Guest editorial: Smart supply chain management to achieve carbon neutrality: risk, challenges and opportunities

1. Introduction

According to statistics from the International Energy Agency, global energy-related carbon emissions reached over 36.8 billion tons in 2022, setting a new historical high. The interim report "State of the Climate in 2022" released by the World Meteorological Organization highlights the severe global warming problem caused by carbon emissions. Currently, climate change remains a global focus and major challenge. As global climate governance enters the comprehensive implementation stage of the Paris Agreement, countries around the world urgently need to implement and enhance their carbon reduction capabilities and strive to achieve global temperature control goals (Abokyi *et al.*, 2021). The United Nations Climate Summit held in Glasgow in 2021 reached consensus on key actions to address climate change (Cohen *et al.*, 2022; Depledge *et al.*, 2022). Many developed countries such as the United States, the United Kingdom, the European Union, Japan and Canada have pledged to achieve net zero emissions or carbon neutrality by 2050, while other developing countries such as China and India have also taken measures to achieve carbon neutrality or net zero emissions by 2060 and 2070, respectively. Therefore, how to promote the achievement of carbon neutrality goals should be an urgent research topic in contemporary academic circles.

Combating global carbon emissions and other greenhouse gas emissions requires significant innovation and transformation from product design to production methods (Dangelico, 2016; Romero and Gramkow, 2021). They also require active collaboration among upstream and downstream members of the supply chain to promote process optimization (Nurjanni *et al.*, 2017), technological upgrading (Saberi *et al.*, 2019) and product innovation (Dangelico, 2016). Hence, efforts at the supply chain level are particularly important for achieving carbon reduction goals. A current core focus concerns the impact of smart supply chains, especially in the Industry 4.0 era, which has attracted widespread attention from both industry and academia (Liu *et al.*, 2023d). Smart supply chains can be defined as self-organizing and self-optimizing systems that utilize advanced information technologies such as the Internet of things (IoT), blockchain, 3D printing, artificial intelligence (AI) and big data analysis (BDA). The smart supply chain provides unprecedented opportunities for achieving cost reduction and efficiency improvement. It will improve the operational efficiency of the entire supply chain and reduce carbon emissions by optimizing resource allocation.

However, it is controversial that the use of advanced technology in supply chain operations may cause an increase in carbon emissions and pose certain challenges to achieve carbon neutrality goals. In practical scenarios, in order to achieve higher operational efficiency, smart supply chains require the use of a large number of electronic devices and

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sensors. In order to ensure the safety and stability of device operations, managers usually need these devices and sensors to operate 24 h a day, which will consume more electricity and other resources (Rong *et al.*, 2016). Given the foregoing considerations, we discuss the topic of "Smart Supply Chain Management to Achieve Carbon Neutrality" from different perspectives such as risks, challenges and opportunities, and aim to furnish critical insights for promoting and accelerating low-carbon transformation of global supply chains.

2. Aims and scope of the special issue

Given the challenges and opportunities faced by smart supply chain management and development, this special issue (SI) seeks to engage scholars, practitioners and policy makers in articulating their perspectives on carbon neutrality in the strategy, technology and operational mechanisms of smart supply chains, especially on how smart supply chains can help achieve carbon neutrality.

In alignment with the interdisciplinary ethos of the *Industrial Management and Data Systems* (*IMDS*) journal, this SI aims to integrate operational management and information systems research, utilizing emerging digital and intelligent technologies of the Industry 4.0 era, to solve practical problems in the development of smart supply chains. These technologies include blockchain, additive manufacturing (AM/3D printing), BDA, AI, IoT, virtual reality (VR), cloud computing (CC), cyber physical system (CPS), among others. This SI encourages the use of various research methods such as industrial data and information system tools and mainly calls for papers related to the following topics: strategic design of smart supply chains (i.e. using emerging digital and intelligent technologies to achieve carbon neutrality), application and development of smart supply chain technology in carbon reduction, smart supply chain operation mechanism from a carbon neutrality perspective, carbon reduction strategies of smart supply chains and operation mechanism design, etc.

3. Accepted papers in this special issue

After multiple rounds of reviews by professional academic reviewers, associate editors and editors-in-chief, a total of 10 papers were ultimately selected for publication in this SI. The papers we have chosen mainly focus on four sub-areas: the impact of smart supply chain technology on green performance, operational mechanisms of smart supply chains from a carbon neutral perspective, the impact of policy factors on low-carbon supply chains in the context of carbon neutrality, and the low-carbon strategy and operational optimization of smart supply chains. Table 1 summarizes the selected papers from the aspects of research content, research methods and key contributions.

3.1 The impact of smart supply chain technology on green performance

Blockchain technology has the potential to improve information transparency of green products and promote consumer purchases. With the continuous rise of the platform economy and the continuous application of emerging technologies in the platform (Wei *et al.*, 2023), Xu *et al.* (2023a) study consumer preferences for overseas green products and the impact of blockchain technology implementation on supply chain performance. This study develops and analyzes four different models based on the manufacturer's selection of sales contracts and platform adoption strategies for blockchain and obtains the optimal solutions of these models using game theory. Research results reveal that consumer migration promotes the manufacturer's green investment, while an increase in the proportion of green consumers is not conducive to the manufacturer's green investment. At the same time, blockchain technology can effectively contain manufacturer cannibalization.

Paper title	Authors	Research context	Research method/ approach	Key findings/ contributions
Blockchain adoption and strategic contracting in a green supply chain considering market segmentation	Xu *et al.* (2023a, b)	The expanding e-commerce and globalization of the economy	• Game theory analysis • Numerical simulation	• This study reveals a cascading effect of advantage • Blockchain technology can bring Pareto improvements to green supply chains
Impact of blockchain on the green innovation performance of enterprises under the policy uncertainty	Wang *et al.* (2023b)	The impact of the option of blockchain on the green innovation performance of enterprises	• Difference-in-difference-in-difference method	• Blockchain can improve green innovation performance, especially for private enterprises • External technological forces can eliminate the negative impact of policy uncertainty
Financing strategy of the capital-constrained supply chain under uncertainty: the impact of blockchain technology on the credit period	An *et al.* (2023)	Relieve the financing pressure faced by small and medium-sized enterprises through emerging digital technologies	• Newsvendor model • Equilibrium analysis	• Blockchain shortens the collection time • Blockchain technology enables efficient and intelligent collaborative development of supply chains, which can reduce carbon emissions during the transportation of goods
The behavioral evolution of the smart electric vehicle battery reverse supply chain under government supervision	Gao *et al.* (2023)	Recycling and reuse of electric vehicle batteries	• Evolutionary game theory • Numerical simulation	• This study reveals the relevance of government regulation, blockchain applications, and collaborative strategies in the smart electric vehicle battery reverse supply chain
Carbon allowance approach for capital-constrained supply chain under carbon emission allowance repurchase strategy	Wang *et al.* (2023a)	The carbon emission allowance repurchase strategy	• Game theory analysis	• This study analyzed the equilibrium under two CAAMs, GCAA and BCAA • This study provides a basis for the government to choose a reasonable carbon allowance allocation method

(*continued*)

Table 1.
Overview of the papers accepted in the special issue

Paper title	Authors	Research context	Research method/ approach	Key findings/ contributions
The impact of carbon neutrality policies on the stock market from a supply chain perspective	Liu *et al.* (2023a)	Supply chain structure and the impact of carbon neutrality policies	• Event study method • Cross-sectional regression model	• The carbon neutrality policy has a negative impact on the market value of enterprises • The supply chain structure can significantly moderate the stock market impact of the carbon neutrality policy • Smart supply chains have a negative moderating effect on the stock market impact of carbon neutrality policy
Manufacturers' emission reduction investment strategy under carbon cap-and-trade policy and uncertain low-carbon preferences	Xu *et al.* (2023a, b)	Emission reduction investment strategies under carbon cap-and-trade policies and uncertain low-carbon preferences	• Game theory analysis • Stackelberg model • Numerical simulation	• This paper considers the investment of emission reduction technologies in different processes and provides theoretical guidance for manufacturers to make a low-carbon transformation • The paper provides suggestions for governments to effectively implement carbon cap-and-trade policy
Sustainable supplier selection with multidimensional overlapping criteria under carbon neutrality	Chen and Chung (2023)	Sustainable decision-making of supply chain under carbon neutrality conditions	• Data envelopment analysis • Case study	• The approach using an aggregate weight-constrained DEA model with additional constraints is better in balancing the development among all dimensions • Discussing overlapping criteria in the context of sustainable supplier evaluation and other multi-criteria evaluation has a noticeable impact on evaluation systems

Table 1.

(*continued*)

Paper title	Authors	Research context	Research method/ approach	Key findings/ contributions
The optimal carbon emission reduction and advertising strategy with dynamic market share in the supply chain	Tan *et al.* (2023)	Dynamic carbon emission reduction strategies, advertising strategies and cooperation methods	• Differential game model	• This paper develops an extend Vidale-Wolfe model to discuss the dynamic joint emission reduction strategy in the supply chain • The results of this paper can provide theoretical basis for the joint emission strategy of supply chain members in low-carbon environment
Achieving carbon neutrality with smart supply chain management: a CE imperative for the petroleum industry	Yousaf *et al.* (2023)	Smart technologies and the circular economy model for the petroleum industry	• Game theory analysis • Stackelberg model	• Green technology improvement is directly influenced by the reprocessing capability and refund price and digital technologies are significant to consider • A two-part-tariff contract coordinates the supply chain for limited reprocessing capability by the retailer • The government can manipulate the development of green technology by changing the permit price

Source(s): Authors'

Table 1.

Blockchain technology can provide a reliable channel for information sharing (Liu *et al.*, 2023b) and promote collaboration and value creation among enterprises. From this angle, Wang *et al.* (2023b) empirically test how blockchain can respond to climate change by improving its green innovation performance under policy uncertainty. This study is based on data from listed companies in China from 2013 to 2021, using the difference-in-difference-in-difference (DDD) method to analyze the impact of blockchain on green innovation performance of enterprises. Empirical results indicate that enterprises registered in low-carbon pilot city areas can significantly improve their green innovation performance by adopting blockchain, which will have a more positive impact on the green efficiency of private enterprises.

Emerging technologies such as blockchain can help improve supply chain transparency and effectively address information exchange and mutual trust between different entities (Liu *et al.*, 2023c). In this context, An *et al.* (2023) explore the effectiveness of using blockchain technology to address financial constraints faced by small and medium-sized suppliers in capital-constrained supply chains. This study develops a newsvendor model to describe the impact of blockchain on credit periods and corporate credit levels in a supply chain. Three repayment methods are entertained: the benchmark case without blockchain and two blockchain enabled cases with a hybrid repayment mode and single repayment mode (SRM). This research shows that when both the bank interest rate and the carbon cap are low, manufacturers who choose to implement blockchain technology have higher profitability than those who do not use it. Within the framework of blockchain technology, manufacturers exhibit a preference for SRM between the two repayment models. In addition, under certain conditions of the bank interest rate, blockchain technology can effectively promote consensus among supply chain members in channel selection.

3.2 Operational mechanisms of smart supply chains from a carbon neutral perspective

Building a smart electric vehicle battery reverse supply chain using blockchain technology can solve the difficulties of lacking trust and data. In this context, Gao *et al.* (2023) explore the behavioral evolution of a smart electric vehicle battery reverse supply chain under government regulation. This study employs evolutionary game theory to examine the decision-making behavior of governments, electric vehicle manufacturers using recyclable old batteries and third-party electric vehicle battery recyclers lacking professional recycling qualifications. This research finds that in the smart reverse supply chain incorporating blockchain technology the cooperative recycling strategy of third-party electric vehicle battery recyclers is the best choice under active government regulation. In addition, if the probability of the EV manufacturer choosing the blockchain adoption strategy is high (low), the government prefers negative (positive) supervision.

In order to alleviate short-term funding shortage of low-carbon transformation in traditional manufacturing, the carbon emission allowance procurement strategy (CEARS) has been implemented in parallel with the carbon trading mechanism. In this context, Wang *et al.* (2023a) examine two types of carbon allocation methods (CAAMs), namely grandfathered system carbon allocation (GCAA) and baseline system carbon allocation (BCAA), and determine which is more conducive to capital constrained supply chains under CEARS. This study analyzes the equilibrium under two CAAMs through a game model. This research reveals that higher carbon-saving can better utilize CEARS, thereby achieving higher supply chain profits. When carbon-saving is small, GCAA achieves both economic and environmental benefits. BCAA reduces carbon emissions at the expense of economic benefit. The government and supply chain members are more inclined to choose GCAA.

3.3 The impact of policy factors on low-carbon supply chains in the context of carbon neutrality

The impact of carbon neutrality policies may be uncertain on the market value of enterprises. In this context, Liu *et al.* (2023a) explore the impact of carbon neutrality policies on the Chinese stock market from a supply chain perspective. This study is based on a dataset of 354 A-share listed companies and uses a cross-sectional regression model to reveal the moderating effect of supply chain characteristics on the stock market reaction brought about by the carbon neutrality policy. This research shows that the carbon neutrality policy has brought negative stock market reactions. Customer concentration and out-degree centrality have the significant negative moderating effect. Supplier concentration and in-degree centrality have the significant positive moderating effect. Surprisingly, this study also finds that smart supply chains have a negative moderating effect, indicating the possibility that the adoption of new technologies and equipment may increase carbon emission risks.

To incentivize manufacturers to undergo low-carbon transformation, several countries have implemented the carbon cap-and-trade policy. In this context, Xu *et al.* (2023b) investigate the impact of carbon cap-and-trade policies and uncertain low-carbon preferences on emission reduction investment strategies, aiming to find the best emission reduction investment strategy for manufacturers. This paper divides emission reduction into two processes (production process and use process) and proposes three different Stackelberg game models to explore the profits of the manufacturer under different situations. Analytical results indicate that the manufacturer's optimal emission reduction strategy is dynamic. When consumers' low-carbon preferences are low and the government implements a carbon cap-and-trade policy, the manufacturer can obtain the highest profit by increasing the emission reduction investment in the use process. The carbon cap-and-trade policy can encourage the manufacturer to reduce emissions only when the initial carbon emission is low. The emission reduction, order quantity and the manufacturer's profit increase with the consumers' low-carbon preferences.

3.4 The low-carbon strategy and operational optimization of smart supply chains

How to choose sustainable suppliers is an important optimization and decision-making issue at the operational level in the carbon neutrality era. In this context, Chen and Chung (2023) propose three approaches to solve the multidimensional overlapping criteria issue by data envelopment analysis (DEA) methods. The first approach uses all dimensional criteria and "dimensional overlapping criteria" in a single DEA model. The second approach consists of a two-stage DEA. The first stage is to find sustainable development (SD) dimensional performances, which are used in the second stage. The third approach uses an aggregate weight-constrained DEA model with additional constraints. These approaches are applied to an empirical case study with six dimensions. This empirical analysis finds that the third method offers more balanced development across all dimensions.

More and more companies are increasing their investment in carbon reduction and using advertising to attract environmentally friendly consumers to purchase low-carbon products. Following this line, Tan *et al.* (2023) apply a realistic differential game model to examine dynamic carbon emission reduction strategies, advertising strategies and cooperation methods for supply chain members from a long-term perspective. This study indicates that the manufacturer's advertising subsidy to one of the retailers is the best choice. Advertising can alleviate the adverse effects of prisoner's dilemma in a semi-cooperative state, but it cannot achieve the Pareto optimization result.

Smart technologies and circular economy (CE) models can be a solution for promoting carbon neutrality in the petroleum industry. By taking this perspective, Yousaf *et al.* (2023) study how to maximize the reprocessing lead capability rate and carbon-neutral benefits through green technology improvement. A game theoretic approach with Stackelberg equilibrium is considered under government cap-and-trade regulation to stimulate green technology improvement. This study reveals that green technology improvement is directly influenced by the reprocessing capability, and refund price and digital technologies are significant factors. A two-part tariff contract coordinates the circular supply chain (CSC) resulting in higher green technology development and overall performance. The government can effectively manipulate the development of green technology by changing the permit price.

4. Looking back and moving forward: future research directions for exploring smart supply chain management to achieve carbon neutrality

Current research has focused on the impact of emerging technologies on green transformation of supply chains and has summarized some operational and policy recommendations. The papers in this SI can make important contributions to scholars, practitioners, governments and decision-makers. However, from the perspective of technological breadth and risks, there are still many issues worth studying in the areas that this SI focuses on. Considering the diversity of emerging technologies in smart supply chain, as well as potential uncertainty in technology applications, operational management and policy implementation, further research can be carried out from the following aspects to better achieve carbon neutrality goals as follows.

(1) Research on different emerging technologies. For example, in smart supply chains, it is important to examine the impact of technologies such as artificial intelligence, big data technology, and the IoT on the performance of low-carbon transformation.

(2) Research on the supply chain carbon reduction path based on multi-technology integration. For example, it is a promising direction to explore performance differences caused by diverse combinations of emerging technologies under various scenarios through empirical analysis or case studies, thereby deriving optimal technology application solutions.

(3) Research on the carbon reduction strategies for smart supply chain equipment. For example, it is a worthy topic to study the scheduling optimization problem of smart equipment operations, thereby improving operational efficiency of smart devices and reducing energy waste caused by redundancy and bottleneck issues.

(4) Research on the pharmaceutical and food industries. This industry has higher requirements for storage conditions and timeliness in production and circulation, which may lead to more severe carbon emissions and energy consumption. In the future, carbon reduction strategy research can be carried out for special scenarios such as the pharmaceutical supply chain and fresh product supply chain.

(5) Research on policy design for achieving low-carbon transformation through smart supply chain construction.

5. Concluding remarks

The climate change problem caused by greenhouse gas emissions has become increasingly severe, posing a huge challenge to human society. Currently, the issue of “energy conservation and carbon reduction” has become the focus of international attention. This SI discusses some key issues in achieving carbon neutrality goals through smart supply chain management, ranging from technology application and development to supply chain strategy design, supply chain operation optimization and the impact of carbon neutrality policies. Through multiple rounds of reviews, we selected ten papers to form this SI, which has a couple of peculiarities and contributions First, the papers we have chosen cover different research perspectives, analyzing the impact of smart supply chain technologies on the low-carbon transformation from multiple perspectives of opportunities, risks and challenges. Second, the papers we have chosen also integrate a variety of methodologies and disciplinary ideas, being in line with the interdisciplinary of the *Industrial Management and Data Systems* journal. Finally, we also propose several future research directions around the theme of “carbon neutrality” for scholars, practitioners and policy-makers.

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