how to price natural resources. Therefore, every province can use its unique advantages to achieve the goal of carbon peak and carbon neutral, which solves the problem of how to price natural resources that we talked about at the beginning.

In this paper, we analyze the behaviors of every participants in the initial allocation market of carbon emission rights and the secondary carbon trading market in China by using the game theory. By analyzing and summarizing the possible behaviors of the three parties (the competent government departments, the carbon emission enterprises and the third-party verification institution constitute) in the carbon trading market, the influence of strategy adopted by each party on China's carbon trading market is clarified. The relevant research conclusions will provide reference for China's carbon trading policy formulation.

2. The game theory model

2.1. Game model and solution procedure of the initial allocation of carbon emission rights

The carbon emission trading is a market trading system involving the government, carbon emission enterprises and third-party service institutions, and its soundness is the decisive factor for the realization of optimal resource allocation. The initial allocation of emission rights is a prerequisite for the normal operation of the emission rights trading market. It is also the key to total volume control and the important factor to ensure the maximization of global economic benefits. The reasonable and practical initial allocation of emission rights is conducive to realizing reasonable allocation and economical utilizing of resources, promoting technological innovation, and forming a production pattern with low pollution emission level and high economic benefits. There are two methods of initial allocation of carbon emission rights. One is the free allocation, including the Grandfathering allocations mode that the number of carbon emission rights is determined by a certain proportion of the historical emissions of carbon emission enterprises and allocations mode that the carbon emission rights obtained by the current total output and per unit of output. The other initial allocation method is the public auction. At present, China's initial allocation of emission rights is mainly free allocation mode, following the monitoring, reporting and verification mechanism (MRV). Under this style, the emission enterprises can make up the difference of emission reduction through energy saving and emission reduction or carbon emission right trading to fulfill their emission reduction commitment, which does not involve the cost transfer between the government and emission enterprises. However, if the initial allocation of emission rights is excessive or insufficient, the constraint effect of emission reduction will be lost that resulting in the price fluctuate of carbon emission rights. According to China's overall deployment of carbon emission reduction in the early stage of the carbon trading system, the carbon emission verification task of quota allocation is jointly completed by the government and third-party verification institution, in which the former play a leading role in the current. With the continuous development and expansion of third-party verification institution, they will become the leading force of verification task, and the MRV mechanism will be widely applied in the process of free allocation of carbon emission rights. The social cost of verification will be reduced, and the competent government departments will also reduce the cost of carbon emission verification. In the context of "whoever pollutes, treats" policy, the carbon emission enterprises will inevitably strive for more carbon emission allocation quota to maximize their interests in the initial allocation of carbon emission rights. The enterprises driven by interests will inevitably have the incentive to lie about their own information. Therefore, the dynamic game model of Stackelberg (Bernard *et al.* 2008; Manuel *et al.*, 2016; Zhao *et al.*, 2017) was introduced to study the mixed game behavior of government departments, carbon emission enterprises and third-party verification institutions in MRV mechanism in this paper, providing guidance for the improvement of China's carbon trading market mechanism in the future.

In the operation process of MRV mechanism, the competent government departments, carbon emission enterprises and third-party verification institution constitute the tripartite game behavior that influence each other. The external independent third-party verification institutions are generally responsible for the measurement and verification of corporate carbon emission rights. The third-party institutions must possess relevant qualifications and meet capability requirements which must be recognized by the government. Currently, this institution recognized by the Chinese government is the China National Accreditation Commission for Conformity Assessment. The third-party verification institutions can make full use of their own effective resources and technical advantages to reduce the cost of carbon emission verification for the government, and at the same time directly avoid the risk of administrative liability. The income source of third-party verification institution depends on the carbon emission reduction enterprises, and they have the motivation to collude with carbon emission reduction enterprises to obtain additional income. It is necessary for competent government departments to check a certain proportion of the carbon emissions enterprises. If collusion is found in the verification process, the third-party verification institution and emission reduction enterprises will be subject to administrative penalties.

The strategy of the competent government department is recheck or not recheck. If the recheck was selected, it is assumed that the cost paid was C_0. If the collusion between the carbon emission enterprise and third-party verification institution existed, the administrative penalty will be imposed on them, assuming C_1 and C_2, respectively. And the cost is zero if not rechecked. The strategy of the carbon emission enterprises and third-party verification institution is collusion or no collusion. If the strategy of no collusion was adopted, the income of carbon emission enterprises and third-party verification institutions is E_1 and E_2, and the increased returns of both was ΔE_1 and ΔE_2, respectively, when adopted the collusion strategy.

Since the game players of the three parties are not sure which strategy the other party will adopt in choosing specific strategies process, the game is a mixed strategy game in the static game with incomplete information (Lin *et al.*, 2019). It suppose that the probability of recheck strategy adopted by government departments and the sampling ratio is p_1 and r, respectively. The probability of carbon emission enterprises taking collusion strategy with third-party verification institution is p_2, and the probability of being selected to recheck is r, the same as that of the competent government departments. Accordingly, the returns matrix of the tripartite game between competent government department, carbon emission enterprises and third-party verification institution is shown in Table 1.

Table 1. Returns matrix of the tripartite game

	Review(p_1)		No double-check ($1-p_1$)
	Be selected (r)	Not be selected ($1-r$)	
Collusion (P_2)	($C_1+C_2-rC_0$, $E_1+\triangle E_1-C_1$, $E_2+\triangle E_2-C_2$)	($-rC_0$, $E_1+\triangle E_1$, $E_2+\triangle E_2$)	(0, $E_1+\triangle E_1$, $E_2+\triangle E_2$)
No Collusion ($1-P_2$)	($-rC_0$, E_1, E_2)	($-rC_0$, E_1, E_2)	(0, E_1, E_2)

(1) The Nash equilibrium solving of competent government department.

The expected revenue of the competent government department can be expressed as:

$$U_1 = p_1p_2r(C_1+C_2-rC_0) - p_1p_2(1-r)rC_0 \\ -p_1(1-p_2)r(rC_0) - p_1(1-p_2)(1-r)(rC_0) \quad (1)$$

If the competent government departments maintains the continuous recheck strategy, that the p_1=1, then:

$$U_1 = p_2r(C_1+C_2-rC_0) - p_2(1-r)rC_0 \\ -(1-p_2)r(rC_0) - (1-p_2)(1-r)(rC_0) \quad (2)$$

The Nash equilibrium point is the critical point for selecting the recheck strategy, indicating that the expected return is the same no matter whether the recheck strategy is adopted at this point. That means the first-order condition of the equilibrium point is satisfied as: $\frac{\partial U_1}{\partial r} = 0$, and the calculation gives following results.

$$p_2 = C_0/(C_1+C_2) \quad (3)$$

When the probability p_2 of collusion between third-party verification institution and carbon emission enterprises meets $p_2>C_0/(C_1+C_2)$, the competent government departments tend to take the rechecked strategy. When $p_2<C_0/(C_1+C_2)$, the non- rechecked strategy is preferred.

(2) The Nash equilibrium solving of carbon emission enterprises

The expected revenue of the carbon emission enterprises adopted collusion strategy can be expressed as follow:

$$U_2 = p_1p_2r(E_1+\Delta E_1-C_1) \\ +p_1p_2(1-r)(E_1+\Delta E_1) + (1-p_1)p_2(E_1+\Delta E_1) \quad (4)$$

The Nash equilibrium point of carbon emission enterprises is the critical point for selecting the collusion strategy, indicating that the expected return is the same no matter whether the collusion strategy is adopted at this point. That means the first-order condition of the equilibrium point is satisfied as: $\frac{\partial U_2}{\partial p_2} = 0$, and following results can be obtained.

$$\frac{\partial U_2}{\partial p_2} = p_1r(E_1+\Delta E_1-C_1) \\ +p_1(1-r)(E_1+\Delta E_1) + (1-p_1)(E_1+\Delta E_1) = 0 \quad (5)$$

The equilibrium solution can be expressed as:

$$p_1r = E_1+\Delta E_1/C_1 \quad (6)$$

Therefore, the carbon emission enterprises prefer to take the collusion strategy when $p_1r>E_1+\Delta E_1/C_1$. On the contrary, when $p_1r<E_1+\Delta E_1/C_1$, the collusion strategy will be more likely not to be used.

(2) The Nash equilibrium solving of third-party verification institution

The expected revenue of the third-party verification institution adopted collusion strategy can be expressed as follow:

$$U_3 = p_1p_2r(E_2+\Delta E_2-C_2) \\ +p_1p_2(1-r)(E_2+\Delta E_2) + (1-p_1)p_2(E_2+\Delta E_2) \quad (7)$$

The Nash equilibrium point of third-party verification institution is the critical point for selecting the collusion strategy, indicating that the expected return is the same no matter whether the collusion strategy is adopted at this point. That means the first-order condition of the equilibrium point is satisfied as: $\frac{\partial U_3}{\partial p_2} = 0$, and following results can be obtained.

$$\frac{\partial U_3}{\partial p_2} = p_1r(E_2+\Delta E_2-C_2) \\ +p_1(1-r)(E_2+\Delta E_2) + (1-p_1)(E_2+\Delta E_2) = 0 \quad (8)$$

The equilibrium solution can be expressed as:

$$p_1r = E_2+\Delta E_2/C_2 \quad (9)$$

Therefore, the carbon emission enterprises prefer to take the collusion strategy when $p_1r>E_2+\Delta E_2/C_2$. On the contrary, when $p_1r<E_2+\Delta E_2/C_2$, the collusion strategy will be more likely not to be used.

2.2. Game model and solution procedure of the secondary market of carbon emission rights

The trading of carbon emission rights in the secondary market is analyzed by using the game model of alternate bargaining. The buyer and the seller concluded the deal after n rounds of bargaining. The specific process is as follows, in the first round (n=1), the buyer makes an offer, if the seller accepts, the game is over, and if the seller refuses, it goes to the next round. In the second round (*n*=2), the seller makes an offer, if the buyer accepts, the game is over, and it goes to the third round (*n*=3) if the buyer does not accept. This cycle continues until the end of the n round. The discount factor (patience extent) of buyers and sellers is often determined by the total number of people on both sides. If the number of sellers and buyers is s and b, respectively, and we assume that the s and b remains the same throughout the bidding process. The greater proportion of sellers in the transaction is, the more patient the buyer is to bid. Therefore the discount factor for the buyer is $\delta_b=sb/(s+b)$, and similarly, the discount factor of the seller is $\delta_s=b/(s+b)$, in which the parameters meet the following conditions: $0<\delta_i<1$, $i=(b,s)$. The commodity value provided by the seller is c for the seller and v for the buyer. The seller and buyer bid P_s and P_b according to the value what they think the goods are worth, and each round of quotation satisfies the $P\in[P_s,P_b]$ relationship. The earnings of seller is $P–P_s$, and the additional earnings obtained by buyer is $P_b–P_s$, that is the additional earnings of $P_b–P_s$ will be distributed by the two sides. The allocation ratio of the buyer and seller is denoted as x_b and $1-x_b$, x_s and $1-x_s$ when the buyer and seller bid in turn, respectively.

When n= 2k, the buyer's optimal bid is:

$$P_{2K}(\delta_b,\delta_s,P_s,P_b)=\frac{(\delta_b\delta_s)^k-1}{\delta_b\delta_s-1}(1-\delta_s)(P_b-P_s) \tag{10}$$

$$\chi_{2k}(b,s,P_s,P_b)=\frac{b^k s^{k+1}-s(b+s)^{2k}}{bs(b+s)^{2k-1}-(b+s)^{2k+1}}(P_b-P_s) \tag{11}$$

When n= 2k+1, the buyer's optimal bid is:

$$\begin{aligned}&P_{2K+1}(\delta_b,\delta_s,P_s,P_b)\\&=\left[\frac{(\delta_b\delta_s)^k-1}{\delta_b\delta_s-1}(1-\delta_s)+(\delta_b\delta_s)^k\right](P_b-P_s)\end{aligned} \tag{12}$$

$$\begin{aligned}&\chi_{2k+1}(b,s,P_s,P_b)\\&=\left[\frac{b^k s^{k+1}-s(b+s)^{2k}}{bs(b+s)^{2k-1}-(b+s)^{2k+1}}+\frac{b^k s^k}{(b+s)^{2k}}\right](P_b-P_s)\end{aligned} \tag{13}$$

It can be seen that the factors affecting the equilibrium price include discount factor, game times and bid in the final game stage under the condition of limited bargaining times. In the process of carbon emission trading, the trading center stipulates that the buyer and seller shall determine the final transaction price through bargaining within a certain period of time. If the two sides fail to reach an agreement on the trading price through negotiation, they can choose to abandon the current round of trading and wait for the next round. Therefore, the bargaining process of carbon emission trading should be an indefinite game, what means the optimal bid of the buyer in the indefinite bargaining game can be obtained when k approaches infinity as follows.

$$P_\infty=\frac{1-\delta_s}{1-\delta_b\delta_s}(P_b-P_s) \tag{14}$$

Then the transaction price of two sides is:

$$P^*=P_b-P_\infty=\frac{\delta_s(1-\delta_b)}{1-\delta_b\delta_s}P_b+\frac{1-\delta_s}{1-\delta_b\delta_s}P_s \tag{15}$$

The P_∞ and P^* satisfy the following relationship: $P_\infty=\frac{1}{2}(P_b-P_s)$ and $P^*=\frac{1}{2}(P_b+P_s)$ when $\delta_b=\delta_s=1$. This indicates that the trading center generally matches the transaction price of $P=\frac{1}{2}(P_b+P_s)$ by matchmaking trading type in two-way open bidding. The precondition for this transaction price is that both the discount factor of buyer and seller are 1, what means they have enough patience and the numbers of buyer and seller tends to infinity. In reality, the number of two sides is limited, it is urgent for sellers to make a deal in order to sell the carbon emission quota that is about to expire and for buyers to fulfill the contract in order to buy the carbon emission quota. Therefore, the transaction price of $P=\frac{1}{2}(P_b+P_s)$ cannot fully accord with the real transaction intention of buyer and seller.

3. Results and discussion

3.1. Analysis on the three-party game of initial allocation of carbon emission rights

It can be seen from the equilibrium solution of competent government departments that the probability of adopting the review strategy is positively correlated with review cost paid and negatively correlated with administrative penalty intensity when the carbon emission enterprises and third-party verification institution adopting collusion strategy. The carbon emission enterprises and third-party verification institution believe that the lower review cost and the greater administrative penalty is, the greater probability of adopting the review strategy by competent government departments, and the smaller probability that they will adopt the collusion strategy. On the contrary, the higher review cost and the smaller administrative penalty is, the more likely they will adopt the collusion strategy because carbon emission enterprises and third-party verification institution will think that the competent government departments will prefer to adopt the no review strategy. In conclusion, the competent government departments should improve the review efficiency effectively to reduce cost. Specifically, the review work can be outsourced to universities, research institutes and other scientific research units, and at the same time, they should increase punishment for the collusion behavior between the carbon emission enterprises and third-party verification institution.

From the equilibrium solution of carbon emission enterprises and third-party verification institution, it can be seen that the greater benefits brought by the collusion strategy of false reporting of carbon emissions and the smaller penalty for collusion behavior is, the greater product of the probability of adopting the review strategy by competent government departments and sample proportion of review. If the competent government department always adopts the review strategy, namely the p_1=1, the sample proportion is positively correlated with the additional benefit brought by conspiracy to falsify carbon emission and negatively correlated with the penalty intensity for collusion. At present, free allocation of carbon emission rights can basically meet the needs of carbon emission enterprises. As the carbon trading system continues to improve, the collusion strategy will bring more additional revenue. The proportion of is inversely proportional to the severity of punishment. The proportion of review is inversely proportional to the additional revenue. The greater the government's punishment for the collusion strategy, the smaller the proportion and cost of review sampling. Therefore, except to the fixed fine for the collusion strategy, the most effective countermeasure for competent government departments is to impose additional fine that is several times the revenue obtained by the collusion strategy, which can largely avoid the occurrence of the collusion strategy and reduce the compound cost.

3.2. Analysis on the game of secondary market of carbon emission rights

In the process of bilateral open bidding, the time cost of negotiating the transaction price between buyer and seller is high. The trading center can directly determine the transaction price by combining the number of buyers and sellers and quantity of carbon emission, but not simply take the arithmetic average of bidders as the transaction price. At the same time, the trading center can determine the two sides that meet certain conditions to complete the compulsory transaction according to the forces of buyer and seller. This form can eliminate the process of seeking confirmation from both sides.

If the buyer and seller take turns to bid and determine the transaction price in the bilateral open bidding process, the equilibrium transaction price can be expressed as follow.

$$P^* = \frac{\delta_s(1-\delta_b)}{1-\delta_s\delta_b}P_b + \frac{1-\delta_s}{1-\delta_s\delta_b}P_s \tag{16}$$

4. Conclusions

China's carbon emission trading market needs to development and improvement focus on the following aspects. Firstly, China should vigorously support and build third-party verification institution to realize the rapid development and specialization of entire industry. It is necessary to strengthen the professional training on operational skills of the personnel carbon emission verification that reducing the verification costs of carbon emission industry effectively. Secondly, the competent government departments should establish a regular mechanism to review the carbon emission reports submitted by carbon emitting enterprises and strictly prevent third-party verification institution from colluding with carbon emitting enterprises. A strict punishment mechanism for discovered collusion should be established, combining punishment with unlawful act. The competent government departments can establish long-term cooperation with universities, research institutes and other research institutions, and outsource the review work to improve the review efficiency. Thirdly, in order to improve the transaction efficiency, the trading center should directly determine the transaction price in combination with the forces of the buyers and sellers, and select the qualified buyers and sellers to make transactions directly at the secondary carbon trading market in process of bilateral open bidding.

References

Bernard A., Haurie A., Vielle M., Vielle M. and Viguier L. (2008). A two-level dynamic game of carbon emission trading between Russia, China, and Annex B countries, *Journal of Economic Dynamics & Control*, **32**, 1830–1856.

Chen Y.F., Wang Y.Q., Cao Y.W., Zeng M., Zhu B. and Hou X.Z. (2019). Research on the business model of electric vehicle charging facility construction project participating in carbon trading market, *Materials Science and Engineering,* **612**, 042020.

Chen Y.H., Jiang P., Dong W.B. and Huang B.J. (2015). Analysis on the carbon trading approach in promoting sustainable buildings in China, *Renewable Energy,* **84**, 130–137.

Fang G.C., Tian L.X., Liu M.H., Fu M. and Sun M. (2018). How to optimize the development of carbon trading in China-Enlightenment from evolution rules of the EU carbon price, *Applied Energy,* **211**, 1039–1049.

Gong J. and Zhou J. (2019). The current situation and correlation analysis of the new energy industry in Chinese carbon trading market. *2019 IEEE Asia Power and Energy Engineering Conference,* 341–-346.

Guo C.F., Li X.J. and Lan H.J. (2018). The equilibrium model of dual channel closed-loop supply chain network based on carbon trading and carbon tax, *International Journal of Internet Manufacturing and Services,* **5**(1), 1–21.

Han R., Yu B.Y., Tang B.J., Liao H. and Wei Y.M. (2017). Carbon emissions quotas in the Chinese road transport sector: A carbon trading perspective, *Energy Policy,* **106**, 298–309.

Hu Y.J., Li X.Y. and Tang B.J. (2017). Assessing the operational performance and maturity of the carbon trading pilot program: The case study of Beijing's carbon market, *Journal of Cleaner Production,* **16**, 1263–1274.

Huang Y.S., Hu J.J., Yang Y.Q., Yang L. and Liu S.J. (2020). A low-carbon generation expansion planning model considering carbon trading and green certificate transaction mechanisms, *Polish Journal of Environmental Studies,* **29**, 1169–1183.

Jin J.L., Zhou P., Li C.Y., Guo X.J. and Zhang M.M. (2019). Low-carbon power dispatch with wind power based on carbon trading mechanism, *Energy,* **170**, 250–260.

Kanchinadham S.B.K. and Kalyanaraman C. (2017). Carbon trading opportunities from tannery solid waste: a case study, *Clean Technologies and Environmental Policy,* **19**, 1247–1253.

Li H. and Lei M. (2018). The influencing factors of China carbon price: a study based on carbon trading market in Hubei province, *IOP Conference Series: Earth and Environmental Science,* **121**, 052073.

Li L.X., Ye F., Li Y.N. and Chang C.T. (2019). How will the Chinese Certified Emission Reduction scheme save cost for the national carbon trading system?, *Journal of Environmental Management,* **244**, 99–109.

Li Y., Fan J., Zhao D.T., Wu Y.R. and Li J. (2016). Tiered gasoline pricing: A personal carbon trading perspective, *Energy Policy,* 89, 194–201.

Lin W., Jin X.L., Mu Y.F., Jia H.J., Yu X.D., Pu T.J. and Chen N.S. (2019). Game-theory based trading analysis between distribution network operator and multi-microgrids, *Energy Procedia,* **158**, 3387–3392.

Liu X.Y. and Cui Q.B. (2018). Value of performance baseline in voluntary carbon trading under uncertainty, *Energy,* **145**, 468–476.

Manuel G., Chávez Á. and Mpaid S. (2016). Cooperation and the carbon trading game: A system dynamics approach to the prisoner's dilemma, *International Journal of Game Theory and Technology,* **2**, 9–23.

Munnings C., Morgenstern R.D., Wang Z.M. and Liu X. (2016). Assessing the design of three carbon trading pilot programs in China, *Energy Policy,* **96**, 688–699.

Nath A.J., Lal R. and Das A.K. (2015). Managing woody bamboos for carbon farming and carbon trading, *Global Ecology and Conservation,* **3**, 654–663.

Pan Y.T., Zhang X.S., Wang Y. and Yan J.H. (2019). Application of blockchain in carbon trading, *Energy Procedia,* **158**, 4286–4291.

Qu K.P., Yu T., Huang L.N., Yang B. and Zhang X.S. (2018). Decentralized optimal multi-energy flow of large-scale integrated energy systems in a carbon trading market, *Energy,* **149**, 779–791.

Shan S., Genc S.Y., Kamran H.W. and Dinca G. (2021). Role of green technology innovation and renewable energy in carbon neutrality: A sustainable investigation from Turkey, *Journal of Environmental Management,* **294**, 113004.

Tan D., Gao S. and Komal B. (2020). Impact of carbon emission trading system participation and level of internal control on quality of carbon emission disclosures: insights from Chinese state-owned electricity companies, *Sustainability,* **12**, 1788.

Tan X.P. and Wang X.Y. (2017). The market performance of carbon trading in China: A theoretical framework of structure-conduct-performance, *Journal of Cleaner Production,* **159**, 410–424.

Wang M., Zhao L.D. and Hergy M. (2018). Modelling carbon trading and refrigerated logistics services within a fresh food supply chain under carbon cap-and-trade regulation, *International Journal of Production Research,* **56**(12), 4207–4225.

Wang M., Zhao L.D. and Hergy M. (2019). Joint replenishment and carbon trading in fresh food supply chains, *European Journal of Operational Research,* **277**, 561–573.

Wang Q. and Wu S.T. (2018). Carbon trading thickness and market efficiency in a socialist market economy, *Chinese Journal of Population Resources and Environment,* **16**(2), 109–119.

Wang Z.X., Zhao J. and Li M. (2017). Analysis and optimization of carbon trading mechanism for renewable energy application in buildings, *Renewable and Sustainable Energy Reviews,* **73**, 435-451.

Weng Q.Q. and Xu H. (2018). A review of China's carbon trading market. *Renewable and Sustainable Energy Reviews,* **91**, 613–619.

Woo C.K., Chen Y., Olson A., Moore J., Schlag N., Ong A. and Ho T. (2017)., Electricity price behavior and carbon trading: New evidence from California, *Applied Energy,* **204**, 531–543.

Xia Y. and Tang Z.P. (2017). The impacts of emissions accounting methods on an imperfect competitive carbon trading market, *Energy,* **119**, 67–76.

Yang S.T., Chen Q., Yu J., Geng J., Du H.W., Jin Z.Q. and Zeng W. (2019)., Distributed generation low-carbon trading strategy based on cooperative game nucleolus method, *2019 IEEE Innovative Smart Grid Technologies-Asia,* 1369–1374.

Yu Z.J., Geng Y., Dai H.C., Wu R., Liu Z.Q., Xu T. and Bleischwitz R. (2018). A general equilibrium analysis on the impacts of regional and sectoral emission allowance allocation at carbon trading market, *Journal of Cleaner Production,* **192**, 421–432.

Zhang D., Alhorr Y., Elsarrag E., Marafia A.H., Lettieri P. and Papageorgiou L.G. (2017). Fair design of CCS infrastructure for power plants in Qatar undercarbon trading scheme, *International Journal of Greenhouse Gas Control,* **56**, 43–54.

Zhao T.Y., Choo F.H., Zhang L.Q. and Gu Y. (2017). Game theory based distributed energy trading for microgrids parks, *2017 Asian Conference: Energy, Power and Transportation Electrification,* 8168563.

Zheng T.L., Wang Z., Liu S.H., Bao X., Liu Z.C. and Ji M.X. (2021). The development trend and prospect of automobile energysaving standard system under the goal of peak carbon dioxide emissions, *E3S Web of Conferences,* **271**, 02006.

Zhou J.P., Xiong S.Q., Zhou Y.C., Zou Z.J. and Ma X.M. (2017). Research on the development of green finance in Shenzhen to boost the carbon trading market, *IOP Conference Series: Earth and Environmental Science,* **81**, 012073.

Zhu B.Z., Zhang M.F., Huang L.Q., Wang P., Su B. and Wei Y.M. (2020). Exploring the effect of carbon trading mechanism on China's green development efficiency: A novel integrated approach, *Energy Economics,* **85**, 104601.

Zhu C.Z., Wang M. and Du W.B. (2020). Prediction on peak values of carbon dioxide emissions from the chinese transportation industry based on the SVR model and scenario analysis, *Journal of Advanced Transportation,* 8848149.