Sustainable Supply Chain Management: A Survey on Integrated Approaches to Pricing Strategy, Inventory Decision, Resource Utilization, Waste Reduction, Game Theory, and Supply Chain Optimization

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Abstract

This survey paper provides a comprehensive examination of sustainable supply chain management (SSCM) by integrating key components such as pricing strategy, inventory decision-making, resource utilization, waste reduction, game theory, and supply chain optimization. The study begins with an introduction to SSCM, emphasizing the balance among economic, environmental, and social objectives. It further explores the Triple Bottom Line framework's impact on competitive priorities and supply chain collaboration, highlighting the role of digital transformation and technological innovations like Blockchain in enhancing sustainability. The paper also investigates dynamic, variance-based, and menu-based pricing strategies, alongside the application of machine learning for adaptive pricing. Additionally, it examines inventory decision and resource optimization, focusing on closed-loop and continuous review systems, inventory pooling, and resource allocation strategies. Game theory principles are applied to supply chain optimization, emphasizing fair and efficient outcomes in collaborative networks and decision-making under uncertainty. The survey concludes by summarizing key findings and suggesting emerging trends and future research directions. Overall, this comprehensive examination of sustainable supply chain management and its multifaceted components draws on insights from current research, providing a holistic understanding of the challenges and opportunities within this field. The survey highlights the need for integrated approaches to balance economic, environmental, and social objectives, while emphasizing the role of digital transformation and technological innovations in enhancing supply chain sustainability, particularly in developing countries.

1 Introduction

1.1 Structure of the Survey

This survey comprehensively examines sustainable supply chain management by integrating critical elements such as pricing strategy, inventory decisions, resource utilization, waste reduction, game theory, and supply chain optimization. It begins with an introduction to sustainable supply chain management, highlighting its significance in balancing economic, environmental, and social objectives. Key strategies, including strategic pricing, effective inventory management, resource optimization, and waste reduction, are emphasized for companies striving for sustainability while achieving economic success and social responsibility. The integration of these strategies enhances operational efficiency and fosters collaboration among supply chain partners, providing a competitive advantage in a market increasingly oriented toward sustainable practices [1, 2, 3, 4, 5].

The subsequent section offers a background and definitions of core concepts, laying the groundwork for further discussions. Following this, the third section explores sustainable supply chain manage-

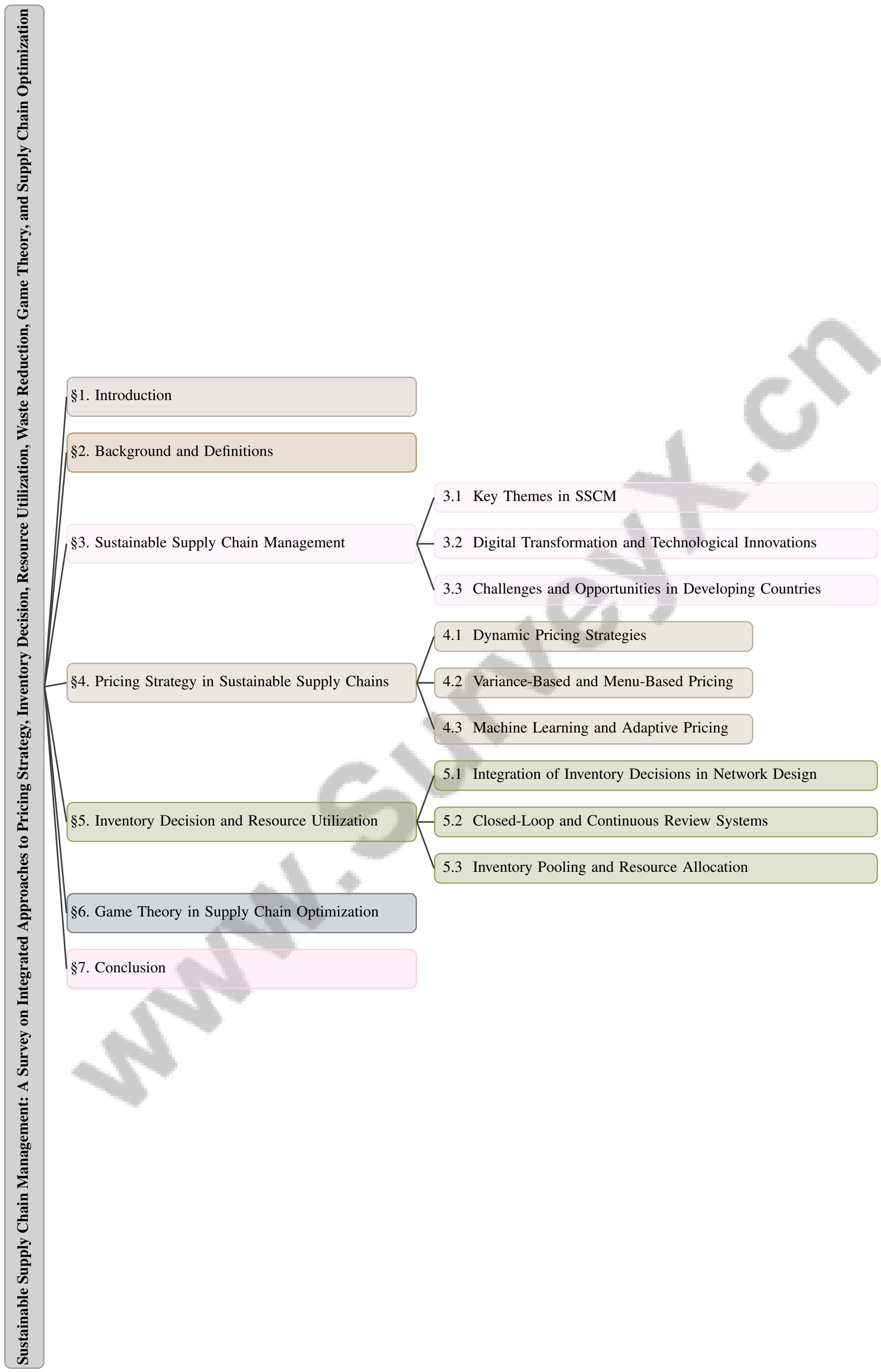

Figure 1: chapter structure

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ment through the lens of the Triple Bottom Line framework, assessing its influence on competitive priorities and supply chain collaboration. This section also addresses the role of digital transformation and technological innovations, such as Blockchain, in promoting sustainability, alongside the unique challenges and opportunities faced by developing countries.

The fourth section investigates pricing strategies within sustainable supply chains, analyzing dynamic, variance-based, and menu-based pricing approaches, as well as the application of machine learning for adaptive pricing. The fifth section focuses on inventory decisions and resource utilization, examining the integration of inventory strategies in network design and reviewing models such as closed-loop and continuous review systems for inventory management, including strategies for inventory pooling and resource allocation.

The sixth section applies game theory principles to supply chain optimization, emphasizing its role in achieving equitable and efficient outcomes in collaborative networks and optimizing decisions under uncertainty. The conclusion synthesizes the survey's key findings and outlines emerging trends and future research directions. This structured approach ensures a holistic understanding of sustainable supply chain management and its multifaceted components, drawing on insights from contemporary research in movement analytics and resource allocation frameworks.The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Concept of Sustainable Supply Chain Management

Sustainable Supply Chain Management (SSCM) integrates economic, environmental, and social objectives within supply chain operations, promoting resilience and long-term planning [6]. It addresses the challenge of embedding sustainability by balancing these objectives to enhance environmental performance and corporate responsibility, compelling industries to adopt environmentally conscious and socially responsible practices as sustainable development gains global significance [7]. SSCM's alignment with circular economy principles is critical for improving environmental performance and achieving sustainability goals [8]. It offers a holistic view of social issues, ensuring supply chains are economically viable and socially equitable [9]. Moreover, decision-making under uncertainty, a key aspect of SSCM, requires robust frameworks capable of adapting to dynamic market conditions and resource limitations [10]. Intelligent platforms like fog computing enhance SSCM by localizing storage, computing, control, and networking functions, facilitating efficient resource management [11]. By adopting a comprehensive approach, SSCM contributes to business sustainability, ensuring resilience and adaptability in response to escalating environmental and social pressures [12].

2.2 Balancing Economic, Environmental, and Social Objectives

Balancing economic, environmental, and social objectives is crucial in SSCM, addressing the complex challenges within supply networks. This integration demands a nuanced understanding of supply risks and environmental impacts, particularly regarding raw materials, as highlighted by methodologies prioritizing resource strategy and sustainability [13]. Empirical evidence underscores the necessity of maintaining economic viability while addressing societal and environmental needs, which is critical for sustainable supply chains [4]. The complexity of mineral supply chains necessitates integrated approaches to harmonize these objectives [14]. This complexity is further compounded by the multi-tier nature of supply chains and the need for sustainability compliance among global brands, where non-compliance poses significant risks [15]. Distribution channels and socio-economic conditions present additional challenges requiring innovative solutions to ensure sustainability across all dimensions [16]. Despite focusing on environmental and economic factors, there remains a notable gap in addressing social sustainability, vital for a comprehensive SSCM approach. The allocation of limited resources, such as fog resources in tech-driven supply chains, highlights the need for efficiency and fairness in distribution, critical elements of a balanced SSCM strategy [11]. Understanding human decision-making under uncertainty, especially in failure-prone systems, is crucial for implementing taxation mechanisms that regulate human utilization and support sustainable practices [17]. In the context of market fragmentation, particularly among freight forwarders, inefficient shipping capacity utilization poses challenges that necessitate strategic interventions to optimize resource use and enhance sustainability [18]. Balancing these objectives influences strategic decisions, ensuring supply chains remain resilient and adaptable amidst evolving environmental and social pressures, thus advancing sustainable development goals. Primary challenges include a lack of awareness among SMEs regarding sustainable practices, limited resources, and the complexities of implementing sustainable supply chain strategies [19]. Existing methods often struggle to optimize resource utilization and minimize energy consumption effectively, hindering alignment with sustainable development goals [7]. Additionally, the computational difficulty of optimizing multiple objectives simultaneously, due to complex constraints involving binary and integer variables, presents a significant challenge [6].

3 Sustainable Supply Chain Management

3.1 Key Themes in SSCM

Sustainable Supply Chain Management (SSCM) is fundamentally anchored in the Triple Bottom Line (TBL) framework, integrating economic, environmental, and social objectives to foster sustainability [20]. This framework evaluates supply chain performance across these dimensions, promoting initiatives that balance economic efficiency with environmental and social responsibilities [3, 1]. A key theme is strategic resource allocation, with market-based frameworks in edge computing enhancing sustainability through optimized management [21]. Similarly, economic models in cloud networking highlight efficient resource allocation's role in SSCM [22]. The link between green technological innovation and resource utilization efficiency provides insights into how technology drives supply chain sustainability [23]. Research themes include supply chain integration, stakeholder engagement, and social risk management, emphasizing social dimensions crucial for SSCM, especially for SMEs prioritizing social objectives [19]. Concepts of non-wastefulness in market equilibrium selection and metaheuristic algorithms enhance resource allocation efficiency, supporting SSCM goals [11, 7]. Decentralized decision-making in retail chains and its impact on inventory management require further exploration [24]. These themes highlight the complexity and interconnectedness of strategies necessary for achieving sustainability in supply chains.

3.2 Digital Transformation and Technological Innovations

Digital transformation and technological innovations are pivotal in advancing SSCM through technologies like Blockchain, big data analytics, and IoT [2]. These technologies enhance transparency, traceability, and efficiency, with Blockchain playing a crucial role in enforcing sustainability standards, particularly in developing countries [25]. Industry 4.0 technologies, including Blockchain, promote environmentally friendly behavior and product lifecycle visibility [26]. Overcoming sustainability obstacles, such as political support and regulatory enforcement, is essential [27]. Methodologies like the continuous review production-inventory model integrate remanufacturing to minimize carbon emissions [28]. Smart logistics solutions, including Smart Industrial Parks and AI-based technologies, enhance logistics operations and reduce costs [29]. Machine learning in supply chain optimization addresses complex problems, enabling dynamic and adaptive strategies [30]. Genetic algorithms in container loading and unloading exemplify advanced technologies enhancing operational efficiency [31].

As illustrated in Figure 2, the role of key technologies, Industry 4.0 applications, and optimization methods is crucial in advancing sustainable supply chain management (SSCM). This figure highlights the integration of Blockchain, IoT, and AI-based technologies, alongside innovative logistics solutions and optimization models that enhance operational efficiency and sustainability. By visualizing these components, we can better understand the interconnectedness of technological innovations and their impact on sustainable practices within supply chains.

3.3 Challenges and Opportunities in Developing Countries

Implementing SSCM in developing countries involves challenges shaped by economic, environmental, and social factors [27]. A primary challenge is the disparity in sustainability standards between nations, particularly in commodity treatment and compensation [25]. Integrating Industry 4.0 technologies faces hurdles due to scalability, regulatory challenges, and high energy consumption [26]. Despite these challenges, Blockchain enhances transparency and accountability, mitigating sustainability violations [25]. Economic feasibility is critical, especially for SMEs adopting advanced technologies without substantial support [29]. Opportunities include resource-sharing markets enhancing efficiency and collaborative consumption [32]. Optimizing container loading and unloading

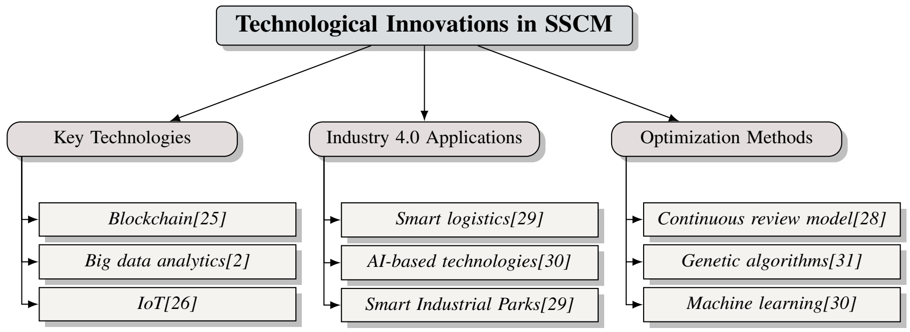

Figure 2: This figure illustrates the role of key technologies, Industry 4.0 applications, and optimization methods in advancing sustainable supply chain management (SSCM). It highlights the integration of Blockchain, IoT, and AI-based technologies, alongside innovative logistics solutions and optimization models that enhance operational efficiency and sustainability.

can significantly reduce operation times, benefiting supply chain operations [31]. Information systems support SSCM by exploring social dimensions and integrating sustainable practices [33]. Future research should address gaps in smart technology application in diverse urban settings, particularly in developing countries [34]. Accurately modeling uncertainty is crucial for robust frameworks adapting to market conditions [10], enhancing sustainable supply chain implementation in developing countries.

4 Pricing Strategy in Sustainable Supply Chains

Category	Feature	Method
Dynamic Pricing Strategies	Strategic Interaction Models	DDPS[35], MBRAF[11]
Variance-Based and Menu-Based Pricing	Customization Strategies	MBPM[36], DPSD[37], OPG-LQG[38]
Machine Learning and Adaptive Pricing	Adaptive Learning Techniques Metaheuristic Optimization	MP[39] VNS[40]

Table 1: This table provides a comprehensive overview of the various pricing strategies employed in sustainable supply chains. It categorizes these strategies into dynamic pricing, variance-based and menu-based pricing, and machine learning and adaptive pricing, detailing the specific methods and features associated with each category. The table highlights key methodologies such as Dynamic Differential Pricing Strategy, Market-Based Resource Allocation Framework, and Variable Neighborhood Search, which are integral to optimizing resource allocation and enhancing sustainability within supply chains.

In sustainable supply chains, pricing strategies are pivotal for managing market dynamics and optimizing resource allocation. This section delves into dynamic pricing strategies, which enable firms to adapt to real-time demand fluctuations and resource availability, thus enhancing supply chain sustainability and securing competitive advantages. As illustrated in Figure 3, the hierarchical structure of pricing strategies in sustainable supply chains encompasses various categories, including dynamic, variance-based, menu-based, and machine learning-enhanced adaptive pricing. Each of these categories highlights distinct methods and approaches that contribute to optimizing resource allocation and enhancing sustainability. Table 2 presents an organized summary of different pricing strategies and methods employed in sustainable supply chains, emphasizing their role in optimizing resource allocation and enhancing market adaptability.

4.1 Dynamic Pricing Strategies

Dynamic pricing strategies are integral to sustainable supply chains, allowing firms to adjust to market demand and resource availability changes. This adaptability is crucial in volatile environments, where demand and resource constraints significantly impact operations. By employing dynamic pricing, firms can respond to market demand variations, achieving equilibrium, optimizing resource allocation, and enhancing profitability. This approach enables businesses to tailor pricing based on demand

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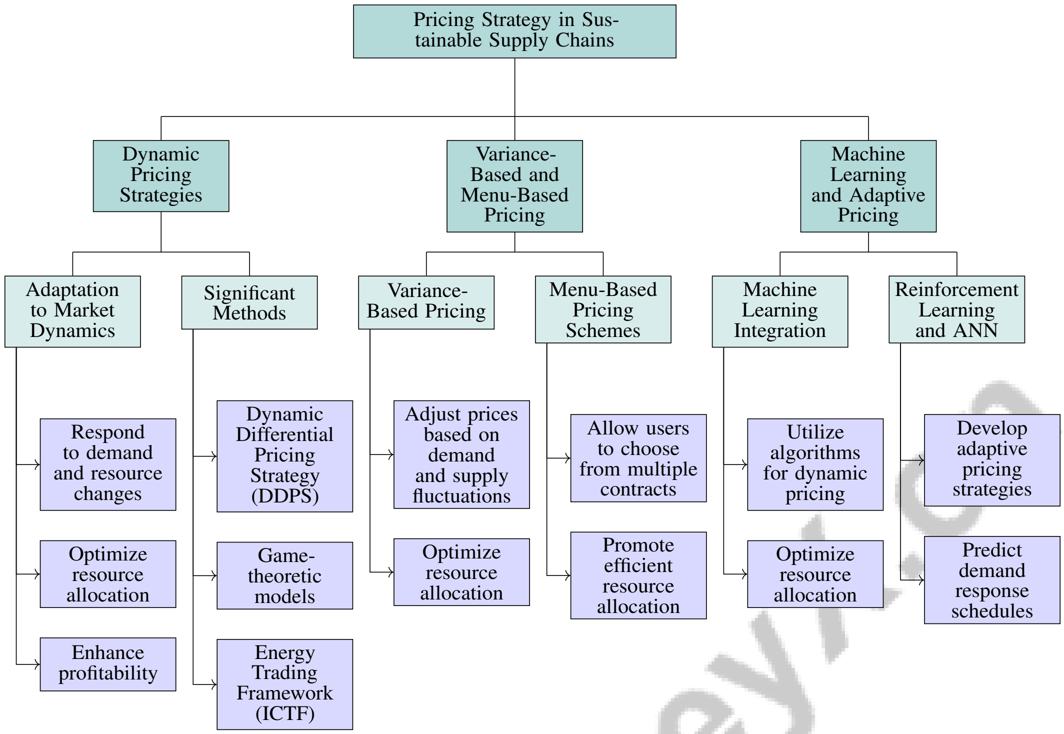

Figure 3: This figure illustrates the hierarchical structure of pricing strategies in sustainable supply chains, emphasizing dynamic, variance-based, menu-based, and machine learning-enhanced adaptive pricing. Each category highlights methods and approaches that contribute to optimizing resource allocation and enhancing sustainability.

characteristics, such as immediate purchases versus delayed orders, maximizing expected profits and managing inventory effectively [41, 42, 37, 43].

As illustrated in Figure 4, the hierarchical structure of dynamic pricing strategies in sustainable supply chains highlights key methods, challenges, solutions, and applications. The Dynamic Differential Pricing Strategy (DDPS) is a significant method in dynamic pricing, aligning pricing with consumer behavior models to optimize resource allocation [35]. Understanding consumer behavior, influenced by reference prices, enables firms to balance demand fluctuations with resource availability, contributing to SSCM goals.

Pricing competition and quality of service (QoS) are critical aspects of dynamic pricing. Recent studies introduce the concept of an equilibrium cycle, reflecting dynamic pricing behaviors among competing platforms and emphasizing strategic adaptation for maintaining competitive advantage [44]. By anticipating competitor pricing strategies, firms can better position themselves in the market.

Market-based frameworks for resource allocation, as proposed by [11], enable firms to set resource prices based on demand, a core principle of dynamic pricing. This ensures efficient resource allocation, aligning with SSCM principles.

Game-theoretic models enhance understanding of consumer behavior, allowing firms to refine pricing strategies in response to market demands and resource limitations. This not only improves competitive responsiveness but also helps achieve an optimal balance between profitability and sustainability, fostering long-term growth and environmental responsibility [41, 42, 14, 37].

In energy markets, incentive-compatible frameworks like the Energy Trading Framework (ICTF) utilize a leader-follower Stackelberg game model to optimize pricing decisions. This encourages users to disclose energy usage data, allowing shared energy storage providers to enhance price signals and revenue. Case studies demonstrate that ICTF can reduce peak demand by 28% to 45%, showcasing its effectiveness in promoting efficient pricing strategies [41, 45, 46]. This is particularly relevant in prosumer-centric markets, where dynamic pricing can mitigate uncertainty in future energy prices and optimize resource allocation.

Dynamic pricing strategies are crucial in SSCM for addressing demand fluctuations and resource availability while ensuring efficient resource utilization and competitive advantage. By leveraging advanced pricing models and game-theoretic approaches, firms can navigate dynamic market complexities and enhance supply chain sustainability. The interplay between pricing strategies, competition, and QoS underscores the importance of dynamic pricing in achieving sustainable supply chains [44].

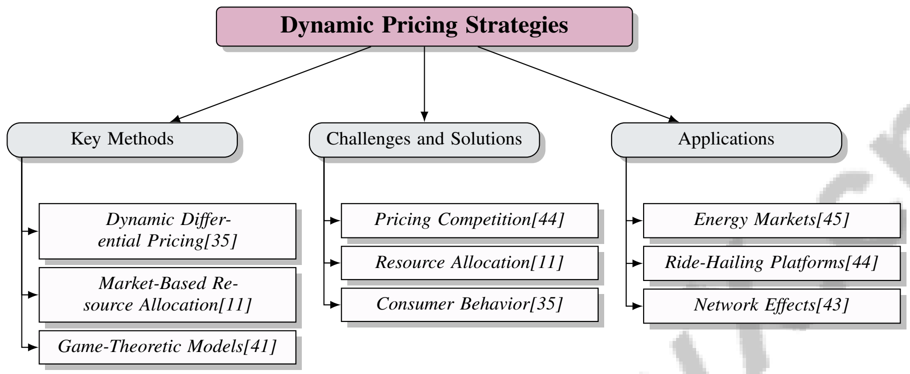

Figure 4: This figure illustrates the hierarchical structure of dynamic pricing strategies in sustainable supply chains, highlighting key methods, challenges, solutions, and applications.

4.2 Variance-Based and Menu-Based Pricing

Variance-based and menu-based pricing strategies significantly enhance supply chain sustainability by facilitating adaptive pricing mechanisms that respond to market conditions. Variance-based pricing allows managers to adjust prices based on demand and supply fluctuations, optimizing resource allocation and maintaining sustainability [36]. This approach is particularly relevant in stochastic inventory systems where price-dependent demand follows a Brownian motion, enabling firms to maximize profits through tailored dynamic pricing policies [37].

Menu-based pricing schemes (MBPS) offer an innovative pricing approach, allowing users to choose from multiple contracts tailored to their energy and utilization needs [36]. This customization aligns with SSCM principles by promoting efficient resource allocation and consumption, contributing to overall sustainability.

The integration of automated systems and data sharing, as highlighted by [26], enhances logistics efficiency, essential for sustainable supply chains. Data-driven insights enable companies to optimize pricing strategies, ensuring competitiveness while aligning with sustainability goals.

The inherent NP-complete nature of variance-based and menu-based pricing strategies complicates the search for optimal solutions due to the complexity of the combinatorial optimization model [40]. Enhanced heuristic frameworks have been proposed to help supply chains navigate these complexities and achieve optimal solutions in dynamic environments.

Aligning incentives among supply chain stakeholders is critical for successfully implementing variance-based and menu-based pricing strategies. Innovative pricing models, such as optimal pricing strategies in linear quadratic games, can help align the incentives of data providers and consumers, fostering collaboration and sustainability [38]. Ensuring mutual benefits from pricing strategies allows supply chains to balance economic viability with sustainability.

4.3 Machine Learning and Adaptive Pricing

Machine learning is revolutionizing adaptive pricing strategies in SSCM. By utilizing sophisticated algorithms, machine learning enables companies to implement dynamic pricing that adjusts to real-time market fluctuations, optimizing resource allocation and enhancing sustainability. Recent studies demonstrate the integration of machine learning with mathematical programming to improve decision-making under uncertainty, addressing challenges such as unpredictable demand and limited data. For instance, a two-phase online learning algorithm developed for e-commerce pricing has shown a 55

Reinforcement learning is a key methodology in this domain, allowing for the development of pricing strategies that adapt to demand and supply changes. These models can outperform traditional expert-driven methods by learning optimal strategies through extensive training and suitable reward systems [30]. Such adaptability is crucial in SSCM, where dynamic market environments require rapid responses to fluctuations.

The integration of machine learning into adaptive pricing is further enhanced by artificial neural networks (ANNs), which predict demand response schedules based on historical data and current conditions [39]. This predictive capability enables firms to develop precise adaptive pricing strategies that align with SSCM objectives.

Menu-based pricing schemes (MBPS) offer a flexible, user-centric alternative to adaptive pricing, allowing consumers to select contracts tailored to their energy consumption and utilization preferences. This enables users to pay for charging services at electric vehicle (EV) stations based on individual needs, such as energy amount, service duration, and urgency. Incorporating factors like renewable energy usage and vehicle-to-grid (V2G) services enhances user satisfaction and optimizes resource allocation, leading to improved social welfare and profitability for operators [47, 36, 48]. This pricing flexibility allows supply chains to dynamically respond to market conditions, optimizing resource allocation and supporting sustainability goals.

The complexity of adaptive pricing strategies is further addressed by innovative algorithms like the Variable Neighborhood Search (VNS), which significantly outperforms traditional mixed-integer programming (MIP) solvers in achieving optimal solutions in dynamic environments [40]. These methodologies underscore the importance of integrating machine learning into supply chain optimization, enabling firms to navigate market complexities and enhance sustainability.

Moreover, integrating machine learning with economic models in cloud networking emphasizes the significance of adaptive pricing strategies in optimizing resource allocation and enhancing sustainability [22]. This alignment supports the broader goals of SSCM by facilitating efficient resource management and promoting sustainable practices.

Feature	Dynamic Pricing Strategies	Variance-Based and Menu-Based Pricing	Machine Learning and Adaptive Pricing
Adaptability	Real-time Demand	Demand Fluctuations	Real-time Market
Optimization Focus	Resource Allocation	Stochastic Systems	Algorithmic Learning
Complexity	Market Competition	Np-complete	Algorithmic

Table 2: This table provides a comparative analysis of various pricing strategies utilized in sustainable supply chains, focusing on dynamic pricing, variance-based and menu-based pricing, and machine learning-enhanced adaptive pricing. It highlights key features such as adaptability, optimization focus, and complexity, demonstrating how each strategy contributes to resource optimization and market adaptability.

5 Inventory Decision and Resource Utilization

The integration of inventory decision-making with resource utilization is crucial for sustainable supply chain management (SSCM), enhancing operational efficiency and aligning with sustainability across economic, environmental, and social dimensions. The following subsection examines how inventory strategies are incorporated into sustainable supply chain network design to optimize resource use and performance.

5.1 Integration of Inventory Decisions in Network Design

Incorporating inventory decisions into sustainable supply chain network design is vital for optimizing performance while balancing economic, environmental, and social goals [3]. Effective inventory management reduces waste and enhances resource utilization, key SSCM principles [13]. Sustainable design often involves closed-loop systems, where products and materials are reused, remanufactured, or recycled, aligning with circular economy principles to minimize waste [49, 8].

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Strategic resource management is essential amid uncertainty and dynamic markets. Robust frameworks like the H2O-Cloud use hierarchical and hybrid deep reinforcement learning (DRL) to optimize resource allocation and maintain quality of service (QoS) in cloud service providers, significantly improving energy efficiency and cost-effectiveness [50, 51, 52]. Inventory pooling and resource allocation strategies are crucial for small and medium-sized enterprises (SMEs), which often face resource optimization challenges due to limited resources and complex supply chains [19].

Integrating circular economy principles into supply chain design is fundamental for sustainability, promoting efficient resource use and waste minimization [8]. Closed-loop systems, emphasizing recycling and remanufacturing, are key strategies in this regard [49].

5.2 Closed-Loop and Continuous Review Systems

Closed-loop supply chains and continuous review systems are essential for advancing SSCM, focusing on efficient resource use and waste reduction. Closed-loop systems emphasize product and material recovery, aligning with circular economy principles to reduce environmental impact while enhancing economic efficiency [8]. Continuous review systems enable real-time inventory monitoring, mitigating risks of stockouts and overstocking [2]. Techniques like the Minimum-Cost Flow Model optimize logistics scheduling and minimize work-in-progress (WIP) fluctuations, contributing to efficient and sustainable supply chains [53].

Bandit algorithms enhance closed-loop supply chain efficiency by optimizing inventory decisions under uncertainty [54]. These data-driven approaches facilitate informed decision-making, reducing waste and aligning with SSCM goals. Implementing closed-loop systems and continuous review models in developing countries addresses resource constraints and limited infrastructure challenges [27]. Smart technologies and information systems support these efforts by integrating sustainable practices within the service sector [33].

Cost-sharing contracts optimize supply chain operations by aligning stakeholder incentives, promoting collaboration and sustainability, especially in developing countries where economic constraints hinder advanced technology adoption [54].

5.3 Inventory Pooling and Resource Allocation

Inventory pooling and resource allocation are pivotal in advancing SSCM, focusing on optimizing resource utilization, minimizing waste, and enhancing supply chain efficiency. By consolidating inventory across multiple locations, inventory pooling reduces safety stock levels and improves service levels through shared resources [18]. This approach benefits resource-constrained contexts, like developing countries, where infrastructure challenges impede efficient supply chain operations.

Advanced resource management frameworks are necessary for integrating inventory decisions into sustainable supply chains. A market-based framework for resource allocation optimizes utilization by aligning resource prices with demand, promoting equitable distribution and reducing waste [11]. Closed-loop and continuous review systems are crucial for SSCM, focusing on product reuse and recycling to minimize waste [8] and facilitating real-time inventory adjustments [2].

Innovative methodologies, such as bandit-based replenishable resource allocation, provide adaptive management solutions that maximize rewards while minimizing waste. These approaches align with SSCM objectives of efficient resource utilization and waste reduction across economic, environmental, and social dimensions. This alignment is particularly crucial in sectors like mineral supply chains, where sustainable practices enhance overall performance by addressing upstream and downstream processes [14, 55, 56, 27].

Market-based frameworks for resource allocation enhance supply chain efficiency by ensuring optimal and equitable resource distribution, especially relevant for SMEs facing resource allocation challenges [19]. Decentralized decision-making in retail chains improves inventory management by leveraging local managers' knowledge, addressing the complexities of implementing sustainable supply chain strategies in diverse contexts [24].

6 Game Theory in Supply Chain Optimization

6.1 Fair and Efficient Outcomes in Supply Chains

Game theory is integral to sustainable supply chain management (SSCM), providing an analytical framework for evaluating strategic interactions among stakeholders to achieve fair and efficient outcomes. It enhances cooperative dynamics and fosters mutually beneficial relationships, crucial for addressing challenges like information asymmetry and environmental sustainability across sectors, including consumer behavior and pharmaceutical collaborations [16, 57, 58, 4]. Integrating risk aversion and sales efforts into inventory management through game-theoretic models offers valuable insights for optimizing resource allocation and sustainability goals, especially in e-commerce [54].

Game-theoretic models are crucial in designing optimal pricing strategies in competitive markets, where pricing competition and quality of service (QoS) are interdependent [44]. By anticipating competitor pricing behaviors and understanding consumer preferences, firms can strategically adjust pricing to maintain a competitive edge and achieve market equilibrium. These models also inform resource allocation strategies, optimizing resource distribution and ensuring dynamic adjustments based on demand, aligning with SSCM principles [11]. Advanced pricing models allow companies to adapt to market fluctuations, promoting profitability while ensuring alignment with sustainable practices [41, 42, 14, 37].

Moreover, frameworks that integrate risk aversion and sales efforts in inventory management provide comprehensive tools for modeling stakeholder interactions, facilitating informed decision-making and promoting collaboration and sustainability [58].

6.2 Optimization under Uncertainty

Game theory provides a robust framework for optimizing decisions under uncertainty in SSCM, especially in volatile markets where demand and resource availability fluctuate significantly [2]. Dynamic pricing, a key SSCM component, benefits from game-theoretic models that consider real-time market conditions and consumer behavior. Implementing dynamic pricing strategies using reinforcement learning techniques like Q-Learning and Actor-Critic Information-Directed Pricing (ACIDP) enables firms to adjust pricing in response to market fluctuations, optimizing resource allocation and improving profitability [59, 51].

Game-theoretic models also enable firms to analyze and predict competitor pricing strategies and consumer behavior, allowing strategic adjustments in pricing tactics. By incorporating elements such as information asymmetry and consumer reference points, these models help optimize pricing decisions, enhance revenue management, and sustain a competitive edge. Innovative pricing strategies, such as Pay-What-You-Want and variance-based pricing, leverage consumer psychology to maximize profits while responding to competitive pressures [51, 38, 60, 43, 57]. Bi-objective mixed-integer nonlinear programming models further align with SSCM principles by optimizing cost efficiency and carbon emissions.

Game theory's application extends to various market contexts, including ride-hailing, where stochastic generalized Nash equilibrium models address demand uncertainties and optimize resource allocation. These models illustrate game-theoretic approaches' effectiveness in navigating complex market dynamics, fostering collaboration among stakeholders, and optimizing resource utilization for improved operational efficiency and sustainability [14, 57, 58, 38].

Market-based frameworks for resource allocation, as described by [11], enable firms to set resource prices based on demand, ensuring efficient resource allocation in line with SSCM principles. Incentive-compatible frameworks, like the Energy Trading Framework (ICTF), enhance pricing decisions by encouraging users to disclose true energy usage information. Dynamic pricing strategies in prosumer-centric energy markets mitigate uncertainties surrounding future energy prices and improve resource allocation. Employing a prospect-theoretic approach within a Stackelberg game framework accounts for prosumers' subjective decision-making, shaped by past experiences and future aspirations. Additionally, distributed online pricing strategies optimize demand response programs, allowing utilities to adapt to time-varying consumer behaviors and operational uncertainties, enhancing energy distribution efficiency and maximizing profits for both utilities and prosumers [61, 62].

7 Conclusion

7.1 Emerging Trends and Future Research Directions

Sustainable supply chain management (SSCM) continues to evolve through the integration of advanced technologies and innovative frameworks. A significant trend is the merging of resource allocation strategies with cutting-edge computing paradigms such as edge and cloud computing, which enhance resource efficiency and support sustainability. This synergy enables more dynamic resource allocation and real-time decision-making, thereby streamlining supply chain operations.

The application of nonlinear approaches in game-theoretic models presents a promising avenue for research, with potential to refine pricing strategies and align stakeholder interests more effectively. Extending current methodologies to incorporate complex nonlinear scenarios could increase their applicability across diverse SSCM contexts.

Standardizing indicators to assess social performance within supply chains, particularly in industries like textiles and apparel, remains a critical area for further exploration. Understanding the socio-economic factors that drive social compliance is essential for developing SSCM strategies that address industry-specific challenges.

Resource allocation and utilization optimization remains a central focus, with current methods often facing challenges in balancing multiple objectives amidst complex constraints. Enhancing existing algorithms to tackle real-world scheduling and dynamic market conditions more effectively is a key area for future research.

Developing frameworks that account for energy forecast errors and price differentiation strategies is also crucial. Modeling uncertainty accurately can provide insights into the dynamic nature of supply chains, aiding in the development of robust, adaptive strategies that foster sustainability.

In developing countries, research should address the unique challenges and opportunities for SSCM implementation, especially in the textile and apparel sectors. Investigating socio-economic influences on social compliance and establishing standardized social performance indicators are vital for a holistic SSCM approach.

Furthermore, creating tailored solutions for micro, small, and medium enterprises (MSMEs) is essential for advancing sustainable practices in these regions. Innovative financial models and policy interventions are necessary to facilitate the adoption of advanced technologies and sustainable practices, overcoming the economic constraints faced by these enterprises.

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