

Sustainable Healthcare Supply Chain Innovations: A Systematic Literature Review

Salma Elabed

Biomedical Engineering Graduate Program, Department of Industrial Engineering,
American University of Sharjah, Sharjah, United Arab Emirates

Abdulrahim Shamayleh

Biomedical Engineering Graduate Program, Department of Industrial Engineering,
American University of Sharjah, Sharjah, United Arab Emirates
Email: ashamayleh@aus.edu (*Corresponding Author*)

Abdelkader Daghfous

Department of Marketing and Information Systems
American University of Sharjah, Sharjah, United Arab Emirates

Linda Angell

Department of Marketing and Information Systems
American University of Sharjah, Sharjah, United Arab Emirates

ABSTRACT

The concept of sustainability-oriented innovation (SOI) requires intentionally applying new or improved changes at both organizational and process levels to create social and environmental value and promote economic returns. Within the healthcare sector, however, organizational priorities are often directed toward short-term goals and easily accessible resources, and responsibilities relating to sustainable development tend to be disregarded. Due to the complexity of the sustainability concept within the healthcare context, research explicitly focused on this topic remains scarce. This research presents a systematic literature review (SLR) of SOI sustainable healthcare supply chain innovations, revealing current research themes in the field. The content-based conceptual guide analysis identifies the current research and knowledge gaps by analyzing collected literature and developing an understanding of sustainable healthcare supply chain innovations. The findings encompass both technological and organizational practices and models in healthcare. The conceptual guideline for future practices and research is presented through building on two theoretical concepts: circularization and the diffusion of innovation. Furthermore, the SLR reveals potential future research avenues which improve both the practical implementation and theoretical understanding of SOI within the healthcare supply chain.

Keywords: *healthcare innovation, healthcare supply chain, healthcare sustainability, sustainability, sustainability-oriented innovation, systematic literature review*

1. INTRODUCTION

The healthcare supply chain is lengthy and complex, including manufacturers, distributors, service providers (e.g., pharmacies, hospitals), patients, governmental

institutions, regulatory agencies, and insurance companies (Kwon *et al.*, 2016; Mathur *et al.*, 2018), and encompassing the procurement, production and delivery of goods and services from global suppliers all the way through to the delivery of patient care (Mathur *et al.*, 2018). In hospitals, the flow of materials (e.g., supplies for wards and operating theatres) throughout the supply chain requires equal attention to that given the provision of diagnostic and therapeutic services to patients. In fact, the healthcare supply chain has been found to significantly impact not only health care outcomes, but also economic and environmental outcomes; for example, the healthcare supply chain has been found to account for 80% of all greenhouse gas emissions in the US, and these emissions can have major impacts on both public health and healthcare expenditures (Eckelman *et al.*, 2020).

A smooth-flowing health care supply chain is essential for meeting human needs, yet the global COVID pandemic disrupted international supply chains considerably. In fact, the COVID-19 outbreak revealed how fundamentally the healthcare supply chain has failed to balance demand and supply (Hensel *et al.*, 2020). Shortages of personal protective equipment and other healthcare supplies demonstrated the need to understand real-time disruptions and to develop a robust and effective supply chain response (Bala *et al.*, 2022; Omar *et al.*, 2022), necessitating changes across the entire system. Healthcare administrators recognized the imperative to build a healthy supply chain that addresses economic, social, and environmental demands, and still provides transparency in terms of data, demand and supply availability. Accordingly, the need to build a resilient healthcare supply chain characterized by high reliability, quality, on-time delivery, as well as improved environmental impact should be of equal importance to the desire to contain supply chain costs.

Healthcare institutions, such as hospitals, face highly regulated environments and constantly changing patient and consumer expectations, and these complexities both necessitate and impact innovative supply chain practices. Innovative technologies expedite the transformation of the healthcare industry, making it more efficient, convenient and personalized (Tian *et al.*, 2019; Zeadally *et al.*, 2019). Smart healthcare requires the use of advanced information technologies, such as conventional mobile and wearable medical devices, the internet of things (IoT), cloud computing and big data. These kinds of innovations are essential to improve access to health records, support strategic collaboration between stakeholders, and manage demand and procurement (Akenroye, 2012; Lindskog *et al.*, 2017).

Sustainable practices throughout healthcare supply chain can improve the triple bottom line (i.e., profit, people, planet) of various organizational participants by enhancing supply chain agility, reducing chemical exposure and emissions, managing wastes efficiently, improving access to healthcare, enhancing employee well-being and cutting down operational costs (Hallam & Contreras, 2018; Kinney, 2010; Saviano *et al.*, 2018; Wang & Wang, 2024). Healthcare sustainability innovations, such as anaesthetic gas-destroying waste technology or telehealth services, contribute toward an agile supply chain system characterised by high responsiveness, flexibility and real-time data access. The Sustainability-Oriented Innovation (SOI) approach intentionally applies new and improved practices to organizations and their processes to create social and environmental value, as well as to promote economic returns (Adams *et al.*, 2016). SOI emphasizes sustainability measures when adopting new technologies or innovations and encourages healthcare organizations to enhance service and care quality while simultaneously improving economic and environmental outcomes.

SOI-related research has grown considerably in recent years, and a number of SOI-focused systematic literature reviews (SLRs) have been completed to date. Wehnert *et al.* (2018) examine the concepts of stakeholder participation, analytical methods, innovation management and SOI, developing an approach for integrating external sources into innovation processes. Adams *et al.* (2016) review SOI literature published between 1992 and 2012 and point out how innovative activities shift over time to become more radical and systemic, rather than incremental and localized. Maier *et al.* (2020) explore the sustainability innovation literature between 2010 and 2019, documenting the intellectual structure, volume and knowledge-development directions of research in these areas. Gao *et al.* (2017) explore sustainable supply chain innovations between 1996 and 2014, directing future research and considering the three sustainability dimensions (i.e., environmental, economic and social) as they relate to practitioners. Calabrese *et al.* (2018) systematically review sustainability-oriented service innovations, between 2004 and 2015, clarifying future research direction for policymakers and researchers. And, most relevant for the purposes of this paper, Elabed *et al.* (2021) propose an SOI-driven framework based on a supply chain perspective that serves as a guide for healthcare managers and decision-makers to enhance SOI implementation in hospitals.



Figure 1 Factors driving sustainable healthcare management, adapted from (Tushar *et al.*, 2023)

Figure 1, adapted from (Tushar *et al.*, 2023) presents five main factors driving sustainable healthcare management, including the healthcare environment, community, government, employees and management. Given these increasing pressures on healthcare providers to be sustainable, an SLR focused on SOIs in healthcare supply chains could provide useful insight and help bridge the gap between practice and research. To the best of our knowledge, a review of research focusing on sustainability, innovation, and supply chains within the context of the healthcare industry has yet to be conducted. Although a few SLRs have explored one or two of these topics, none have focused on all of them collectively (Adams *et al.*, 2016; Calabrese *et al.*, 2018; Gao *et al.*, 2017; Maier *et al.*, 2020; Wehnert *et al.*, 2018). A SLR focused on sustainable healthcare supply chain innovations will outline and evaluate the current state of practice and research relating to this important topic, highlighting gaps, providing a better understanding of the practical development and integration of sustainability into health sector supply chains and proposing a way forward.

A critical reading of the above-referenced SLRs reveals that a comprehensive research framework remains missing. There is considerable need for further research into the adoption of and challenges facing sustainable healthcare supply chain innovations, particularly in hospitals. This study explores SOI research focused on healthcare supply chains and proposes future research avenues relating to sustainable healthcare supply chains. In addition, this SLR maps existing research relating to sustainable healthcare supply chain innovations; thus, determining the potential for growth and development in this field.

Therefore, the main objectives of this study are to:

- Perform a SLR reporting research conducted on sustainable healthcare supply chain innovations over the last twenty years (2000-2020) and analyze the various findings from both the thematic and application context perspectives.
- Develop an understanding of the adoption of and challenges facing sustainable healthcare supply chain innovations through an analysis of the current state of research, as well as the research gaps.
- Identify and discuss future research possibilities that will enable the further adoption of sustainable healthcare supply chain innovations to lead to improvement in economic, social and environmental performance measures.

This study contributes to the literature through the conceptual development of sustainable healthcare supply chain innovations, identifying concepts and practices related to SOI in healthcare.

The rest of the paper is organized as follows. Section 2 provides the theoretical background and systematic literature review, while Section 3 highlights the methodology used. Section 4 presents and discusses the findings and insights from the SLR. Finally, Section 5 concludes and highlights the limitations of this study and proposes several future research pathways.

2. LITERATURE REVIEW WITH EMERGENT THEMES

2.1 Healthcare Sustainability

Opportunities for integrating sustainability into the healthcare sector are wide-ranging, offering both short- and long-term benefits. Annually, the healthcare sector produces two million tons of waste and spends over eight billion U.S dollars on energy (Kinney, 2010). In addition, as a result of the COVID-19 pandemic, medical waste generation (i.e., masks, gloves, gowns and other personal protective equipment) and the consumption of single-use plastics have increased considerably (United Nation Environment Programme, 2020). Hospitals benefit from improved waste management efficiencies by reducing waste disposal costs and ultimately by improving public health and safety (Scavarda *et al.*, 2019). Raising awareness about healthcare sector sustainability is essential for the public as well as for healthcare managers. Through sustainable healthcare training or workshop programs, healthcare managers have the opportunity to network with professionals specialized in sustainability-oriented healthcare, and gain insight into the latest environmental sustainability practices within the healthcare industry.

2.2 Sustainable Healthcare Supply Chains

The healthcare supply chain consists of multiple stakeholders such as manufacturers, distributors, medical groups, insurance companies, governmental organizations and authorities, employers, and patients (Christos *et al.*, 2014). Although healthcare supply chains do not match the profitability of industrial supply chains, effective management enables a reasonable level of profitability (Kim & Kwon, 2015). Sustainable supply chain management (SSCM) in healthcare is essential to maximize resource optimization, increase long-term profitability and improve performance and productivity (Saviano *et al.*, 2018). Through resource optimization, the number of resources required decreases while service availability increases (Mathur *et al.*, 2018). Productivity is improved when the patient's hospital cycle time is minimized (Tamir *et al.*, 2017). Thus, effective healthcare SSCM satisfies patient demand by providing the right product at the right time and quantity, and at the best possible quality level.

Routine evaluation and assessment audits are a key factor in the success of sustainable healthcare supply chains, as achieving environmental sustainability requires continuous tracking to ensure compliance with sustainability standards (Kusi-Sarpong *et al.*, 2019). Several initiatives and evaluation systems enable the tracking and monitoring of compliance with sustainability standards. For instance, the National Evaluation System for health Technology (NEST) tracks the total product lifecycle of medical devices (NESTcc, 2020), and aims to synthesize data from various

healthcare sources to help providers make better treatment decisions (NESTcc, 2020). Other sustainability evaluation systems applicable within the healthcare sector include Leadership in Energy and Environmental Design (LEED), Building Research Establishment's Environmental Assessment Method (BREEAM), and Istituto per l'Innovazione e la Trasparenza degli Appalti e la Compatibilità Ambientale (ITACA) (Buffoli *et al.*, 2015). The LEED healthcare system promotes performance standards for environmental practices in building design, and scoring levels include certified, silver, gold and platinum. The BREEAM evaluation likewise focuses on the environmental performance of buildings and provides insights on potential improvements. Finally, ITACA standards manage practices related to enhancing environmental sustainability (Buffoli *et al.*, 2015).

Providing healthcare managers with regular training programs regarding sustainable supply chain practices, innovative solutions and preventative programs enhances sustainable supply chains in healthcare, and ultimately enhances patient wellness (Khan *et al.*, 2018; Mitra & Datta, 2014). Healthcare organizations can either develop internal training programs or purchase available international programs related to innovative and sustainable healthcare management. For example, the Environmental Sustainability Certification Program launched by the Association for the Healthcare Environment (AHE) aims to provide healthcare managers with guidance on effective value-added environmentally sustainable healthcare operations (*Environmental Sustainability Certificate Program*, n.d.) Introducing technological innovations to healthcare organizations requires training medical professionals regarding proper usage and implementation to increase efficiency and reduce non-added value activities.

2.3 Emerging Themes: Sustainable Healthcare Supply Chain Innovations

Healthcare innovations are increasing due to their beneficial impact on sustainable supply chains, including quality improvement, cost reduction and improved efficiency (Ancarani *et al.*, 2016). However, Iandolo *et al.* (2018) found a lack of accepted and standardized assessment methods for healthcare innovations, proposing an evaluation framework linking the complexity of innovations to appropriate evaluation methodologies within the healthcare context. Ancarani *et al.* (2016) investigated the relationship between the adoption of innovation and healthcare efficiencies, finding that the practice of sharing supply chain processes helps to align requirements with purchased resources. Supply chain innovations include product, process, and resource allocation innovations; and adopting or developing supply chain innovations improves process efficiency and effectiveness (Gao *et al.*, 2017). In particular, healthcare innovations are rapidly developing and producing effective outcomes in the areas of personalized care, big data analytics, wearables, mobile applications, virtual care and other areas. Akenroye (2012) develop a conceptual framework for policy makers, presenting factors driving innovation in the healthcare supply chain. Research suggests that the lack of knowledge sharing in healthcare is driven by a variety of factors, including the difficulties inherent in extracting useful knowledge from the vast amounts of data

recorded, classifying what information should be confidential, and addressing the disconnect between medical professional and information technology skills (Ben Hamouda *et al.*, 2015; Fu *et al.*, 2019; Moro Visconti & Morea, 2019).

Sustainable business models: Sustainability focuses on managing business impacts on people and the environment. Govindan *et al.* (2016), reviewing literature about sustainable supply chain management and governance structures, propose several future research avenues focused on green human resources and sustainable supply chain management. Khan *et al.* (2018) investigate social sustainability in the UAE healthcare supply chain, finding that motivation is a strong driver of positive change, while attitudes can be a significant barrier to change. Khosravi & Izbirak (2019) present a model for measuring social sustainability from the point of view of several healthcare stakeholders, including: suppliers, patients, patient relatives, employees, government, and decision makers. Lopes *et al.* (2019) propose a comprehensive plan enabling hospitals to achieve sustainable supply chains through visionary business models, innovative approaches, and sustainable transitions. Shi & He (2018) propose a verified disturbance management tool for emergency decision-makers, enabling them to minimize the waste of cost and time while distributing medical supplies during natural disasters. Nosratabadi *et al.* (2019) demonstrate state of the art sustainable business models in a variety of contexts, illustrating an increased reliance on advanced technologies.

Technological management: Sustainable business models are often associated with digital technology in healthcare literature. Bloomfield (2015) indicate that technological innovation, more than mandates, enable good practices in sustainable hospital food procurement. Visconti & Morea (2020) investigate the impact of healthcare digitalization on smart hospital project financing; finding that digital applications improve value for money and target patient-centered approaches. Wicks *et al.* (2006) discuss the strategic benefits, applications and challenges of radio frequency identification (RFID) applications within healthcare supply chains; finding that RFID improves healthcare marketing, operational efficiency and patient satisfaction. Chircu *et al.* (2014) explore the implementation and business value of RFID technology in the pharmaceutical supply chain, finding that supply chain participants differ in their perceptions of tangible and intangible benefits.

The management of healthcare technology involves all health service processes involving equipment within a healthcare system (Oloyo *et al.*, 2019). Wong *et al.* (2012) explore the influence of medical innovation on age-specific trends in healthcare utilization; concluding that advances in medical technology influence healthcare utilization and result in a higher probability of hospitalization for older patients. Medical expertise enhances the procurement process for eco-innovative medical equipment (Diaconu *et al.*, 2017). Healthcare managers must be proficient at both managerial and technical levels to efficiently promulgate innovative technologies and organizational methods (Oloyo *et al.*, 2019). Technical expertise amongst healthcare personnel enables benefits ranging from ensuring that materials comply with standards to improving overall healthcare provided to patients (Leitner *et al.*, 2010).

Introducing technological innovations to healthcare organizations requires the system to be equipped with professional technical experts that have the skills to manage and deal with such innovations (Kurhekar & Ghoshal, 2010).

Medical equipment is usually associated with high energy consumption; thus, energy monitoring systems are crucial for successful energy management. Given that the average hospital uses more energy than any other commercial building type, embracing sustainability in healthcare is fundamental to reducing the environmental impact in healthcare (Schoen & Chopra, 2018). For instance, the installation of sub-meters to measure the energy consumption of medical equipment can provide a better understanding of the energy usage and costs of various departments and timeframes. Proper energy monitoring techniques allow healthcare managers to determine how and where energy savings can be attained within a hospital setting. Another important feature to be considered for medical equipment is the standby mode feature, which enables energy saving in idle mode when the device is not being used. Several studies recommend entirely shutting off devices during periods of the day when they are least used, since "standby" mode also consumes energy (Rohde & Martinez, 2015). However, this energy-saving practice is restricted for devices with long start-up times, such as Magnetic Resonance Imaging (MRI) machines. Fathollahi-Fard *et al.* (2019) proposed a modified green home healthcare supply chain algorithm that addresses a system's total cost and environmental pollution.

An important contribution to sustainability in the healthcare sector comes when manufacturers consider environmental specifications when designing medical equipment (Ghadimi & Heavey, 2014). Energy consumption and maintenance efficiency are other key factors when purchasing medical equipment (Rohde & Martinez, 2015). Healthcare purchasing agents increasingly pay attention to new product information about energy consumption, maintenance, operational noise levels and operator impacts following multiple hours of usage (Lindgreen *et al.*, 2009). Easily maintainable medical equipment ensures a safer and more user-friendly environment for both medical professionals and patients, in addition to benefits such as reducing the financial and operational impacts of repair downtimes, increasing system efficiency, and enabling higher patient satisfaction. High performance medical equipment is essential given the complexity and urgency of demand within a healthcare setting, so hospitals must ensure equipment maintenance programs that maintain and carry out periodic inspections. Sezdi (2016) develops preventative and predictive maintenance strategies for managing devices using both older technology and newer high-tech features to increase efficiency in hospitals.

Resource management: Resource tradeoffs are paramount in healthcare management; considering for example the increasing costs of medical diagnostic and imaging procedures balanced against the impacts of such procedures on patient health (Newman-Toker *et al.*, 2013). Aranda-Jan *et al.* (2014) review the mobile health (mHealth) program in Africa using the strengths, weaknesses, opportunities, and threats analysis (SWOT) methodology, concluding that the program usually tackles issues relating to critical resource shortages. Meehan *et al.* (2017) apply a resource-based view to study the UK'S National Health

Service, and the program's potential to adopt value-based approaches, finding that the lack of value-based procurement practices translates into resource immobility in public procurement and a lack of capacity more generally. Xu *et al.* (2018) review the validity of incentive income distribution mechanisms for green healthcare supply chain development in China. Massa *et al.* (2018) study the overuse of medical diagnostic procedures and find an increasing tendency to overuse medical diagnostic procedures for end-of-life patients, resulting in higher healthcare costs and unnecessary procedures which impact healthcare supply chains both financially and in terms of service quality. Thus, minimizing the overuse or misuse of medical diagnostic procedures translates into time and cost reductions, as well as patient health and well-being (Massa *et al.*, 2018).

Healthcare big data: Healthcare supply chains typically collect and record vast amounts of data, although this data may not be utilized efficiently or effectively. In the context of healthcare supply chains, while data is available in large volumes, the availability of quality information remains limited (Kritchanchai, 2012). Several researchers have studied the potential role of big data in facilitating sustainable innovations in healthcare management and supply chains. Pramanik *et al.* (2017) critically analyze big data and smart system technologies in healthcare systems, proposing a big data-enabled smart healthcare system framework. Alam Khan *et al.* (2020) study the use of blockchain technology for healthcare applications, to address data security concerns and enhance precision medicine. Within the context of the COVID-19 pandemic, Adil & Khan (2021) explore network architecture, data preservation and security inherent in emerging healthcare internet-of-things applications. Moro Visconti & Morea (2019) investigate the role of big data in improving the quality and timeliness of information for healthcare project investments, considering opportunities to make these investments more sustainable and efficient. Rahman *et al.* (2021) develop a framework to address healthcare sustainability through internet-of-things applications and contributions, focusing on data security, data privacy and social acceptance of the deep learning process. Jayaraman *et al.* (2011) study the adoption and implementation of standards for hospital supply chain data and underscored the importance of technological solutions supporting the implementation of GS1-based standards.

Sustainable supply chain management: Verma *et al.* (2018) develop a conceptual model regarding green supply chain management and sustainable development to reduce cost and environmental liability. Jarrett *et al.* (2020) explore the involvement of manufacturers in the vaccine supply chain to identify possible opportunities for innovation adoption. Atinga *et al.* (2020) conduct a mixed-method study in the Northern Region of Ghana to determine gaps in healthcare supply chain competency, structure, and resources, proposing techniques to enable optimal performance of healthcare supply chain functions. Scavarda *et al.* (2019) apply a healthcare supply chain management framework to analyze the central sterilization service and stockroom of a private healthcare institution, recommending the integration of risk management and healthcare infection prevention and control. Healthcare supply chain managers must adopt a proactive risk management approach, diversify supply sources, and integrate advanced technologies like AI and blockchain to improve visibility and responsiveness,

thereby reducing disruption vulnerabilities (Ahmad *et al.*, 2024). Nematollahi *et al.* (2018) investigate the sustainable management of pharmaceutical supply chains and service levels, developing a novel model for multi-objective coordination.

Hong *et al.* (2014) propose that firms with a strategic customer service orientation adopt human and technical aspects of lean manufacturing practices to achieve less waste and better performance outcomes. Hart & McMurtrey (2018) discuss opportunities and challenges in managing pediatric healthcare supply chains, suggesting that children's hospitals can collaborate to form strong buying alliances, receive supportive services and adopt standardized practices, all of which improve the quality and cost of pediatric care. Integrating quality improvement initiatives with financial strategies is essential for enhancing overall hospital performance and patient outcomes (Chakraborty, 2020). Fu *et al.* (2019) discuss the successful implementation of green purchasing practices through a cloud model of optimizing resource allocation, highlighting the benefits of green-purchasing capabilities and improvements, and enumerating theoretical and practical implications of these approaches. Eagan & Kaiser (2002) develop an environmental purchasing tool for healthcare management focused on minimizing the use of mercury to protect community health and promote greener medical products.

Stakeholder relationships: The adoption of innovative technologies for information and communication in healthcare improves the transparency of economic activities and the availability of real-time information for a variety of key stakeholders, including suppliers and patients (Mettler & Rohner, 2009). Managers within sustainable supply chains select suppliers based on their alignment with environmental standards and criteria (Mitra & Datta, 2014). Efforts to enhance Supplier Relationship Management (SRM) lead to improved operational efficiency and patient responsiveness (Mettler & Rohner, 2009). Healthcare organizations can apply innovative practices to improve SRM, such as electronic ordering and invoicing systems to improve their pricing transparency, product variety, data quality, and online order tracking capabilities (Mettler & Rohner, 2009). The importance of group purchasing strategies in healthcare supply chains is underscored by effective supplier selection processes, which play a crucial role in optimizing procurement efficiency across various units (Miah *et al.*, 2013). Likewise, value-based healthcare can be achieved by engaging patients in addressing their concerns and needs via Patient Relationship Management (PRM), leading to improvements in patient satisfaction, patient-clinician communications, and other efficiencies (Amini *et al.*, 2011). Abdulsalam *et al.* (2015) suggest that consolidated service centers reduce the complexity of hospital supply chain systems, improving performance by reducing the interactions between components. Acharyulu (2012) explores the customer relationship management practices incorporated in hospital operations and how they enable increased efficiency and value, concluding that front offices, labs, diagnostics, and billing require improvements to achieve patient satisfaction. In general, service offerings are enhanced when stakeholder networks are built through SOI practices (Calabrese *et al.*, 2018).

Performance Measurement: Several papers identify performance measurement as an important theme within the

context of sustainable healthcare supply chains, exploring the linkages between various management innovations and improved performance. Walley *et al.* (2006) explore performance measurement systems within hospital improvement activities and their influence on the success and sustainability of process changes. Leksono *et al.* (2019) develop a model for sustainable healthcare supply chain performance measurement; this model maintains customer and stakeholder satisfaction by considering both sustainability and intangible characteristics. Chang *et al.* (2019) propose development of an emergency medical service simulation to solve hospital emergency department crowding and waste challenges to improve quality outcomes. Chandra *et al.* (2013) suggest a hospital revolving fund as an innovative practice to maintain the quality of healthcare delivery by ensuring the availability of necessary hospital supplies. The main aim of both the simulation and the fund was to facilitate optimal quality healthcare delivery at an affordable cost.

Sustainable waste management: Hospital waste management and minimization are typically addressed by analyzing materials that can be reused or recycled (Lino & Ismail, 2013). Waste classification and segregation are essential in identifying hazardous versus non-hazardous, and infectious versus non-infectious, byproducts. According to the WHO, non-hazardous wastes account for 75 percent to 90 percent of overall waste generated by healthcare facilities (Ali *et al.*, 2017). The remaining 10 to 25 percent accounts for hazardous waste, requiring more intensive consideration and management. Hazardous wastes often contain infections, poisons and toxics which are detrimental for both the natural environment and for human well-being (Bdour *et al.*, 2007); and governmental authorities are imposing strict regulations regarding waste management in healthcare organizations (Marinković *et al.*, 2008). As a result, an important area of research focuses on the effective and efficient identification of waste types (e.g., infectious, and non-infectious) generated by the healthcare industry (Al-Khatib *et al.*, 2016), and the effective disposal of these different categories of waste (Bdour *et al.*, 2007).

Scavarda *et al.* (2019) present a procedure for providing higher visibility for sustainable management by segregating healthcare solid waste, selling materials to recycling cooperatives and providing educational programs for appropriate disposal. They suggest incorporating multi-professional healthcare teams to lead sustainable application of solid waste management. De Souza & Sami (2018) illustrate the risks and consequences of improper pharmaceutical waste disposal by examining recyclable material cooperatives in Sao Paulo. They propose an increased focus on biosafety, which can be achieved by educating the public and training collectors regarding the risks and benefits of separating pharmaceutical residues.

Manufacturers must provide end of life disposal requirements for used and unwanted medical equipment, and several environmentally friendly solutions are available (Rohde & Martinez, 2015), such as returning devices to manufacturers for disposal, re-selling or donating (Elabed *et al.*, 2019). Re-selling or donating devices requires provision of thorough documentation to ensure safety. Innovative techniques for disposal of equipment allows an increasing the level of recycling and other sustainable end-of-life practices, and governmental legislation and taxation ensure disposal compliance with environmental regulations and standards (Lindgreen *et al.*, 2009).

3. METHODOLOGY

Tranfield *et al.* (2003) developed a context-sensitive systematic literature review methodology that can be effectively applied, and has been widely adopted (Baan Wahn *et al.*, 2020; Khorasani *et al.*, 2020; Korherr & Kanbach, 2023; Lattacher & Wdowiak, 2020), within the management research sector. This SLR methodology consists of three stages: 1) plan the review; 2) conduct the review; and 3) report and disseminate the review. **Table I** presents the first two stages relating to the planning and conducting of this SLR focused on sustainable healthcare supply chain innovations; while the third stage, i.e., the reporting and disseminating of review findings, is presented in Section 4.

Table 1 Steps in planning and conducting SOI in healthcare review

Stage	Sub-stage	Description	Number of Records
1) Planning the review	i. Identification of search space	Create an initial list of academic journals which publish in the fields of healthcare, sustainability, innovation, and supply chain management.	-
	ii. Keyword and search string list	Search for: i) Enviro*, Sustainab* ii) Innovat* iii) Health* iv) Supply chain Search string format: <sustainability keyword> AND <innovation keyword> AND <healthcare keyword> AND <supply chain keyword>	-
	iii. Develop the analytical framework	Thematic Content: What and How? Application Context: Where (i.e., healthcare sector and geographical region)?	-

Table 1 Steps in planning and conducting SOI in healthcare review (Con't)

2) Conducting the review	i) Search Scopus & ProQuest Citations	Carry out the search process via Scopus and ProQuest databases using the following filters: i) Find the search string in Title (TI) OR Abstract (AB) OR Subject terms (SU) ii) Search timeline: 2000-2020 iii) Language: English iv) Source Type: Academic journals	249
	ii) Extract & Remove Duplicate Records	Extract Scopus and ProQuest citations to Mendeley and remove duplicate records.	216
	iii) Filter Titles and Abstracts	Study and filter titles and abstracts of all selected papers. <ul style="list-style-type: none"> <u>Inclusion criteria:</u> Studies addressing innovation and sustainability issues in the healthcare field; studies addressing sustainable supply chains in healthcare. <u>Exclusion criteria:</u> Studies not addressing at least two of the predetermined topic concepts (sustainability, innovation, healthcare, supply chain); studies addressing diseases or medicine purely; studies addressing water/urban/sewage/food related issues. 	32
	iv) Code the Articles	Code the resulting articles, each of which addresses (i) multiple and significant health-related themes, dimensions of sustainability, regions and methodologies (ii) one or more aspects of supply chain and (iii) innovation.	

In the initial stage, (i) relevant citation databases are selected, (ii) a keyword and search string is identified based on relevance to the inter-related fields of sustainability, innovation, and the healthcare supply chain (i.e., SOI in the healthcare supply chain domain), and (iii) an analytical framework relating to SOI in the healthcare supply chain is developed. The research scope explores studies published between 2000 and 2020, covering SOI sustainability and innovation in the healthcare supply chain. In the second stage, the various steps listed in **Table I** filtered the relevant articles to be reviewed down from 249 to 32 articles, for which the findings and research themes are described and discussed in Section 4 of this paper.

The content-based conceptual guide analysis identifies the current state of research and gaps by analyzing collected literature and developing an understanding regarding the nature of SOIs implemented within the healthcare supply chain. The first stage of analysis consisted of coding and analyzing collected literature in terms of objectives that address the main aim of this study. This process was guided by the following analytical framework:

Thematic content: (i) *what has been studied in terms of the role of sustainable healthcare supply chain innovations within the literature and (ii) how have issues relating to sustainable healthcare supply chain innovations been addressed?*

What: The role of sustainable healthcare supply chain innovation is analyzed across *major themes and types of innovation*. Major themes were sequentially identified after studying the selected articles.

How: The selected studies were classified based on the research methodology employed to address and understand the different issues relating to sustainable healthcare supply chain innovations.

Context of application: (iii) *where have issues related to sustainable healthcare supply chain innovations been studied?*

Where: The selected studies are analyzed as to the *type of healthcare* and the *geographical region(s)* in which the thematic content has been addressed.

To highlight research development in the field, this SLR coded and analyzed the 32 selected articles based on these *what, where* and *how* categories and questions.

4. REVIEW FINDINGS AND DISCUSSION

4.1 What: Major Themes and Types of Innovations

WordStat, a content analysis and text mining software utilized for the rapid and precise processing of large and unstructured data (*WORDSTAT*, n.d.), identified five major research topics are extracted from the literature over the studied period, including: (i) healthcare big data, (ii) sustainable business models, (iii) performance quality, (iv) literature review and (v) supply chain. These research topics were further refined during the course of the SLR and formed the basis of the emerging research themes discussed. **Figure 2** illustrates, over the period 2000 to 2020, that journals – particularly those focused on environmental sustainability and supply chain operations – have increasingly focused on SOI-related aspects in healthcare.

In particular, the selected healthcare-related SOI literature focused on several interesting supply-chain areas, including medical equipment, medical material, general or operational management aspects, healthcare facilities and ‘others’ (**Figure 3**). The highest number of studies (N=23) focused on "general/operation" management.

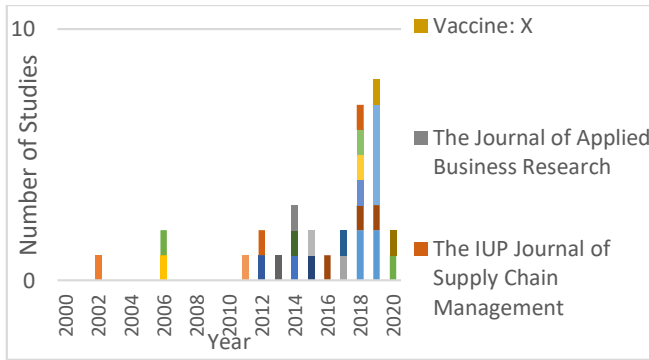


Figure 2 Journals publishing studies focused on "sustainable healthcare supply chain innovations", from 2000 through 2020

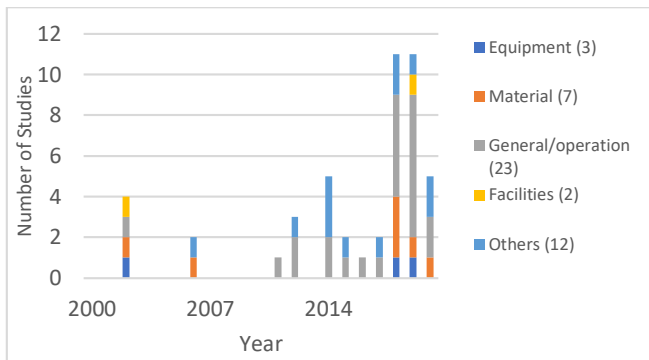


Figure 3 Supply chain focus of SOI healthcare literature

The frequency of thematic content over the publication year demonstrates the overall increasing trend in this research focus, specifically relating to supply chain and sustainable business models in the healthcare industry. Additionally, network visualization (**Figure 4**) using VOSviewer software presents a clustered map of keywords in this healthcare-related SOI literature. This map illustrates four colors according to the initial search terms, i.e., sustainability, supply chain, healthcare, and innovation. As would be expected, sustainability and sustainable development themes are prominent in this map, and by extension, in this literature, confirming the search conducted. The following sections discuss findings relating to the major concepts studied in the literature, building from the literature focused on healthcare sustainability, sustainable healthcare supply chains and sustainable healthcare supply chain innovations (**Figure 5**).

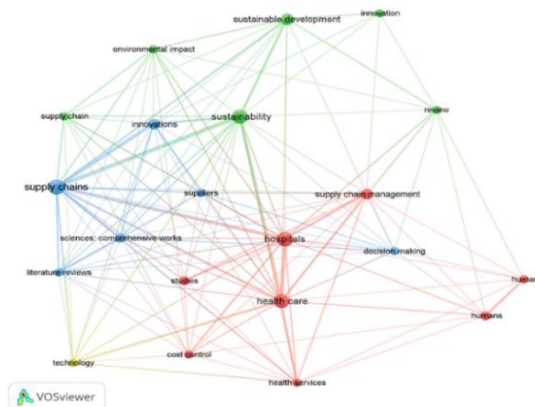


Figure 4 Overall cluster map of keywords in the healthcare-related SOI literature

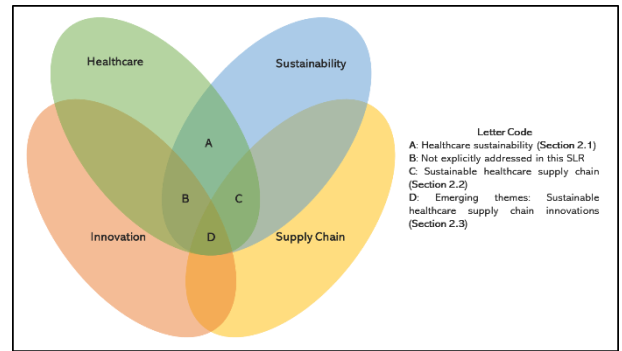


Figure 5 Major themes and types of innovations

4.2 How: Research Methodologies Employed

The predominant research methodologies employed in the papers selected for this literature review relating to sustainable healthcare supply chain innovations are shown in **Figure 6**. The two most common methodologies applied to date are literature review and conceptual studies, followed by empirical and case studies, while mathematical modeling and simulation techniques are relatively underutilized.

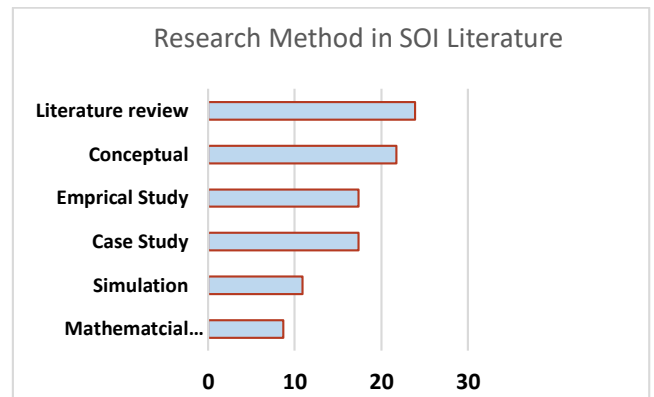


Figure 6 Research method by number of studies

The conceptual and literature review studies address all three themes, namely healthcare sustainability, supply chain and innovation, presenting select administrative challenges and opportunities relating to sustainable healthcare supply chain innovations (Fu *et al.*, 2019; Govindan *et al.*, 2016). In comparison, the empirical and case studies focus on exploring topics such as green e-procurement system implementation (Fu *et al.*, 2019), and the positive impact of digital innovations on vaccine manufacturers and supply chains (Jarrett *et al.*, 2020). Mathematical modeling and simulation methods address the context and implementation of various innovative management practices. For instance, Nematollahi *et al.* (2018) study decision variables related to drug shortages and other complications within pharmaceutical supply chains.

Most of the examined literature focuses on issues relating to material sustainability such as waste management (Chang *et al.*, 2019; De Souza & Sami, 2018), with minimal effort to mirror such studies in real-life practices and applications. **Figure 7** presents the trend in research methodologies employed over the study period, illustrating an increasing trend over the past few years toward literature reviews, conceptual studies, and mathematical modeling methods. Future research should undertake a more

collaborative approach to considering organizational sustainability within the healthcare supply chain.

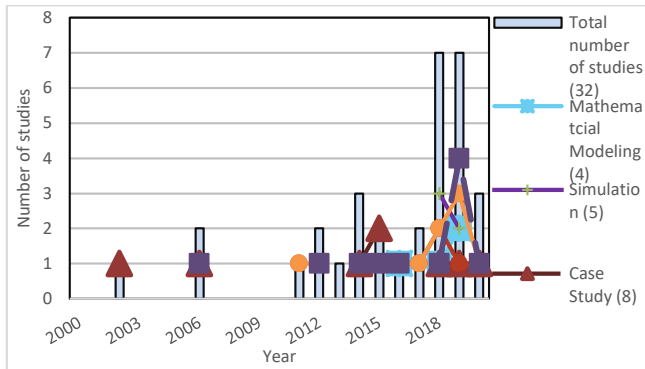


Figure 7 Progress of research methods between 2000 and 2020

4.3 Where: Healthcare Sectors and Geographical Regions

Figure 8 shows the breakdown between private and public (governmental) healthcare sectors within the selected literature. Most (i.e., 70%) of the reviewed studies did not specify the sector, but research focusing on identifiable sectors showed a breakdown between public and private of 21% and 9% respectively.

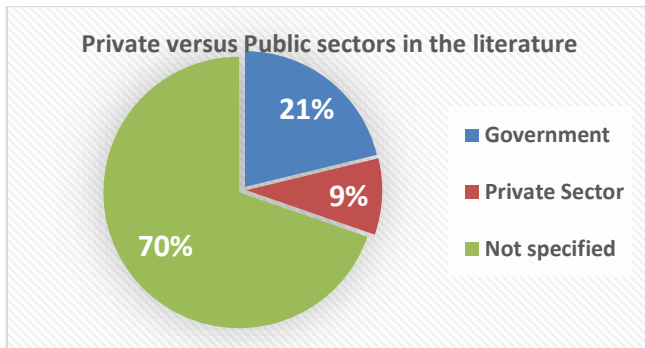


Figure 8 Distribution of private versus public sector in the literature.

Figure 9 shows the healthcare supply chain sectors addressed in this literature review, illustrating that the greatest number of studies focused on hospital-based operations.

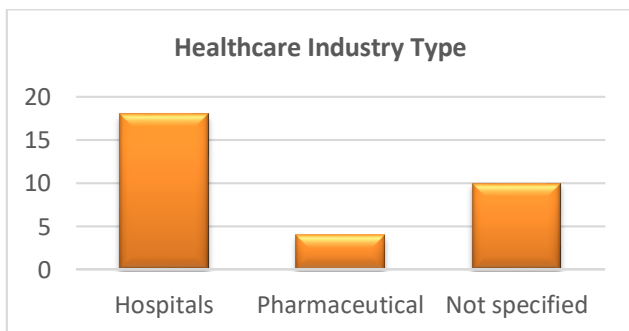


Figure 9 Number of studies over healthcare industry type.

Figure 10 presents the geographical distribution of studies included in this literature review, conducted between 2000 and 2020. It appears that the United Kingdom, Brazil, China and United States lead research efforts focused on SOI

within the healthcare supply chain, probably due to national action plans promoting sustainability in healthcare. Additionally, international environmental agreements (IEA) significantly contribute to global health governance (Morin & Blouin, 2019). While most countries and studies address waste and product management as paths to achieving sustainability, more research is required to determine the best approach to embedding sustainable healthcare supply chain innovation into organizational culture, and more generally to achieving sustainability at an organizational level within healthcare supply chains. Future research should consider national and international regulations and incentives that promulgate or alternatively hinder SOI in healthcare supply chains.

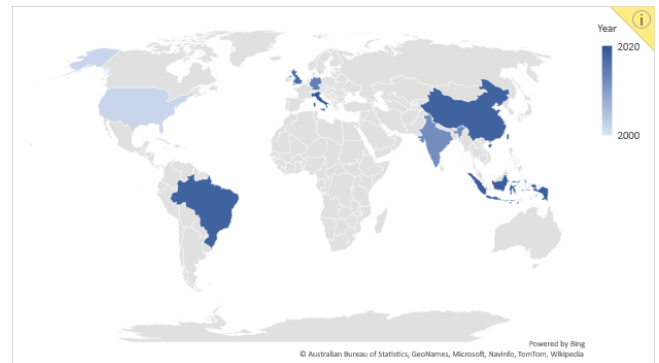


Figure 10 Distribution of the origin of studied literature across different regions

4.4 Encouraging Sustainable Healthcare Supply Chain Innovations.

Insights from the thematic and contextual analysis of this literature review promote the adoption of sustainable healthcare supply chain innovations. These innovations are categorized under several themes, including sustainable business models, technological management, healthcare big data, sustainable supply chain management, stakeholder relationships, resource management, performance measurement and sustainable waste management. Future research relating to the adoption of sustainable healthcare supply chain innovations can be supported by various organizational theories relating to the circular design and diffusion of innovation.

The circular design concept focuses on physical characteristics of a product, starting with the manufacturing stage, where material selection is emphasized and end of product life is reversed via processes such as disassembly and remanufacture in order to minimize waste and maximize energy recovery (Wastling *et al.*, 2018). Fundamentally, the ability to achieve circular designs and processes in healthcare requires a common ideology and shared values among stakeholders. Governmental entities and authorities should regulate current healthcare practices and models to expedite the transition from traditional linear economies to new and innovative circular systems. Lai & Chrysikou (2020) suggest several procedures to promote innovative models: improving coordination between levels of care, supporting the use of innovative health technologies and readjusting clinical guidelines to reflect environmental sustainability. Research is crucial to validate the most innovative models (Balas & Chapman, 2018).

The diffusion of innovation is the process by which new ideas, products, and technologies spread through a society or group of people. According to the theory, the adoption of a new innovation by individuals or organizations follows a predictable pattern, which is characterized by five stages: awareness, interest, evaluation, trial, and adoption. The rate and extent of adoption are influenced by various factors such as the perceived benefits and relative advantage of the innovation, compatibility with existing values and practices, complexity, observability, and communicability. The diffusion of innovation theory has been used to explain the adoption of new technologies, the success of new products

in the market, and the adoption of new health behaviors, among other things (Rogers, 1983).

Table 2 presents the conceptual framework resulting from this SLR and recommends directions for future research relating to sustainable healthcare supply chain innovations. This framework identifies key literature themes, and research gaps relating to these themes. The framework suggests addressing these research gaps via circular design and diffusion of innovation theories. The main aim is to achieve sustainable development through embracing innovation in healthcare supply chains.

Table 2 Conceptual research framework and future research suggestions for sustainable healthcare supply chain innovation

Themes	Existing research	Theoretical support for future research	
		Circular Design Theory	Diffusion of Innovation Theory
Sustainable Business Models	<ul style="list-style-type: none"> Develop innovative business models addressing sustainable development goals (Rosati <i>et al.</i>, 2023). Analyze external dimensions of business models for sustainable transition (Lopes <i>et al.</i>, 2019; Nosratabadi <i>et al.</i>, 2019). Verify disturbance management tools for emergency decision-makers (Shi & He, 2018). 	<ul style="list-style-type: none"> Develop business models that comprise healthcare service circularity. Collaborate with healthcare stakeholders to adopt sustainable models addressing circularity by design. Tailor healthcare processes for performance-based circularity. 	<ul style="list-style-type: none"> Redesign current health business models to incorporate innovation. Study current hospitals adopting innovation and the influence on supply chains efficiency. Invest in models directed towards normalizing innovation culture in healthcare. Use innovative health business models.
Technological Management	<ul style="list-style-type: none"> Investigate healthcare digitization's impact on hospital financing (Visconti & Morea, 2020). Optimize RFID applications in healthcare supply chains (Wicks <i>et al.</i>, 2006). Implement energy monitoring and standby systems for healthcare equipment (Rohde & Martinez, 2015). 	<ul style="list-style-type: none"> Develop life-cycle models for end-of-life medical products. Standardize healthcare manufacturer requirements for circular design of medical products. 	<ul style="list-style-type: none"> Address delays in health tech adoption by connecting research studies to practical outcomes. Identify innovative policies for effective medical equipment availability and use.
Resource Management	<ul style="list-style-type: none"> Manage overuse/misuse of medical diagnostic procedures (Massa <i>et al.</i>, 2018). 	<ul style="list-style-type: none"> Optimize resources utilization for sustainable healthcare supply chains innovations. 	<ul style="list-style-type: none"> Develop technologies and processes to increase efficiency and reduce waste in healthcare delivery. Encourage early adopters, who help demonstrate the benefits and feasibility of new approaches.
Healthcare Big Data	<ul style="list-style-type: none"> Assess big data's impact on financing sustainability and efficiency projects (Moro Visconti & Morea, 2019). Explore how big data enables smart, sustainable healthcare systems (Pramanik <i>et al.</i>, 2017). Exploit healthcare big data to enhance value co-creation, improve value for money, and reduce risk (Raghupathi & Raghupathi, 2014). Implement GS1-based standards (Jayaraman <i>et al.</i>, 2011). 	<ul style="list-style-type: none"> Explore healthcare big data to create sustainable healthcare supply chain innovation and risk reduction. Collaborate with governmental and private sectors to address security and ethical in healthcare big data exploitation. Use digital aided big data tools for sustainable healthcare supply chain innovation. Utilize healthcare big data for continuous feedback and fine tuning of SOI methods or procedures. 	<ul style="list-style-type: none"> Analyze patterns of healthcare big data with AI innovations. Implement the five main factors of diffusion of innovation theory in healthcare. Study factors influencing the adoption of healthcare big data analytics.
Sustainable Supply Chain Management	<ul style="list-style-type: none"> Develop sustainable solutions for sustainable supply chains and procurement (Fu <i>et al.</i>, 2019). Integrate risk management and quality control (Scavarda <i>et al.</i>, 2019). Adopt lean manufacturing practices (Hong <i>et al.</i>, 2014). Develop multi-objective coordination models (Nematollahi <i>et al.</i>, 2018). 	<ul style="list-style-type: none"> Promote stakeholder adoption of green supply chain innovations for circular economy transition. Transition from linear to circular healthcare supply chains. Encourage governmental standards/policies supporting circular collaborations among healthcare stakeholders. Focus on healthcare service sustainability. 	<ul style="list-style-type: none"> Identify enablers for innovation diffusion in green healthcare supply chains. Collaborate with government and private sectors to transform supply chains sustainably. Raise awareness and train workforce in sustainable healthcare supply chain innovations.

Table 2 Conceptual research framework and future research suggestions for sustainable healthcare supply chain innovation (Con't)

Themes	Existing research	Theoretical support for future research	
		Circular Design Theory	Diffusion of Innovation Theory
Stakeholder Relationships	<ul style="list-style-type: none"> Align supplier selection with environmental standards (Mitra & Datta, 2014). Enhance Supplier Relationship Management (SRM) through e-ordering and invoicing (Mettler & Rohner, 2009). Implement Patient Relationship Management (PRM) systems (Amini <i>et al.</i>, 2011). Implement consolidated service centers (Abdulsalam <i>et al.</i>, 2015). 	<ul style="list-style-type: none"> Promote stakeholder adoption of green healthcare supply chain innovations for circular economy transition. Collaborate with stakeholders to adopt circular, sustainable business models in healthcare. 	<ul style="list-style-type: none"> Develop understanding of the different stages of innovation adoption, to tailor healthcare communication and engagement strategies to meet the needs of different stakeholders, e.g. early adopters may be more receptive to in-depth technical discussions, while late adopters may require more hands-on support and training. Leverage networks to promote new stakeholder engagement approaches.
Performance Measurement (PM)	<ul style="list-style-type: none"> Improve sustainability and firm's performance through green healthcare supply chain (Walley <i>et al.</i>, 2006). Embed performance measurement systems into continual improvement and sustainability programs (Leksono <i>et al.</i>, 2019). 	<ul style="list-style-type: none"> Prioritize reuse and recycling to reduce waste and resource consumption. Engage with stakeholders to align performance systems with their recycling needs. Incorporate feedback loops and adaptive management strategies to continuously improve PM practices. Build partnerships with healthcare providers to promote circularization. 	<ul style="list-style-type: none"> Develop new performance management technologies and processes to increase efficiency. Engage early adopters to demonstrate the benefits and feasibility of new approaches. Tailor communication strategies to stakeholders' needs at different innovation adoption stages. Leverage existing networks to support performance management adoption.
Sustainable Waste Management	<ul style="list-style-type: none"> Improve pharmaceutical and personal care waste management (De Souza & Sami, 2018). Solve emergency department crowding and waste issues through innovative, green supply chain management (Chang <i>et al.</i>, 2019). Incorporate multi-professional healthcare teams to lead sustainable application of solid waste management (Scavarda <i>et al.</i>, 2019). Develop recyclable material coops (Lindgreen <i>et al.</i>, 2009). 	<ul style="list-style-type: none"> Develop life-cycle models for end-of-life medical products and equipment solutions. Standardize healthcare manufacturers requirements for circular design of medical products. 	<ul style="list-style-type: none"> Track current innovative practices in medical disposal to reflect upon the rate of diffusion of innovation. Tailor engagement strategies to the needs of stakeholders at different stages of innovation adoption. Leverage existing relationships to develop new approaches to waste management. Foster a culture of innovation and sustainability in waste management and reduction.

In general, the potential for emerging technologies such as the Internet of Things, blockchain and artificial intelligence to transform healthcare supply chains should be explored. Researchers can contribute to shaping the trajectory of technological innovation that meets sustainability objectives in the healthcare supply chain by examining the impact and potential drawbacks of these technologies. In order to foster a widespread culture of sustainability and innovation in healthcare institutions, stakeholder involvement should be explored as part of an interconnected role with health professionals, administrators, suppliers or patients. Such research holds promise for unveiling effective approaches to bring about and sustaining organizational transformations aligned with sustainability objectives.

Future research should also explore the process and benefits of the exchange of best practices and lessons learned in sustainability innovation by exploring opportunities for cooperation among healthcare and other sectors. To this end, knowledge transfer mechanisms aimed at successfully adapting sustainability-oriented practices from other sectors

should be considered in order to take advantage of external insights into improving sustainable health practice within the healthcare sector. Lastly, future research should examine the critical role played by government policies and legal frameworks in promoting or inhibiting sustainable healthcare supply chain innovation. Research in this area can help to shape a regulatory environment that is compatible with sustainability objectives of the healthcare supply chain, taking into account the policy landscape.

5. CONCLUSION

This study presents the results of a systematic literature review (2000 to 2020), organizing research findings to gain insights into research themes, concepts and practices in the area of sustainable healthcare supply chain innovations. A conceptual guideline for future research, presented in **Table 2**, highlights the current state of sustainable healthcare supply chain innovations research, proposing future research topics framed by circular design and diffusion of innovation theories in order to address research gaps. The SLR highlighted the adoption of and challenges facing sustainable

healthcare supply chain innovations, and suggested research areas to support the adoption of these practices in order to improve triple bottom line (i.e., economic, social and environmental) performance. While the concept of sustainability has been widely researched, actual sustainable practices are often overlooked in healthcare supply chain research. Healthcare organizations would benefit from applying theoretical models and research outcomes to practice, and this in turn would foster the ability of researchers to identify and understand practical limits in healthcare, allowing them to better address requirements, challenges, and gaps within the healthcare sector.

To the best of our knowledge, this study is the first to conduct a systematic literature review focused on sustainable healthcare supply chain innovations. The highlight of this study is that it contributes to the conceptual development of sustainable healthcare supply chain innovations via content outlining. The work is unique as it adopts a comprehensive analytical approach to review the past 20 years' worth of literature and is not limited to a specific type of healthcare organization or to particular geographical regions. Also, the work encompasses both a range of innovations and models in healthcare. **Table 2** identifies opportunities to collect more data related to sustainable development and innovation adoption, mapping the relationships between healthcare business models and visions, and considering opportunities to re-design these models and visions towards sustainable healthcare supply chain innovations.

This study contributes to the literature through the conceptual development of sustainable healthcare supply chain innovations. Our research suggests that healthcare organizations are transitioning to more circular design economies, driven by the environment, community, government, employees and management pressures to select healthcare innovations that support sustainable development. Significant advances in science and technology enable the diffusion of such innovations, and offer significant opportunities to revolutionize current healthcare systems, improve economic, social and environmental outcomes, and enhance everyday practices. Healthcare managers benefit from taking a more proactive stance in encouraging the use of sustainable technologies, such as waste management tools, energy-efficient systems, or even ecologically responsible purchasing procedures. Healthcare managers may evaluate the effectiveness of SOI projects by using sustainability-related key performance indicators (KPIs), which have the added benefit of enhancing transparency and accountability via regular reporting on sustainability measures such as emissions, energy consumption, waste reduction and carbon footprint. Evidence-based decision-making and continual improvement initiatives both benefit from this type of data.

On the public policy front, incentives, funding and resources are needed to enable research projects centered on advances in the sustainable healthcare supply chain. Encouraging academic and industrial research endeavors that enhance and progress the comprehension of social innovation is a critical function of policy makers. The creation of evidence-based procedures and the sharing of information within the healthcare industry may result from this support. Industry standards and certifications are also needed to encourage sustainable practices in the healthcare supply chain.

There are a few limitations to be noted in this review. The literature reviewed in this study was limited to those research-based articles indexed on specific major databases; some studies published in grey literature on the topic may have been excluded. The sole focus on English-language studies may have limited the number of reviewed papers. Additionally, time constraint limitations may have resulted in overlooking significant studies published in the focus area.

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Salma Elabed is currently a PhD candidate in Engineering Systems Management with a specialization in Supply Chain at the American University of Sharjah. She holds a bachelor's degree in mechanical engineering and a Master's degree in Biomedical Engineering. Her research interests focus on healthcare management, particularly in healthcare supply chain optimization and the integration sustainability-oriented solutions for healthcare operational challenges. Her work aims to bridge engineering principles with healthcare systems to drive innovation and continuous improvement. She has presented her research at academic conferences and is dedicated to advancing knowledge in healthcare systems management.

Abdulrahim Shamayleh received the Ph.D. degree in industrial, systems and operations engineering from Arizona State University. He is a Certified Supply Chain Professional and an Instructor from the American Association for Operations Management. He is currently an Associate Professor of industrial engineering and engineering systems management at the American University of Sharjah. His research has appeared in *Computers and Industrial Engineering*, *Journal of Cleaner Production*, and *Sustainable Cities and Society*. His research interests include operation research in healthcare, scheduling, supply chain management, and facilities planning and design.

Abdelkader Daghfous received his PhD degree in Technology and Innovation Management from The Pennsylvania State University, University Park, Pennsylvania, USA. He is currently a Professor of Business Administration at the American University of Sharjah. His current research addresses the issues of knowledge loss, collaborative innovation, digital transformation, knowledge-enabled risk management in supply chains, and sustainability-oriented innovation. His research has been published in journals such as *Omega*, *Technovation*, *Journal of Enterprise Information Management*, and the *Journal of Knowledge Management*. He presented papers in various international conferences for academics and practitioners.

Linda C. Angell received her D.B.A. degree in Operations Management from Boston University, Massachusetts, USA. She is Associate Professor of Supply Chain Management at the American University of Sharjah, U.A.E., and previously held academic roles at The Pennsylvania State University, University Park, Pennsylvania, USA and Victoria University of Wellington, New Zealand. She has extensive practitioner experience working in managerial administrative roles in the U.A.E., New Zealand, and the United States, and across various sectors including academia, government and industry. Her research spans an array of topics such as sustainable operations, group work, quality management and knowledge management.