Emission Reduction Decisions in Blockchain-Enabled Low-Carbon Supply Chains

Subjects: Mathematics, Applied

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With the rapid development of the global economy, carbon emissions are increasing year by year. The continuous promotion of low-carbon policies has led to a gradual increase in consumers' carbon perception sensitivity and environmental awareness. With the increasing maturity of blockchain technology, its distributed database technology realizes the transparency and traceability of the carbon emission reduction process, which effectively enhances consumers' trust in low-carbon products.

Keywords: power structures ; blockchain ; low-carbon supply chain ; carbon emission reduction

1. Introduction

With the rapid development of the global economy, carbon emissions are increasing year by year [1]. According to research data from the Global Carbon Project (GCP), carbon emissions will reach a new high by 2023 and grow by more than 1.1%, while the average growth rate in the past decade has been 0.5% per year. Many studies have confirmed that carbon emissions are a main cause of global warming [2][3]. Excessive emission of greenhouse gases has led to rapid changes in the global climate, which has not only caused serious damage to the ecological environment, but also brought great challenges to the survival and development of mankind. As a management model that aims to reduce carbon emissions in the whole supply chain process, a low-carbon supply chain is of great significance in improving the ecological environment and coping with climate change. However, with the complexity and asymmetry of low-carbon supply chain structures, consumer trust in low-carbon products is reduced. Uniform carbon emission standards and regulatory mechanisms have not been established globally, and standards differ in different countries and regions. This makes it difficult for enterprises to choose partners and formulate emission reduction strategies, and it also increases the implementation costs of carbon emission reduction [4]. The promotion of related technologies such as the Internet of Things (IoT), blockchain, and the circular economy has brought new opportunities for low-carbon supply chains. For example, IoT technology is used to monitor operational processes to reduce energy consumption and carbon emissions. Blockchain technology can improve the transparency and traceability of the production process and enhance consumers' trust in low-carbon products. The circular economy model promotes the recycling of resources and reduces the generation and emission of waste. In addition, through financial support, tax relief, and the establishment of carbon emission trading markets and other measures, the government encourages and supports enterprises to adopt advanced technologies to build a green and low-carbon development system, strictly control the total carbon emissions in their products, and gradually transform to clean and low-carbon.

The continuous promotion of low-carbon policies has led to a gradual increase in consumers' carbon perception sensitivity and environmental awareness. This not only improves their understanding of carbon emissions but also affects their purchase decisions. In order to meet consumers' needs, enterprises use low-carbon technologies to increase the carbon emission reduction in products and produce green and low-carbon products [5]. For example, Hesteel Group utilizes hydrogen technology to help green development in the iron and steel industry, as well as to build a green and low-carbon special steel producer. Volkswagen cooperates with Nippon to adopt cured tin-free electrophoretic coatings to improve the green and low-carbon environmental performance in products and to promote the development in both parties towards green circulation and synergy.

In the trend of current environmental protection, not only are manufacturers actively engaged in the research and development of low-carbon products, but retailers are also involved in the sales process of low-carbon products. With the application of big data technologies, retailers have access to more market information, which makes their position in the supply chain competition change significantly. Retailers hope that low-carbon products can bring them more benefits, while manufacturers need to balance the relationship between the costs and benefits of carbon emission reduction to

make decisions. However, due to the differences in the information held by enterprises, the status and discourse power of enterprises in decision-making is obviously different [5]. This asymmetry in power structures has an important impact on the operational efficiency and emission reduction in low-carbon supply chains.

Considering information asymmetry and opaque production processes, it may be difficult for consumers to distinguish the differences between low-carbon and high-carbon products when making purchases, thus affecting their willingness to purchase. With the increasing maturity of blockchain technology, its distributed database technology realizes the transparency and traceability of the carbon emission reduction process, which effectively enhances consumers' trust in low-carbon products [6]. Manufacturers adopt blockchain to record the carbon emission information of their products, and they utilize the tamper-proof characteristics of blockchain technology to transfer the emission reduction information to consumers to help them make purchase decisions for low-carbon products. For example, characteristic agricultural products such as West Lake Longjing and the Dangshan Crispy Pear use blockchain technology to accurately track and predict their carbon footprint so as to manage carbon emissions effectively [7]. Therefore, it is of great practical significance for the sustainable development of low-carbon economies to study the emission reduction decisions of supply chain enterprises under different power structures, as well as how blockchain technology empowers decision optimization for the sustainable development of low-carbon economies.

Although the development of blockchain technology has achieved remarkable results, its application areas are yet to be explored [8]. Especially in the current context of increasingly serious global environmental problems, how to utilize blockchain technology to promote the practice of supply chain emission reduction has become an important research direction. In addition, unequal power structures exacerbate the complexity of low-carbon supply chain management decisions.

2. Carbon Emission Reduction Strategies

In recent years, the environmental awareness of consumers has gradually increased, and more and more people have begun to pay attention to the environmental performance of products and the social responsibility of enterprises. This forces supply chain enterprises to pay attention to environmental protection and sustainable development while pursuing economic benefits. Therefore, how to achieve carbon emission reduction under the premise of ensuring economic benefits has become an urgent problem for supply chain enterprises. At present, many scholars have studied carbon emission reduction strategies for supply chains from various perspectives, such as low-carbon policy [2][9][10][11], consumers' low-carbon preferences [12][13], and supply chain coordination mechanisms [14][15]. Wang et al. [2] used differential games to study the carbon emission reduction decisions of construction supply chains under government subsidies. The results showed that the government subsidy strategy could not only achieve the optimal carbon emission reduction in buildings, but it could also improve the market demand for low-carbon buildings. Wang et al. [9] investigated non-cooperative, cooperative, and contractual game scenarios under the constraints of carbon cap-and-trade rules and compared the carbon reduction efforts and optimal profits of supply chain members under the three scenarios. Fu et al. [10] showed that low-carbon enterprises were more likely to benefit from green technologies after the implementation of a carbon tax policy, and that green technologies can mitigate or even eliminate the asymmetry of initial emissions. Jauhari et al. [11] studied that under stochastic demand, the government used a carbon tax policy to regulate manufacturers, so that they could invest in green technology and reduce the total carbon emissions generated by the supply chain. Sun et al. [12] analyzed the relationship between consumers' preferences for low carbon and the timeliness of carbon emitting technologies on the carbon transfer behavior of manufacturers and suppliers. Yang and Xu [13] researched the impact of consumers' low carbon preferences on product production and carbon emission reduction decisions. Liu et al. [4] illustrated that under the low carbon preferences of consumers, the carbon emission reduction cost sharing strategy could improve the sales volume and profit of retailers, as well as enhance the cooperative relationship between supply chain enterprises. Yuan et al. [14] proposed a contract model combining option and cost allocation to realize the optimal carbon emission reduction and supply chain coordination under the circumstance of the low carbon preferences of consumers. In the existing research, researchers have found that consumers have a very high degree of trust in the carbon reduction in products. They believe that enterprises will take effective measures to reduce the carbon emissions in their products and thus have a positive impact on the environment. However, due to information asymmetry, consumers often only have access to limited product information, which makes it difficult for them to accurately judge the degree of carbon reduction in products. This leads to lower consumer trust in low-carbon products, which affects their purchasing decisions and weakens the market share of low-carbon products.

3. Power Structures in Supply Chains

The power structure in a supply chain reflects the status and discourse power of the enterprise, which has a significant impact on operational decision-making and performance [15][16]. Currently, the research on supply chain decision-making under different power structures has achieved obvious results. Luo et al. [17] studied the pricing strategy of vertically and horizontally competitive enterprises under different combinations of power structures. Yang et al. [18] compared the product pricing and purchasing decisions of retailers based on trust under different power structures. Yu et al. [19] discussed the role of different power structures on influencer marketing and found that consumer utility and social welfare are maximized when the power is equal. Li et al. [20] explored the impact of three different power structures on price adjustment and inventory decisions under stochastic demands. Chen et al. [21] studied the influence of manufacturers' and retailers' output uncertainty and corporate social responsibility on enterprises' optimal decisions under different market power structures.

The power structure not only directly affects the pricing strategy of products but also has a profound impact on the profit distribution of supply chain enterprises. More importantly, it also plays a crucial role in the emission reduction decisions of low-carbon supply chains. Meng et al. [22] analyzed the product selection strategies of two competing enterprises with different power structures under different carbon tax levels. Zhang et al. [23] studied the production and emission reduction decisions of manufacturers under three power structures in the supply chain, as well as the government's regulatory strategy on carbon emission allowances. Tang et al. [24] found that under different power structures, the early return of bank loans by manufacturers with limited funds was conducive to promoting carbon emissions and social welfare. Cao et al. [25] considered the choice of platform channels by traditional retailers under different power structures. Xu et al. [26] analyzed the influence of three power structures on low-carbon emission reduction and product pricing decisions for manufacturers with disappointment avoidance behavior. Huang et al. [27] investigated the government's carbon emission reduction target allocation decision under different supply chain power structures and discussed the impact of supply chain power structures on carbon emission reduction allocation decisions and social welfare. Cai et al. [28] used a differential game model to study the issues of carbon trading limits and trading systems under power structures and consumers' low-carbon preferences, and they analyzed the optimal pricing and carbon emission reduction decisions of supply chain members. Gong et al. [29] investigated the selection of low-carbon strategies and live marketing models for supply chains under two power structures. The above literature adequately considers the differences in power structures between enterprises and analyzes the influence of different power structures on enterprise decision-making. However, with the promotion of blockchain technology, more and more enterprises use it to coordinate the differences in power structures between enterprises, balance the profit distribution of enterprises, and improve energy conservation and emission reduction, so as to maximize the overall profits of the supply chain.

4. Application of Blockchain in Supply Chain Management

The emergence of blockchain technology provides an effective solution to solve the problem of information asymmetry in the traditional operation process. It uses the advantages of decentralization, traceability, and non-tampering to record and track product-related information, and it provides a unified platform for data sharing in all links of the supply chain. In recent years, with the increasing development and application of blockchain technology, more and more scholars have begun to pay attention to the value of blockchain technology in supply chain management. Blockchain technology not only improves the transparency of the supply chain [30], but it also realizes the information sharing among supply chain members [31]. Enterprises use blockchain technology to achieve product traceability [32][33], improve supply chain costs [34][35], and reduce their operational risks [36][37]. Hastig and Sodhi [30] investigated that implementing blockchain can enable supply chain traceability, which improves coordination among supply chain enterprises. Wang et al. [31] have pointed out that blockchain technology can optimize the risk control system of supply chain financing and reduce both enterprise costs and supply chain financing risks. Paulo et al. [32] analyzed that blockchain technology can save costs in the flower supply chain and improve product differentiation and freshness. Wu et al. [33] studied the relationship between the application of blockchain technology and consumers' awareness of traceability as well as traceability cost sharing. Wu and Yu [34] researched the impact of blockchain technology on platform supply chains from the perspective of information transparency and transaction costs. Qu et al. [35] aimed at the problems in enterprise financing and used blockchain technology to effectively improve the disadvantages of information asymmetry and increase the transparency of information, so as to solve the problem of financing difficulties. Liu et al. [36] studied that blockchain technology solves the trust problem between enterprises in the process of supply chain financing, reduces the operational risk, and improves the efficiency of financing. Tian and Hu [37] investigated the effect of blockchain technology on the pricing of gaming products and the level of platform effort with or without its implementation, finding that enterprises implement blockchain technology only when players have moderate or high price tolerance for their products.

In addition, for the information asymmetry characteristics of low-carbon products, scholars have carried out research on the impact of blockchain technology on green emission reduction. Yang et al. [8] investigated blockchain adoption and value-added service information sharing in a low-carbon supply chain. Lu and Liao [38] analyzed the effects of consumer blockchain acceptance and green uncertainty on product pricing, greenery decision-making, and supply chain members' profits in a green supply chain under three power structures. Li et al. [39] considered the premise of market uncertainty and risk to analyze the relationship between the risk attitude of supply chain enterprises and consumer surplus and social welfare. Xu et al. [40] investigated the impact of blockchain technology on low-carbon emission reduction inputs in the supply chain of a dual-channel platform. Zhang et al. [41] studied the incentive effects of two low-carbon product subsidy strategies adopted by the government on enterprises' low-carbon emission reduction with or without the implementation of blockchain. Li et al. [42] established a three-stage Stackelberg game model for the shipping supply chain consisting of the government, port authorities, and shipping companies, and explored the role of blockchain technology and low-carbon subsidies in the decision-making of each stakeholder. These research results have solved many practical problems for enterprises and improved the transparency and efficiency of supply chain management. However, most studies still focus on the discussion of single issues in supply chain management. When enterprises face the challenges of carbon emission reduction and unequal power status at the same time, the way in which blockchain technology affects their decision-making, and how they can deal with the unequal power of discourse for low-carbon emission reduction, have yet to be further studied.

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