

Supply Chain Carbon Emissions Reduction

Subjects: Operations Research & Management Science

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While carbon emissions reduction brings about environmental benefits, it can also create financial pressure on many manufacturing enterprises. Many manufacturing enterprises have begun to pledge their own carbon emissions right quotas for financing and the funds from this financing are being used to implement energy savings and emissions reduction strategies. Methods for reducing the carbon emissions that are produced in supply chains and ensuring the sustainability of society have attracted the attention of the world. In fact, to decrease carbon emissions, countries have formulated many policies that are related to carbon emissions reduction.

Keywords: carbon emissions reduction ; financing ; power structures ; carbon quota

1. Introduction

With the development of the economy and society, carbon emissions from energy consumption are considered to be one of the important causes of climate change and environmental deterioration ^[1]. It is clear that carbon emissions are causing irreversible damage to the climate. In supply chains, the production processes of upstream enterprises inevitably produce carbon emissions. In addition, logistics and other parts of supply chains also produce some carbon emissions that cause environmental pollution ^{[2][3]}. Methods for reducing the carbon emissions that are produced in supply chains and ensuring the sustainability of society have attracted the attention of the world. In fact, to decrease carbon emissions, countries have formulated many policies that are related to carbon emissions reduction. The cap-and-trade system is considered to be one of the most effective market mechanisms for reducing carbon emissions ^[4]. The cap-and-trade system first appeared in the Kyoto Protocol, which came into effect in 2005. The Kyoto Protocol stipulated that each party's carbon emissions should not exceed the allocated carbon quota but also allowed those carbon quotas to be traded among the parties (<http://baike.baidu.com/view/41423.htm>, accessed on 4 June 2022). The cap-and-trade system generally operates within carbon trading systems. There are currently 24 carbon trading systems in place around the world, with 22 countries and regions considering or actively developing carbon trading systems (http://www.tanpaifang.com/tanjaoyi/2021/0428/77660_3.html, accessed on 4 June 2022).

It is known that the traceability of products within supply chains is becoming an increasingly urgent requirement that makes it easier for consumers to see the carbon emission levels of products ^{[5][6]}. With the increase in the consumer awareness of environmental sustainability, low-carbon products have become more popular ^[7]. Therefore, manufacturers and retailers are willing to participate in low-carbon supply chains. More than 300 enterprises have joined The Climate Pledge, which was co-founded by Amazon and Global Optimism, to actively implement carbon reduction actions (<http://www.cb.com.cn/index/show/gd/cv/cv1361573801490>, accessed on 4 June 2022). Theoretical studies have shown that investments in carbon emissions reduction technologies can help enterprises to better accomplish the task of carbon emissions reduction ^[8]. For example, the application of mixed ammonia combustion technology in coal-fired boilers can greatly reduce the carbon emissions from coal-fired units (<http://gs.people.com.cn/n2/2022/0124/c183342-35109146.html>, accessed on 4 June 2022). However, the application of new technologies often faces unforeseen challenges, so it is also important to investigate whether carbon emissions reduction technologies can be well translated into practice ^[9].

However, due to the lack of funds that are being invested in carbon reduction technologies, some enterprises have difficulty in reducing their carbon emissions. To solve this problem, commercial banks have begun to provide loans for enterprises that are specifically for reducing carbon emissions. Financing for carbon emissions reduction can effectively restrain the carbon emissions from supply chains ^[10]. However, in traditional financing modes, carbon emissions constraints are usually treated as negative factors for enterprise operation ^[11]. To enhance the enthusiasm of enterprises and supply chains for carbon emissions reduction, enterprises can pledge their carbon emissions right to borrow from the bank ^[12]. For example, in 2014, the Hubei Yihua Group borrowed CNY 40 million in loans from the Industrial Bank by pledging its carbon emissions rights to implement energy savings and emissions reduction strategies (<http://www.tanpaifang.com/tanguwen/2020/0704/72142.html>, accessed on 4 June 2022). In 2021, a state-owned

enterprise used its surplus carbon emissions rights as a pledge and obtained a loan of CNY 36.52 million, according to the market value of carbon quotas (https://www.zj.gov.cn/art/2021/10/31/art_1554467_59131862.html, accessed on 4 June 2022). Theoretical studies have also shown that when carbon emissions permits become a factor in financial and operational decisions, supply chain performance and sustainability can be significantly improved ^[11]. However, it is still unclear how the financing mechanisms in carbon pledge financing affect the different parts of supply chains and how many carbon permits manufacturers are willing to pledge for financing.

Moreover, the existing practices and literature have shown that power structures have a great influence on the operation and carbon emissions reduction decisions of supply chains ^[13]. In general, upstream companies are more likely to be Stackelberg leaders in supply chains. The large automobile manufacturing company BYD announced that it would stop the production of fuel vehicles from March 2022 and start to focus on the production of new energy vehicles (<http://www.tanpaifang.com/tanguwen/2022/0405/84462.html>, accessed on 4 June 2022). This decision is bound to have certain impacts on the strategies and interests of the other supply chain members. In addition, some large retailers may also become supply chain leaders, such as Wal-Mart and Amazon. Most of Wal-Mart's carbon emissions are produced by its supply chain. To reduce the impact of its business on the environment, Wal-Mart has urged suppliers to seek ways to reduce their carbon emissions from energy and product design (<http://www.tanpaifang.com/tanguwen/2020/0907/73747.html>, accessed on 4 June 2022). A large number of researchers have studied the influence of power structures on supply chain pricing and performance and have found that the pricing decisions and profits of supply chain members are different in different power structures ^[14]. With the development of more sustainable practices, scholars have begun to study the influence of different power structures on carbon emissions reduction in supply chains ^[15]. However, when the carbon emissions reduction levels of manufacturers are constrained by capital, it is unknown whether the power structures of supply chains affect manufacturer decisions on financing and carbon emissions reduction.

2. Supply Chain Carbon Emissions Reduction

With the development of low-carbon economies, the carbon emissions reduction levels of enterprises are no longer only related to the enterprises themselves but also affect the development and interests of whole supply chains. Low-carbon supply chains pay more attention to their sustainability and strive to balance economic, social and environmental issues from a microeconomic perspective ^[16]. In low-carbon supply chains, consumers are often considered to have low-carbon preferences. Du et al. ^[7] studied the influence of the low-carbon preferences of consumers on low-carbon supply chains and found that emissions reduction not only incurred higher production costs but also stimulated the reverse demand function. Xia et al. ^[17] took into account the behavioral factors of supply chain members and studied the influences of reciprocity preferences and the low-carbon consciousness of consumers on supply chain pricing and carbon emissions reduction decisions. Wang et al. ^[1] found that a green reputation is closely related to emissions reduction. As a result, supply chain members can enhance their reputation by undertaking emissions reduction activities, which in turn increase the demand for low-carbon products. Since investing in carbon emissions reduction technologies can improve the emissions reduction efficiency of supply chains, Ma et al. ^[18] studied sustainable supply chain management under the influence of investments in green technology and government interventions. Their results showed that higher emissions reduction subsidies encouraged more investments in green emissions reduction technologies. Based on the above research, this entry considered the low-carbon preferences of consumers and investments in carbon emissions reduction technologies. In addition, many other factors in supply chains can also affect their carbon emissions reduction levels. Yang et al. ^[19] considered two competitive supply chains and studied the vertical cooperation for emissions reduction within a single supply chain and the horizontal cooperation between two manufacturers in two supply chains. Their results showed that vertical cooperation could improve carbon emissions reduction rates while horizontal cooperation between manufacturers could harm retailer profits and consumer welfare. Xu et al. ^[20] studied energy conservation and emissions reduction in closed-loop supply chains by considering the factors of uncertain demand and carbon prices. Yu et al. ^[21] studied the impact of information sharing on carbon emissions reduction in supply chains. Their study found that information sharing was beneficial to suppliers but unfavorable to retailers and that sharing information on demand significantly reduced emissions from producing unwanted products. Bai et al. ^[22] and Daryanto et al. ^[23] studied the influence of carbon emissions reduction on supply chains with vendor-managed inventories for dealing with deteriorated goods. Zhang et al. ^[24] studied the influence of different carbon quota allocation rules on product prices, carbon emissions reduction and profit distribution within supply chains.

The above literature on carbon emissions reduction in supply chains has not considered the problem of the financial constraints of supply chain members. In fact, enterprises in supply chains often face situations involving difficult turnovers or a lack of capital. Moreover, supply chains also need a large amount of funds to achieve reductions in their carbon

emissions, which also increases financial pressure on supply chain members. Therefore, it is of great significance to analyze the carbon emissions reduction levels of supply chains that are under capital constraints. In addition, the above literature has only analyzed low-carbon supply chains from the perspective of investments in carbon emissions reduction technologies. In this entry, the effects of technology development after investments in carbon emissions reduction are taken into account, which could better explore the whole process of investing in carbon emissions reduction technologies and technology development.

3. Supply Chain Financing

3.1. Traditional Financing Model

Within the research field that is related to supply chain financing, most of the previous literature has found that supply chain members increase their outputs using financing and thus, increase their own profits and those of the whole supply chain. For example, Chen et al. [25] studied the impacts of buyback guarantee financing and fairness concerns on the performance of supply chains. Due to the diverse range of financing methods, comparative research on financing methods has also been favored by scholars. Ding et al. [26] studied advance payment financing and bank loan financing under capital constraints for supply chains with uncertain outputs and proposed a loan repayment contract that could coordinate supply chains. In addition to single financing strategies, mixed financing models and cooperation between supply chain members have also been gradually taken into consideration by scholars. Jin et al. [27] compared the advantages and disadvantages of cooperative and non-cooperative financing strategies when both suppliers and retailers had financial problems. Their study showed that cooperative financing strategies were more desirable for suppliers and supply chains but retailers preferred non-cooperative strategies. Fang et al. [28] compared the optimal decisions of green supply chains for green credit financing and mixed financing and presented the best applicable scenarios for the different financing methods.

3.2. Financing for Carbon Emissions Reduction

In order to ensure the sustainable development of supply chains, the members of low-carbon supply chains also use financing funds to invest in carbon emissions reduction technologies. An et al. [10] developed a supply chain model that used financing funds to invest in production and green improvements. They found that both green credit financing and trade credit financing could effectively curb the carbon emissions of enterprises. Lu et al. [29] considered two financing strategies for manufacturers that invested in carbon emissions reduction using external financing. Their study showed that manufacturers were more willing to invest in carbon emissions reduction technologies than purchase carbon quotas. Cong et al. [30] analyzed the impacts of green finance mechanisms, cap-and-trade mechanisms and output uncertainty on the carbon emissions reduction decisions of manufacturers that had limited capital. Qin et al. [31] studied the influence of advance payment financing on carbon emissions reduction and supply chain production. Their results showed that mixed financing could encourage manufacturers to increase their carbon emissions reduction levels even more. Cao and Yu [32] studied trade credit financing in emissions-dependent supply chains and found that caps on carbon emissions only had an impact on the optimal order quantities in decentralized supply chains. Subsequently, Cao et al. [33] discussed supply chain financing modes following investments in carbon emissions reduction and found that manufacturer profits decreased when they invested in carbon emissions reduction while the profits of suppliers and supply chains increased. Therefore, investments in carbon emissions reduction strategies are necessary for emissions-dependent supply chains that have limited capital.

3.3. Supply Chain Carbon Financing

Although supply chain financing can solve the problem of insufficient funds for carbon emissions reduction strategies, it cannot effectively revitalize the carbon assets of enterprises. To help enterprises to revitalize their carbon assets, scholars have found that supply chain members use carbon assets for financing. For example, Wang et al. [34] considered the financing methods of manufacturers using the Carbon Emissions Permits Repurchase Strategy (CEPRS) and studied the production decisions of manufacturers for normal products and remanufactured products on this basis. Wang et al. [35] found that under carbon emissions trading mechanisms, carbon credit repurchase policies could help manufacturers to obtain more loans for production activities, thus improving their production quantity and total profit. Cao et al. [11] found that when carbon emissions permits were allowed to be part of financial and operational decisions, the performance and sustainability of supply chains could be significantly improved. Moreover, it has been found that manufacturers that have limited capital can obtain financing by pledging carbon emissions permits to reduce their carbon emissions. Yang et al. [36] combined carbon financing and supply chain financing to analyze the impact of supply chain carbon financing (SCCF) on supply chain cooperation and carbon emissions reduction. The SCCF model pledged the overall carbon quotas of supply

chains to banks for financing and the results showed that the carbon emissions reduction levels that were produced by SCCF were significantly higher than those of traditional carbon financing models. Chen et al. [37] also showed that loans that were based on emissions rights produced significant social and environmental benefits.

Although there have been some studies on the use of carbon assets for supply chain financing, there have been few studies on carbon emissions right pledge financing. Moreover, the previous research models have not highlighted the inherent logic of carbon emissions pledge financing. Therefore, this entry investigated carbon emissions pledge financing in low-carbon supply chains. Researchers analyzed the impact of carbon emissions pledge financing on the operation and decision-making of low-carbon supply chains, thus enriching the literature within the field of supply chain financing.

4. Supply Chain Power Structures

When the power structures of supply chains begin to change, it usually leads to changes in optimal decisions and profits. The studies of Wang et al. [38] and Li et al. [39] showed that dominant supply chain members always benefited and that whole supply chains gained the most profits in the Nash model. By studying the influence of power structures on the CSR of supply chains, Liu et al. [40] found that CSR efforts were the highest in the Nash model. In addition, the influence of power structures on sustainable development and carbon emissions reduction has also been considered by scholars. Chen et al. [41] found that the power structures of supply chains could affect the design of optimal carbon emissions taxes and that appropriate channel leadership was necessary to achieve sustainable development goals. Chen et al. [42] studied the pricing and carbon emissions reduction decisions of two-echelon supply chains in different power structures. Their study showed that carbon emissions were the lowest in the Nash power structure and the highest in manufacturer-led power structures. Zhang et al. [8] studied the low-carbon strategies that were chosen by manufacturers in different power structures and found that imbalanced power structures were conducive to reducing carbon emissions. They concluded that governments should advocate for manufacturers to adopt green technologies to reduce emissions in imbalanced power structures. Ji et al. [15] constructed single emissions reduction models and cooperative emissions reduction models in different power structures and found that supply chain profits were higher under manufacturer leadership but when unit carbon prices increased, retailer leadership had better effects on improving the profits and low carbon levels of supply chains than manufacturer leadership. However, Jiang et al. [43] explored prefabricated building supply chain models in different power structures and carbon cap-and-trade systems and found that supply chain pricing was different in different power structures but it had no influence on carbon emissions reduction decisions. Compared to supply chain pricing and carbon emissions reduction strategies, there has been little research on the influence of power structures on supply chain financing. Tang et al. [44] studied the optimal emissions reduction and pricing decisions of supply chains in two power structures and under the capital constraints of manufacturers and analyzed financing mechanisms in the different power structures. They found that the power structure had no influence on the choice of financing mechanism among retailers.

However, few of the previous studies have combined power structures with supply chain capital constraints. In fact, the members of supply chains often face financial problems. Therefore, this entry considered a manufacturer that was constrained by a lack of funds for carbon emissions reduction. On this basis, researchers investigated the influence of different power structures on the optimal decisions of supply chains. **Table 1** shows the differences between researchers' model and previous studies.

Table 1. The differences between researchers' model and those from previous studies.

Author(s)	Carbon Emissions Reduction	Power Structures	Capital Constraints	Financing Mode	
				Carbon Pledge Financing	Other
Du et al. (2015) [7]	P	P			
Ma et al. (2021) [18]	P				
Fang et al. (2020) [28]			P		P
Cong et al. (2020) [30]	P		P		P
Cao and Yu (2019) [11]	P		P	P	
Chen et al. (2021) [37]	P		P	P	

Author(s)	Carbon Emissions Reduction	Power Structures	Capital Constraints	Financing Mode	
				Carbon Pledge Financing	Other
Yang et al. (2018) ^[36]	P		P	P	P
Liu et al. (2021) ^[40]		P			
Ji et al. (2022) ^[45]	P	P			
Tang et al. (2020) ^[44]	P	P	P		P
Researchers' model	P	P	P	P	

In conclusion, it can be seen from the above literature review that there has been some progress made within the fields of supply chain carbon emissions reduction, supply chain financing and supply chain power structures. However, there have been few studies on carbon emissions reduction in supply chains that are under the influence of capital constraints and power structures. Moreover, there has been especially little literature on the financing methods of carbon emissions right pledge financing. Therefore, this entry constructed a two-echelon low-carbon supply chain, which was composed of a manufacturer and a retailer. Researchers developed a model for carbon emissions pledge financing in low-carbon supply chains that have capital constraints and considered three different supply chain power structures. On this basis, researchers analyzed the optimal pricing, profitability and carbon emissions reduction decisions of low-carbon supply chains.

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