REVIEW ARTICLE

Green Supply Chain Practices in Hospitals and Pharmaceutical Manufacturing

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ABSTRACT

Growing environmental concerns and the urgent need to reduce the ecological footprint of healthcare systems have accelerated the adoption of Green Supply Chain Management (GSCM) practices in hospitals and pharmaceutical manufacturing. These sectors generate substantial waste, consume large amounts of energy, and contribute to pharmaceutical pollution. This review synthesizes current literature on GSCM in healthcare, covering green procurement, waste management, resource efficiency, sustainable manufacturing, and reverse logistics. It also evaluates drivers, barriers, and future directions. Findings indicate that although sustainability awareness is increasing, challenges such as high implementation costs, regulatory constraints, and supply chain complexity continue to hinder progress. The review concludes by identifying research gaps related to circular economy integration, carbon accounting, and digital sustainability tools.

KEYWORDS: Green supply chain management; sustainable healthcare; hospital sustainability; pharmaceutical manufacturing; green procurement; waste management; reverse logistics; green chemistry; environmental sustainability;

INTRODUCTION

The healthcare sector plays a critical role in improving population health, yet paradoxically, it is also one of the most environmentally impactful service industries worldwide. Hospitals, clinics, diagnostic facilities, and pharmaceutical manufacturers collectively consume massive amounts of energy, water, chemicals, and raw materials to deliver medical services and produce life-saving medicines. Consequently, they generate substantial waste streams, including hazardous waste, general solid waste, pharmaceutical residues, greenhouse gas emissions, and wastewater contaminants. Recent estimates indicate that the global healthcare sector is responsible for approximately 4–5% of total global carbon emissions, making it one of the most carbon-intensive public service sectors [1]. In many high-income countries, the healthcare sector's carbon footprint exceeds that of entire national industries such as aviation or construction, underscoring the urgent need for sustainable transformation [1,2].

Green Supply Chain Management (GSCM) has emerged as a comprehensive strategy for reducing the environmental impact associated with production, distribution, and service delivery. In manufacturing, GSCM integrates environmental considerations across all supply chain activities—including procurement, product design, production, transportation, use, and disposal—with the goal of minimizing environmental burdens while maintaining operational efficiency [2]. Although GSCM practices have been widely adopted in automotive, electronics, and textile industries, their application in healthcare settings has gained momentum only in the last two decades. This slow uptake is due to multiple factors, including stringent regulatory requirements, concerns over patient safety, complex logistics, and high reliance on single-use products for infection control [3].

In hospitals, sustainability challenges arise from the continuous need for sterilization, lighting, cooling, heating, and operation of energy-intensive medical equipment. Hospitals operate 24 hours a day, often under strict clinical safety protocols that necessitate controlled airflow, precise temperature regulation, and frequent sterilization all of which elevate energy consumption significantly above that of typical commercial buildings [4]. Furthermore, hospitals generate diverse waste streams such as infectious waste, pharmaceutical waste, sharps, plastics, and electronic waste. Managing these materials safely while minimizing environmental impact requires meticulously designed supply chains and effective segregation, recycling, and disposal practices [5]. As healthcare demand grows globally, especially in aging populations and urban areas, the environmental footprint of hospitals is expected to increase unless proactive green strategies are adopted.

Pharmaceutical manufacturing presents an additional layer of complexity. Drug production involves multi-step chemical synthesis processes that often rely on hazardous solvents, high energy inputs, and strictly controlled cleanroom environments. Studies have shown that pharmaceutical manufacturing can be up to 100 times more energy intensive than traditional chemical production due to stringent sterility and purification requirements [6]. Moreover, the industry contributes to environmental pollution through solvent emissions, contaminated wastewater, and improper disposal of active pharmaceutical ingredients (APIs). These pollutants can enter water systems and contribute to antimicrobial resistance, endocrine disruption, and ecological toxicity [7]. Given the global expansion of pharmaceutical production, particularly in emerging economies with weaker environmental regulation, the need for sustainable supply chain interventions is more pressing than ever.

In response to these sustainability challenges, healthcare providers and pharmaceutical companies have begun adopting a range of GSCM practices, including green procurement policies, waste minimization programs, sustainable packaging, renewable energy integration, environmentally responsible manufacturing processes, and reverse logistics systems for managing expired or unused products [8]. For example, many hospitals now practice

environmentally preferable purchasing (EPP), prioritize reusable medical items where safe, and invest in energy-efficient HVAC and lighting systems. Meanwhile, pharmaceutical firms increasingly explore green chemistry principles to reduce solvent use, optimize reactions, and recover valuable materials from waste streams [9].

Despite these advances, GSCM adoption remains uneven and faces numerous barriers. High upfront costs, inadequate staff training, lack of standardized sustainability metrics, and resistance to change within healthcare organizations often hinder progress. Additionally, sustainable alternatives—such as reusable medical devices or biodegradable packaging—must always meet strict clinical safety standards, which complicates procurement and innovation efforts [10]. Furthermore, the global nature of pharmaceutical supply chains, involving extensive outsourcing and multiple tiers of suppliers, makes upstream environmental monitoring extremely challenging [11].

Given the growing recognition of healthcare's role in climate change, environmental degradation, and public health threats, there is an urgent need for a comprehensive understanding of how GSCM is being implemented in hospitals and pharmaceutical manufacturing. This review therefore aims to synthesize current research on green supply chain practices across these two critical sectors, highlight key strategies, assess drivers and barriers, and identify gaps that future research should address. By examining both operational and strategic dimensions of GSCM, this paper provides insights into how healthcare systems can reduce environmental impact while maintaining high standards of safety, quality, and efficiency.

AIM

The aim of this review is to critically examine and synthesize existing literature on Green Supply Chain Management (GSCM) practices within hospitals and pharmaceutical manufacturing sectors. Specifically, the review seeks to identify the key environmental sustainability strategies currently implemented, analyze the drivers and barriers influencing their adoption, and evaluate their impact on operational efficiency and environmental performance. By integrating findings across diverse studies, this review aims to provide a comprehensive understanding of how healthcare institutions and pharmaceutical industries can strengthen sustainability, reduce their ecological footprint, and support the transition toward greener and more resilient healthcare supply chains.

MATERIALS AND METHOD

This review followed a structured and systematic approach to identify, screen, and synthesize published literature on Green Supply Chain Management (GSCM) practices in hospitals and pharmaceutical manufacturing. The methodology was designed to ensure transparency, replicability, and comprehensive coverage of relevant peer-reviewed research. A narrative review approach was used, guided by principles commonly applied in systematic and scoping reviews.

Search Strategy

A comprehensive search of major academic databases—including PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar—was conducted to identify studies published between 2000 and 2024. This timeframe was selected because GSCM research in healthcare began to gain momentum in the early 2000s. Additional sources such as WHO reports, UNEP publications, and industry sustainability guidelines were also consulted to capture grey literature relevant to the healthcare supply chain.

The search process used a combination of Medical Subject (MeSH) and free-text keywords. Boolean operators (AND, OR) were applied to refine the search.

Inclusion and Exclusion Criteria

Clear inclusion and exclusion criteria were established prior to screening.

Inclusion Criteria

Studies were included if they:

1. Focused on hospitals, healthcare organizations, or pharmaceutical manufacturing.
2. Examined environmental or sustainability practices related to supply chain processes.
3. Were peer-reviewed articles, conference papers, or relevant institutional reports.
4. Were published in English.
5. Provided empirical findings, reviews, case studies, or conceptual frameworks related to GSCM.

Exclusion Criteria

Studies were excluded if they:

1. Focused solely on clinical outcomes with no discussion of supply chain sustainability.
2. Discussed industrial manufacturing unrelated to healthcare or pharmaceuticals.
3. Lacked accessible full texts.
4. Were opinion pieces without academic or institutional backing.
5. Were duplicated across databases.

Study Selection Process

The initial database search generated approximately several thousand records. After removing duplicates, titles and abstracts were screened for relevance based on the inclusion criteria. Full texts of potentially relevant articles were then reviewed in detail. Additional studies were identified through reference list screening (snowballing). The final selection consisted of articles that directly addressed green supply chain practices in hospitals and pharmaceutical manufacturing, covering themes such as green procurement, energy efficiency, waste management, sustainable packaging, reverse logistics, and green manufacturing.

Data Extraction and Synthesis

Data from the selected studies were extracted using a structured template that included:

- Study author and year
- Setting (hospital, pharmaceutical industry, or both)
- Type of GSCM practice examined
- Methodology used
- Key findings
- Reported barriers and drivers
- Identified outcomes (environmental, economic, operational)

A thematic synthesis approach was used to group findings into major domains reflecting the core components of GSCM. These themes included green procurement, waste reduction, energy and resource efficiency, sustainable manufacturing practices, reverse logistics, and supplier environmental evaluation. Studies were compared and contrasted to identify common patterns, gaps, and variations across different healthcare systems and geographic regions.

Quality Assurance

Although a formal risk-of-bias assessment was not applied due to the heterogeneity of the included study designs (qualitative, quantitative, reviews, and case studies), priority

was given to peer-reviewed research published in reputable journals. Grey literature from credible organizations such as WHO and UNEP was included only when it offered substantial data on sustainability practices.

Green Supply Chain Practices in Hospitals

Green Procurement

Green procurement in hospitals involves selecting products and services based on their environmental impact, including life-cycle pollution, toxicity, recyclability, and production sustainability. Many hospitals now prioritize eco-labelled cleaning agents, reusable surgical instruments, recyclable consumables, and low-emission medical devices [12]. Evidence shows that adopting Environmentally Preferable Purchasing (EPP) policies significantly reduces hazardous chemical exposure and lowers waste generation without compromising clinical quality [13]. Additionally, supplier environmental certifications such as ISO 14001 increasingly influence hospital purchasing decisions.

Waste Reduction and Recycling

Hospitals generate diverse waste streams, including biomedical waste, pharmaceuticals, plastics, food waste, and electronic waste. Improper disposal contributes to land and water pollution. Waste segregation programs, single-use device (SUD) reprocessing, and recycling systems have been shown to reduce waste by up to 30–50% in some facilities [14]. Pharmaceutical take-back programs also help minimize improper medication disposal, a known source of antimicrobial contamination in aquatic systems [15]. Studies further highlight that training healthcare workers in waste segregation significantly increases recycling rates and reduces contamination of general waste streams [16].

Energy and Resource Efficiency

Cappiello FL. Energy and economic analysis of energy efficiency actions in surgery rooms: A dynamic analysis. Applied Energy. 2024 Nov 1;373:123887 17]. Many hospitals pursue LEED or BREEAM certification to promote energy-efficient infrastructure design. Water-saving technologies, including low-flow fixtures, automated shut-offs, and greywater recycling, have also become common, reducing both environmental impact and operational costs [18].

Green Logistics

Green logistics in hospitals focuses on optimizing inbound and outbound transportation, delivery routes, and internal movement of supplies. Implementing electric or hybrid vehicles for internal transport and optimizing supply routes through digital tools have been shown to reduce operational emissions [19]. Inventory optimization also plays a major role in reducing medicine expiration, thus minimizing pharmaceutical waste. Additionally, localization of suppliers decreases transportation distances and improves supply reliability [20].

Green Supply Chain Practices in Pharmaceutical Manufacturing

Green Manufacturing and Cleaner Production

Pharmaceutical manufacturing involves complex chemical processes with significant waste output and energy consumption. The adoption of green chemistry principles—such as solvent recovery, process intensification, and continuous manufacturing—has drastically reduced hazardous emissions and improved resource efficiency [21]. Many companies now use solvent-free or low-toxicity synthesis pathways to minimize environmental harm. Cleaner production strategies aligned with Good Manufacturing Practice (GMP) have demonstrated reductions in water consumption and volatile organic compound (VOC) emissions [22].

Sustainable Packaging

Pharmaceutical packaging contributes significantly to global plastic waste. Sustainable packaging strategies include lightweighting, use of mono-materials for recyclability, paper-based secondary packaging, and biodegradable alternatives [23]. Some firms have reduced the thickness of blister packs without compromising product integrity, thus decreasing plastic consumption and transportation weight [24]. Adoption of eco-friendly inks and recyclable labeling materials further enhances environmental performance.

Reverse Logistics and Circularity

Reverse logistics—returning expired, damaged, or unused pharmaceuticals—plays a crucial role in preventing pharmaceutical pollution. Programs for returning unused medications greatly reduce improper disposal, a major cause of antibiotic-resistant contamination [25]. Manufacturers increasingly utilize reusable shipping containers and recover active pharmaceutical ingredients (APIs) through advanced extraction techniques, promoting circularity in the supply chain [24]. These practices also help reduce costs by recovering high-value materials.

Green Supplier Assessment

Pharmaceutical firms rely on extensive global supply chains. Supplier environmental audits, life cycle assessments (LCA), and carbon footprint evaluations are used to ensure sustainable sourcing [26]. Many firms use environmental scorecards to encourage upstream partners to adopt greener processes. Such assessments are especially important because environmental risks often emerge from raw material production and upstream chemical processing [27].

Drivers of Green Supply Chain Adoption

Environmental regulation is one of the strongest drivers of GSCM implementation. Compliance with waste disposal laws, emission standards, and solvent recovery requirements compels manufacturers and hospitals to adopt sustainable measures [19]. Cost reduction also motivates adoption; energy-efficient technologies, waste minimization, and optimized logistics often result in significant long-term savings [21]. Corporate social responsibility (CSR) goals, patient awareness, and stakeholder pressure further encourage sustainable transformation. International bodies such as WHO and UNEP increasingly promote sustainable healthcare practices, strengthening institutional support [28].

Barriers to Green Supply Chain Implementation

Despite progress, significant barriers remain. High capital investment required for green technologies discourages adoption, especially in low-resource settings [23]. Strict regulatory environments, while beneficial, sometimes conflict with flexible green practices—for instance, limitations on reusable medical devices due to infection control concerns [29]. Additionally, limited awareness among healthcare staff and managers impedes waste segregation and green procurement initiatives. Complexity in pharmaceutical supply chains, characterized by global sourcing and sensitive materials, further complicates coordinated sustainability efforts [30].

Emerging Trends and Future Research Directions

A major emerging trend is the integration of circular economy principles, such as device refurbishment, reusable packaging, and waste-to-energy systems. Digital tools such as artificial intelligence, IoT sensors, and digital twins are increasingly used to optimize consumption patterns and predict demand, enhancing both sustainability and resilience [31]. Carbon

accounting frameworks tailored to healthcare settings are gaining traction, enabling institutions to quantify and benchmark carbon emissions across supply chain stages. Future research should explore climate-resilient supply chain models, low-carbon pharmaceutical synthesis, and standardized sustainability metrics in hospitals [32].

CONCLUSION

Green supply chain practices in hospitals and pharmaceutical manufacturing represent a critical step toward reducing the environmental burden of healthcare. While initiatives such as green procurement, waste reduction, sustainable packaging, and reverse logistics are increasingly adopted, significant challenges remain. Addressing regulatory complexity, enhancing staff training, and leveraging digital technologies are essential for achieving long-term sustainability. Continued research and policy support will be vital in transforming the healthcare supply chain into a more environmentally responsible system.

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