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A Review of AI-Driven Dynamic Pricing and Emission Reduction Strategies in Green Supply Chains

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Abstract

This paper reviews the application of artificial intelligence technologies in green supply chain management, with a particular focus on the integration of dynamic pricing mechanisms and emission reduction strategies. As global attention to climate change increases, companies face the dual challenge of reducing carbon emissions while maintaining economic benefits. Artificial intelligence is reshaping green supply chain management practices by providing data-driven decision support, optimizing pricing strategies, and allocating resources efficiently. This review analyzes current research progress, application cases, and discusses future directions and challenges, aiming to provide a systematic reference framework for both academia and industry.

Keywords

Artificial Intelligence; Dynamic Pricing; Emission Reduction Strategies; Green Supply Chain Management; Machine Learning.

1. Integration of Artificial Intelligence and Green Supply Chain Management

1.1. Research Background and Significance

Global climate change has become one of the most pressing environmental challenges of our time, with carbon dioxide emissions posing a serious threat to human survival and development. To avoid climate disasters and achieve zero emissions, governments and enterprises are actively taking measures to reduce carbon emissions, such as imposing carbon taxes, promoting clean energy, and shutting down low-productivity and high-energy-consuming enterprises. China has established a "dual carbon" goal aimed at driving economic transformation toward green, high-quality development. President Xi Jinping emphasized that "green development is the foundation of high-quality development, and new productivity is inherently green productivity." China is accelerating green technology innovation and the promotion of advanced green technologies, developing green low-carbon industries and supply chains, and constructing a green low-carbon circular economic system (Liang & Zhang, 2020).

Supply chains, as core components of business operations, account for a significant proportion of global greenhouse gas emissions. Green Supply Chain Management (GSCM) has therefore become an important lever for emission reduction. As governments intensify emission reduction efforts, consumers' awareness of low-carbon environmental protection is also gradually strengthening, and they tend to purchase low-carbon products (Khosroshahi et al., 2021). To implement government environmental policies and gain consumer recognition, upstream manufacturers in the supply chain, such as Gree Electric Appliances, Carrier Corporation, and Haier Group, regard energy conservation and emission reduction as one of their core competitiveness, committed to low-carbon transformation and upgrading of products. Meanwhile, downstream retailers in the supply chain are also actively responding to actions. For example, Walmart launched the "Billion Ton Emission Reduction Project" aimed at

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reducing or avoiding one billion tons of greenhouse gas emissions in its business value chain by 2030 (Zhang et al., 2019).

In the wave of digital transformation, artificial intelligence (AI) technology is developing at an unprecedented pace, providing new technical support and solutions for GSCM. Dynamic pricing, as a strategy that flexibly adjusts product or service prices, can respond to changes in market demand, cost fluctuations, and the competitive environment. When combined with emission reduction targets, dynamic pricing can guide consumers and supply chain partners to adopt more environmentally friendly behaviors. AI technology, through its powerful predictive capabilities, optimization algorithms, and adaptive learning characteristics, makes this combination more efficient and precise (Zhou & Ye, 2018).

Big data analytics and artificial intelligence (BDA-AI) technologies have attracted widespread attention from academia and practitioners in recent years. However, few empirical studies have investigated the benefits of BDA-AI in supply chain integration and its impact on environmental performance. Benzidia et al. (2021) extended the organizational information processing theory to incorporate BDA-AI and positioned digital learning as a moderating factor in green supply chain processes. Using a data sample from 168 French hospitals and a structural equation modeling method based on partial least squares regression, they found that the use of BDA-AI technology has a significant impact on environmental process integration and green supply chain collaboration. The study also emphasized that environmental process integration and green supply chain collaboration have a significant impact on environmental performance, and highlighted the moderating role of green digital learning in the relationship between BDA-AI and green supply chain collaboration, which is an important finding not emphasized in existing literature.

1.2. Evolution of Green Supply Chain Management Concepts

Green supply chain management is a management philosophy and practice that integrates environmental factors into traditional supply chain management. From initial pollution control to clean production, and now to whole-life-cycle management, GSCM has gone through three main development stages:

(1) Compliance Stage (1990s-2000s): Primarily aimed at meeting environmental regulations

(2) Prevention Stage (2000s-2010s): Focusing on source reduction and resource recycling

(3) Strategic Integration Stage (2010s to present): Using environmental factors as a source of competitive advantage

Currently, with rising stakeholder expectations and strengthened climate policies, GSCM has transformed from purely compliance activities to a core component of corporate strategy (Bai et al., 2019).

1.3. The Role of Artificial Intelligence in Supply Chain Management

AI technology has revolutionized supply chain management through:

(1) Demand Forecasting: Using machine learning to improve forecasting accuracy, reducing excess inventory and resource waste

(2) Optimization Algorithms: Solving complex multi-objective optimization problems in supply chain network design

(3) Intelligent Automation: Reducing human errors and resource consumption

(4) Real-time Decision Support: Processing large-scale data and providing timely insights

In the green supply chain environment, these capabilities of AI technology are further expanded for emission measurement, environmental risk assessment, and sustainable decision support (Chen et al., 2019).

ISSN: 2710-0170

Generative artificial intelligence offers multiple potential solutions for sustainable supply chain management, but not all companies can effectively master the methods of using generative AI and realize potential benefits. Li et al. (2024) adopted a practice-based view (PBV) to study the impact of generative AI use on sustainable supply chain performance. By analyzing survey data from 213 Chinese manufacturing enterprises, they confirmed a positive correlation between generative AI use and sustainable supply chain performance, and found that green supply chain collaboration (GSCC) and circular economy implementation (CEI) serve as serial mediating factors connecting this relationship. This research contributes to existing AI-driven supply chain management research by clarifying the potential mediating mechanisms between generative AI use and sustainable supply chain performance.

2. Big Data Analytics and AI-Driven Pricing Mechanisms

2.1. Machine Learning-Based Demand-Emission Prediction Models

Accurate demand forecasting is a prerequisite for effective dynamic pricing. AI-driven demand-emission prediction models combine traditional demand factors and environmental variables, mainly including:

(1) Time Series Prediction Models: Using LSTM (Long Short-Term Memory networks) and GRU (Gated Recurrent Units) to capture the time dependence of demand and emissions

(2) Causal Prediction Models: Analyzing the impact of factors such as price, policy, and environmental awareness on demand and emissions through Bayesian networks

(3) Hybrid Prediction Models: Combining multiple techniques to improve prediction accuracy

Research shows that compared with traditional methods, these AI models can reduce prediction errors by 15-30%, providing a more reliable basis for dynamic pricing decisions (Xu et al., 2016). The combination of big data analytics and artificial intelligence technologies provides new possibilities for improving hospital environmental performance. Benzidia et al. (2021) found that the use of BDA-AI technology has a significant impact on hospital environmental process integration, helping hospitals better process and analyze data from various internal and external sources, thereby supporting environmental decisions.

2.2. Application of Reinforcement Learning in Pricing Decisions

Reinforcement Learning (RL) finds optimal pricing strategies through trial and error learning, particularly suitable for handling green supply chain pricing problems with long-term returns and complex constraints. Main applications include:

(1) Multi-objective Reinforcement Learning Framework: Simultaneously optimizing economic returns and environmental performance

(2) Multi-agent Systems: Simulating the interaction and game theory among various supply chain participants

(3) Deep Reinforcement Learning: Handling high-dimensional state spaces, such as complex decision scenarios containing multiple environmental indicators

These methods can dynamically balance short-term profit and long-term sustainability goals, providing companies with more flexible pricing strategies (Wang & Wang, 2021). In the medical field, Benzidia et al. (2021) found that BDA-AI supported decision processes can help hospital managers develop more environmentally friendly procurement strategies, optimize resource use, and reduce environmental impact.

2.3. Blockchain-Based Green Value Allocation Mechanism

The combination of blockchain technology and AI provides transparent, trustworthy value allocation mechanisms for green supply chains:

ISSN: 2710-0170

(1) Smart Contract Automatic Execution: Automatically adjusting prices and rewards based on preset conditions (such as meeting carbon reduction targets)

(2) Distributed Trust Mechanism: Ensuring the credibility of environmental data and the verifiability of emission reduction results

(3) Tokenized Incentive System: Quantifying and trading environmental value through digital tokens

This mechanism effectively solves the problems of information asymmetry and insufficient incentives in traditional green supply chains, promoting collaborative emission reduction across the entire supply network. Li et al. (2024) further confirmed that the use of generative artificial intelligence can improve sustainable supply chain performance through two key practices: green supply chain collaboration and circular economy implementation, forming a clear path from technology to practice to performance.

3. Green Supply Chain Collaborative Practices and Environmental Performance

3.1. Green Supply Chain Collaboration Mechanisms

Green Supply Chain Collaboration (GSCC) refers to strategic cooperation between enterprises and their supply chain partners to effectively implement environmental protection initiatives (Luo et al., 2014). This collaboration includes:

(1) Shared Environmental Goals: Collectively setting and achieving environmental objectives

(2) Joint Environmental Management Systems: Developing and implementing common environmental management measures

(3) Collaborative Emission Reduction Actions: Working together to reduce environmental impact

Research shows that GSCC can promote the sharing of information about raw materials and energy consumption among supply chain members, laying a solid foundation for resource optimization and use within the supply chain (Kong et al., 2021). In addition, GSCC promotes the sharing of expertise among supply chain members, fostering innovative solutions to address sustainability challenges (Hong et al., 2019). By prioritizing environmental management and social responsibility, cultivating collaborative relationships can build more stable and resilient supply chains, further enhancing companies' ability to withstand disruptions and turbulence (Scholten and Schilder, 2015).

Benzidia et al. (2021) confirmed that the use of BDA-AI technology has a significant positive impact on green supply chain collaboration. This technology enables hospitals to collaborate more effectively with suppliers, jointly design and implement green procurement programs, optimize logistics transportation methods, reduce waste generation, thereby improving overall environmental performance.

3.2. Circular Economy Implementation Strategies

Circular Economy Implementation (CEI) describes how companies efficiently execute value-added activities by adopting circular strategies (Kristoffersen et al., 2021). These strategies include:

(1) Reinvention and Rethinking: Developing modular, repairable products and services

(2) Restoration, Reduction, and Avoidance: Enhancing recycling potential in production by minimizing material and process waste

(3) Recycling: Reusing, refurbishing, and remanufacturing products to extend their life cycle

Li et al. (2024) presented CEI as a second-order construct, emphasizing the importance of these three dimensions in sustainable supply chain management. They found that the use of

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generative artificial intelligence has a significant positive impact on CEI, especially in generating multiple iterations during the product design process, identifying design options that minimize waste and environmental impact while improving product lifespan.

CEI alleviates pressure on natural resources and minimizes waste generation, leading to higher resource utilization efficiency in the supply chain (Khan et al., 2021). Additionally, CEI often brings long-term cost savings, as using recycled materials can reduce the demand for expensive virgin resources (Cheng et al., 2022). Finally, CEI promotes supply chain resilience by fostering a closed-loop system where resources are continuously reused and recycled (Kennedy and Linnenluecke, 2022). This reduces dependence on external sources, minimizing exposure risks to external shocks such as resource scarcity or supply chain disruptions.

3.3. Environmental Performance Assessment and Enhancement Mechanisms

Environmental performance assessment is a key link in measuring the effectiveness of green supply chain management. Performance indicators typically include:

(1) Emission Indicators: Greenhouse gas emissions, air pollutant emissions

(2) Resource Indicators: Energy consumption, water resource use, raw material consumption

(3) Waste Indicators: Solid waste, liquid waste, hazardous waste generation

Benzidia et al. (2021) studied how BDA-AI technology affects hospital environmental performance through environmental process integration and green supply chain collaboration. Their results indicate that environmental process integration and green supply chain collaboration both have significant positive impacts on environmental performance. This finding is consistent with the conclusions of Li et al. (2024), who also confirmed that GSCC and CEI have significant impacts on sustainable supply chain performance.

To enhance environmental performance, companies can adopt the following measures:

(1) Environmental Management System Implementation: Establishing and certifying environmental management systems that comply with standards such as ISO 14001

(2) Life Cycle Assessment: Systematically assessing the environmental impact of products throughout their life cycle

(3) Green Supplier Assessment and Development: Evaluating and selecting suppliers based on environmental criteria, and helping suppliers enhance their environmental capabilities

Research shows that BDA-AI technology can support these environmental performance enhancement measures by providing more accurate data analysis and predictions, helping companies formulate more effective environmental strategies (Benzidia et al., 2021).

4. Future Directions and Challenges

4.1. Data Quality and Standardization Challenges

AI-driven green pricing faces data quality challenges:

(1) Incomplete Carbon Emission Data: Lack of standardized methods for measuring supply chain carbon footprints

(2) Cross-border Data Consistency: Inconsistent environmental data standards across different countries and regions

(3) Privacy and Sharing Concerns: Inadequate data sharing mechanisms

To address these challenges, future research needs to focus on several key areas:

First, establishing unified information platforms to update and share key data in real-time, such as market demand, inventory levels, and emission reduction effectiveness, promoting rapid response and coordination among supply chain members. By improving information sharing, supply chain members can better coordinate their emission reduction efforts and marketing

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strategies, avoiding duplicate investments and redundant activities, thereby enhancing the operational efficiency and environmental performance of the entire supply chain.

Second, developing standardized methods and tools for measuring supply chain carbon footprints, ensuring data accuracy and comparability. Establishing cross-regional and cross-industry environmental data standards to promote carbon emission management coordination in global supply chains.

Additionally, constructing secure and reliable data sharing mechanisms, balancing the contradiction between data transparency and privacy protection, encouraging supply chain members to actively participate in data sharing, providing comprehensive and accurate data foundations for AI-driven green pricing.

Benzidia et al. (2021) pointed out that a major environmental delay challenge faced by hospitals is the lack of ability to measure and utilize qualitative and quantitative data from various internal and external sources to support green practices in hospitals. Therefore, future research should focus on how to use BDA-AI technology to improve data quality and establish more comprehensive data sharing and standardization mechanisms.

4.2. AI Ethics and Fair Pricing Issues

Ethical issues in green pricing are increasingly prominent:

(1) Risk of Price Discrimination: AI pricing may cause unfair impacts on vulnerable groups

(2) Transparency and Explainability: The "black box" nature of AI decision processes raises questions

(3) Allocation of Emission Reduction Responsibility: How to fairly distribute the costs and benefits of emission reduction

This requires establishing a responsible AI pricing framework to ensure environmental justice and social equity. Li et al. (2024) pointed out that policymakers should provide clear ethical guidelines and standards for the development and deployment of generative artificial intelligence in supply chains. These standards should include addressing issues of bias, transparency, accountability, and fairness in artificial intelligence-generated decisions and practices.

4.3. Practical Applications and Development Trends

The innovation of this research is reflected in three aspects:

First, approaching from the perspective of dynamic game theory provides a new analytical perspective for joint emission reduction in green supply chains. By introducing low-carbon goodwill equations and dynamic pricing strategies, using dynamic game models to explore optimal emission reduction levels and price adjustment strategies in supply chains, while considering the time dynamics of policy changes and market demands, it provides a comprehensive perspective for evaluating the long-term impact of policy and market changes on joint emission reduction in supply chains.

Second, the research on bidirectional free-riding behavior is an important supplement to the existing research on green supply chain free-riding effects. By introducing bidirectional free-riding coefficients, quantifying spillover effects between online and offline channels, and precisely identifying and evaluating the economic and environmental impacts of bidirectional free-riding behavior.

Finally, the analysis method for industry-specific coordination contracts is an important extension of existing green supply chain research methods, focusing on designing and implementing coordination contracts based on the characteristics of specific industries to systematically enhance cooperation among supply chain members and the overall environmental efficiency of the supply chain.

Benzidia et al. (2021) proposed that hospital organizations have begun to adopt the wave of BDA-AI technology, and the French government seems to have recognized the technological opportunities and adopted a new strategy "My Health 2020" aimed at transforming hospitals into connected organizations. The government is investing in large big data projects such as ConSoRe and Health Data Hub. Big data sources in hospitals can rely on various technological devices such as electronic medical records, cloud computing, smartphones, tablets, and smartwatches. However, despite the rich research on the connection between BDA and AI at the medical level, there is little research mobilizing these technologies to improve hospital supply chain processes, especially green practices.

Li et al. (2024) emphasized the key role of policymakers in promoting the effective integration of generative artificial intelligence into sustainable supply chain practices. They suggested that policymakers could provide fiscal incentives such as tax credits, grants, and subsidies to companies that adopt generative artificial intelligence that contributes to sustainable supply chain practices. Additionally, policymakers could establish platforms for companies, research institutions, and policymakers to exchange insights and experiences, promoting knowledge sharing, best practices, and collaborative initiatives in generative AI-driven sustainable supply chain management.

The key challenges lie in constructing more comprehensive interdisciplinary theoretical frameworks, developing practical tools adapted to complex realities, and cultivating professionals with cross-domain knowledge. Through collaborative efforts of academia, industry, and government, AI-driven green supply chain pricing has the potential to become a powerful tool for addressing climate change, providing effective technical and management support for achieving the "dual carbon" goals.

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