International Journal of Multidisciplinary Research and Growth Evaluation.

Integrating Environmental Sustainability into Healthcare Supply Chain Management: A Triple Bottom Line Framework for Enhanced Efficiency, Resilience, and Ecological Responsibility

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Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 8.04
Volume: 07
Issue: 01
Received: 20-12-2025
Accepted: 21-01-2026
Published: 23-02-2026
Page No: 819-826

Abstract
Healthcare systems face increasing pressure to balance environmental responsibility, operational efficiency, and resilience to disruptions. While prior research has examined sustainability and resilience in healthcare supply chains, these dimensions are often treated separately, resulting in fragmented strategies. This study develops a conceptual framework for a Sustainable Healthcare Supply Chain (SHSC) that integrates sustainability, efficiency, and resilience within a unified model. Drawing on the literature on sustainable supply chain management, circular economy, and healthcare operations, this study proposes that sustainability-oriented practices, particularly circular economy initiatives, can simultaneously enhance cost efficiency and system resilience. The framework positions sustainability as a strategic driver, rather than a compliance obligation. This study advances the theory by conceptualizing interdependencies among key supply chain dimensions and offers practical guidance for healthcare organizations seeking long-term operational viability. Future research is encouraged to empirically validate the proposed relationships across diverse healthcare contexts.

DOI: https://doi.org/10.54660/.IJMRGE.2026.7.1.819-826

Keywords: Healthcare Supply Chain Management, Environmental Sustainability, Triple Bottom Line, Circular Economy, Green Supply Chain, Resilience, Sustainable Healthcare

1. Introduction

Healthcare supply chains play a central role in delivering safe and timely patient care, yet they also contribute substantially to environmental degradation. The healthcare sector accounts for approximately 4–5% of national carbon emissions in developed countries (Pichler *et al.*, 2019) [38], while the broader system generates significant waste and pollution (Eckelman & Sherman, 2016; Karliner *et al.*, 2019) [14, 31]. These environmental impacts threaten public health, creating a paradox in which systems intended to promote health contribute to ecological harm (Watts *et al.*, 2021) [56].

Concurrently, healthcare supply chain research has prioritized efficiency and resilience. Lean management and just-in-time systems focus on cost minimization (Almutairi *et al.*, 2020; Balkhi *et al.*, 2022) [2, 5], while pandemic-related studies emphasize disruption mitigation and adaptive capacity (Friday *et al.*, 2021; Spieske *et al.*, 2022) [19, 50]. Environmental sustainability, however, is often treated as an auxiliary concern rather than a core design objective (Apeh *et al.*, 2024; Betcheva *et al.*, 2021) [3, 8]. This separation limits strategic integration and obscures potential complementarities among sustainability, efficiency, and resilience.

This study addresses this gap by developing a Sustainable Healthcare Supply Chain (SHSC) framework that integrates these three dimensions. Grounded in Triple Bottom Line theory (Elkington, 1997) [15], Circular Economy principles (Ellen MacArthur Foundation, 2013; Geissdoerfer *et al.*, 2017) [16, 21], Stakeholder Theory (Freeman, 1984) [18], and Resource Dependence Theory (Pfeffer & Salancik, 1978) [37], the framework conceptualizes environmental sustainability as a driver of efficiency and resilience.

By synthesizing fragmented literature through theory-building methods (Jaakkola, 2020; Whetten, 1989) [28, 57], the study provides conceptual clarity and establishes propositions for future empirical research.

2. Literature Review

2.1. The Sustainability Gap

The healthcare supply chain literature emphasizes efficiency (cost minimization and inventory optimization) and resilience (disruption mitigation and adaptability). These paradigms systematically exclude environmental sustainability from their core frameworks (Apeh *et al*., 2024) [3]. When sustainability appears, it is relegated to brief policy mentions disconnected from substantive contributions (Apeh *et al*., 2024; Betcheva *et al*., 2021) [3, 8].

Despite the growing recognition of environmental concerns, traditional supply chain theories have been applied to healthcare, including just-in-time inventory systems (Balkhi *et al*., 2022; Ufua *et al*., 2022) [5, 53], lean management approaches (Almutairi *et al*., 2020; Prado-Prado *et al*., 2020) [2, 39], and general supply chain management frameworks (Benton, 2020; Habib *et al*., 2022; Srivastava *et al*., 2021) [7, 25, 51], and continue to prioritize operational metrics while marginalizing environmental considerations.

2.2. Environmental Impacts

Healthcare supply chains generate substantial environmental impacts through greenhouse gas emissions, waste generation, resource depletion, and chemical pollution (Karliner *et al*., 2019; Eckelman and Sherman, 2016) [31, 14]. International comparisons revealed significant variations in healthcare carbon footprints across countries, with the sector contributing 4-5% of national emissions in developed nations (Pichler *et al*., 2019) [38]. The pharmaceutical industry is a major contributor to global carbon emissions (Belkhir and Elmeligi, 2019) [6]. Comprehensive assessments have demonstrated that climate change and environmental degradation directly threaten the health outcomes that healthcare systems seek to improve (Watts *et al*., 2021) [56]. The linear take-make-dispose model accelerates resource depletion, while generating externalities that are excluded from conventional efficiency calculations (Macneill *et al*., 2021) [34]. Early reviews of green supply chain management have identified environmental sustainability as a critical concern across industries (Srivastava, 2007; Fahimnia *et al*., 2015; Green *et al*., 2012) [52, 17, 24]. However, healthcare has been slower to integrate these principles than in the manufacturing and retail sectors. The COVID-19 pandemic has exacerbated environmental challenges through increased single-use plastic consumption and medical waste generation (Prata *et al*., 2020) [40].

2.3. Theoretical Foundations

The SHSC framework integrates Triple Bottom Line (TBL) theory (Elkington, 1997) [15], Circular Economy principles (Ellen MacArthur Foundation, 2013) [16], Stakeholder Theory (Freeman, 1984) [18], and Resource Dependence Theory (Pfeffer and Salancik, 1978) [37]. Each provides essential insights into sustainable supply chain management. While influential, has faces critiques regarding measurement challenges and potential trade-offs between the economic, social, and environmental dimensions (Norman and MacDonald, 2004) [36]. The stakeholder Theory posits that organizations must strategically manage relationships with multiple constituencies whose interests may conflict or converge (Freeman, 1984; Donaldson & Preston, 1995) [18, 13]. The Circular Economy represents a fundamental paradigm shift from linear economic models, emphasizing resource regeneration and waste elimination (Ellen MacArthur Foundation, 2013; Geissdoerfer *et al*., 2017) [16, 21]. Together, these theories provide complementary lenses for understanding how healthcare supply chains can pursue efficiency, resilience, and environmental sustainability simultaneously.

3. Methodology (Conceptual Framework Development)

This study adopts a conceptual theory-building methodology to integrate fragmented sustainability and healthcare supply chain literature into a coherent analytical framework. Conceptual research is appropriate when existing knowledge is dispersed across disciplines and requires theoretical integration rather than empirical measurement (Jaakkola, 2020) [28].

First, foundational theories relevant to sustainability and organizational behavior–the Triple Bottom Line, Circular Economy, Stakeholder Theory, and Resource Dependence Theory–are selected based on their explanatory relevance to the environmental, operational, and institutional dimensions of healthcare supply chains.

Second, peer-reviewed academic literature, policy reports, and healthcare sustainability studies were examined to identify recurring mechanisms linking operational efficiency, resilience, and environmental performance. The review emphasizes explanatory constructs rather than frequency counts, focusing on causal logic and complementarities across disciplines, consistent with theory-building literature review approaches (Snyder, 2019) [49].

Third, constructs identified across theories are comparatively mapped to detect overlaps, reinforcing relationships, and dependency structures. These relationships are then abstracted into an integrated Sustainable Healthcare Supply Chain (SHSC) framework. Subsequently, propositions were deductively derived from theoretical relationships to enable future empirical testing (Whetten, 1989) [57].

4. The Sustainable Healthcare Supply Chain Framework

The SHSC framework conceptualizes healthcare supply chain management with three co-equal strategic objectives: economic efficiency, resilience, and environmental sustainability. These objectives are interconnected and mutually reinforcing rather than competing. Environmental sustainability enhances efficiency by eliminating waste, reducing disposal costs, conserving energy, lowering expenses, and improving material efficiency, thereby decreasing procurement costs. This enhances resilience by reducing resource dependency, decreasing regulatory risk, and mitigating climate-related disruptions.

Recent global disruptions, particularly the COVID-19 pandemic, have exposed vulnerabilities in healthcare supply chains, while simultaneously demonstrating the interconnections among efficiency, resilience, and sustainability (Friday *et al*., 2021; Goodarzian *et al*., 2021; Spieske *et al*., 2022) [19, 22, 50]. Research on pandemic-related supply chain disruptions reveals that organizations with greater flexibility, redundancy, and diversified supplier networks demonstrate superior resilience (Sen Gupta, 2020; Coslett, 2022; Sharma *et al*., 2022) [45, 10, 48]. Healthcare supply chain resilience frameworks emphasize the importance of antecedents, such as risk management capabilities; mediators, including information sharing and collaboration; and consequences, including operational performance and patient outcomes (Senna *et al.*, 2023; Rehman and Ali, 2022) [46, 41]. The integration of resilience and sustainability objectives enhances overall system adaptability and long-term viability (Furstenau *et al.*, 2022) [20].

5. Circular Economy Principles in Healthcare Supply Chains

Circular economy principles- reduce, reuse, recycle, and redesign- offer operational mechanisms for achieving sustainability objectives while enhancing efficiency and resilience. Conceptualizing redundancy and flexibility as essential design features enables supply chains to absorb shocks and adapt to unforeseen changes (Mackay *et al.*, 2020; Kamalahmadi and Parast, 2022) [33, 29]. This section examines healthcare-specific applications of each principle.

5.1. Reduce: Demand Management and Product Longevity

Reduction strategies address unnecessary consumption at multiple levels. Clinical protocol optimization eliminates redundant testing, duplicate imaging, and excessive pharmaceutical prescriptions. Evidence-based standardization reduces product variety; hospitals typically stock 3,000-8,000 distinct products, creating inventory complexity and wastage (Schneller *et al.*, 2023) [44]. Product standardization through value analysis teams can reduce inventory by 20-30% while improving availability and reducing costs (Schneller *et al.*, 2023) [44].

Equipment-sharing arrangements enable multiple departments or facilities to share expensive capital equipment (such as MRI machines and surgical robots) rather than maintaining underutilized capacity. Sharing models reduce capital expenditure, space requirements, and material consumption, while improving equipment utilization. Predictive maintenance extends equipment life by preventing failures and optimizing replacement timing, thereby reducing premature disposal (MacNeill *et al.*, 2021) [34].

Demand forecasting improvements through data analytics reduce safety stock requirements and expired product waste. Pharmaceutical waste from expiration represents significant economic and environmental costs, and improved forecasting captures value while reducing disposal burden (Chapman *et al.*, 2022) [9]. Decision support systems for demand management can optimize inventory levels and reduce waste, which are critical during epidemic outbreaks and supply disruptions (Govindan *et al.*, 2020) [23]. Cold chain management presents specific challenges that require specialized logistics capabilities to prevent the spoilage of temperature-sensitive products (Danso, 2021; Sharma *et al.*, 2021) [11, 47]. Healthcare organizations in resource-constrained settings face additional complexities in managing essential medicine supply chains, where reduction strategies must balance efficiency while ensuring adequate availability (Kaupa and Naudé, 2021; Umoren *et al.*, 2021) [32, 54]. Right-sizing packaging eliminates excess material. For example, single-use surgical kits often contain items that are never used, generating waste and increasing costs.

5.2. Reuse: Reprocessing and Refurbishment

Single-use device reprocessing is a mature reuse strategy, with established regulatory frameworks. Third-party reprocessors collect used devices, clean, sterilize, test, and repackage them for subsequent use at substantially lower costs than new devices, while meeting identical safety standards (MacNeill *et al.*, 2021) [34]. The US Food and Drug Administration (FDA) regulates reprocessed devices to be equivalent to the original devices, ensuring safety and efficacy.

Reprocessing reduces costs by 40-60% compared to new devices while eliminating 30-50% of medical device waste (MacNeill *et al.*, 2021) [34]. Environmental benefits include reduced raw-material extraction, manufacturing emissions, and landfill burden. Commonly reprocessed devices include cardiac catheters, orthopedic surgical instruments, endoscopic accessories, and electrophysiological catheters. Hospitals implementing comprehensive reprocessing programs report annual savings of hundreds of thousands to millions of dollars depending on the surgical volume.

Refurbishment of medical equipment extends product life through systematic repairs, part replacements, and software updates. Refurbished imaging equipment, surgical robots, and patient monitoring systems perform equivalently to new equipment with a 30-70% cost reduction (MacNeill *et al.*, 2021) [34]. Original equipment manufacturers increasingly offer certified refurbishment programs that provide warranties and service agreements that are comparable to those of new equipment. Refurbishment diverts equipment from premature disposal, captures residual value, and reduces the demand for manufacturing processes.

Reusable products that substitute single-use items offer another pathway for reuse. Surgical gowns, drapes, and instrument trays manufactured from durable materials and designed for repeated sterilization and use demonstrate lower life-cycle environmental impacts and costs than single-use equivalents when the use frequency exceeds the break-even points typically between 50-75 uses (Rizan *et al.*, 2021) [42]. Similarly, reusable sharps containers, anesthesia breathing circuits, and patient warming blankets reduce waste while generating cost savings for the hospital.

5.3. Recycle: Material Recovery Systems

Material recycling recovers value from healthcare waste streams through waste segregation, processing, and remanufacturing. Healthcare facilities generate diverse recyclable materials including plastics, metals, glass, paper, and cardboard. However, recycling rates in healthcare lag behind those in other sectors due to contamination concerns, regulatory complexities, and operational challenges (Windfeld & Brooks, 2015) [58].

Effective recycling programs require source segregation to distinguish between general waste, recyclables, regulated medical waste, and hazardous wastes. Training staff on proper segregation is critical; improper disposal of non-contaminated materials as regulated medical waste increases costs 5-10 fold while eliminating recycling opportunities (Windfeld and Brooks, 2015) [58]. Blue wrap (sterile packaging material used in operating rooms) recycling programs collect clean polypropylene for re-manufacturing into new products, diverting thousands of pounds from landfills annually, and generating modest revenue.

Recycling of medical devices recovers valuable materials from end-of-life (EOL) equipment. Electronic medical devices contain precious metals (gold, silver, and platinum), base metals (copper and aluminum), and rare-earth elements that can be extracted through specialized recycling processes. Battery recycling programs capture lead, lithium, and other materials from batteries used in medical devices. Some manufacturers operate take-back programs that accept end-of-life devices for material recovery and responsible disposal, thereby supporting the principles of extended producer responsibility.

Owing to safety concerns, pharmaceutical waste presents recycling challenges. However, programs that recover unused medications from patients prevent environmental contamination from improper disposal while potentially enabling redistribution to underserved populations through pharmacy collection programs, although regulatory frameworks vary by jurisdiction. Although controlled substance regulations complicate pharmaceutical recycling, environmental contamination from flushed or landfilled medications has motivated the development of improved collection and disposal systems (Verlicchi and Zambello, 2014) [55].

Food safety and drug quality considerations intersect with recycling and waste management practices throughout healthcare supply chains, thus requiring careful contamination control and regulatory compliance (Haji *et al*., 2022) [26]. The integration of environmental management systems with the existing quality and safety protocols remains a critical challenge.

5.4. Redesign: Product and System Innovation

Redesign represents the most transformative circular economy principle, addressing the root causes of resource consumption and waste generation through product and system innovation. Design for the Environment (DfE) integrates environmental considerations into product development, emphasizing material reduction, recyclability, disassembly, and reduced toxicity (MacNeill *et al*., 2021) [34]. Medical device manufacturers implementing DfE principles reduce material intensity through lightweighting and miniaturization, select materials facilitating recycling (mono-material designs), design for disassembly enabling component separation and material recovery, eliminate hazardous substances, reduce disposal complexity, and extend product life through modular design, enabling component replacement rather than complete device disposal. Some manufacturers now offer modular surgical instruments, in which individual components can be replaced instead of discarding entire instrument sets.

Packaging redesign addresses the substantial waste generation. Medical products require protective packaging to ensure sterility and prevent damage; however, conventional packaging is oversized and material intensive. Optimized packaging uses appropriately sized containers, replaces plastics with recyclable materials, incorporates recycled content, and is designed for efficient transportation, thereby reducing fuel consumption (MacNeill *et al*., 2021) [34]. Some suppliers now offer reusable shipping containers returned after delivery, thereby eliminating single-use packaging.

Service-based business models represent system-level redesign. Equipment-as-a-service arrangements transfer ownership to manufacturers who retain responsibility for maintenance, upgrades, and end-of-life management, whereas healthcare facilities pay per use. This incentivizes manufacturers to design durable and maintainable equipment that optimizes lifecycle value rather than maximizing sales volume. Pay-per-procedure models for surgical robots and imaging equipment align manufacturers' incentives with equipment longevity and performance, rather than replacement frequency.

Supply chain network redesign optimizes distribution and reduces transportation emissions and costs. Consolidated distribution centers that serve multiple facilities can achieve economies of scale. Local sourcing, where feasible, reduces transportation distance. Route optimization algorithms minimize fuel consumption. These redesign strategies simultaneously enhance efficiency and resilience through reduced supply chain complexity, and sustainability through emission reduction.

6. Regulatory Landscape and Stakeholder Pressures

Environmental regulations and stakeholder expectations are transforming the strategic context of healthcare supply chain management, making sustainability integration imperative, rather than discretionary. This section examines regulatory developments and driving changes in stakeholder dynamics.

6.1. Evolving Environmental Regulations

Carbon pricing mechanisms, such as carbon taxes and emissions trading systems, increasingly encompass the health care sector. The European Union Emissions Trading System, which is the world's largest carbon market, includes healthcare facilities above the size thresholds. Carbon prices create direct financial incentives for emission reduction throughout the supply chain (MacNeill *et al*., 2021) [34]. As carbon prices increase, supply chain emissions represent growing financial liabilities, which motivate the development of mitigation strategies.

Extended Producer Responsibility (EPR) regulations mandate that manufacturers assume responsibility for end-of-life product management. EPR frameworks for medical devices are emerging in multiple jurisdictions, requiring manufacturers to establish take-back programs, achieve recycling targets, and finance waste-management systems (Macneill *et al*., 2021) [34]. EPR shifts disposal costs from healthcare facilities to manufacturers, while incentivizing the design for recyclability and reducing material intensity.

Mandatory environmental reporting requirements create transparency and accountability in an industry. The UK National Health Service mandates the gas emissions by all healthcare organizations. California requires large healthcare systems to report emissions and to establish reduction targets. The proposed US Securities and Exchange Commission climate disclosure rules would require publicly traded healthcare companies to report Scope 1, 2, and 3 emissions, including supply chain impacts (MacNeill *et al*., 2021) [34]. The disclosure requirements enable stakeholder scrutiny and performance comparison.

Waste management regulations restrict disposal options and increase the costs of non-compliant practices. Medical waste incineration regulations require expensive pollution control equipment or mandates the use of alternative treatment technologies. Landfill restrictions prohibit the disposal of specific materials. Pharmaceutical waste disposal regulations prevent environmental contamination and increase compliance costs (Windfeld & Brooks, 2015) [58]. Regulatory complexity creates compliance risks that can be mitigated using proactive sustainability strategies.

Single-use plastic regulations are proliferating globally, banning and restricting certain plastic products. Although medical exemptions often exist, regulatory trajectories toward plastic reduction affect medical-device packaging and products. Anticipating regulatory evolution has led healthcare organizations and manufacturers to proactively reduce plastic use, develop alternative materials, and design circularity (MacNeill *et al*. 2021) [34].

6.2. Stakeholder Expectations and Pressures

Employee expectations include environmental responsibilities. Healthcare workers, particularly those of younger generations, seek employment in organizations that demonstrate environmental commitment. Sustainability initiatives enhance recruitment, retention, and employee engagement Staff-led sustainability committees, green teams, and environmental champions mobilize grassroots support for supply chain transformations. Employee activism regarding climate change and environmental health motivates organizational actions (MacNeill *et al*., 2021) [34].

Patient preferences increasingly incorporate environmental considerations into health care. Survey research indicates that substantial patient segments prefer environmentally responsible healthcare providers and would switch providers, based on their environmental performance (MacNeill *et al*., 2021) [34]. Given the health consequences of pollution and climate change, patient advocacy organizations are demanding reductions in the environmental impact of health care. Hospitals market environmental initiatives to attract environmentally conscious patients and communities to their facilities.

Investor pressure for environmental performance manifests through environmental, social, and governance (ESG) investment frameworks. Institutional investors are increasingly screening portfolios based on ESG criteria, excluding poor environmental performers, and rewarding leaders. Shareholder resolutions demand climate action and environmental disclosure. Healthcare companies with superior environmental performance have access to lower-cost capital, whereas laggards face divestment and higher capital costs (MacNeill *et al*., 2021) [34]. Supply chain environmental performance is increasingly being included in ESG ratings and investor assessments.

Community expectations reflect the growing recognition of the environmental impact of health care on local environmental quality and public health. Communities surrounding healthcare facilities experience air pollution from heating systems and emergency generators, water pollution from pharmaceutical residues, and waste-management problems. Community advocacy demands emissions reduction, pollution prevention, and environmental justice. Healthcare organizations positioned as community health anchors face legitimacy challenges when their environmental practices contradict their health-promotion missions.

Purchaser requirements are increasingly incorporating environmental considerations. Group purchasing organizations (GPOs) have developed sustainable procurement programmes. Government payers establish environmental requirements for the contracted providers. Accountable care organizations integrate environmental performance into the provider selection process. Environmental criteria in purchasing decisions create competitive advantages for sustainable suppliers, while pressuring laggards to improve their performance (Schneller *et al*., 2023) [44].

6.3. Sustainability as Resilience Strategy

Regulatory and stakeholder pressure have transformed environmental sustainability from corporate social responsibility to strategic resilience. Organizations that fail to anticipate and adapt face regulatory penalties, operational disruptions, reputational damage, talent recruitment challenges, market share losses, and increased capital costs. Conversely, proactive sustainability integration provides competitive advantage through regulatory compliance, stakeholder satisfaction, operational efficiency, innovation capabilities, and risk mitigation.

Resource Dependence Theory illuminates these dynamics (Pfeffer and Salancik, 1978) [37]. Healthcare organizations depend on regulatory legitimacy, employee talent, patient volume, investor capital, and community support, all of which are increasingly contingent on environmental performance. Managing these dependencies requires sustainability integration throughout the supply chain's strategies and operations. Organizations treat sustainability as a peripheral risk-dependent disruption, as regulations tighten and stakeholder expectations increase.

6.4. Government Support and Policy Enablers

Government policies and institutional support play crucial roles in enabling sustainable healthcare supply chain transformation. An analysis of government-supported healthcare supply chain initiatives revealed that policy frameworks, financial incentives, and regulatory mechanisms significantly influence the adoption of sustainability practices (Dixit *et al*., 2020) [12]. Public-sector healthcare organizations often lead sustainability initiatives because of policy mandates and accountability to public stakeholders. However, effective implementation requires coordination among multiple government agencies, healthcare providers, and private sector suppliers. Strategic government interventions can address market failures, provide transitional support for capability building, and establish standards that create a level-playing field for sustainable practices.

7. Implementation Strategies and Performance

7.1. Strategic Implementation Domains

The SHSC framework is operationalized through six strategic domains: sustainable procurement; integration of environmental criteria into supplier selection and purchasing decisions; green logistics; optimizing transportation and distribution to reduce emissions; circular material flows; implementing reduce-reuse-recycle-redesign principles; waste minimization through source reduction and segregation improvement; energy and emissions reduction throughout supply chain operations; supplier environmental management; and cascading sustainability requirements through supply networks. Each domain offers specific intervention opportunities, which require coordination.

Technology adoption and digitalization are critical enablers across all implementation domains. Advanced technologies, including the Internet of Things (IoT), blockchain, artificial intelligence, and data analytics, are transforming healthcare supply chain operations (Bag *et al*., 2021; Sallam *et al*., 2024) [4, 43]. Big data analytics capabilities enable organizations to identify sustainability opportunities, monitor environmental performance, and optimize resource allocation; however, implementation faces challenges, including data quality, integration complexity, and capability gaps (Hussain *et al*., 2024; Kamboj and Rana, 2023) [27, 30]. Organizations must assess their readiness to adopt Healthcare 4.0, considering the technical infrastructure, workforce capabilities, and change management requirements (Narayanamurthy *et al*., 2021) [35]. Artificial intelligence and automation technologies offer particular promise for optimizing processes and reducing waste; however, their integration requires careful planning and phased implementation (Aldoseri *et al*., 2023) [1].

7.2. Performance Measurement

Triple bottom-line performance measurement encompasses economic metrics (supply chain costs and efficiency indicators), social metrics (employment practices, health equity, and community engagement), and environmental metrics (greenhouse gas emissions, waste generation, resource consumption, and pollution). Balanced scorecards incorporating all three dimensions prevent suboptimization and ensure a comprehensive performance assessment. Leading organizations establish key sustainability performance indicators alongside traditional supply chain metrics, integrate environmental performance into executive compensation, and publicly report triple-bottom-line outcomes. Measurement models for green supply chain management practices provide frameworks for assessing implementation effectiveness and identifying opportunities (Zhu *et al*., 2008) [59]. However, healthcare-specific adaptations are necessary to account for the unique performance requirements, including patient safety, regulatory compliance, and clinical outcomes.

8. Barriers and Enablers

8.1. Implementation Barriers

Organizational barriers include competing priorities, resource constraints, and short-term financial pressures that favor conventional methods. Cultural resistance among staff who are unfamiliar with sustainability concepts impedes adoption. Knowledge gaps regarding sustainable alternatives and their performance characteristics create uncertainty in decision making. Measuring challenges in quantifying environmental impacts and attributing benefits complicates the development of business cases.

Supply chain barriers include supplier capabilities, which vary widely, with some suppliers lacking the capacity or motivation to improve their sustainability. Product availability constraints limit the sustainable options for certain medical devices and pharmaceuticals. Regulatory uncertainties regarding reprocessing and reuse create liabilities. Upfront investment requirements for infrastructure, training, and systems deter organizations with limited budgets from adopting AI.

8.2. Enablers and Success Factors

Leadership commitment is an essential enabler, with executive sponsorship legitimizing sustainability as a strategic priority. Cross-functional governance structures ensure coordination across clinical, operational, and supply chain functions. Staff engagement through green teams and sustainability training builds grassroots support for sustainability initiatives. Supplier partnerships with environmental leaders accelerate capability development. Technology platforms that enable environmental data collection, analysis, and reporting support the measurement and improvement of environmental performance. Peer learning through sustainability collaboratives and consortia accelerates adoption through shared learning and collective action.

9. Research Propositions

The SHSC framework generates testable propositions for future empirical research.

P1: Healthcare supply chains implementing circular economy principles demonstrate higher environmental performance and operational efficiency than those implementing linear models.

P2: Environmental sustainability practices are positively associated with supply chain resilience through reduced resource dependency and enhanced compliance with regulations.

P3: Stakeholder pressure mediates the relationship between environmental sustainability adoption and supply chain performance.

P4: Integrating environmental criteria into supplier management enhances sustainability outcomes and supplier relationship quality.

P5: Triple bottom-line orientation in supply chain management predicts superior long-term performance across economic, social, and environmental dimensions.

10. Limitations and Future Research

Although the Sustainable Healthcare Supply Chain (SHSC) framework provides a comprehensive conceptual model integrating efficiency, resilience, and environmental sustainability, this study is inherently theoretical and does not empirically test the proposed relationships. This framework is based on literature synthesis and deductive reasoning, which may limit its applicability across diverse healthcare contexts with varying regulatory, cultural, and operational conditions. Additionally, the framework focuses primarily on environmental sustainability, with less emphasis on other social dimensions such as equity or patient-centered outcomes. Future research should empirically validate these propositions, examine contextual contingencies, and explore additional social and technological factors influencing sustainable healthcare supply chain performance.

11. Conclusion

This study addresses a critical gap in the healthcare supply chain management literature: the systematic neglect of environmental sustainability despite substantial environmental footprints and strategic imperatives that drive integration. The Sustainable Healthcare Supply Chain framework repositions environmental sustainability from a peripheral concern to a core strategic objective alongside efficiency and resilience.

The framework challenges the prevailing dual-focus paradigms by demonstrating that environmental sustainability is fundamentally interconnected with efficiency and resilience objectives. It synthesizes disparate theoretical perspectives into coherent healthcare-specific guidance. It identifies circular economy mechanisms to operationalize sustainability. It articulates regulatory and stakeholder dynamics, making strategic sustainability integration imperative.

Healthcare's mission to protect and promote human health cannot be fulfilled while contributing to the environmental degradation that undermines health. Sustainable healthcare supply chains represent fundamental strategic imperatives that align with the operations and values. The SHSC framework provides theoretical and practical foundations for essential transformations toward supply chains that serve current needs without compromising the viability of future healthcare systems.

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How to Cite This Article

Etugbo OB. Integrating Environmental Sustainability into Healthcare Supply Chain Management: A Triple Bottom Line Framework for Enhanced Efficiency, Resilience, and Ecological Responsibility. Int J Multidiscip Res Growth Eval. 2026;7(1):819–26. doi:10.54660/.IJMRGE.2026.7.1.819-826.

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