A FRAMEWORK FOR SUSTAINABILITY-ORIENTED INNOVATION IN HEALTHCARE

by

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Approval Signatures

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Dedication

To my family and my beloved country, Palestine

Abstract

The concept of sustainability in healthcare has received significant attention in the last decade due to the associated progressive impacts on the environment. With the continuous growth and the associated challenges in healthcare, healthcare managers and experts are promoting the integration of sustainability into their supply chains to achieve sustainable healthcare. Embracing a sustainable approach in healthcare supply chains entails improving current organizational practices and processes by adopting sustainable innovations. Studies have shown that going sustainable in the healthcare industry is essential to achieve cost reduction, improved quality, and lower environmental impact. Sustainability-Oriented Innovation (SOI) is the introduction of new products or organizational processes for achieving sustainable improvement. While there have been significant research contributions conducted towards the adoption of innovations in healthcare and the incorporation of sustainability in healthcare supply chains, there has been no evidence of research collectively considering the concepts of sustainability, innovation, and healthcare supply chains. This work fills the gap in research by providing an SOI framework in healthcare with a focus on sustainable supply chain management. The main objective of this research is to propose an SOI driven assessment guide and decision-making framework for healthcare managers to enhance sustainability by getting informed on which criteria to focus on. To demonstrate the applicability of the proposed framework, healthcare experts from seven large known UAE-based hospitals were interviewed to assess the healthcare SOI criteria using a multi-criteria decision-making (MCDM) method. The results of this study indicate the need to increase knowledge and clarity over the concept of SOI to lead the advancement of the healthcare industry. The SOI framework is used as a guide for administrative managers, and decision-makers in the healthcare industry to assess and enhance sustainability in healthcare by improving existing capabilities, and implementing innovative practices with available resources. The framework provides a direction for future research in SOI practices in the healthcare sector and its supply chains.

Keywords: ***Sustainability-Oriented Innovation; Healthcare Supply Chain Management; Healthcare Innovation; Environmental Sustainability; Healthcare Sustainability-Oriented Innovation.***

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List of Abbreviations

AHE	Association for the Healthcare Environment
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
BO	Best-to-Others
BREEAM	Building Research Establishment's Environmental Assessment Method
BWM	Best-Worst Method
CRM	Customer Relationship Management
CSSD	Central Sterilization Service Department
DHA	Dubai Health Authority
DHCA	Dubai Healthcare City Authority
EoL	End of Life
GCC	Gulf Cooperation Council
HAAD	Health Authority in Abu Dhabi
HTM	Healthcare Technology Management
ICT	Information and Communication Technology
ITACA	Istituto per l'Innovazione e la Trasparenza degli Appalti e la Compatibilità Ambientale
LEED	Leadership in Energy and Environmental Design
LP	Linear programming
MCDM	Multi-Criteria Decision-Making
MENA	Middle East and North Africa
MOHAP	Ministry of Health and Prevention
NEST	National Evaluation System for Health Technology
NGS	Next-generation sequencing
OW	Others-to-Worst
POC	Point-of-care
PRM	Patient Relationship Management
PVST	Performance Verification and Safety Testing
SCM	Supply Chain Management
SHA	Sharjah Health Authority

SHSC	Sustainable Healthcare Supply Chain
SOI	Sustainability-Oriented Innovation
SRM	Supplier Relationship Management
SSCI	Sustainable Supply Chain Innovation
SSCM	Sustainable Supply Chain Management
TBL	Triple Bottom Line
UAE	United Arab Emirates
VR	Virtual reality
WHO	World Health Organization

Chapter 1. Introduction

In this chapter, a brief introduction about the healthcare industry and the healthcare authorities in the United Arab Emirates (UAE) is provided. The concept of sustainability in healthcare is then introduced, along with the associated challenges in the field. Also, healthcare supply chain management and innovation in healthcare are discussed. Then, the problem investigated in this study is presented as well as the thesis contribution. Finally, the general organization of the thesis is presented.

1.1. Healthcare Industry

Healthcare is one of the largest and most complex industries as it involves human lives and well-being. In most countries, the healthcare industry is growing substantially, and the demand for integrating sustainability in healthcare is increasing. In general, the healthcare industry consists of organizations that provide any type of medical services, manufacture medical equipment or drugs, provide medical insurance, or otherwise facilitate the provision of healthcare services to patients. Healthcare spending globally has common driving factors, which are the growing populations, medical technological advances, increased costs in the industry, and continuous market expansion [1]. According to a global healthcare report by Deloitte, healthcare spending is increasing dramatically and is expected to reach $10.059 trillion by 2022 [2]. Figure 1 presents how annual spending globally and across continents is expected to increase during 2017-2022 from $7.724 trillion to $10.059 trillion [3]. Challenges in healthcare have stimulated the healthcare sector in the Middle East and North Africa (MENA) to improve health services quality. Healthcare expenditure in the MENA region is expected to grow to $144 billion in 2020, of which approximately $69 billion is expected to come from the Gulf Cooperation Council (GCC) countries [4]. Investment in the healthcare sector is increasing in the GCC region as building a well-integrated healthcare system reduces wastes and improve services provided to patients [5]. The increase in spending in the GCC is due to a significant increase in demand for various healthcare services. The United Arab Emirates (UAE) is targeting sustainable growth and practices in the healthcare industry, addressing the UAE vision 2021, which is to become an internationally leading country of sustainable healthcare [6]. Figure 2 demonstrates Dubai's healthcare vision, mission, and main health sector entities according to Dubai clinical services capacity plan [7]. Developing a sustainable

healthcare system is therefore considered as a main goal in the UAE. The United Arab Emirates accounts for about 26 percent of the total healthcare spend by GCC governments. The healthcare sector is currently witnessing a structural shift, and it is poised to record strong growth of 60 percent in the next five years to reach $27.8 billion by 2021. This constitutes more than a 50 percent increase compared to the current $17 billion market. The aim is to achieve a world-class healthcare system and feature among the leading countries, not only regionally, but in the world in terms of quality of healthcare in the UAE.

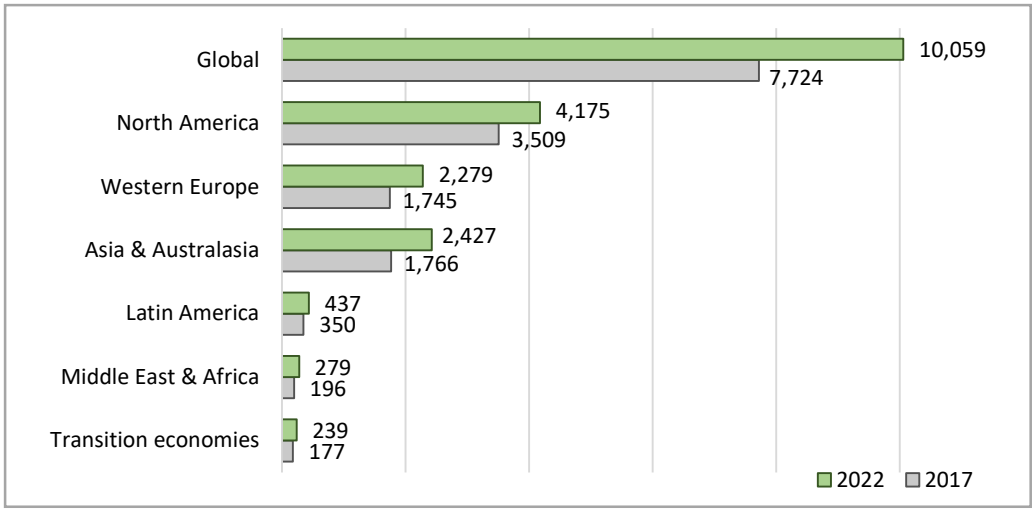

Figure 1: Healthcare spending globally and across continents (USD billion) [2].

Figure 2: Dubai healthcare sector's strategy [11].

1.2. Healthcare Governmental Authorities and Organizations in UAE

The United Arab Emirates federal government is made up of seven emirates which share common goals in terms of foreign affairs, defense, security, and social services [8]. In response to the UAE federal government's strategic perspective, the healthcare sector has been developing to provide high-quality healthcare [9]. Hence, the healthcare system in the UAE is becoming more competitive internationally by targeting significant improvements in terms of quality and access to care. In the UAE, the healthcare authorities and regulations are classified under two categories, the federal level and the emirate level [10]. The federal-level consists of the most important federal authorities in the UAE healthcare sector: Ministry of Health and Prevention (MOHAP) and the Insurance Authority. The MOHAP supervises the implementation of governmental policies over healthcare for all citizens and residents in the UAE. It also manages public healthcare services. The Insurance Authority manages the insurance sector in the UAE. The emirate level, however, covers the three main zones, southern zone (Abu Dhabi), central zone (Dubai), and the northern emirates zone. It consists of the Health Authority in Abu Dhabi (HAAD), Dubai Health Authority (DHA), Dubai Healthcare City Authority (DHCA), and Sharjah Health Authority (SHA). According to Dubai Healthcare Authority (DHA), the investments in healthcare in Dubai are massively increasing as well as the demand for healthcare services [11]. In 2017, a total of 328 new healthcare facilities and 14,314 healthcare professions were licensed in Dubai [11]. Figure 3 shows the corresponding pie distribution for each facility and professional categories of issued licenses.

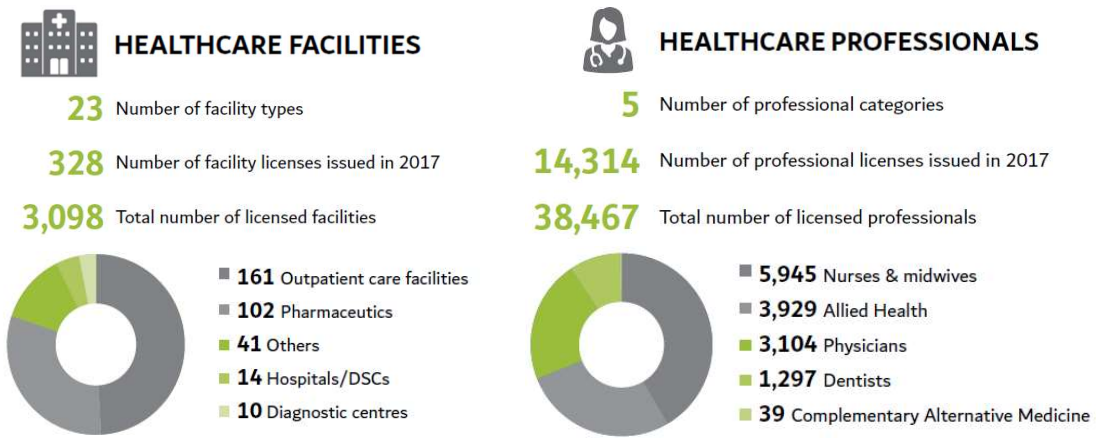

Figure 3: Healthcare facilities and professional licenses issued by DHA in 2017 [10].

1.3. Sustainability in Healthcare

UAE healthcare governments and authorities are imposing strict policies and regulations on healthcare organizations to ensure compliance with sustainability standards and requirements. Sustainability can be defined as meeting current requirements while considering future generations' ability to meet their own needs. Healthcare organizations are considering sustainable practices to develop over the Triple Bottom Line (TBL) initiatives and witnessed improvements over the environmental, social, and economical aspects [12]. The healthcare industry is a rapidly changing field and a complex one that requires governmental collaboration and stakeholder's engagement to respond to such challenges. The process of optimizing interactions between multi-stakeholders in the healthcare sector will ensure achieving common goals of better service provided and higher patient satisfaction through sustainability approach. Integrating sustainability in the healthcare industry is, therefore, a necessity to increase the efficiency of the system and lower environmental impacts.

Social sustainability in healthcare deals with human rights, health and safety, and community [13]. Improving healthcare organizational practices and attitudes fall under social sustainability. Economic sustainability in healthcare, however, draws attention to redefining priorities in resource allocation and providing financial improvement [14]. Nonetheless, achieving environmental sustainability in healthcare requires improvements in various aspects such as waste management and reduction, material segregation and transportation, and reduced consumption [15].

1.4. Healthcare Supply Chain Management

Healthcare managers and government officials are focusing on supply chains as it has shown enhanced financial management and improved quality [16]. Understanding the importance of supply chain management in healthcare lies in the supply chain's effective coordination and integration of all stakeholders. Supply chain management in healthcare comprises facilitating business networks between suppliers, distributors, inbound and outbound transportation, third-party logistics companies, and information systems providers [17]. Lack of understanding of supply chain management by healthcare professions often leads to leaving out many supply chain areas unexplored and neglected [18].

Moreover, the importance of successful supply chain management in healthcare is underrated due to the lack of understanding of what SCM in healthcare compromises. Although the industrial supply chain shares some common grounds with the healthcare supply chain, yet the same approach cannot be followed for both. In healthcare, the supply chain generally is related to several organizational factors such as building relationships, allocating authorities and responsibilities, and organizing interface processes [19]. Healthcare supply chains differ due to several aspects, which include but are not limited to the fact that the healthcare industry includes complex technologies and multiple stakeholders internally and externally. The unique features of the healthcare sector contribute to having financial and information flows very critical in supply chain management and decision-making [20]. Successful supply chain management in healthcare is achieved by determining stakeholders' ability to engage in effective communication that contributes to the most important aspects, which is achieving sustainability while improving the patient's experience.

1.5. Healthcare Innovation Initiatives

To provide better outcomes and more value for less costs and environmental impacts, healthcare organizations must break current constraints by adopting new business models. When it comes to innovation, the main drive shall be reducing the negative environmental impacts of the healthcare industry. Innovation can be defined as creating new techniques, modifications, organizational methods, and products in business practice [21], [22]. Organizational competitiveness and success are determined by innovation [23]. Sustainable healthcare systems generate various constructive outcomes, such as increased efficiency, improved quality, and waste reduction. The significance of adopting innovation in healthcare lies in associating sustainability with innovative practices and products. As such, the importance of promoting Sustainability-Oriented Innovation (SOI) in healthcare is increasing. SOI in healthcare is driven by building strong networks between stakeholders, complying with the rigorous governmental regulations, targeting noticeable cost savings, and satisfying customer demand [24]. The need to create and adopt innovations in healthcare is increasing with the rising costs and inconsistent outcomes. Healthcare organizations are aiming to achieve improved healthcare while reducing costs and spending. This can be explained by the concept of providing "more for less". Healthcare innovations expand

what is currently possible by providing more value and outcomes for less costs and time than what is required [25].

According to a report by Deloitte [25], the top 10 healthcare innovations in 2018 are: Next-generation sequencing (NGS), 3D-printed devices, immunotherapy, artificial intelligence (AI), point-of-care (POC) diagnostics, virtual reality (VR), leveraging social medical to improve patient experience, biosensors and trackers, convenient care, and telehealth. Although incorporating these innovations in a healthcare organization requires changing current models, yet they contribute to achieving performance breakthrough. The concept of eco-innovation is defined as the production of a product, process, service, or organizational method that supports the reduction of negative environmental impacts [26]. Eco-innovations consist of various categories, contributing to offering environmental benefits, which include: environmental technologies, organizational innovation, product and service innovation, and green system innovations. Several eco-innovations are being adopted by healthcare organizations to reduce environmental risks such as water pollution, wastes, and gas emissions. For instance, electronic health (e-health) and telehealth improves health access and outcomes while reducing pollution and expenses of transportation. Additionally, the use of innovative packaging solutions in healthcare contributes to enhancing the traditional medical packaging from a sustainability perspective. For instance, intelligent barcodes, biometric capabilities, and radio-frequency identification (RFID) are all considered eco-innovative alternatives to improve medical packaging's efficiency and sustainability.

1.6. Problem Statement

The healthcare industry is generating massive negative environmental impacts, and the consequences are drastic. Currently, there is a growing global concern regarding resource over-consumption, environmental degradation, and social inequity. This concern is leading to a massive transition towards a more sustainable society, economy, and environment. Thus, the urge to integrate sustainability in healthcare is increasing yet it is associated with various challenges related to the complexity of the healthcare supply chains [27], [28]. The complexity of the healthcare industry is mainly due to the multiple stakeholders that compete for limited resources [28]. In healthcare, dealing with multiple stakeholders internally and externally from various departments to achieve common goals and form effective collaborations and networking is considered

a challenge. Other challenges that healthcare managers face in achieving sustainability in healthcare/hospitals include but are not limited to the absence of direct alliance between suppliers and consumers, the rising costs of healthcare, reducing negative environmental impacts [29], [30], [31]. The healthcare industry pressure to innovate and become competitive by offering improved treatments to patients is increasing. Accordingly, integrating the concept of sustainability-oriented innovation in healthcare facilitates smoother communications, improves operational efficiency, provides better patient experience, while, most importantly, reducing costs and environmental impacts.

Healthcare organizations should not limit their objectives to obtaining only financial sustainability as environmental sustainability have to be prioritized as well. Sustainability-oriented innovation targets the holistic and integrated improvement of healthcare supply chain's environmental, social, and economic performances. The purpose of this study is to develop a framework and a platform for sustainability-oriented innovation in the healthcare sector that is concerned with the environmental aspect from a supply chain perspective. Hence, the proposed work lies at the nexus of healthcare management, sustainability, and innovation. As such, to provide healthcare managers in hospitals, a framework for obtaining sustainability-oriented innovation in supply chains, the following research questions are raised:

- How can hospitals become more innovative in the context of sustainability?
- What are the most important SOI factors that enhance healthcare especially in hospitals?

1.7. Thesis Objectives

Driven by the developing interest in healthcare services over reducing cost, improving operational transparency, and reducing negative environmental outcomes [31], the main objectives of this study are as follows. First, to identify sustainability-oriented innovative criteria to propose a sustainability-oriented innovation (SOI) decision-making and assessment guide framework for sustainable supply chain management (SSCM) in hospitals. Second, to classify the factors of the proposed SOI framework and determine the relative importance of each factor using multi-criteria decision-making methods (MCDM). Third, provide a further theoretical and practical understanding of SOI in the supply chain context.

The main purpose of this study is to further study sustainability-oriented innovative criteria in the healthcare industry. This thesis proposes an assessment and

decision-making framework based on SOI in the healthcare sector from a supply chain perspective. The benefits of this study are not restricted to healthcare organizational boundaries as adopting an SOI framework, strengthens internal and external business networking. However, the scope of this research is mainly focused on hospital's internal organizational procedures and practices that will, as a result, enhance the integration of SOI in firm's culture and practice. Thus, the proposed framework directs healthcare managers and decision-makers on SOI practices across a hospital's internal boundaries. The results of this study provide healthcare experts a guide on evaluating SOI and on determining the most important supply chain aspect, which requires further SOI integration in their organizations. Additionally, a better comprehensive understanding of the SOI concept in healthcare is illustrated. Though current research has several contributions focused on sustainable supply chains in healthcare and healthcare innovation, yet there is no research evident in implementing SOI in the healthcare context. This study fills the gap in research and literature by exploring and evaluating a comprehensive framework for sustainability-oriented innovation (SOI) in healthcare supply chain management by prioritizing criteria using the "best worst" method in the context of UAE-based hospitals. This research focuses on capturing the outcomes of integrating sustainability and innovation in healthcare supply chains.

1.8. Research Contribution

The contributions of this research work can be summarized as follows:

- Propose a sustainability-oriented innovation (SOI) assessment and decision-making framework for hospital managers to achieve sustainable supply chain management (SSCM). The framework is initially drawn from a review of the literature of current-criteria for sustainability in healthcare and will be further modified and analyzed based on feedback from healthcare managers and experts.
- Evaluate and analyze factors of the proposed sustainability innovation framework by using decision-making methods to assign weights for each main criteria and sub-criteria.
- To further analyze the applicability and efficiency of the proposed framework, analysis and insights from healthcare experts/managers from 7 hospitals based in UAE are provided.

1.9. Thesis Organization

The rest of the thesis is organized as follows: Chapter 2 provides the literature review about sustainable healthcare supply chain management (SHSC) and sustainable innovation in healthcare. Moreover, related works to the topic of interest are discussed. The employed methodology is presented in Chapter 3, along with the strategy followed to gather the required data and undertake interviews. Chapter 4 discusses the results and analysis of the framework. Finally, Chapter 5 concludes the thesis and outlines possible future research work in the subject.

Chapter 2. Literature Review

In this chapter, we discuss the concept of sustainability-oriented innovation (SOI) in healthcare as well as the healthcare supply chain. The main components of sustainability in healthcare are defined alongside the sustainable supply chain management approaches. Then, the factors of achieving sustainable innovation in hospitals' supply chains are presented. Finally, we discuss previous frameworks proposed in the field of SOI.

2.1. Sustainability in Healthcare: Triple bottom line (TBL)

In general, sustainability is meeting current needs with available resources without compromising the future generations' ability to meet their own needs. The importance of integrating sustainability in healthcare is demonstrated in the improved overall healthcare delivery. Sustainability in healthcare is achieved by proper utilization of available resources by reducing environmental and social impacts while maintaining financial improvement [32]. Studies have shown that the healthcare sector spends more than eight billion U.S dollars on energy annually [33]. Thus, the opportunities for integrating sustainability in healthcare are broad, and the benefits range from short-term to long-term benefits for the overall system. Kinney [33] found that the needs of patients, community, and the environment are met by implementing sustainability in healthcare. Adopting sustainability in healthcare constitutes public and shared benefits among internal and external operations.

Achieving sustainability in healthcare requires considering the three dimensions of sustainability or triple bottom line (TBL): social, economic, and environmental. Social sustainability in healthcare mainly focuses on social responsibility towards society [34], improving the social image of the organization [35], and conducting sustainability educational training [36]. Khan et al. [37] investigated social sustainability in the healthcare supply chain are the corresponding motivators in UAE. The results of the study showed that the highest and lowest impact on social sustainability motivation were organizational practices and attitudes, respectively. On the other hand, economic sustainability in healthcare includes the ability to achieve cost and consumption reduction while maintaining sustainable practices [22]. Lastly, environmental sustainability in healthcare consists of various aspects, which include but are not limited to waste management and reduction, resource maximization, and

conducting regular environmental audits. Blass et al. [15] proposed a framework for measuring environmental performance in Brazilian hospitals in terms of feasibility, usability, and utility of operational processes. The framework was built based on a review of the literature and feedback from healthcare managers. The resultant framework from this study provides a systematic representation of general guidelines as bases for initial environmental evaluation. Our proposed framework, however, stands out in providing an empirical, theoretical, and practical interpretation of the concept of SOI in healthcare supply chains. The ideas proposed and formulated in this research set the ground for future research in the implementation of SOI in the healthcare industry.

2.2. Medical Materials and Equipment

In this section, various sustainability methods in medical equipment and materials are discussed. Reducing waste produced by healthcare organizations and ensuring proper material segregation and storage aid in achieving environmental sustainability.

2.2.1. Waste management and reduction. Waste management and reduction in hospitals are addressed by analyzing materials that can be reused or recycled [38]. Studies show that two million tons of wastes annually are produced from the healthcare industry [33]. Thus, integrating sustainability in healthcare is not a local concern but a global one. According to the World Health Organization (WHO), waste management in hospitals includes waste minimization, waste identification, waste segregation, waste handling, waste treatment and disposal, record keeping, training, supervision, and monitoring [39]. Using mathematical modeling, Bdour et al. [40] examined waste management practices incorrect handling, storage, and disposal of wastes generated in healthcare facilities in Jordan. The study concluded that proper waste management is possible with practicing effective management, availability of recycling programs, implementing medical waste management programs, and educating workers for guidance and proper training. Waste reduction in hospitals has shown to reduce environmental impact by improving public health and safety and reducing waste disposal costs [12]. Waste classification and segregation are important to identify hazardous versus non-hazardous wastes, and infectious versus non-infectious wastes. According to the WHO, non-hazardous wastes account for 75 percent to 90 percent of waste generated by healthcare facilities [41]. The remaining percent accounts for

hazardous waste that requires greater attention as such wastes may contain infectious or toxic items. Healthcare governments and authorities are enforcing strict programs regarding waste management that healthcare organizations have to abide to [42]. Research has been conducted regarding the importance of identifying types of infectious and non-infectious wastes generated by the healthcare industry [43]. Lack of proper waste disposal contributes to presenting health risks related to the environment and well-being of individuals [40].

2.2.2. Material segregation, transportation, and storage. Proper material segregation, transportation, and storage are important to ensure that the material is in a dry and clean place and this is reflected on the patient's care being provided. The process of material transportation involves various internal and external services in healthcare supply chain. The two healthcare units highly involved are the Central Sterilization Service Department (CSSD) and the storeroom. The CSSD supplies the whole healthcare institution from diversity of products [12]. The storeroom has the end product delivered to all healthcare units. Scavarda et al. [12] analyzed the central sterilization service department and the stockroom in hospitals by proposing a sustainable supply chain management framework. They found that adopting sustainable innovative practices in the healthcare supply chains contributes positively to public life quality based on TBL. Healthcare organizations, hospitals, for instance, are to manage correct material packaging, labeling, and transportation while considering the environmental impacts. Material transportation includes, as well as appropriate handling of chemical substances from one unit to another [44]. Maintaining such practices helps in achieving sustainability in hospitals' supply chains.

2.2.3. Ease of maintenance. Healthcare procurement managers shall consider the importance of ease of maintenance when purchasing medical equipment. Selecting the correct manufacturer of sustainable medical equipment is essential for enhancing safety and efficiency during usage and equipment maintenance. Thus, achieving sustainability in medical equipment starts by selecting manufacturers that consider sustainability specifications when designing medical equipment. Various comfort indicators of manufacturer's material include but are not limited to proper information about maintenance, level of noise created during operation, and impact of the operator after multiple hours of usage [45]. Ease of medical equipment maintenance will ensure a safer and user-friendly environment for medical professions and patients. As well as,

saving man-hours for repairing, increased efficiency of the system, and higher patient satisfaction. Due to the complexity and urgency of care need in hospitals, ensuring high performance of medical equipment at all times is necessary. Therefore, hospitals could consider various equipment maintenance programs that ensure the periodic inspection is carried out. Sezdi [46] generated two different strategies for managing older technology devices and newer high-tech devices to increase device management efficiency in the hospital environment. The two strategies are preventive and predictive maintenance. Preventive maintenance is for older technology devices and predictive maintenance is for newer high-tech devices. Predictive maintenance was developed mainly to ensure regular feedback from users is collected and the smallest failure to be reported by conducting time scheduled maintenance according to manufacturers' recommendations [46]. While Preventive maintenance for older technology devices was conducted based on analysis of the periodical performance verification and safety testing (PVST) results of equipment.

2.2.4. Energy consumption. In the healthcare industry, the power quality of medical equipment is critical and essential at all times as it involves human lives. Hospitals can't have machines going down yet several technologies can be adopted by healthcare facilities to improve energy efficiency in hospitals. The average hospital uses more of total energy than any other commercial building types; embracing sustainability in healthcare is fundamental in reducing environmental impacts [47]. Medical equipment usually is of high consumption of energy; thus, energy monitoring systems are crucial for successful energy management. Installing submeters for measuring the energy consumption of medical equipment aids in providing a better understanding of energy usage and costs between various departments and timeframes [48]. By proper energy monitoring techniques, healthcare managers will be able to determine how and where energy savings can be attained in a hospital. 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 devices are least used since "stand-by" mode also consumes energy [49]. However, this energy-saving practice is restricted to some devices, such as MRI, since they have long start-up times.

2.2.5. End of life (EOL) disposal. Medical equipment end of life disposal requirement is to be provided by manufacturers. There are several environmentally friendly solutions for end of life disposal that healthcare organizations can consider when they want to get rid of medical devices and equipment. For instance, returning devices to manufacturers for disposal, or re-selling or donating devices for reuse [50]. Nevertheless, when re-selling or donating devices, all relevant documents that ensure safety to use and working according to specifications are to be provided. Also, according to the Medicines and Healthcare products Regulatory Agency, such devices are required to comply with various national provisions such as Health and Safety at Work Act and Trade Description Act [50]. Considering innovative techniques for disposal of equipment aids in increasing the level of recycling and sustainability. Governmental legislation and taxations are being implemented to ensure disposal compliance with environmental regulations and standards.

2.3. Sustainable Healthcare Facilities

Sustainable healthcare organizations, such as hospitals, are considering sustainable building design and construction. Pinzone et al. [51] examined improving sustainability in healthcare in terms of organizational and architectural levels by providing a conceptual framework. The framework constitutes of four main propositions that can be followed to achieve sustainable design buildings and organizational, operational sustainability. Attaining sustainable building design includes internal architectural design and features, such as the spatial layout and functionality, and signs and symbols used in hospitals [51]. More factors include utilizing natural lighting to reduce costs and save energy, and exposure to natural landscaping views for balancing the air-polluting emissions from medical equipment [51].

2.4. Resource Management

2.4.1. Resource allocation and utilization. Avoiding overuse or misuse of medical diagnostic procedures has various benefits on time consumption, costs reduction, and, most importantly, patient's well-being and health. Various factors have to be considered when providing healthcare services, such as the increasing costs of medical diagnostic procedures and imaging, and, most importantly, the side effects such procedures have on the patients' health. Several studies have been conducted to investigate the overuse of medical diagnostic procedures by studying the frequency and

number of medical procedures done for patients [52]. Massa et al. [52] found that there is an increase in overusing medical diagnostic procedures for end-of-life patients. Such assessment results in higher healthcare costs and unnecessary procedures that have an impact on the healthcare supply chains financially and service quality. Delivering a better quality of life and care requires providing the medical team and staff with the appropriate training and awareness to determine service misutilization and reduce it [52]. For proper resource allocation and utilization processes, healthcare managers should consider the wholistic perspective in which resource allocation is not limited to material resources. Human resources, who provide healthcare resources using material resources, are often neglected [53]. Healthcare resource allocation becomes a concern when demand exceeds supply.

2.4.2. Availability of technical expertise. Introducing technologies to healthcare organizations requires the system to be equipped with professional technical experts that have the skills to manage and deal with such innovations. Healthcare Technology Management (HTM) describes all processes of health service that manage equipment within a health system [54]. Skilled medical staff is required to be proficient at both technical and managerial levels to efficiently carry out all innovative technologies and organizational methods. The availability of technical expertise that effectively handles health technologies has benefits that range from ensuring safe quality materials comply with standards and extends to improving provided health care to patients. Involving medical expertise will enhance the process of procuring eco-innovative medical equipment.

2.5. Supply Chains in Hospitals

The supply chain is defined as the lifecycle process a product goes through beginning from the manufacturer and ending at the point of use [16]. In the healthcare industry, the healthcare supply chain consists of multi-stakeholders such as manufacturers, distributors, medical groups, insurance companies, governmental organizations and authorities, employers, and patients. The healthcare industry has witnessed supply chain strategies that improve profitability and reduce costs. Although supply chain management in healthcare is behind the industrial supply chain, yet it has shown accomplishing a good level of profitability [55]. Successful supply chain management in healthcare enhances effective internal and external organizational integration. Healthcare supply chain management controls capacity planning and

scheduling, service delivery systems, and technology in services [55]. Sustainable supply chain management (SSCM) can be defined as considering economic, social, and environmental impacts when integrating supply chains [56]. Hence, a successful sustainable healthcare supply chain achieves the goal of delivering the right material and information with the right quantities to the right place to provide patients with quality care [16]. The following sections will discuss how employing sustainable healthcare supply chains in hospitals will aid in benefits to the overall system, such as reducing operation rooms waits and length-of-stay.

2.5.1. Supply chain planning and operation.

2.5.1.1. Operational transparency. Although it is considered critical, yet sharing information and knowledge in the healthcare sector plays a role in improving organizational performance [57]. While the healthcare supply chains usually lack information sharing, studies have shown that sharing risks and profits with certain groups maintains service quality and cost estimation [58]. Visibility obtained from sharing information between stakeholders provides sustainable, functional integration. Also, operational transparency between internal and external stakeholders is essential to meet supply and demand. To achieve the success of a sustainable supply chain in healthcare, all relevant information should be shared with corresponding entities [55]. Hospitals usually are considered as one of the most organizations that records a vast amount of data, yet it is not consumed beneficially. Research has shown that lack of knowledge sharing in healthcare is caused by various reasons, which include the confusion of identifying useful knowledge from the great amount of data being recorded, classifying what information should be confidential, and lack of skilled professions to use information technologies [57].

2.5.1.2. Maintaining profitability and improving productivity. Sustainable supply chain management in healthcare is essential to maintain or increase profitability, on the long-run, while improving productivity. The main factor that drives accomplishing the outcome of increased profitability and improved productivity is the correct and effective integration of sustainable supply chain management in healthcare. Sustainable supply chain management in healthcare aims to maximize resource optimization, which as a result leads to improved performance and productivity [59]. By resource maximization, the amount of resources required is decreased and consequently, product availability is increased [60]. Moreover, productivity is

improved when the patient's hospital cycle time is minimized [61]. Thus, effective services by sustainable supply chains in healthcare satisfy customers' demand by providing the right product at the right time with the right quantity. Saviano et al. [59] use a conceptual framework to study healthcare organizations' business models and control systems to track viability and sustainability effectiveness. Management control in healthcare supports healthcare managers to achieve reduced costs and expenses. Hospitals can, therefore, achieve customer satisfaction while reducing costs by improving supply chain performance.

2.5.2 Supply chain sourcing and delivery

2.5.2.1. Supply chain visibility: Stakeholder engagement. One of the supply chains' objectives is to obtain networks between multi-stakeholders involved in the system. Supply chain visibility gives healthcare decision-makers an insight on maintaining the right inventory. As a result, complete inventory can be achieved by decision-makers at a faster pace. Additionally, the accuracy of data is enhanced, and clients' satisfaction is increased [60]. Belal [62] found that stakeholders' engagement has a positive impact on organizational profit. In the long-run, supply chain visibility between stakeholders contributes to determining the correct quantities required, which improves overall supply chain performance.

2.5.2.2. Market pressure and demand. Along with being complex, the healthcare industry is facing challenges related to complying with the increasing market pressure and rapidly varying customer's demand. Governmental policies and regulations are progressively increasing towards healthcare organizations integrating and achieving sustainability. Healthcare supply chain managers are under pressure to reduce risk-related disruption, which is caused by various factors such as demand variability, medical supplies shortage, and regulations [63]. The flow of patients, or patient logistics, is the supply chain management that aims to satisfy supply and demand in healthcare [19].

2.5.3. Supplier relationship management. Improving supplier relationship management (SRM) has direct relation to enhance operational efficiency and improve responsiveness to patients. SRM, by definition, is the process of an organization's interactions with its suppliers. Supply chain managers of sustainable supply chains select suppliers based on their alignment with environmental standards and criteria [64]. Assessing and analyzing the life-cycle of products and processes through various stages

is important to track environmental impacts [64]. Regulations on suppliers are being imposed to ensure willingness to share knowledge and practices and achieve effective collaboration between multi-stakeholders. Adopting innovative methods for information and communication in healthcare such as information and communication technology (ICT) improve the transparency of economic activities and the availability of real-time information [65]. Various methods have been created to increase healthcare organizations' engagement in innovative solutions that improve supplier relationship management, such as electronic ordering systems and electronic invoicing systems. Adopting SRM tools serves hospitals several benefits such as obtaining transparency of prices and product variety, enhancing data quality, and online tracking of orders [66].

2.5.4. Customer relationship management. Customer Relationship Management (CRM) or Patient Relationship Management (PRM) in healthcare consists of managing patients' relationships and interactions, efficiently, and effectively using innovative technologies. Managing patient relationships using CRM causes improvements in patient satisfaction, communications between patient-clinician, and efficiency [67]. A study conducted by Khoshraftar and others [67] found that the most critical factors that enhance the quality of customer relationships in a healthcare organization are tangibles, responsiveness, empathy, assurance, and reliability. Hence, an effective PRM in healthcare improves patient's overall experience and satisfaction within a healthcare setting. Value-based care in healthcare systems is achieved by engaging patients in addressing their concerns and needs.

2.6. Environmental Management Initiatives and Standards Commitment

2.6.1. Conducting regular environmental audits. Conducting evaluation and assessment audits on a regular basis is a key factor in the success of sustainable supply chains in healthcare. Achieving environmental sustainability in healthcare supply chains requires continuous tracking to ensure compliance with sustainability standards [22]. Several initiatives and evaluation systems have been structured to track and ensure compliance with sustainability standards. For instance, the National Evaluation System for health Technology (NEST) is a system that aims to synthesize data from various sources in a healthcare environment to help healthcare providers make better treatment decisions [68]. The NEST system tracks the total product lifecycle of medical devices. Other healthcare sustainability evaluation systems 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) [69]. LEED healthcare system promotes performance standards for environmental practices in building design. The LEED certification level depends on the scoring of the healthcare organization evaluation, and they range from certified, silver, gold, to platinum. BREEAM evaluation gives evidence on the environmental performance of buildings in terms of sustainability and insights on potential improvement methods. Whereas ITACA standards are developed to manage practices related to enhancing environmental sustainability [69].

2.6.2. Awareness and training. Providing healthcare professionals with regular training programs on sustainable supply chain practices, sustainable, innovative solutions, and preventive behaviors is necessary for sustainable healthcare supply chains and patients' wellness [37] [64]. Healthcare organizations can either consider internal training programs or international ones related to innovative and sustainable healthcare management. For example, the Environmental Sustainability Certification Program launched by the Association for the Healthcare Environment (AHE) to provide healthcare facilities with guidance on effective value-added environmentally sustainable healthcare operations [70]. Introducing technological innovations to healthcare organizations requires training medical staff and professions on proper usage and implementation to increase efficiency and reduce non-added value activities. Moreover, raising awareness on the importance of sustainable innovation in healthcare is essential to the public community as well as healthcare staff. The Center for Sustainable Healthcare [71] provides training workshops and masterclasses on healthcare facilities management and quality improvement to achieve sustainability. Through such programs, healthcare professions have the opportunity to network with sustainability-oriented healthcare professionals and get insights on the latest environmental sustainability practices in the healthcare industry.

2.7. Innovation in Healthcare: Hospitals

Adopting innovation in healthcare organizations is increasing due to the benefits it has on healthcare sustainable supply chains. Healthcare innovation enables quality development, cost-reduction, and improved efficiency [72]. Iandolo et al. [73] found that healthcare innovation assessment methods lack a standard accepted approach. They proposed an evaluation framework to present the linkage between the complexity of

innovations and evaluation methodologies in the healthcare context. Ancarani et al. [72] investigated the relationship between adopting innovation and efficiency in healthcare. The study found that sharing supply chain processes is essential to have an alignment between purchased and required resources. In general, building networks between stakeholders through sustainability-oriented innovative practices foster service offerings [74].

Innovation for supply chain management can be classified into two types, technological innovation and administrative innovation [75]. Technological innovation is adopting innovation for the purpose of improving performance. Organizational innovation is a result of adopting technological changes [21]. Other supply chain innovation types range from product innovation, process innovation, to resource allocation innovation. Adopting or creating innovation in supply chains improves process efficiency and effectiveness [21]. In terms of novelty, innovation can be further classified into two types: incremental innovation and radical innovation. Incremental innovation can be defined as improving current processes and practices in an organization. Nevertheless, radical innovation is replacing current services or methods with new innovative solutions. Gao et al. [21] asserted that radical innovation is more common than incremental innovation in organizations due to the success it has on best practices adoption. In general, innovation in healthcare is becoming a major focus since it fosters the growth process of integrating digital technologies. As such, innovation in healthcare is rapidly increasing and producing effective outcomes on personalized care, big data analytics, wearables, mobile applications, virtual care, and other new opportunities.

2.8. Sustainability-Oriented Innovation

In order to integrate sustainability, innovation, and supply chain management in healthcare, the concept of sustainability-oriented innovation is introduced. Sustainability-Oriented Innovation (SOI) can be defined as applying intentional modifications to organizational processes or practices, techniques, products, and systems to create social, economic, and environmental value [22], [76]. Several studies have been conducted to explore the notion of SOI as it is considered an emerging research field. Gao et al. [21] built a conceptual framework that comprehends all dimensions of sustainable supply chain innovation (SSCI). They emphasize integrating the three aspects of innovation, supply chain management, and sustainability in

organizational firms is fundamental to encompass all degrees of SSCI. Eight main characteristics of SSCI were identified by Goa et al. [21] which are: systematic, complex, internal and external, dynamic, collaborative, complementary, sustainable, and from incremental to radical. Table 1 lists the eight characteristics and the corresponding description of each.

Table 1: SSCI eight characteristics' description

SSCI Characteristic	Description
Systematic	SSCI consists of a group of activities operating to achieve a shared objective
Complex	SSCI complexity is driven from the various supply chain entities: product, process, technology, network, and so on
Internal and external	SSCI requires integration between internal and external stakeholder to share information
Dynamic	SSCI addressing rapidly changing customers' demand and new technologies
Collaborative	SSCI involves collaboration to share resources, risks and rewards
Complementary	SSCI requires participants to contribute in doing more than one activity that in return increases the outcome/benefits
Sustainable	SSCI aims to achieve balance over TBL dimensions
From incremental to radical	SSCI results in fundamental and significant changes over organizations

Furthermore, Goa et al. [21] found that the main industry in supply chain innovations is manufacturing and that surveys and case studies are the most common research methodologies applied. Calabrese et al. [74] provided a systematic literature review of current research jointly investigating service, sustainability, and innovation. Compared to the growing interest in SOI, the research found that there are relatively few studies conducted on SOI. While SOI is a developing field in research, yet none investigated SOI in healthcare supply chains specifically. Figure 4 presents a diagram of the terminologies and concepts of SOI in healthcare supply chains. Thus, the integration of sustainability in supply chains is known as sustainable supply chain

management which consists of behavioral and cultural adoption of sustainability in supply chain processes. Moreover, the combination of the concept of innovation with supply chain management generates the notion of innovation in supply chains which is improving the overall supply chain efficiency by innovating to meet consumers' needs and reduce costs. Also, sustainability and innovation come together to generate the concept of sustainability-oriented innovation. Sustainability-Oriented Innovation in Healthcare Supply Chains is the main focus of our research and study.

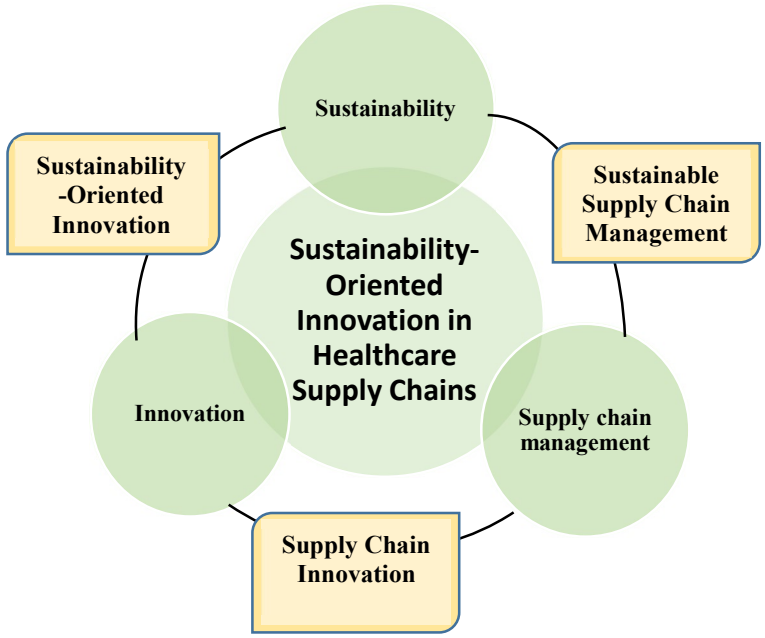

Figure 4 : Conceptual representation of SOI in Healthcare Supply Chains

2.9. Literature Review Analysis

A systematic literature review analysis is provided to incorporate the reviewed literature altogether. The analysis represents the frequency of topics in healthcare reviewed with respect to the research method used, supply chain aspects, and innovation dimension. The reviewed papers are categorized into five areas of focus: healthcare equipment, healthcare material, general/operation, facilities, and others. Table 2 summarizes the total papers reviewed in terms of the area of interest in healthcare, research methods, supply chain aspects, and innovation dimensions. The total number of reviewed papers is 84. In terms of the area of focus, the highest number of papers reviewed are mostly related to general organizational operations. As for the

supply chains, the highest number was for the ones related to supply chain operation, planning, and delivery. For innovation, the highest number was for organizational innovation. In general, the most commonly used research methods are a literature review and a conceptual framework. Although there are studies conducted in investigating sustainable supply chains, and supply chain innovation, yet none collectively integrated all aspects in the healthcare industry. Few papers discussed the concept of sustainability-oriented innovation; however, it is observed that there are significant research gaps in the field of sustainable innovation in healthcare. Figure 5 shows the time distribution of the reviewed papers. The time frame set on the graph is 2000-2019. Nevertheless, 85 percent of the total number of reviewed papers were published in the last 7 years.

Studying and integrating supply chain management, sustainability, and innovation in the healthcare industry is significant to measure how SOI will improve healthcare services by achieving patients' needs, cost reduction, and enhanced quality. The current challenges and future opportunities in the healthcare industry will be addressed in this study. Hence, enabling healthcare organizations to obtain excellence in service quality, operational efficiency, and technology and knowledge adoption and implementation.

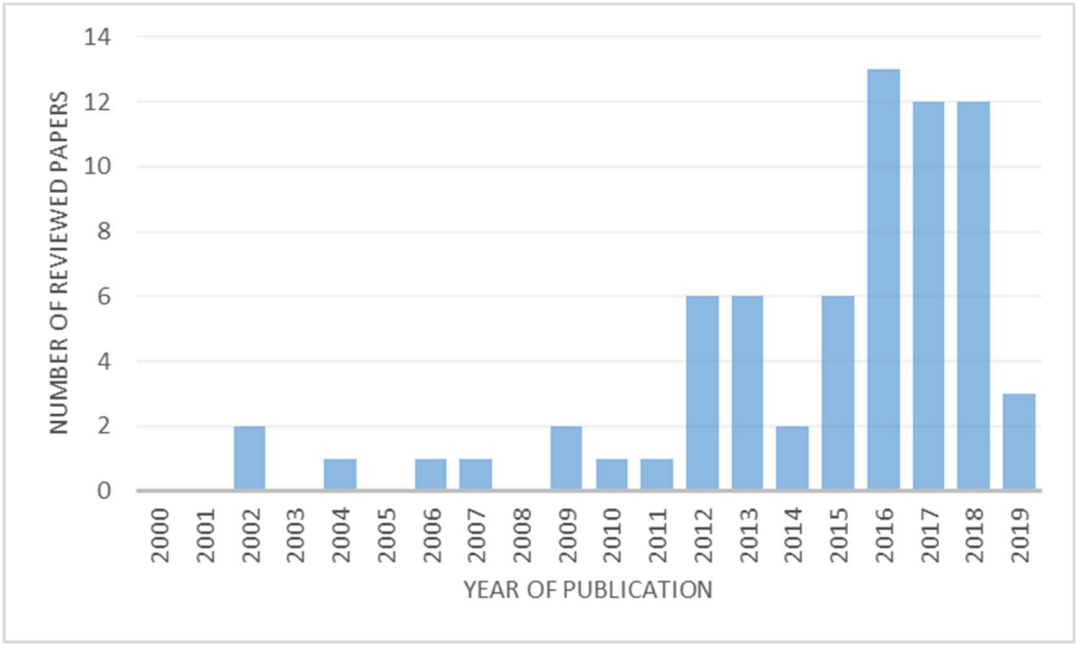

Figure 5: Distribution of number of reviewed papers over year of publication

Table 2 : Reviewed papers based on area of focus, research method, supply chain, and innovation

Area of Focus	No. of papers	Paper Ref. Sample	Research Method							Supply Chain				Innovation					
			Mathematical Modelling	Simulation	Case Study	Empirical Study	Conceptual	Literature review	Planning	Operation	Sourcing	Delivery	Adoption	Creation	Outsourcing	Radical	Incremental	Technology	Organizational
Equipment	11	e.g. Barberoa et al.; Ancarani et al.	4	0	4	0	10	2	3	3	0	1	1	1	0	0	0	2	0
Material	9	e.g. Scavardaa et al., Gabriel et al.	3	0	2	2	9	2	3	3	0	3	0	0	0	0	0	0	1
General/ Operation	57	e.g. Scavardaa et al., Silva et al.	4	1	20	3	47	32	20	26	8	22	13	10	2	1	4	4	13
Facilities	11	e.g. Calabrese et al., Kwon & Kim, Khan et al.	0	1	3	0	9	6	4	5	3	5	4	5	0	0	2	1	6
Other	7	e.g. Saada et al., Diaz-Balteiro et al.	2	1	0	0	4	6	1	2	0	3	2	1	0	0	2	1	3

	0 papers
	1-10 papers
	13-47 papers

Chapter 3. Methodology

This chapter describes the methodology employed to build and analyze the sustainability-oriented innovation framework. The first step consisted of an extensive review of literature of current and previous research concentrating on sustainability in the healthcare industry. The review of the literature also included research addressed on sustainable supply chains in healthcare and innovation in healthcare. Hence, determining the topics that have been already addressed and the existing research opportunities in the field. Based on the literature review, factors that drive or determine SOI in healthcare supply chains are extracted. An initial framework is developed based on these factors. The framework consists of 5 main criteria and 16 sub-criteria where each main criterion has its own corresponding sub-criteria.

Along with a review of the relevant literature, methods followed for collecting data include semi-structured interviews and follow up conversations. Healthcare managers who are knowledgeable about this issue in their hospitals, as well as directly involved in sustainability-related decisions were interviewed. Questions were somehow deliberately broad to allow the interviewees as much freedom and flexibility in their answers as possible. However, there were some specific questions for the purpose of analyzing the factors of the SOI framework using a multi-criteria decision-making method (MCDM). As a condition of consent for the interviews, a letter was provided to participants to assure that any information or data shared is treated with confidentiality. Hospitals are referred to as Hospital A, B, C... G for the purpose of ensuring anonymity.

A multi-criteria decision-making method (MCDM) is set of techniques utilized for operational management decision making. In general, levels of certainty in MCDM consists of three levels: certainty, uncertainty, and risk. MCDM consists of various methods that can be employed under uncertainty. One of the methods is the best-worst method (BWM) which is based on generating a consistent pairwise comparison [36]. BWM is used to determine the corresponding weights of each criterion based on importance or the most desirable alternative. Although Analytical Hierarchy Process (AHP) is the most commonly used method to determine weights of criteria based on pairwise comparison of alternative, yet it has been associated with lack of consistency. The BWM is selected for deriving weights of proposed SOI framework because it

solves the problem of the lack of consistency by increasing the overall consistency [77]. Additionally, the BWM requires pairwise comparison only between the best (most important) criteria and the other criteria; along with pairwise comparison between the given criteria and the worst (least important) criteria. Thus, BWM requires lower datasets and time, and is considered easier for calculations.

According to Rezaei [78], a detailed BWM structural is provided below:

Step 1. Determine a set of decision criteria.

In this step, the decision-maker identifies n criteria $(c_1, c_2, \dots, c_n)$ that are used to make a decision.

Step 2. Determine the best (e.g. most desirable, most important) and the worst (e.g. least desirable, least important) criteria.

Step 3. Determine the preference of the best criterion over all the other criteria, using a number between 1 and 9. The resulting best-to-others (BO) vector would be:

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}) \quad (1)$$

where a_{Bj} indicates the preference of the best criterion B over criterion j. It is clear that $a_{BB} = 1$. Table 3 presents the 1-9 scale representation of the best worst method.

Table 3: Scale description of 1-9 of the BWM

Scale for Best Worst Method								
Equally important	Equal to moderately more important	Moderately more important	Moderately to strongly more important	Strongly more important	Strongly to very strongly more important	Very strongly more important	Very strongly to extremely more important	Extremely more important
1	2	3	4	5	6	7	8	9

Step 4. Determine the preference of all the criteria over the worst criterion, using a number between 1 and 9. The resulting others-to-worst (OW) vector would be:

$$A_w = (a_{1W}, a_{2W}, \dots, a_{nW})^T \quad (2)$$

where a_{jW} indicates the preference of the criterion j over the worst criterion W. It is clear that $a_{ww} = 1$.

Step 5. Find the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$.

The aim is to determine the optimal weights of the criteria, such that the maximum absolute difference $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jW}\right|$ for all j is minimized, which is translated to the following minmax model:

$$min\ max_j\ \left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|\ , \left|\frac{w_j}{w_w} - a_{jW}\right|\right\}$$

s.t.

$$\sum_j w_j = 1$$

$$w_j \geq 0, \text{ for all } j \tag{3}$$

The following linear model is obtained from solving the above:

$$\min \xi$$

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \text{ for all } j$$

$$\left|\frac{w_j}{w_w} - a_{jW}\right| \leq \xi, \text{ for all } j$$

$$\sum_j w_j = 1$$

$$w_j \geq 0, \text{ for all } j \tag{4}$$

From solving the above model, the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^* are obtained. The consistency and reliability of the comparison is determined from their inverse relation to the value of ξ^*. Thus, the closer the value of ξ^* to zero, the higher the consistency and reliability [36]. Considering the consistency index in Table 4, the consistency ratio is calculated using the following formulation:

$$Consistency\ Ratio = \frac{\xi^*}{Consistency\ Index} \tag{5}$$

Table 4: Consistency Index (CI)

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency Index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Consistency Ratio $\in [0, 1]$, values close to 0 show more consistency, while values close to 1 show less consistency and, therefore, less reliability.

For solving the model, the linear programming (LP) with excel solver was used. The constrains for the linear model were set such that ξ is minimized. The resultant ξ for each pairwise comparison along with the corresponding consistency index (based of the preference of the best to worst criteria a_{BW}) are used to obtain the consistency ratio.

Chapter 4. Results and Analysis

In this chapter, the results obtained from the comprehensive literature review are presented. Factors that contribute to achieving sustainability-oriented innovation (SOI) in healthcare are built in a framework. Also, the results of the analysis and evaluation of the framework are obtained and discussed.

4.1. SOI Framework

Based on a review of the literature and several discussions with healthcare managers involved in sustainability-related decision-making; the SOI framework is formed and further classified into 5 main criteria and 16 sub-criteria. A brief description of each main criteria and the corresponding sub-criteria is provided along with the supporting literature. The framework's main criteria are: sustainable material management (SMM), eco-innovation of medical equipment, healthcare supply chain management (HSCM), sustainable and innovative resource management and environmental initiatives and awareness. The first main criterion is the sustainable material management (SMM) which includes any innovative organizational practice that aims to reduce the environmental impacts of medical material management processes. The three sub-criteria under sustainable material management (SMM) are: sustainable and innovative products or practices, transportation and storage, and medical waste management. The second main criterion is the eco-innovation of medical equipment which ensures the environmental compatibility of medical equipment procurement. Ease of maintenance, energy efficiency, and end-of-life disposal are the three sub-criteria related to eco-innovation of medical equipment. Healthcare supply chain management is the third main criteria involved in stakeholder's effective collaboration and demand management. The third main criteria consists of the following sub-criteria: organizational collaboration, supplier relationship management (SRM), demand management, and customer relationship management (CRM). The fourth main criterion is dealing with resource management in terms of resource allocation, green investments, and availability of technical experts. Environmental initiatives and awareness is the last main criterion dealing with regular environmental audits, environmental awareness, and sustainability-related training. The criteria are further described in details along with an example of each in Table 5.

Table 5: The proposed SOI framework

Main Criteria	Description	Sub-criteria	Description	Supporting Literature
1. Sustainable Material Management (SMM)	Organizational and innovative practices to minimize the environmental impact of products and materials used in healthcare.	**1.1 Sustainable and Innovative Products/Practices**	Adoption of sustainable products and development of innovative procedures that use less or recycled products such as using biodegradable materials.	[12], [15], [17], [18], [30], [32], [33], [34], [35], [40], [41], [44], [56], [64], [74], [76], [79], [80], [45], [81], [82], [83], [84], [85], [86] [87], [88], [89], [90]
		1.2 Transportation and Storage	Implementation of innovative methods for material packaging, transportation, handling, and storage such as the use of automated guided systems (AGV) for transportation of heat-sensitive drugs and vaccines.	
		1.3 Medical Waste Management	Innovative healthcare waste management aiming to reduce environmental impacts such as using "Hygimed" which deals with bio-medical wastes.	
2. Eco-innovation of Medical Equipment	Innovative medical equipment that comply to sustainability standards which includes high energy efficiency, and green solutions for disposal.	**2.1 Ease of Maintenance**	Ensuring accessibility and ease of disassembly of device components by using, for example, color coding for critical components determination.	[15], [30], [31], [44], [63], [79], [45], [85], [86], [87], [91]
		2.2 Energy Efficiency	Adoption of the use of equipment of low energy consumption and the use of innovative technologies for standby energy such as "Demand-side management" to reduce the need for energy.	
		2.3 End of Life (EOL) Disposal	Receiving information from suppliers on products' disposal at the end of life; implementing innovative solutions such as resale or end-of-life recycling "Medical Equipment Recycling Program".	
3. Healthcare Supply Chain Management (HSCM)	Managing, organizational collaboration, capacity planning and scheduling, products lifecycle, inventory, and technology in service.	**3.1 Organizational Collaboration**	Managing operational collaboration between stakeholders involved by applying innovative organizational processes for effective networking such as "Collaborative Healthcare Leadership".	[12], [14], [15], [16], [17], [18], [19], [20], [22], [28], [31], [32], [34], [44], [56], [60], [64], [72], [74], [75], [76], [92], [81], [88],
		3.2 Supplier Relationship Management (SRM)	Managing product information, payments, invoice verification, and performance of procurement processes using innovative techniques/software such as "Tradeshift" for e-invoicing and early payments.	

		3.3 Demand Management	Implementation of innovative techniques of knowledge management and sharing for efficient inventory tracking/monitoring such as using predictive analytics or central demand planning (CDP).	[93], [91], [94], [95], [96], [97], [98], [99], [100], [101], [102]
		3.4 Customer Relationship Management (CRM)	Managing patients' interactions with supporting suppliers, providers, and employees to improve patient satisfaction such as using "Salesforce" which improves patients' engagement with superior CRM in healthcare.	
4. Sustainable and Innovative Resource Management	Organizational practices for resource management by ensuring proper and efficient resource allocation and utilization.	**4.1 Resource Allocation**	Implementation of innovative processes for resources aligning such as the use of GS1 barcode standards which is a barcode system to minimize errors when dispensing medication.	[12], [16], [15], [22], [28], [33], [35], [44], [56], [45], [81], [82], [86]
		4.2 Investment for Green Practices	Amount of investment (budget and effort) in innovative and sustainable practices which is indicated by rising resources costs and demand such as adopting the "Healthier Hospital Initiative".	
		4.3 Availability of Technical Expertise	Reducing non-value adding activities in a healthcare organization by the availability of technical expertise to ensure proper resource consumption by engaging, for example, in Lean Healthcare Certificate Program.	
5. Environmental Initiatives and Awareness	Conducting continuous organizational audits to track compliance with environmental standards.	**5.1 Environmental Audits**	Conducting regular environmental audits to track compliance with sustainability standards such as "NEST" National Evaluation System of Technology.	[12], [15], [17], [20], [22], [28], [31], [32], [34], [35], [41], [44], [51], [56], [60], [64], [72], [73], [76], [80], [92], [82], [84], [85], [88], [103], [93], [91], [94], [98], [102]
		5.2 Environmental Awareness	Raise the awareness and understanding of sustainability-related issues and stimulate a sustained trend towards the establishment of a sustainability-oriented innovation culture and practices such as "environmental safety in hospitals."	
		5.3 Sustainability-related training	Training medical staff on environmental sustainability-oriented innovative initiatives/practices that can be implemented such as the "Environmental Sustainability Certificate Program" by AHE.	

4.2. Setting Description and Evaluation

The analysis of the framework was performed using feedback from a total of 7 hospitals based in UAE. Hospital A is a private hospital in Dubai operating for more than 15 years; it has more than 200 beds and over 700 employees. Hospital B is a public hospital in Sharjah with more than 500 employees. Hospital C is a private hospital in Sharjah with more than 70 beds and over 20 operational hospitals. Hospital D is a public hospital in Dubai operating for more than 40 years; it has over 800 beds and over 900 employees in total. Hospital E is a private hospital in Dubai with over 80 beds and more than 400 employees. Hospital F is a private hospital in Sharjah with more than 100 beds in total and has been operating for more than 20 years now. Hospital G is a private hospital in Dubai with more than 100 beds in total and has been operating for more than 5 years. Hospital H is a private hospital in Dubai operating for more than 20 years. Participants were selected as senior and upper-level managers from each hospital who engage in the decision-making of sustainable practices/products. Table 6 shows the participant's current position and total years of experience in the healthcare field. All healthcare experts and managers participating are ensured to have at least 10 years of experience in the healthcare industry.

Table 6: Participants' current position and years of experience in the field

Participant from	**Position**	**Years of Experience**
Hospital A	Acting Head of Department of Biomedical Engineering	10+
Hospital B	Biomedical Service Supervisor	25
Hospital C	Senior Biomedical Engineer	14
Hospital D	Medical Doctor	N/A
Hospital E	Manager of Biomedical Engineering Department	15+
Hospital F	Deputy Director of Engineering	34
Hospital G	Biomedical Manager	20
Hospital H	Project Manager of Biomedical Engineering	13

A total of eight hospitals were interviewed; however, the participant from Hospital H refused to give a rating or to select the most and least important preference for all criteria, therefore, this response wasn't included in the analysis. He emphasized on the equal importance of all factors of the framework and only by the consideration and implementation of all factors simultaneously will we come up with a holistic approach to target SOI in healthcare.

A brief introductory presentation regarding the main objectives and expected outcomes of the study was given to the participants. The framework was presented along with an explanation of all main criteria and corresponding sub-criteria. In most cases, the presentation was followed by a detailed discussion regarding real-life examples and issues in hospitals related to the factors of the SOI framework. The participants were then asked to identify first their preference on the most important main criteria and the least important criteria to achieve SOI in hospitals. Next, the participants were asked to rate the preferred most important criteria on a scale of 1 to 9 and then rate the best of the other criteria. Likewise, the participants were asked to rate the preferred least important criteria on a scale of 1 to 9 and then rate other criteria with respect to the least important criteria. Similarly, the approach was followed for the sub-criteria. Later, the responses are analyzed and used to obtain weights for each main criteria and sub-criteria using MCDM.

Responses from healthcare experts/managers of identifying their preference on the most and least important main criteria in achieving SOI in hospitals are presented in Table 7. Somehow, each main criterion was selected as least once as the most important and the least important from participants. However, an interesting overlap of 3 healthcare managers' responses from 3 different hospitals in which all participants selected the second main criteria "eco-innovation of medical equipment" as the least important and the fifth main criteria "environmental initiatives and awareness" as the most important. This overlap demonstrates the trend of the way healthcare managers perceive the concept of SOI in hospitals which will be further elaborated upon in the latter part of this section. The same procedure is followed for the sub-criteria in which the healthcare managers' preference as most important and least important for each set of sub-criteria are shown in Table 8. Sub-criteria under each main criteria with the highest scoring of most important preference by participants are marked in green. While sub-criteria with the highest scoring selected by participants as least important are

marked in red. Although responses of the most and least important preference seem to vary somehow, yet we notice that overall there is a trend to how healthcare experts view the concept of SOI in healthcare supply chains. Sub-criteria that received the highest preference from all healthcare experts' as the most important criteria are medical waste management, end of life (EOL) disposal, organizational collaboration, customer relationship management, availability of technical expertise, and sustainability-related training. Sub-criteria that received the highest preference from all healthcare experts' as least important criteria are transportation and storage, ease of maintenance, demand management, investment for green practices, and environmental awareness. Among the last set of sub-criteria under environmental initiatives and awareness, all healthcare managers of all hospitals selected "sustainability-related training" as the most important for achieving SOI. This indicates healthcare expert's firm belief that training is fundamental in the practical implementation of SOI in hospitals.

Table 7: Manager's preference of the most and least important main criteria

SOI Main Criteria	**Healthcare managers' preference as:**	
	Most Important	**Least Important**
Sustainable Material Management (SMM)	A	E
Eco-innovation of medical equipment	E	B, C, F
Healthcare supply chain management (HSCM)	G	A
SOI Resource Management	D	G
Environmental Initiatives	B, C, F	D

The BWM, a MCDM method, is used to evaluate the set of criteria using a systematic pairwise comparison between each of the two criteria (most important and least important) and the other criteria. Participants from all hospitals were asked to evaluate the main criteria using a 9-scale of 1 to 9. The most important and least important criteria depend on the preference of the healthcare expert/manager being interviewed. Table 9 shows the pairwise comparison of the main criteria from the participant of Hospital A. Table 10, Table 11, Table 12, Table 13 and Table 14 present

the pairwise comparison for Hospital A for sub-criteria of first, second, third, fourth, and fifth main criteria, respectively. The best-to-others or BO column shows healthcare experts' preference for the most important sub-criteria and the comparison with others. The other-to-worst (OW) shows healthcare expert's preference of the least important sub-criteria and the comparison of others with respect to the OW.

Table 8: Most and Least important criteria based on experts' preference

SOI Criteria	**Healthcare managers' preference as:**	
	Most Important	***Least Important***
Sustainable Material Management (SMM)	**A**	**E**
1.1 Sustainable Innovative Products/Practices	F, G	B, C
1.2 Transportation and Storage		A, D, E, F, G
1.3 Medical Waste Management	A, B, C, D, E	
Eco-innovation of medical equipment	**E**	**B, C, F**
2.1 Ease of Maintenance	B, G	C, D, E
2.2 Energy Efficiency	F	A, G
2.3 End of Life (EOL) Disposal	A, C, D, E	B, F
Healthcare supply chain management (HSCM)	**G**	**A**
3.1 Organizational Collaboration	C, D, F	G
3.2 Supplier Relationship Management		
3.3 Demand Management	A	B, C, D, E
3.4 Customer Relationship Management	B, E, G	A, F
Sustainable and Innovative Resource Management	**D**	**G**
4.1 Resource Allocation		B, D, F
4.2 Investment for Green Practices	F	A, C, E, G
4.3 Availability of Technical Expertise	A, B, C, D, E, G	
Environmental Initiatives and Awareness	**B, C, F**	**D**
5.1 Environmental Audits		B, G
5.2 Environmental Awareness		A, C, D, E, F
5.3 Sustainability-related training	A, B, C, D, E, F, G	

Table 9: Main criteria comparison for Hospital A

BO	**Sustainable Material Management**	**Eco-innovation of medical equipment**	**Healthcare Supply Chain Management**	**Sustainable and Innovative Resource Management**	**Environmental Initiatives and Awareness**
Most Imp. Criterion: ***Sustainable Material Management***	1	6	9	5	2
OW		Least Imp. Criterion: ***Healthcare Supply Chain Management (HSCM)***			
Sustainable Material Management (SMM)		9			
Eco-innovation of medical equipment		6			
Healthcare Supply Chain Management (HSCM)		1			
Sustainable and Innovative Resource Management		4			
Environmental Initiatives and Awareness		6			

Table 10: Pairwise comparison for MC1 for Hospital A

BO	**Sustainable Innovative Products/practices**	**Transportation and storage**	**Medical waste management**
Most Imp. Criterion: ***Medical waste management***	2	6	1
OW		Least Imp. Criterion: ***Transportation and storage***	
Sustainable Innovative Products/practices		4	
Transportation and storage		1	
Medical waste management		6	

Table 11: Pairwise comparison for MC2 for Hospital A

BO	**Ease of maintenance**	**Energy efficiency**	**End of Life (EOL)Disposal**
Most Imp. Criterion: ***End of Life (EOL)Disposal***	3	7	1
OW		Least Imp. Criterion: ***Energy efficiency***	
Ease of maintenance		5	
Energy efficiency		1	
End of Life (EOL)Disposal		7	

Table 12: Pairwise comparison for MC3 for Hospital A

BO	**Organizational Collaboration**	**Supplier Relationship Management**	**Demand Management**	**Customer Relationship Management**
Most Imp. Criterion: ***Demand Management***	2	5	1	8
OW		Least Imp. Criterion: ***Customer Relationship Management***		
Organizational Collaboration		7		
Supplier Relationship Management		4		
Demand Management		8		
Customer Relationship Management		1		

Table 13: Pairwise comparison for MC4 for Hospital A

BO	**Resource Allocation**	**Investment for Green Practices**	**Availability of Technical Expertise**
Most Imp. Criterion: ***Availability of Technical Expertise***	4	8	1
OW		Least Imp. Criterion: ***Investment for Green Practices***	
Resource Allocation		4	
Investment for Green Practices		1	
Availability of Technical Expertise		8	

Table 14: Pairwise comparison for MC5 for Hospital A

BO	**Environmental Audits**	**Environmental Awareness**	**Sustainability-related Training**
Most Imp. Criterion: ***Sustainability-related Training***	2	5	1
OW		Least Imp. Criterion: ***Environmental Awareness***	
Environmental Audits		4	
Environmental Awareness		1	
Sustainability-related Training		5	

After the pairwise comparison of each of the main criteria and sub-criteria by the healthcare experts/managers, the main criteria and sub-criteria weights are determined. Using BWM, the main criteria and sub-criteria weights for all hospitals are calculated. Table 15 presents the overall weights of all the main criteria from all hospital's participants. Each hospital participant rated the main and sub-criteria. After obtaining the weights from each hospital, criteria weights were simply averaged over all hospitals. Figure 6 demonstrates a bar chart of the final weights of all main criteria for the purpose of comparison. The final average weights along with the ranking of the main criteria are summarized in Table 16.

Table 15: Main criteria weights for each hospital and total weights from all hospitals

	Main Criteria	*Hospital A*	*Hospital B*	*Hospital C*	*Hospital D*	*Hospital E*	*Hospital F*	*Hospital G*	*Total Weights*
(MC 1)	Sustainable Material Management	0.46	0.10	0.28	0.10	0.04	0.21	0.24	0.21
(MC 2)	Eco-innovation of medical equipment	0.10	0.04	0.04	0.10	0.44	0.05	0.16	0.13
(MC 3)	Healthcare Supply Chain Management	0.04	0.16	0.14	0.26	0.13	0.09	0.45	0.18
(MC 4)	Sustainable and Innovative Resource Management	0.12	0.21	0.09	0.48	0.13	0.13	0.05	0.17
(MC 5)	Environmental Initiatives and Awareness	0.29	0.49	0.45	0.05	0.26	0.52	0.10	0.31

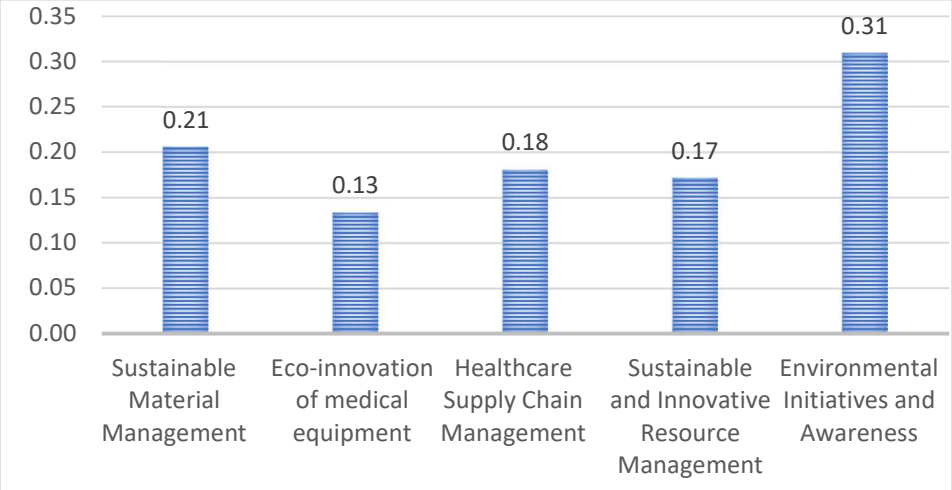

Figure 6: Main criteria total weights comparison

Table 16: Main criteria ranking based on managers' preference

Main Criteria	*Weight*	*Ranking*
Sustainable Material Management	0.21	2
Eco-innovation of medical equipment	0.13	5
Healthcare Supply Chain Management	0.18	3
Sustainable and Innovative Resource Management	0.17	4
Environmental Initiatives and Awareness	0.31	1

The local weights of the sub-criteria are then calculated and averaged from all hospitals. Next, the global weights of sub-criteria are obtained with respect to the main criteria. Table 17 shows the local weights of main criteria and sub-criteria along with the global weights and the ranking of each sub-criteria for Hospital A. Table 18 presents the resultant SOI framework weights based on BWM analysis. Figure 7 shows the ranking preference of the most important to the least important sub-criteria.

Table 17: Weights of main and sub-criteria of Hospital A

Main Criteria	Local Weights Main Criteria	Sub-Criteria	Local Weights Sub Criteria	Global Weights
Sustainable Material Management (SMM) - MC1	0.458	1.1 Sustainable Innovative Products/Practices	0.318	0.146
		1.2 Transportation and Storage	0.091	0.042
		1.3 Medical Waste Management	0.591	0.271
Eco-innovation of medical equipment - MC2	0.097	2.1 Ease of Maintenance	0.262	0.025
		2.2 Energy Efficiency	0.077	0.007
		2.3 End of Life (EOL) Disposal	0.662	0.064
Healthcare Supply Chain Management (HSCM) - MC3	0.037	3.1 Organizational Collaboration	0.305	0.011
		3.2 Supplier Relationship Management (SRM)	0.122	0.005
		3.3 Demand Management	0.519	0.019
		3.4 Customer Relationship Management (CRM)	0.053	0.002
Sustainable and Innovative Resource Management - MC4	0.117	4.1 Resource Allocation	0.205	0.024
		4.2 Investment for Green Practices	0.077	0.009
		4.3 Availability of Technical Expertise	0.718	0.084
Environmental Initiatives and Awareness - MC5	0.291	5.1 Environmental Audits	0.325	0.095
		5.2 Environmental Awareness	0.100	0.029
		5.3 Sustainability-related training	0.575	0.168

Table 18: Aggregate weights of main and sub-criteria for all hospitals

Main Criteria	Local Weights	Sub-Criteria	Local Weights	Global Weights	Ranking
Sustainable Material Management (SMM) - MC1	0.206	1.1 Sustainable Innovative Products/Practices	0.318	0.065	7
		1.2 Transportation and Storage	0.091	0.019	13
		1.3 Medical Waste Management	0.591	0.122	3
Eco-innovation of medical equipment - MC2	0.133	2.1 Ease of Maintenance	0.262	0.035	10
		2.2 Energy Efficiency	0.077	0.010	15
		2.3 End of Life (EOL) Disposal	0.662	0.088	6
Healthcare Supply Chain Management (HSCM) - MC3	0.180	3.1 Organizational Collaboration	0.305	0.055	8
		3.2 Supplier Relationship Management (SRM)	0.122	0.022	12
		3.3 Demand Management	0.519	0.094	5
		3.4 Customer Relationship Management (CRM)	0.053	0.010	16
Sustainable and Innovative Resource Management - MC4	0.171	4.1 Resource Allocation	0.205	0.035	9
		4.2 Investment for Green Practices	0.077	0.013	14
		4.3 Availability of Technical Expertise	0.718	0.123	2
Environmental Initiatives and Awareness - MC5	0.309	5.1 Environmental Audits	0.325	0.101	4
		5.2 Environmental Awareness	0.100	0.031	11
		5.3 Sustainability-related training	0.575	0.178	1

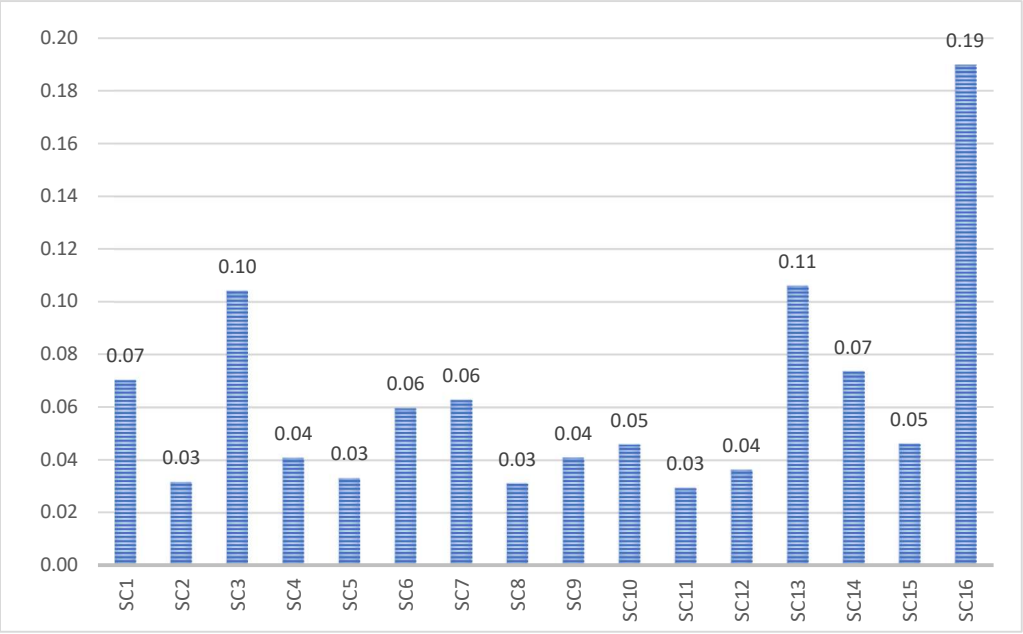

Figure 7: Sub criteria global weights comparison

To determine the reliability of the resultant weighted framework criteria, the consistency ratio is calculated using formula (5). The consistency ratio gives insights into how reliable the comparison is. Table 19 presents the consistency ratio for the pairwise comparison of all cases from all hospitals provided that the closer the consistency ratio to zero the more reliable the comparisons are. The results obtained from the BWM employed in this paper have shown to be of high consistency and reliability since all consistency ratio values to all pairwise comparison cases are almost zero. The consistency ratio was determined using the resultant value of ξ along with the corresponding consistency index from Table 4 based on the best to worst criteria a_{BW} preference value of each pairwise comparison. For instance, the consistency ratio for Hospital A of the main criteria pairwise comparison is calculated as follows:

$a_{BW}=9 \rightarrow \text{Consistency Index} = 5.23; \xi^* = 0.1248$

$$Consistency\ Ratio = \frac{\xi^*}{Consistency\ Index} = \frac{0.1248}{5.23} = 0.02386$$

Table 19: Consistency Ratio for all pairwise comparison of all hospitals

Consistency Ratio							
Pairwise Comparison of:	Hospital A	Hospital B	Hospital C	Hospital D	Hospital E	Hospital F	Hospital G
Main Criteria	0.0239	0.0256	0.0189	0.0080	0.0143	0.0211	0.0075
Sub-criteria of "Sustainable Material Management"	0.0152	0.0200	0.0351	0.0364	0.0278	0.0239	0.0500
Sub-criteria of "Eco-innovation of medical equipment"	0.0330	0.0326	0.0223	0.0123	0.0272	0.0278	0.0109
Sub-criteria of "Healthcare supply chain management"	0.0205	0.0459	0.0258	0.0639	0.0237	0.0300	0.0315
Sub-criteria of "Sustainable and Innovative Resource Management"	0.0229	0.0421	0.0278	0.0447	0.0500	0.0298	0.0295
Sub-criteria of "Environmental Initiatives and Awareness"	0.0326	0.0200	0.0330	0.0278	0.0278	0.0109	0.0278

The results provide an insight to healthcare experts' understanding of the SOI concept. While there are various environmental practices initiated in the healthcare field across UAE, there seems to be a misinterpretation of the concept of SOI in hospitals. Healthcare managers seem to neglect several aspects of SOI of their supply chains due to the lack of comprehensive understanding of SOI and correlations between conceptual theories and practical applications. Based on healthcare managers' preference, the first major observation is that "environmental initiatives and awareness (MC 5)" appear to be ranked the highest for achieving SOI in hospitals. This finding implies that healthcare managers in hospitals somehow consider medical staff and professions lacking the required awareness of the concept of SOI. Moreover, several healthcare experts asserted that regular environmental audits ensure continuous improvements over SOI in hospitals. Participants may view "environmental initiatives and awareness (MC 5)" as the most important due to the effect it has on the daily activities of medical professions and the importance of its presence in supporting other initiatives. Secondly, the first main criteria, "sustainable material management (MC 1)" seems to take precedence as the second most important criterion in achieving SOI. This reflects how healthcare experts seem to limit the concept of SOI to materialistic products and technologies. Also, all participants reported that the government is imposing strict rules and regulations for proper material management in hospitals such as medical waste management, thus, the costs associated with waste management failure may also be another factor influencing healthcare managers' preference. While medical material management is an important aspect of SOI in supply chains, yet organizational processes and methods require equal attention. SOI in healthcare is a dynamic concept achieved over time. It is, however, not limited to technological products and materials as it extends to processes, organizational methods and human behavior. In healthcare, understanding how sustainability-oriented innovations are used, who they involve and how they impact behavior changes is fundamental in the successful implementation of SOI concept. The second main criteria, "eco-innovation of medical equipment (MC 2)" was ranked as the least important among others; suggesting that hospitals do not consider eco-innovation as a determinant factor for medical equipment procurement.

For the SOI sub-criteria, the ranking is: SC16 > SC13 > SC3 > SC14 > SC1 > SC7 > SC6> SC15 > SC10 > SC9 > SC4 > SC12 > SC5 > SC2 > SC8. While we might expect a high consistent correlation between the ranking of all main criteria and their

corresponding sub-criteria, this is not exactly the case throughout. The top three SOI sub-criteria by participants are “sustainability-related training (SC16)”, “availability of technical expertise (SC13)” and “medical waste management (SC3).” The least three SOI sub-criteria by participants are “resource allocation (SC11)”, “supplier relationship management (SC8)”, and “transportation and storage (SC2).” “Sustainability-related training (SC16)” is the most important preference according to all healthcare managers to achieve SOI. This outcome suggests that healthcare managers consider conducting training for medical professions of high necessity, for it enables incorporating SOI into professional practice. The consideration of “availability of technical expertise (SC13)” as the second most important sub-criteria demonstrates the importance of having professional and knowledgeable experts to expedite the process of integrating sustainable innovations and eliminate non-added value activities. According to participants, “medical waste management (SC3)” is the third most important preference to achieve SOI among all sub-criteria. The imposed strict rules and regulations of violating standard medical waste management procedures drive hospitals to manage wastes properly. The outcomes indicate that healthcare managers are not aware of the importance of successful supply chain management in hospitals to achieve SOI. While the results may include some bias as to participants ranking the field in which they are most involved in the highest, a better and comprehensive understanding of supply chains in hospitals is still required to eliminate the detrimental effect of neglecting significant aspects of SOI.

Interestingly, however, “sustainable innovative products/practices (SC1)” was ranked as the 5th most important sub-criteria which suggests that in some way the awareness to adopt innovative sustainability products is increasing. Nevertheless, it does not necessarily mean that actual action in practice is taking place. This brings our discussion to the importance of “investments for green practices (SC12)”, even though it was ranked as 12th in terms of importance. The implication suggested here is that healthcare managers only focus on specific requirements regardless of being environmentally sustainable. While training and environmental awareness are key factors in establishing a sustainably innovative healthcare organization; nevertheless, having the financial support to invest in sustainable practices is essential to the implementation and adoption of eco-innovations in healthcare.

Several healthcare managers reported having an issue with communication and collaboration between various departments in a hospital. The relevant sub-criteria "organizational collaboration" was ranked as 6th in terms of importance. There seems to be a misunderstanding of the relevant concepts associated with the practical real-life complications occurring in hospitals. Several hospitals are adopting innovative electronic systems for reporting and networking where everything is documented eliminating the dependence solely on human memory or integrity. Similarly, there are several other organizational initiatives that requires collaboration among departments in hospitals. Medical professions, for instance, are always behind technologies, thus, an internal managerial study is required for adopting or integrating new technologies. Such a study requires effective communication between healthcare professions and decision-makers as to the underlying benefits of new technologies over the existing one.

While a tendency to adopt and engage in sustainable practices or products is noticed, yet the notion of SOI is not being comprehended correctly. Consequently, non-value adding activities are increasing on a daily bases and reducing the efficiency of the overall system. For instance, the sub-criteria, "demand management (SC9)" is ranked as 10th most important although some healthcare managers declared that lack of proper demand management on the long-run has caused failure in determining the correct required supplies. Thus, demand management or planning supports inventory management by improving stock accuracy, reducing operational costs, and ensuring peak efficiency and profitability.

Though "healthcare supply chain management (MC3)" is ranked as the third most important main criteria, but surprisingly 3 of its corresponding sub-criteria are ranked among the least important sub-criteria. All aspects of our framework are covered under the concept of the supply chain, however, only the organizational networking and collaboration between stakeholders were specified to this main criterion. This implies that healthcare managers may view and consider the importance of supply chain management in hospitals without reflecting and studying the underlying concepts and practical procedures of implementation. The wide misconception that healthcare supply chain management is not as important in achieving SOI is due to the fact that several SCM outcomes are intangible and usually become evident in the long run. Whether SCM generates outcomes on short-term or long-term, both tangible and intangible

processes or practices contribute to the success of effective implementation of SOI in hospitals.

Both “supplier relationship management (SC8)” and “customer relationship management (SC10)” are ranked in terms of importance as the 15th and 10th, respectively. The importance of exploring the potentials of SRM and CRM in achieving overall enhanced efficiency and productivity is unrecognized. Implementing SOI framework requires a comprehensive understanding, consideration, and integration of all criteria together. The SOI approach is generally an inclusive one that calls for collective actions by the multi-stakeholder in the healthcare industry to form strategic partnerships aligned with common organizational goals. Successful coordination of innovative systems for CRM and SRM generates major reductions in wasteful inventory build-ups, builds effective networking for deeper relationships and shared knowledge, and overall improved experiences of customers and suppliers. Several mobile applications are being adopted or customized to support healthcare system efficiency.

“Ease of maintenance (SC4)” and “energy efficiency (SC5)” were ranked as 11th and 13th in terms of importance, respectively. All participants reported that medical equipment, nowadays, is equipped with a “standby” mode. However, as previously discussed, the energy efficiency of medical equipment requires management as of energy consumption and associated costs. While almost all healthcare managers confirmed the easiness of maintenance of their medical equipment, still many revealed that they do not follow daily check-up rounds on equipment. Others, however, emphasized the importance of conducting daily check-up rounds to receive continuous feedback from end-user about equipment performance. Large equipment such as MRI and X-ray are usually maintained by a manufacturer or supplier with a contract agreement on acceptable “down-time” for the maintenance to be completed. As such, equipment maintained by hospitals are categorized based on the associated risk into periodic maintenance of either 4-month, 6-month, or annual.

Despite the fact that this sub-criterion is ranked as 14th in terms of importance, some healthcare managers elaborated on their approach or followed a system in achieving effective “transportation and storage (SC2)” of medical material. They use customized mobile applications linked to an electronic health system that provides healthcare managers with daily monitoring conditions related to transportation and

storage. For instance, distal tracking of medical material temperatures while being imported or supplied to the hospital and the temperature of medical equipment operating inside the hospital. Such innovation-driven changes have remarkable sustainable advances in healthcare in general and specifically in inventory management.

Lastly, "resource allocation (SC11)", was ranked as the 16th or the least important sub-criteria to achieve SOI in hospitals. This might be due to the lack of healthcare managers' understanding of what resource allocation is in actual practice and the benefits it brings to the firm if managed and allocated properly. Resource allocation is crucial to analyzing possible risks and controlling workloads, specifically in the healthcare industry where resources are limited and the demand for healthcare is unlimited. Resource allocations aim to target the problem of limited healthcare resources with the rising cost of healthcare. While the importance of resource allocation in healthcare seems to be underestimated by healthcare managers, failure to successfully allocating resources often leads to catastrophic consequences such as complete firm failure.

Chapter 5. Conclusion and Future Work

The healthcare industry's dynamic nature and complexity require effective management in supply chains to achieve sustainability. Adopting or creating innovative practices and solutions enable healthcare organizations to improve performance and enhance quality care provided to patients. Introducing the concept of sustainability-oriented innovation in hospitals' supply chains is fundamental to accomplish various positive outcomes including reduced environmental impacts. The aim of this study was to propose a sustainability-oriented innovation (SOI) framework from a supply chain perspective for healthcare managers to aid in decision-making and serve as an evaluation guide. To meet this objective, an SOI framework was proposed based on the literature review along with healthcare managers' feedback and evaluations. Hence, best-worst decision-making method was employed to generate weights for the framework's main criteria and sub-criteria based on healthcare experts/managers' preference. The outcomes of this research can be summarized as follows:

1. Healthcare industry is facing serious challenges linked to integrating sustainability in supply chains. SOI approach leads in overcoming such challenges and contributes to the reduction of environmental impacts and enhanced efficiency and performance. Our study has introduced an SOI criteria framework that deals with issues related to the healthcare sector in the United Arab Emirates.
2. According to our proposed framework, the five main criteria contributing to achieving SOI in healthcare supply chains are: Sustainable material management (SMM), Eco-innovation of medical equipment, Healthcare supply chain management (HSCM), Sustainable and innovative resource management, and environmental initiatives and awareness. The proposed framework covers both material and equipment management and organizational supply chain processes management.
3. Healthcare managers consider environmental initiatives and awareness as the most important main criteria in achieving SOI in hospitals, which in turn explains the necessity of conducting regular audits and training as a foundation in supporting other SOI initiatives.

4. There is a lack of clarity in the overall understanding of the SOI concept in the healthcare context as it is being limited to materialistic products and tangible technologies. Neglecting core fundamentals aspects of SOI and limiting it to products is consequently reflecting the overall low efficiency of the system.
5. The concept of SOI is not an "add-on" activity rather an approach that requires sustainability to be deeply embedded in the culture of the hospital. Healthcare SOI practices are designed to address internal issues and target a wider impact that extends beyond hospitals' immediate boundaries and stakeholders.
6. Further knowledge of SOI in healthcare supply chains is required for healthcare experts and managers to correctly associate practical issues with their corresponding theoretical conceptualization and representation.

Although our study has several significant contributions, there exist some limitations which provide a ground for further future research opportunities into the subject of SOI in healthcare. Provided that the study analysis was made from only seven healthcare managers and experts, generalizations cannot be made. Further research may cover a greater number of hospitals to ensure a larger-scale of higher coverage of the healthcare sector. Responses and feedback from healthcare experts may be biased to the actual section they contribute to or are mostly involved within their hospitals. Also, some healthcare managers might be giving a high ratings for factors they understand due to their knowledge limitation of other factors. However, given the high calculated consistency ratio of comparison and the trend of the participants' feedback and rating, we can be confident about certain practices and concerns related to the SOI of the UAE's healthcare sector. We suggest that future research investigates a broader study of SOI over time to track and analyze the progress of integrating SOI in UAE's healthcare supply chains. Also, comparing the results of several other MCDM techniques might provide better insights into the subject. Sustainability-oriented innovation of the healthcare supply chain is clearly an emerging subject that requires further research. Our research focused on capturing the outcomes of integrating the concept of SOI in UAE healthcare supply chains.

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Appendix A

Table 20 shows a sample of how the literature review was conducted based on area of focus, research method, supply chain and innovation aspects covered in all papers reviewed.

Table 20 : Sample of 10 papers (out of 84 in total) reviewed and the analysis of literature

Year	Authors	Area of Focus					Research Method						Supply Chain				Innovation						
		Equipment	Material	General /Operation	Facilities	others	Mathematical Modelling	Simulation	Case Study	Empirical Study	Conceptual	Literature review	Planning	Operation	Sourcing	Delivery	Adoption	Creation	Outsourcing	Radical	Incremental	Technology	Organizational
2019	Scavardaa et al.		✔	✔							✔		✔	✔		✔							
2019	Silva et al.			✔	✔			✔	✔		✔		✔	✔	✔	✔	✔	✔					✔
2019	Saada et al.					✔	✔				✔										✔		
2018	Massa et al.			✔						✔													
2018	Calabrese et al.				✔	✔						✔					✔	✔					✔
2018	Kwon & Kim				✔						✔			✔	✔	✔							
2018	Khan et al.				✔						✔	✔	✔	✔				✔					✔
2018	Simonov et al.			✔	✔				✔		✔		✔			✔		✔					✔
2018	Gabriel et al.		✔			✔					✔	✔				✔							
2018	Saviano et al.			✔							✔	✔						✔	✔				✔

Vita

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