POLITECNICO DI TORINO

Corso di Laurea Magistrale
in Ingegneria Gestionale

Tesi di Laurea Magistrale

An operational and sustainable perspective on the healthcare supply chain. A Systematic Literature Review

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Anno Accademico 2024-2025

Abstract

The healthcare supply chain is a fundamental component of the global healthcare ecosystem, characterized by high complexity, stringent regulations, and often limited budgets. Efficient management and continuous updates are essential to address challenges related to technological innovation, sustainability, and the ever-evolving market dynamics.

This research aims to conduct an in-depth analysis of the healthcare supply chain through three research questions, focusing on the topics most debated in scientific literature, with a particular attention to Lean production and sustainability. The approach adopted is a Systematic Literature Review (SLR), a rigorous and structured method that enables identifying, selecting, and critically analyzing relevant studies, thus providing a clear overview of the state of the art in this field.

The findings of this analysis highlight the areas of the healthcare supply chain that have received the most attention in the existing literature and identify research gaps that offer opportunities for further investigation. The findings reveal that the most extensively covered topic in the literature concerns the operational dimension of Healthcare Supply Chain Management (HSCM). This is followed by the economic, environmental, and social dimensions, which have been explored to a lesser extent. While sustainability and Lean approaches are frequently addressed, their concrete implementation within healthcare systems remains limited due to high costs, structural complexities, and resistance to change. These insights not only trace the current research trends but also pinpoint crucial gaps that future studies can explore to enhance the applicability and impact of innovations in the healthcare supply chain. The main gaps turn out to be: the absence of a structured approach to managing resistance to change, despite being widely discussed in relation to both lean and sustainability practices; the limited use of quantitative methods, which hinders the robustness and generalizability of findings; the lack of measurable performance indicators for the social dimension; and the insufficient integration of clear regulatory frameworks within proposed models.

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Introduction

The healthcare supply chain (HSC) today represents one of the most strategic and complex components of the entire healthcare system, directly influencing the quality of care, service efficiency, and equity in access to medical products.

In recent years, the management of the supply chain in the healthcare sector has gained increasing relevance, not only in academic contexts but also among policymakers, regulatory bodies, and industry operators. Critical events, such as the COVID-19 pandemic, have highlighted the vulnerabilities of healthcare systems, underlining the need to rethink the entire value chain with a more efficient, sustainable, and resilient approach (M. Khalid Anser *et al., 2021*). In response to these challenges, the literature has begun to produce a growing number of contributions exploring solutions to improve the planning, procurement, distribution, and disposal of healthcare products, while integrating digital tools, lean strategies, and principles of environmental and social sustainability.

The efficiency of the healthcare supply chain is a key element in ensuring high performance in economic, operational, and social terms. Effective management enables the reduction of waste and costs, optimization of inventory management, continuity of supply, and improved flexibility of the entire system. These objectives are especially relevant in a healthcare context increasingly exposed to global crises and under growing pressure regarding resource availability. Alongside operational and economic aspects, the social dimension is also gaining importance, often underestimated but essential for building an equitable and inclusive healthcare system. The adoption of innovative organizational models promotes social sustainability, helping to improve the working conditions of healthcare personnel, reduce inequalities in access to services, and foster a more patient-centered healthcare model (Shayma Romdhani *et al., 2022*). As highlighted by Faramarz Khosravi *et al.* (*2019*), it is crucial to consider indicators such as worker safety, stakeholder engagement, and equitable access to care, which directly affect the quality of assistance, trust in services, and the well-being of the communities served.

In parallel, the literature shows growing attention toward the integration of environmental sustainability into the HSC. Sustainable supply chain management helps improve operational efficiency, reduce waste, and strengthen the resilience of healthcare systems (Ngoc-Hong Duong *et al., 2021*; Yagmur Atescan Yuksek *et al., 2023*). The adoption of practices such as green procurement, optimized waste management, the application of circular economy principles, reverse logistics, and the use of low-impact technologies contributes to reducing CO_2 emissions, containing energy consumption, and promoting more responsible and efficient use of resources (Kaviya Sri Suthagar *et al., 2023*; Gláucya Daú *et al., 2019*).

An additional contribution in this direction is provided by lean healthcare practices, which have proven effective not only in minimizing waste but also in supporting environmental sustainability

through more rational resource use and a reduction in the ecological footprint of healthcare facilities (Gabriela Aline Borges *et al., 2019*). The lean approach, adapted to the healthcare sector, also allows for process optimization, service quality improvement, and increased overall supply chain efficiency, thus helping to build a more agile, sustainable, and value-oriented system for the patient.
In light of these considerations, the main objective of this thesis is to conduct a Systematic Literature Review (SLR) to explore in a structured and in-depth manner the current state of the art in healthcare supply chain management and to define the main research trends and gaps. The investigation is designed to answer three main research questions, which guide the entire study:

- **RQ1**: *What are the operational, economic, environmental, and social aspects of healthcare supply chain management addressed?*
- **RQ2**: *How can Lean principles be applied to minimize waste and reduce costs in healthcare supply chains while maintaining quality of care?*
- **RQ3**: *How social and sustainable models based on circular economy and on ESG factors/SDGs goals can reduce adverse externalities along the healthcare supply chain? Are there any regulations to comply with regarding this?*

The research has been structured to provide, in Chapter 1, a general overview of the Healthcare Supply Chain (HSC), outlining its main characteristics, identifying the key stakeholders involved, and analyzing the current challenges affecting its functioning. Additionally, it introduces and discusses the key themes intertwined with healthcare supply chain management, such as lean management, sustainability, and operational, economic, and social dimensions, highlighting their impact on the healthcare system.
Chapter 2 delves into the core of the research, presenting in detail the conducted Systematic Literature Review (SLR). This section introduces the research questions, describes the methodology used for the analysis (including the snowballing approach), and illustrates the process of selection, categorization, and interpretation of the sources. Based on the findings of the literature review, the chapter identifies the main trends and highlights the research gaps that may serve as a foundation for future studies in the field of HSC.
The main findings of the research reveal a predominance of operational themes, with a particular focus on improving the efficiency of the healthcare supply chain, increasing its flexibility, and managing inventory, explored from multiple perspectives. Although sustainability and the lean approach are recurring topics in the literature, their effective implementation in the healthcare context remains limited. The main barriers are linked to high implementation costs, structural complexities, and resistance to change, which hinder the full adoption of such practices. These findings make it possible to identify the main research trends and, at the same time, highlight significant gaps on which future

research can focus to strengthen the applicability and effectiveness of innovations in the healthcare supply chain.

Chapter 1: Theoretical Background

Healthcare Supply Chain Management (HSCM) plays a crucial role in ensuring efficiency, accessibility, and sustainability in healthcare services (A. Dixit and S. Routroy *et al., 2019*). This chapter examines the distinctive characteristics of the healthcare supply chain, highlighting its main challenges and the role of various stakeholders in the sector. Additionally, it explores key topics related to HSC, including Lean Management, sustainability, and the social, operational, and economic dimensions, emphasizing their impact on the resilience and effectiveness of the healthcare system. Furthermore, it provides a comprehensive and clear definition of sustainability and social aspects, outlining their significance in shaping a more efficient, equitable, and sustainable healthcare supply chain.

1.1 An overview of healthcare supply chain management

Healthcare Supply Chain Management (HSCM) is a key concept for improving the efficiency and sustainability of supply chains in the healthcare sector. It requires a highly complex and structured system to ensure efficiency, quality, and accessibility of healthcare services (Riccardo Aldrighetti *et al., 2019*).

Healthcare Supply Chain (HSC) refers to a type of supply chain that encompasses all processes related to the procurement, production, distribution, and management of drugs, medical devices, and other healthcare products, from raw materials to patients (Anuj Dixit *et al., 2019*; Mahmah Samah *et al., 2022*). The entire healthcare supply chain is characterized by strong interdependence among numerous stakeholders, the need for high precision and quality, and stringent regulatory constraints. Unlike supply chains in other industries, any error in the healthcare sector directly affects the quality of patient care, operational efficiency, and healthcare costs; therefore, decisions must also consider their impact on public health.

An efficient, responsive, and reliable supply chain reduces errors, saves resources and costs, and ensures the timely delivery of medical supplies, equipment, and pharmaceuticals while maintaining high standards of patient care and safety.

In healthcare supply chain management, various actors are involved, each with their own interests and the power to significantly influence the overall outcome of the healthcare system. These actors can be divided into two main categories: internal and external stakeholders, as illustrated in *Fig. 1* (Faramarz Khosravi *et al., 2019*).

Internal stakeholders are those directly involved in HSC operations, including:

- **Manufacturers**: responsible for transforming raw materials into finished products.
- **Distributors and logistics providers**: companies managing transportation and storage.
- **Suppliers**: companies providing raw materials, pharmaceuticals, medical devices, and other healthcare products, ensuring quality and timely delivery.
- **Healthcare personnel**: including doctors, nurses, and other healthcare workers whose well-being and working conditions directly impact system effectiveness.
- **Hospitals and healthcare facilities**: final distribution points that ensure the correct administration of products.

Conversely, external stakeholders include all actors who, while not directly involved in daily operations, influence or are influenced by the HSC:

- **Patients**: the primary recipients of the healthcare system, requiring reliable and high-quality products.
- **Government and regulatory authorities**: government bodies and regulatory agencies that oversee the healthcare system and monitor regulatory compliance.

Several challenges must be addressed to ensure an efficient, resilient, and reliable system. The main issues characterizing this sector include:

1. **Logistics Complexity and Storage Challenges**: One of the primary challenges in HSC is inventory management and optimal stock levels (A. Dixit *et al., 2019*), which must balance product availability with the risk of waste. Additionally, some pharmaceuticals require strict storage conditions, such as cold chain preservation, making logistics even more complex. Another critical aspect often overlooked is the incompatibility of certain medical products during storage, due to the risk of chemical reactions or cross-contamination. For instance, some pharmaceuticals and medical supplies require strict separation to avoid degradation, contamination, or adverse interactions that could compromise their efficacy or safety (Shayma Romdhani *et al., 2022*). This issue is particularly critical in hospitals and distribution centers where storage capacity is limited, and multiple products with different storage requirements must be managed efficiently. To mitigate this risk, healthcare facilities need to implement stringent inventory control policies, specialized storage environments, and

advanced monitoring technologies that ensure the physical and chemical stability of stored products.

2. **Traceability and Drug Safety:** According to the World Health Organization (WHO)[1], drug counterfeiting is a global threat (Shaker Alharthi *et al., 2020*). The WHO states that one in ten drugs circulating in developing countries does not meet quality standards or is counterfeit, posing severe public health risks. To counter this phenomenon, traceability systems such as RFID[2], blockchain, and artificial intelligence (AI) must be implemented.
3. **Sustainability and Waste Management:** The pharmaceutical sector generates a high quantity of toxic waste, which is difficult to dispose of and has a significant environmental impact. Integrating Green Supply Chain Management strategies into HSC is increasingly necessary to reduce emissions, waste, and optimize processes sustainably. Another crucial aspect is developing reverse logistics, i.e., the recovery and recycling of expired or unused drugs, a method still poorly implemented in many regions.
4. **Disruption of the HSC**: Events such as COVID-19, natural disasters, or geopolitical conflicts have highlighted the fragility of the healthcare supply chain, causing significant repercussions throughout the ecosystem. A major critical issue that emerged is the heavy dependence on a limited number of global suppliers. To mitigate these risks, it is essential to strengthen supply chain resilience through diversification strategies and preventive measures, ensuring greater adaptability and response capacity to adverse events.
5. **Demand Forecasting Difficulties:** The healthcare sector is highly variable and often unpredictable, making it very complex to provide accurate forecasts of healthcare product demand.
6. **High Costs:** The need to optimize costs often leads to cuts in safety stocks and inventory reduction, increasing the risk of shortages in critical moments. Solutions such as Just-in-Time (JIT)[3] are difficult to implement in the healthcare sector, where ensuring product availability is always essential.

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[1]Farmaci falsi o scadenti, Oms: 1 su 10 nei Paesi in via di sviluppo. Farmacista 33, 2017, https://www.farmacista33.it/archivio-news/14142/farmaci-falsi-o-scadenti-oms-1-su-10-nei-paesi-in-via-di-sviluppo.html

[2] RFID (Radio Frequency Identification): technology that uses radio waves to identify and track objects in real time, improving inventory management and security in the HCSC.

[3] JIT (Just-in-Time): production and inventory management strategy that minimizes stock levels by ensuring that materials and products arrive exactly when needed, reducing waste and storage costs in the HCSC.

7. **High Number of Stakeholders:** The HSC involves a large number of stakeholders, each with their own interests and objectives. Lack of coordination and communication among various actors can lead to inefficiencies, delivery delays, and resource wastage.

These are just some of the complex challenges that the healthcare supply chain faces daily. Addressing these issues is crucial to improving healthcare system effectiveness and ensuring quality care for all patients.

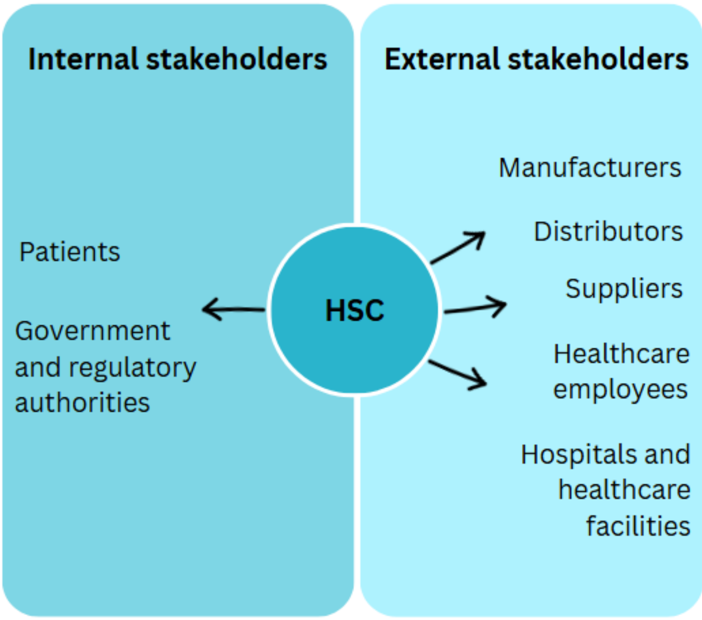

Figure 1: Stakeholders

1.2 Topics related to healthcare supply chain management

The healthcare supply chain is a complex and structured system, characterized by a wide range of interconnected themes. Among the key aspects emerging in this sector, Lean Management, sustainability, and the social, operational, and economic dimensions of the Healthcare Supply Chain (HSC) hold particular importance, as they are essential for ensuring efficiency, equity, and resilience in the healthcare system.

Lean Management refers to the streamlined management of a company, process, or production chain, achieved through the application of Lean Thinking[4] and the Toyota production System[5]. Lean Management, adaptable to all sectors and contexts, is a continuous improvement approach aimed at creating value for the customer, increasing competitiveness, reducing idle times, optimizing workflows, and eliminating waste. Although slowly, the healthcare sector has recently begun to implement these techniques, adopting processes designed to maximize value for the patient, eliminate waste, and ensure patient quality and safety (Gabriela Aline Borges *et al., 2018*; Poonam Singh, *2018*). The existing literature suggests that the transition toward Lean Management in the healthcare industry is a complex process due to the highly political and intricate context (McNulty *et al., 2011*). Nevertheless, various studies have demonstrated that applying Lean principles in the healthcare sector brings significant tangible benefits, improving cost efficiency, reducing waiting times, enhancing patient safety, and increasing patient satisfaction.

Another element that is increasingly integrated into HSC decision-making is the concept of sustainability, a topic of growing relevance in recent decades, which will be further explored in *Section 2.3.* The literature remains rather fragmented regarding the application of sustainable practices in the healthcare sector due to the sector's unique characteristics, such as the complexity of the supply chain and the involvement of numerous stakeholders (Matloub Hussain *et al., 2018*). Despite these challenges, many professionals in the field have recognized the importance of adopting sustainable management practices to reduce waste, minimize environmental impact, and improve access to care. The healthcare industry, in fact, has a significant environmental impact, primarily due to high energy consumption, the production of hazardous waste, and substantial CO_2 emissions. To mitigate these effects, strategies such as

[4] It is a true philosophy, a process of learning and improvement aimed at eliminating waste to create standardized, excellent, and low-cost processes (Poonam Singh, *2018*).

[5] It refers to a production organization method derived from a philosophy based on mass production, often on a large scale, inspired by Henry Ford's assembly line.

circular economy principles, reverse logistics, the use of eco-friendly materials, and material recycling have been implemented to reduce environmental impacts.

To improve the quality of care and access to healthcare services, it is necessary to balance and manage the social, operational, and economic aspects of the HSC effectively. On the *social* level, the main priorities include improving working conditions in the healthcare sector, ensuring patient safety, promoting corporate social responsibility (CSR)[6], and enhancing accessibility to medicines and treatments. These aspects will be further explored in *Section 2.4,* which is dedicated to the definition of social.

On the *operational* level, to make the HSC more resilient and reliable, risk management measures are adopted to reduce supply chain vulnerabilities and ensure a more effective response to crises. Strategies are implemented with the common goal of minimizing waste, increasing the availability of healthcare products, improving product traceability, reducing the risk of shortages or overstocking, and properly disposing of waste.

Finally, from an *economic* perspective, it is essential to balance cost reduction while maintaining high quality and service standards.

The synergistic integration of these aspects is fundamental to ensuring an efficient, sustainable, and resilient HSC, capable of addressing future challenges in the healthcare sector and responding more effectively to the needs of the population.

1.3 Sustainability: a literature-based analysis of its definitions and dimensions

This section explores the meaning of sustainability and its various dimensions, highlighting its relevance to Healthcare Supply Chain Management (HSCM). Given the central role of sustainability in HSCM analysis, understanding its meaning and implications is an essential step before proceeding with the systematic literature review. This analysis provides a solid theoretical foundation for identifying and understanding all concepts related to sustainability, with the aim of offering a broader and more comprehensive perspective on the topic.

Sustainability is a multifaceted concept that encompasses various dimensions, primarily focusing on the balance between meeting current needs and preserving resources for future generations. One of the most recognized definitions comes from the 1987 Brundtland

[6] CSR is a management concept whereby companies integrate social and environmental concerns in their business operations and interactions with their stakeholders. https://www.unido.org/our-focus-advancing-economic-competitiveness-competitive-trade-capacities-and-corporate-responsibility-corporate-social-responsibility-market-integration/what-csr#:~:text=Corporate%20Social%20Responsibility%20is%20a,and%20interactions%20with%20their%20stakeholders

Commission report, which defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Luis Montesinos *et al., 2024*).
To provide a more precise and structured definition of the concept of sustainability, a literature analysis was conducted based on well-defined inclusion criteria:

• **Timeframe:** The entire publication period available in the database has been considered, as both older and more recent publications are deemed fundamental.
• **Language:** Restricts the search for articles and manuscripts exclusively to documents written in English.
• **Publication type(s):** Includes various document types, such as articles, reviews, conference papers, book chapters, notes, editorials, books, letters, short surveys, errata, conference reviews, data papers, and reports.
• **Database:** The research relies exclusively on the Scopus database. Scopus was selected as the primary reference source due to its status as a globally recognized database, encompassing over 25,000 papers that are continuously updated.
• **Keywords:** Selects studies that utilize specific keywords related to the research on Scopus.

The research was conducted on Scopus using the following keywords, selected to ensure a comprehensive analysis of the various dimensions of sustainability:

- *“Environmental” AND “sustainability” AND “definition”*
- *“Economic” AND “sustainability” AND “definition”*
- *“Social” AND “sustainability” AND “definition”*
- *“Cultural” AND “ethical” AND “sustainability”*
- *“Dynamic Equilibrium” AND “sustainability”*

After defining the keywords, the relevant papers on the topic were selected, highlighting that the theme of sustainability encompasses environmental, social, economic, ethical, political, and cultural dimensions. Despite the widespread use of the term, the literature demonstrates that reaching a unified and shared definition remains challenging due to its contextual and adaptable nature (Glavič & Lukman, *2007*).

1. Environmental, Economic, and Social Dimensions (Triple Bottom Line)

One of the most widely discussed models of sustainability is based on the concept of the three pillars: environment, economy, and society, which later evolved into the Triple Bottom Line (TBL) framework. The idea that sustainability should balance environmental, economic, and social aspects gained prominence with the concept of sustainable development, outlined in the Brundtland Report (1987), which defines it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Ukko *et al., 2019*). While the Brundtland Report emphasized this multidimensional approach, the TBL framework, introduced later by Elkington in the 1990s, further structured sustainability assessment by integrating these three dimensions into a measurable model. The environmental dimension concerns the protection of life-support systems, such as climate and biodiversity (Moldan *et al., 2012*), while the economic dimension focuses on the sustainable management of natural and economic capital (Baumgärtner & Quaas, *2010*). The social dimension, often overlooked, involves equity, social justice, and community well-being (Droz, *2019*).

1.1 Environmental Dimension

Environmental sustainability is perhaps the most established aspect, often defined through the conservation of natural systems and the limits of the planet's resources. The scientific approach to planetary boundaries, as theorized by Rockström et al. (2009), emphasizes the need to maintain the vital functions of ecosystems to ensure humanity's future (Ukko *et al., 2019*). Key concepts include maintaining biodiversity, reducing the ecological footprint, and protecting the climate (Moldan *et al., 2012*). However, discussions on this dimension extend beyond quantitative indicators and often address normative issues, such as equity in access to natural resources among different populations worldwide (Ruggerio, *2021*).

1.2 Social Dimension

Social sustainability emphasizes social justice, collective well-being, and quality of life. This dimension is often discussed in terms of social inclusion, local community participation, and equitable access to resources and opportunities. Authors such as Droz (2019) suggest that human well-being derives from self-determination and the creation of meaningful social environments that foster cultural diversity and respect for collective identities. Community involvement is considered essential for ensuring sustainability, as local cultural values influence the perception of resources and social priorities (Glavič & Lukman, *2007*). The social dimension is closely intertwined with the environmental dimension, as social inequalities often emerge in situations of ecological degradation.

1.3 Economic Dimension

Economic sustainability focuses on managing natural, human, and financial capital to ensure that economic development does not compromise resources for future generations. The main debate concerns how to integrate sustainability into traditional economic models. Authors such as Baumgärtner and Quaas (2010) propose the sustainability economics approach, which aims to balance economic efficiency with social and environmental justice. Part of the debate revolves around adopting alternative economic models, such as the green economy and circular economy, which seek to decarbonize and optimize resource use (Ruggerio, *2021*). Furthermore, discussions emphasize the role of small businesses and local economies in promoting sustainable practices through cooperation with external partners, as seen in the open sustainability model (Ukko *et al., 2019*).

2. Ethical Dimension

Sustainability is inherently linked to ethical issues, such as responsibility toward future generations and distributive justice. Droz (2019) highlights the value of individual and collective self-determination as a key principle for defining fair and inclusive sustainability. The ethics of sustainability are connected to the concept of intergenerational equity (justice between generations) and intragenerational equity (justice among individuals within the same generation), which are central to discussions on the equitable distribution of resources and environmental benefits (Baumgärtner & Quaas, *2010*).

3. Political Dimension

Sustainability is heavily influenced by global governance, which must address challenges such as climate change, water resource management, and food security. The literature highlights the need for inclusive and participatory policies involving local, national, and international actors (Ukko *et al., 2019*). Global institutions, such as the

United Nations, promote multilateral approaches through the Sustainable Development Goals (SDGs). However, a common issue is the conflict between local and global interests, often requiring compromises to reconcile cultural and political differences (Glavič & Lukman, *2007*).

4. Cultural Dimension

Sustainability cannot be separated from the promotion of cultural diversity, which offers different interpretations of well-being and ways to achieve it. Droz (2019) argues that respecting the plurality of cultural values and local identities is fundamental to global sustainability. This dimension is particularly relevant in sustainability strategies applied to indigenous communities or regions with strong cultural roots, where resource management models often reflect traditional knowledge and local approaches.

In conclusion, sustainability is a dynamic concept that spans multiple interconnected dimensions. While each dimension presents specific challenges, their integration is essential to systematically addressing environmental, social, and economic issues. A holistic approach to sustainability, incorporating ethical values, inclusive policies, and cultural diversity, is necessary to tackle global challenges and promote truly sustainable development.

1.4 Social: a literature-based analysis of its definitions and dimensions

This section explores the concept of "social" in its multiple dimensions, analyzing the interactions, structures, and dynamics that shape relationships between individuals and groups within societies. Understanding these aspects is essential for Healthcare Supply Chain Management (HSCM), as social dynamics influence resource distribution, equitable access to services, and stakeholder cooperation. Therefore, exploring the meaning of the "social" concept allows for a more comprehensive understanding of the topic, encompassing all its related dimensions and providing a solid foundation for conducting the analysis with greater clarity and depth.

The notion of "social" is multifaceted and varies across academic disciplines. Broadly, it refers to the interactions, relationships, and structures that arise among individuals and groups within societies.

To provide a more precise and structured definition of the concept of social, a literature analysis was conducted based on well-defined inclusion criteria:

• **Timeframe:** The entire publication period available in the database has been considered, as both older and more recent publications are deemed fundamental.

• **Language:** Restricts the search for articles and manuscripts exclusively to documents written in English.

• **Publication type(s):** Includes various document types, such as articles, reviews, conference papers, book chapters, notes, editorials, books, letters, short surveys, errata, conference reviews, data papers, and reports.

• **Database:** The research relies exclusively on the Scopus database.

• **Keywords:** Selects studies that utilize specific keywords related to the research on Scopus.

The research was conducted on Scopus using the following keywords:

- *"Social" AND "Relationship*" AND "Definition"*
- *"Social" AND "Structure*"*
- *"Social" AND "Change"*
- *"Social" AND "Economy"*
- *"Impact" AND "Technology" AND "Social"*
- *(Social AND Issue*) OR (Social AND Inequalitie*)*
- *"Sociological" AND "Theorie*"*
- *(Cultural OR Symbolic) AND "Social"*

After defining the keywords, the relevant papers on the topic were selected, and the concept of "social" was explored as a vast and multidimensional domain, encompassing aspects related to social norms, structures and hierarchies, inclusion and equity, and dynamics of cultural and social change. The analyzed literature highlights how these dimensions are deeply interconnected and crucial for understanding the functioning of modern societies and their challenges.

1. **Social Norms and Collective Behavior**

   Social norms are considered a fundamental element in determining what is acceptable or unacceptable in a social context. They influence individual and collective behaviors, acting as mechanisms of social regulation (Andrighetto *et al., 2024*). Norms are not static but evolve dynamically in response to socio-cultural, political, and economic changes. This evolution is evident in areas such as public health, where norms against smoking in public places have become widely accepted, and environmental sustainability, where behaviors like energy conservation and plastic reduction have gained social approval. Recent examples include the rapid adoption of pandemic-related norms, such as social distancing and mask-wearing, demonstrating how norms adapt to emerging societal challenges (Andrighetto *et al., 2024*). Their effectiveness depends on their ability to remain flexible and responsive to shifting circumstances, including crises like climate change and global health emergencies.

2. **Social Structures and Inequality**
   The literature explores the role of social structures in maintaining or reducing inequalities. Social structures include laws, institutions, social networks, and cultural norms that regulate relationships among individuals (Antonoplis, *2024*). Inequalities, often rooted in the unequal distribution of material and social resources, arise from mechanisms such as the fragmentation of social networks and segregation (Redhead, *2025*). Societies with more fragmented social networks tend to exhibit higher levels of inequality due to limited resource circulation.

3. **Social Inclusion and Social Justice**
   Social inclusion is a central theme in the "social" discourse, as it involves the fair engagement of all individuals in community life and access to opportunities (Greenfield, *2018*). Social exclusion can result from cultural, economic, or institutional barriers, posing a threat to social cohesion and sustainable development (Droz, *2019*). To address these barriers, social inclusion initiatives focus on removing obstacles and promoting policies that foster equity and universal access to resources.

4. **Social Change: Causes and Consequences**
   Social change is a key process in redefining existing norms and structures. According to de la Sablonnière (2017), social change can be incremental or dramatic, with different effects on cultural identities and individuals' psychological well-being. The causes of social change include economic, technological, and political factors, while its consequences can impact areas such as social cohesion, political participation, and inequality levels. Recent theories emphasize the importance of understanding the psychological mechanisms that enable individuals to adapt to rapid or unexpected changes.

5. **Culture and Social Values**
   The cultural dimension plays a fundamental role in shaping social norms and

structures. Sociological and anthropological theories, such as those proposed by Tönnies (1957) and Redfield (1941), distinguish between two primary societal orientations: cooperative and competitive.

In cooperative societies, collective well-being, strong social ties, and mutual support are prioritized. These societies tend to uphold strict social norms to maintain group cohesion and ensure stability. In contrast, competitive societies emphasize individual achievement, autonomy, and market-driven interactions. Here, flexibility and innovation are valued, and personal success is often rewarded over collective stability (Greenfield, *2018*).

This distinction highlights how cultural values influence the way societies function, shaping both interpersonal relationships and broader social structures.

The concept of "social" is fundamental for understanding the complexity of human relationships and contemporary societies.

However, it is important to distinguish between the social dimension of the Triple Bottom Line (TBL), which is a component of sustainability, and the broader social topic analyzed in this review. In the TBL framework, the social dimension focuses primarily on equity, social justice, and community well-being within the context of sustainable development (Ukko et al., 2019). It addresses issues such as fair labor practices, human rights, and corporate social responsibility, ensuring that economic and environmental sustainability also promote societal welfare (Baumgärtner & Quaas, *2010*).

Conversely, the broader "social" concept explored in this review extends beyond sustainability concerns. It examines social norms, structures, inclusion, cultural values, and social change, providing a more comprehensive perspective on how societies function, evolve, and respond to challenges like inequality, globalization, and political shifts (Andrighetto *et al., 2024*).

The literature suggests that while the TBL social dimension is crucial for integrating social equity into sustainable practices, a deeper understanding of social dynamics—including how norms evolve, how inclusion is achieved, and how societies balance cooperation and competition—is essential for building more resilient and adaptive societies (Greenfield, *2018*).

Addressing social challenges requires a combination of inclusive policies, cultural adaptation, and social innovation, ensuring both sustainable and equitable progress (Ngoc-Hong DUONG *et al., 2021*).

Chapter 2: Systematic Literature Review

This chapter outlines the methodology adopted for conducting the research and presents the main results obtained. For this study, the Systematic Literature Review (SLR) methodology was applied, a specific type of literature review that enables a systematic, comprehensive, transparent, and replicable analysis of a given topic (Andy P. Siddaway *et al., 2018*).
The chapter is structured as follows: the first two *Sections (2.1 and 2.2)* introduce the methodology employed and outline the research questions addressed in the study. *Section 2.3* defines the inclusion and exclusion criteria used for the selection of literature, while *Section 2.4* describes the keywords employed for identifying the research papers.
Subsequently, *Section 2.5* delves into the application of the Snowballing approach, followed by 2.6, which presents the search tables. Finally, the last sections analyze the final corpus of selected papers and discuss the key findings emerging from the review.

2.1 Overview of Systematic Literature Review research methodology

The objective of this section is to apply a systematic literature review (SLR) to study healthcare supply chain management, identifying the main trends and gaps in the existing literature.
The systematic literature review is a more structured and rigorous type of literature review that offers several advantages over a traditional literature review. This approach enables the research to be conducted in a methodical, comprehensive, transparent, and replicable manner, ensuring the identification of all studies relevant to the research questions, and thus pertinent to the analyzed topic (Andy P. Siddaway *et al., 2018*; Alex Pollock *et al., 2017*).
The SLR develops through the formulation of research questions, which guide the entire study, the identification of relevant studies, and the critical synthesis of the results obtained. Specifically, the process begins with the formulation of research questions, which shape the direction of the study. Subsequently, inclusion and exclusion criteria are defined, determining which papers will be selected or discarded. Once the criteria have been defined, the most relevant keywords for the research are identified, allowing for the selection of relevant studies through an in-depth analysis using a database. For this research, Scopus has been used as the primary source for identifying pertinent papers.
Furthermore, the snowballing procedure is applied to identify additional papers to be included in the research, ensuring a more comprehensive corpus. Finally, the content of the selected papers is analyzed and summarized to define the trends and research gaps, in relation to the research questions examined.

Each step will be discussed in detail in the following sections. *Fig. 2* illustrates all the steps previously described.

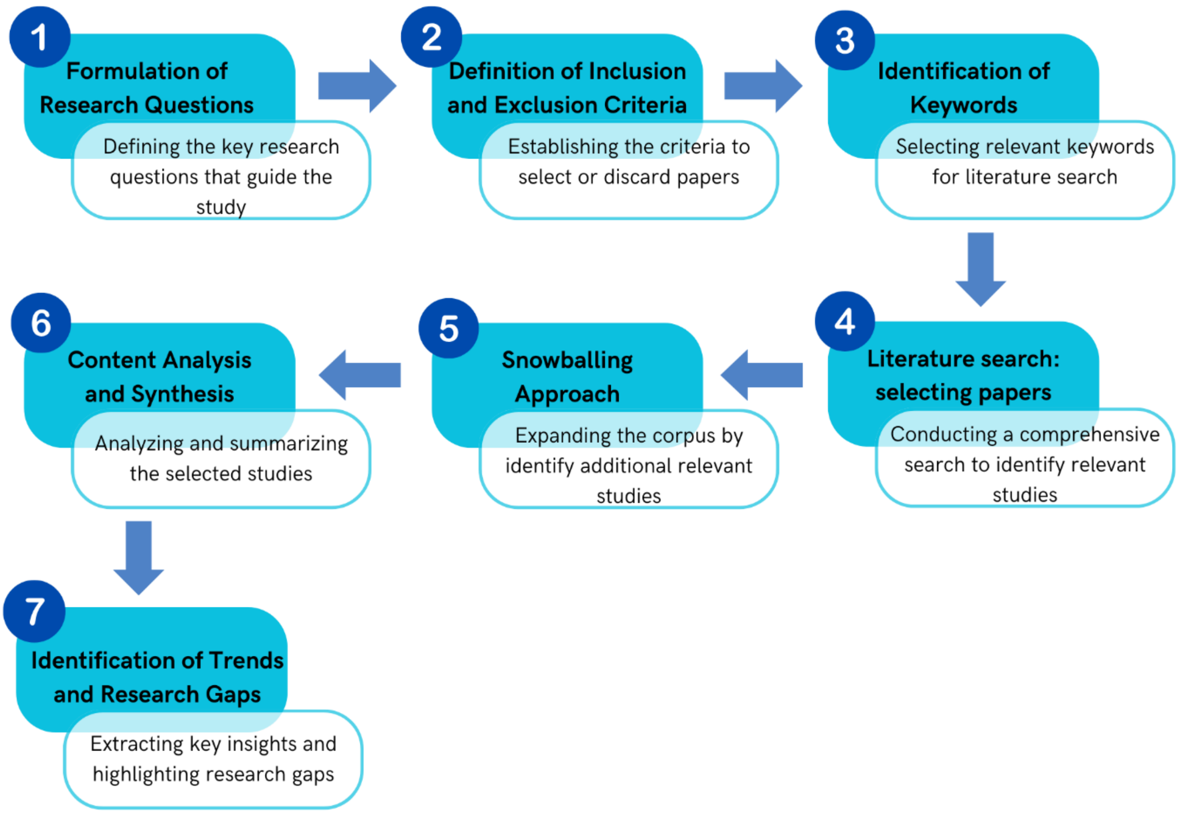

Figure 2: Systematic Literature Review (SLR): Key steps

2.2 Research questions

The first step before starting the research is to define the research questions, which serve as guiding inquiries for the entire systematic literature review and to which the study must provide answers. These questions are essential as they delimit the study's focus, help in selecting the most relevant papers, and provide the foundation for the analysis and synthesis of results.

The research questions should address a topic that is specific enough to allow for a comprehensive answer but not too narrow, to avoid a lack of literature references. At the same time, they should not be overly broad, as this would make the analysis too complex and dispersed.

The selection of the research questions arises from the need to explore the key factors influencing Healthcare Supply Chain (HSC) management. As outlined in *Section 1.2*, ensuring a more efficient, resilient, and equitable healthcare system requires the integration of Lean Management strategies, the adoption of sustainability practices, and a balanced approach to social, operational, and economic dimensions. These aspects not only optimize processes and reduce waste but also promote a more structured and sustainable access to healthcare services. In light of these considerations, the research questions in this study have been formulated to explore the following fundamental themes:

1. What are the operational, economic, environmental, and social aspects of healthcare supply chain management addressed?
2. How can Lean principles be applied to minimize waste and reduce costs in healthcare supply chains while maintaining quality of care?
3. How can social and sustainable models based on circular economy and ESG factors/SDGs contribute to reducing adverse externalities along the healthcare supply chain? Are there any regulations to comply with regarding this?

Specifically, the first question examines the impacts of the healthcare supply chain from an operational, economic, environmental, and social perspective, assessing both positive and negative aspects. These dimensions are closely interconnected and must be managed in a balanced way to enhance the resilience of the healthcare system. Indeed, an integrated approach to HSC management is essential to ensure optimal efficiency, equitable access to care, and greater sustainability in the long term.

The second question delves into the application of Lean principles and tools within the healthcare supply chain. Lean management is increasingly emerging as an effective approach to reducing waste and improving the quality of healthcare services. However, the literature still highlights challenges in its implementation due to the sector's specific and rigid characteristics, such as strict regulations and the need to maintain high safety and quality standards.

Finally, the third question explores the themes of sustainability and circular economy, analyzing the changes already introduced in this area and the relevant regulations. This topic is also becoming increasingly significant in the strategic decisions of the HSC, both due to the need to reduce the environmental impact of the healthcare industry and to ensure a more ethical and efficient management of resources.

2.3 Inclusion and exclusion criteria

After defining the research questions, the next step is the identification of inclusion and exclusion criteria, which are essential for establishing clear and objective parameters in selecting the most relevant and pertinent studies for the research.

Specifically, the inclusion criteria, listed in *Table 1*, define the characteristics that a paper must meet to be included in the review:

- **Timeframe:** Includes documents published between 2010 and 2024 to ensure that the research reflects recent developments, technologies, and regulations in healthcare supply chains. The selection of this timeframe is motivated by the fact that the most relevant and up-to-date documents are found from 2010 to the present.
- **Language:** Restricts the search for articles and manuscripts exclusively to documents written in English.
- **Publication type(s):** Includes various document types, such as articles, reviews, conference papers, book chapters, notes, editorials, books, letters, short surveys, errata, conference reviews, data papers, and reports.
- **Database:** The research relies exclusively on the Scopus[7] database. Scopus was selected as the primary reference source due to its status as a globally recognized database, encompassing over 25,000 papers that are continuously updated. Its choice was not only

[7] https://www.elsevier.com/en-in/solutions/scopus

based on its relevance and comprehensiveness but also on its accessibility through academic institutions, such as the Politecnico di Torino and INSA

- **Keywords:** Selects studies that utilize specific keywords related to the research on Scopus.
- **Settings:** Analyzes studies that examine healthcare supply chains in various operational contexts, such as hospitals, clinics, pharmaceutical manufacturing plants, or distribution networks.

Inclusion criteria	**Description**
Timeframe	Between 2010 and 2024
Language	English
Publication type(s)	Article, review, conference paper, book chapter, note, editorial, book, letter, short survey, erratum, conference review, data paper, report
Database	Scopus
Keywords	See *Section 2.4*
Settings	Various operational contexts

Table 1: Inclusion criteria

The exclusion criteria, listed in *Table 2*, define the characteristics for which a paper should not be considered in the research. Specifically, a paper is excluded if:

- **Timeframe**: It was published before 2010, as it falls outside the established timeframe.
- **Language**: It is not written in English, since the research is limited to this language.
- **Topic**: It is not directly related to the subject of study. In particular, documents that do not analyze the supply chain in the healthcare sector are excluded, as well as those referring to other industrial sectors or addressing general supply chain aspects without a specific focus on the healthcare context.

Exclusion criteria	**Description**
Timeframe	Before 2010
Language	Not in English
Topic	Topics not related to research

Table 2: Exclusion criteria

2.4 Keywords

This section presents the keywords used for the research. Keywords represent the combinations of terms employed to identify and select the most relevant studies within a database, in this case, Scopus. They serve as the starting point for the research, allowing for a consistent filtering of papers in alignment with the defined research questions.

Based on the research questions, specific keywords were identified for each of them to ensure the selection of the most relevant papers. The keywords were organized into a Keyword Tree (*Fig. 3*), a hierarchical structure representing the logic behind the search queries used in Scopus. The tree is structured vertically, with each branch corresponding to a specific search string. For example, one of the search queries used is: *"Healthcare" AND "Supply Chain" AND "Social" AND "impact".*

The application of keywords allowed the identification of 1,904 papers. To define the initial dataset, only studies that met the inclusion criteria were selected, conducting a preliminary analysis based on title and abstract. This step enabled the exclusion of documents that were not relevant to the research topic.

Subsequently, a further selection process was carried out to eliminate less relevant studies, retaining only those that were most pertinent to the analysis. The selection process is described in detail in *Section 2.6*.

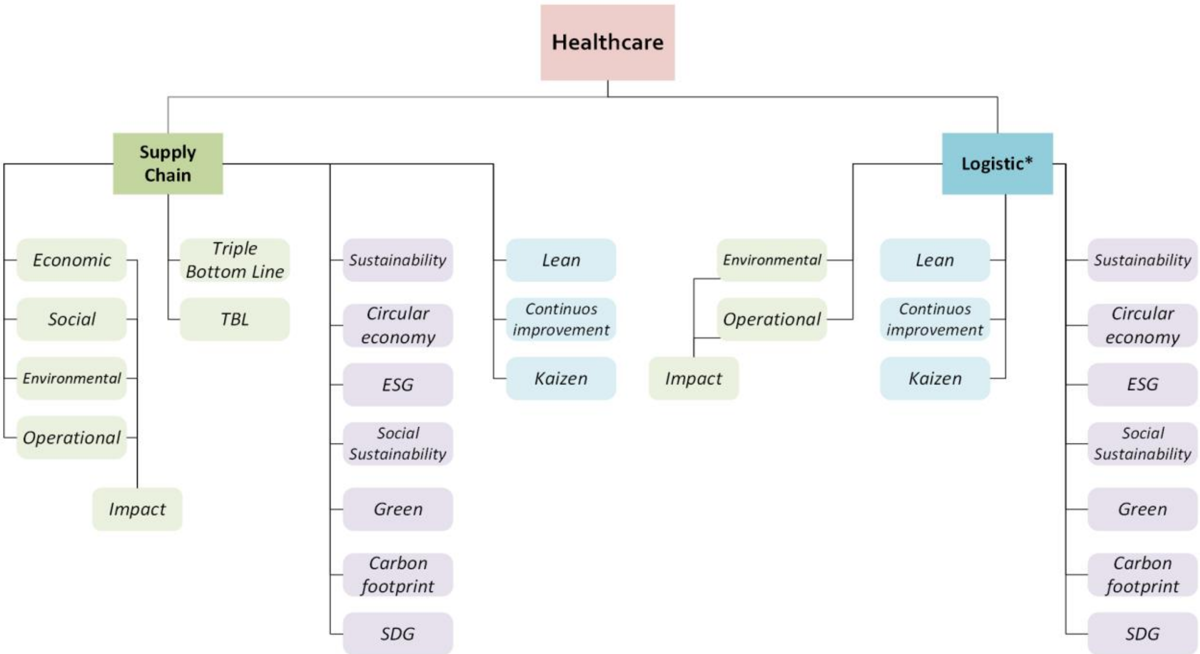

Figure 3: Keywords tree

2.5 Snowballing approach

This paragraph describes the second step of the research process. To ensure a rigorous and comprehensive methodological approach in the systematic literature review (SLR), the Snowballing technique was adopted (Katia Romero Felizardo *et al, 2016*). This approach allows for an expanded analysis by identifying additional relevant studies based on a set of already selected papers that form the corpus. This technique consists of two parallel procedures: backward Snowballing and forward Snowballing.

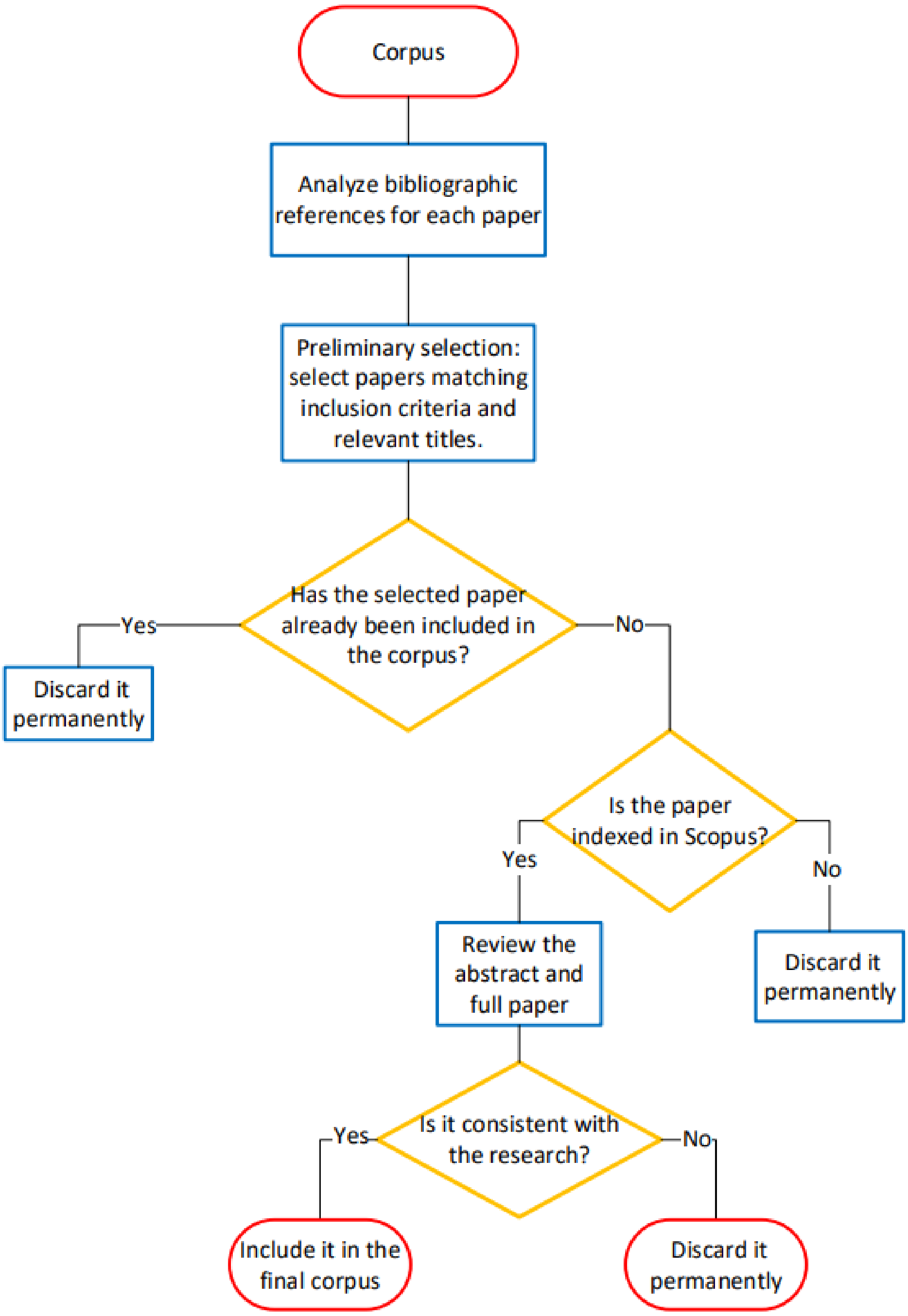

Figure 4: Backward Snowballing

The first involves analyzing the bibliographic references of the papers included in the corpus to identify earlier studies that are potentially relevant to the research and not yet part of the selected document set. Specifically, for each article, the references are examined, and only papers that meet the inclusion criteria and appear consistent with the research topic based on their title are selected. Subsequently, it is verified whether the identified papers are already included in the corpus. If a paper is already present, it is discarded to avoid redundancy. If the paper is not yet included, a search is conducted within the Scopus database. If the document is not available in this database, it is definitively excluded. Conversely, if the paper is found, the abstract and the full article are reviewed to assess its relevance and decide whether to include it in the final corpus. This procedure is illustrated in *Fig. 4*.

The second procedure is forward snowballing, which involves identifying more recent studies by verifying which subsequent papers have cited those already included in the corpus.

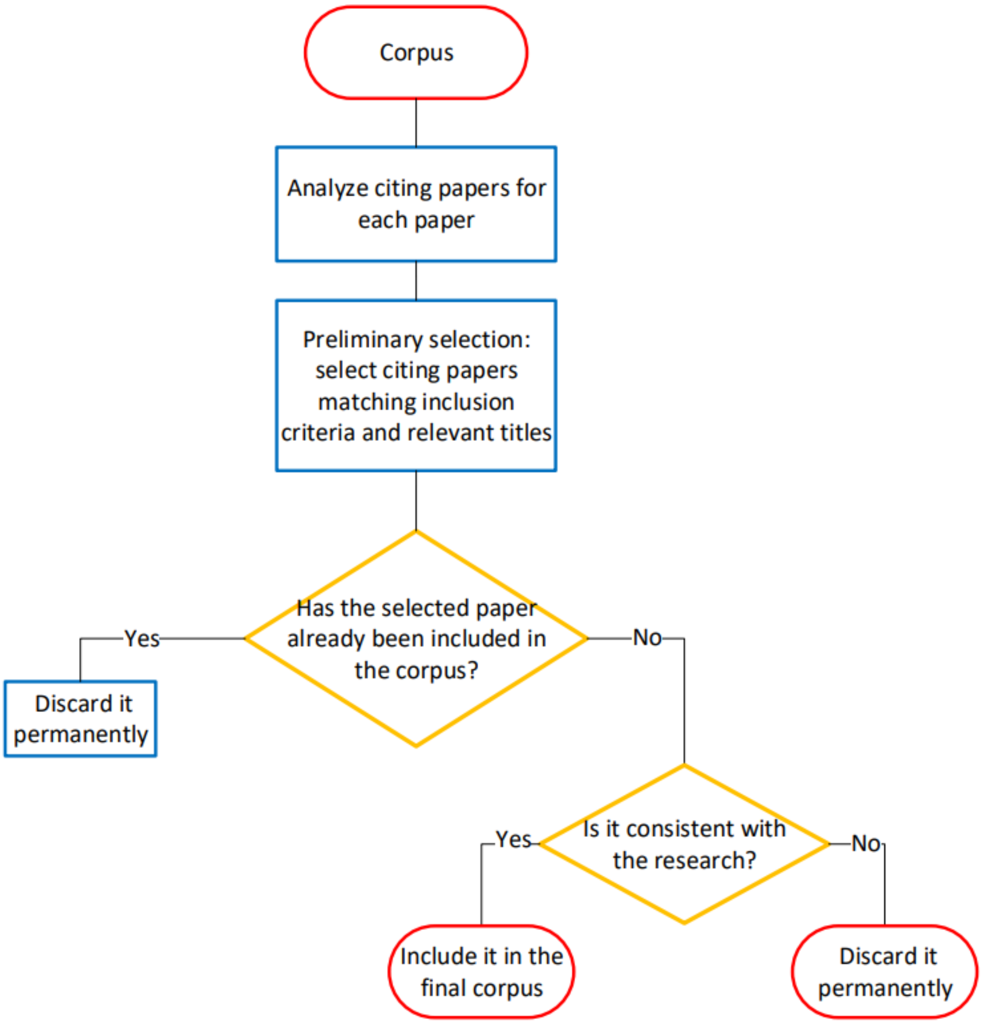

Figure 5: Forward Snowballing

This technique allows for the identification of recent research that may be relevant to the healthcare supply chain topic.

Specifically, for each paper in the initial corpus, all articles citing it are analyzed. From this list, papers that meet the inclusion criteria and appear consistent with the research topic based on their title are selected. Once a set of selected papers is defined, it is checked whether they are already present in the corpus: if so, they are discarded to avoid duplication. If a paper is not yet included, the abstract is analyzed, and if necessary, the full version is reviewed to assess its relevance to the research.

Unlike backward snowballing, in this case, it is not necessary to verify the presence of the paper in the Scopus database, as the selection process in forward snowballing starts directly from articles already indexed on this platform. This process is illustrated in *Fig. 5*.

The application of these two techniques led to the selection of 28 additional papers, of which 21 were identified through backward Snowballing and 7 through forward snowballing, which were integrated into the corpus. This approach allowed for an expanded and more consolidated analysis of the systematic literature review, ensuring a more complete and accurate selection of the literature. While backward Snowballing identified relevant earlier studies, forward Snowballing helped to detect more recent research, ensuring a robust, updated, and relevant corpus of studies.

2.6 Search tables

During the research process, records were kept of the discarded papers and the reasons for their exclusion, with the aim of ensuring a transparent and rigorous selection process in defining the corpus. This section analyzes the search tables, which document the path followed for the selection of articles. The first part is dedicated to the methodology adopted for constructing the table, describing the criteria used to include or exclude papers. Subsequently, the search table related to the main corpus is presented, gathering the papers selected through the systematic search. Finally, the search table related to Snowballing is illustrated, reporting the articles identified through this technique and their contribution to the expansion of the corpus.

2.6.1 Corpus papers selection

The corpus selection was conducted using Scopus, a reliable database for scientific research. The investigation was carried out by inserting the keywords defined in *Section 2.4* into the search string. Subsequently, the identified papers were sorted by relevance and filtered based on the inclusion criteria: only articles published between 2010 and 2024 and written in English were considered.

The selection process took place in multiple stages. Initially, the papers were evaluated by reading only the title and abstract: those deemed relevant were saved and recorded in a summary Excel table. In the next phase, the selected articles were read in full to assess their actual relevance. If found to be irrelevant, they were removed from the table; otherwise, they were retained in the analysis corpus. During this phase, particular attention was paid to avoiding the duplication of the same papers.

Following this methodology, a total of 81 articles were identified. However, the final corpus may not comprehensively represent the entire available literature, as the research was conducted using a single database (Scopus), and some papers, despite initially appearing relevant, were not accessible and therefore were not included in the analysis. Despite these limitations, the selection made provides a thorough and representative coverage of the subject matter.

2.6.2 Corpus search paper

Below is the *Table 3* containing all the queries used in the search bar for the literature analysis. The first column lists the queries used for the search, while the second indicates the number of papers retrieved from Scopus, specifically those that, as described in *Section 2.6.1*, meet the inclusion criteria related to the time frame and language. The third column reports the number of articles selected based solely on the reading of the title and abstract, while the fourth shows the number of papers deemed relevant after a full-text analysis. Finally, the last column presents the final number of articles included in the corpus after verifying the absence of duplicates and ensuring that each paper was unique.

During the selection process, some papers were excluded for various reasons, including:

- **Lack of relevance to the research:** If, after reading the title, abstract, or full content, it emerged that the paper addressed a topic inconsistent with the research question, it was discarded.
- **Limited relevance to the search query:** Some articles, despite including relevant keywords, did not address the topic in sufficient depth.
- **Focus on non-healthcare supply chains:** Papers analyzing supply chains from other sectors or discussing supply chains in general without a specific focus on the pharmaceutical or healthcare sector were excluded.

- **Absence of an analysis of healthcare logistics:** Some articles examined case studies related to diseases, healthcare issues, or surgical interventions without exploring the logistics aspects of the healthcare supply chain.

These selection criteria ensured the creation of a targeted and coherent corpus of papers, consisting of 81 articles aligned with the research objectives.

Query research	**Papers retrieved from Scopus**	**Papers discarded based on *title* and *abstract***	**Papers discarded based on *full text reading***	**Final Papers (after eliminating *duplications*)**
"Healthcare" AND "Supply Chain" AND "Social" AND "impact"	165	139	12	14
"Healthcare" AND "Supply Chain" AND "Environmental" AND "impact"	131	81	31	10
"Healthcare" AND "Supply Chain" AND "Economic" AND "impact"	140	114	16	3
"Healthcare" AND "Supply Chain" AND "Operational" AND "impact"	81	54	18	9
"Healthcare" AND "Logistic*" AND "Environmental" AND "Impact"	164	151	5	4
"Healthcare" AND "Logistic*" AND "Operational" AND "impact"	56	50	6	0
"Healthcare" AND "Supply Chain" AND "Triple Bottom Line"	9	3	4	1
"Healthcare" AND "Supply Chain" AND "TBL"	1	0	1	0
"Healthcare" AND "Supply Chain" AND "Lean"	125	84	25	14
"Healthcare" AND "Supply Chain" AND "Continuous improvement"	0	0	0	0
"Healthcare" AND "Supply Chain" AND "Kaizen"	4	4	0	0
"Healthcare" AND "Logistic*" AND "Lean"	79	65	11	1
"Healthcare" AND "Logistic*" AND "Continuous improvement"	0	0	0	0
"Healthcare" AND "Logistic*" AND "Kaizen"	2	0	2	0
"Healthcare" AND "Supply Chain" AND "Sustainability"	350	297	22	16
"Healthcare" AND "Supply Chain" AND "Circular economy"	40	28	4	3
"Healthcare" AND "Supply Chain" AND "ESG"	4	4	0	0
"Healthcare" AND "Supply Chain" AND "Social Sustainability"	21	16	2	1

“Healthcare” AND “Supply Chain” AND “Green”	116	98	10	2
“Healthcare” AND “Supply Chain” AND “Carbon footprint”	32	21	7	1
“Healthcare” AND “Supply Chain” AND “SDG”	11	10	1	0
“Healthcare” AND “Logistic*” AND “Sustainability”	248	235	8	0
“Healthcare” AND “Logistic*” AND “Circular economy”	15	8	1	2
“Healthcare” AND “Logistic*” AND “ESG”	1	1	0	0
“Healthcare” AND “Logistic*” AND “Social Sustainability”	2	1	1	0
“Healthcare” AND “Logistic*” AND “Green”	81	75	3	0
“Healthcare” AND “Logistic*” AND "Carbon footprint"	4	4	0	0
“Healthcare” AND “Logistic*” AND “SDG”	22	21	1	0
TOT.	**1.904**	**1.564**	**191**	**81**

Table 3: Corpus search table

2.6.3 Snowballing search paper

After defining the initial corpus, the *Snowballing* technique was used to expand the collection of relevant articles. Starting from the 81 papers selected through the initial search, additional articles were identified using *Backward Snowballing* and *Forward Snowballing*, conducted in parallel for each paper and described in detail in *Section 2.5*.

The *Backward Snowballing* procedure was carried out by analyzing the reference lists of the articles included in the corpus. The first table (*Table 4*) presents the entire selection process, including only the papers that yielded relevant results, namely those that led to the addition of new articles to the corpus. The selected papers were numbered; therefore, the first column reports the identification number of the reference paper, while the second indicates the total number of bibliographic references within each article.

Subsequently, papers were selected based solely on the title reading, while those already included in the corpus or not indexed in Scopus were discarded. After a more in-depth full-text analysis, additional papers were excluded due to lack of relevance. The last column of the table shows the final number of articles added to the corpus through this procedure.

Overall, the *Backward Snowballing* process allowed for the integration of 21 new articles into the corpus.

Paper No.	Paper References	Papers selected based on *title*	Papers discarded (already in the corpus)	Papers discarded (not indexed to Scopus)	Papers discarded based on *full text reading*	Final No. of papers
1	112	8	1		4	3
3	45	9	3	2	2	2
4	69	2			1	1
5	28	5	1	1	2	1
6	115	11	5	3	2	1
19	78	3		1		2
20	11	1				1
24	135	5			3	2
30	31	3			2	1
35	54	4	1	1	1	1
40	163	7		4	2	1
42	39	7	1	2	3	1
44	96	7	2	1	2	2
49	91	6	2		3	1
57	106	10	3	1	5	1
TOT.						**21**

Table 4: Backward Snowballing search table

For each article included in the corpus, the *Forward Snowballing* procedure was conducted in parallel. The second table (*Table 5*) illustrates the entire selection process related to this methodology, including only the articles that yielded relevant results, namely those that led to the identification and inclusion of additional contributions in the research.

The selected articles that were effectively added to the corpus were numbered. Consequently, the first column of the table reports the identification number of the reference article, while the second column indicates the total number of publications that cited it, considering only those indexed in Scopus. The column *Papers selected based on title* shows the number of articles selected based solely on the title reading. The next two columns indicate, respectively, the number of articles discarded because they were already present in the initial corpus. The column *Papers discarded based on full-text* reading reports the number of articles excluded after an in-depth full-text analysis. Finally, the last column highlights the final number of articles effectively added through this procedure.

The *Forward Snowballing* process led to the addition of 7 new articles to the corpus.

In conclusion, starting from an initial corpus of 81 articles, a total of 28 relevant contributions were identified and added to the research, which had not been retrieved in the preliminary selection phase through queries. This brought the final corpus to a total of 109 papers.

Paper No.	No. of publications citing the paper (from Scopus record)	Papers selected based on *title*	Papers discarded (already in the corpus)	Papers discarded based on *full text reading*	Final No. of papers
9	5	1			1
21	75	2		1	1
27	25	5	1	2	2
35	108	7	2	4	1
59	5	1			1
64	39	2		1	1
TOT.					**7**

Table 5: Forward Snowballing search table

2.7 Corpus description

Each paper deemed interesting and relevant to the research was saved and included in the corpus, which was organized in an Excel table summarizing the systematic review. For each selected paper, several key elements were recorded, including the title, authors, year of publication, type of publication, journal name, geographical affiliation of the first author, number of citations, Author Keywords, and the methodology adopted.

After collecting this data, specific topics were identified for each research question. If a paper was relevant to one of the research questions and its corresponding topics, the respective field was populated with a brief description explaining how the paper addressed the theme, highlighting its contribution to the research.

Subsequently, specific analyses were conducted on the most significant data collected, which are presented in the next section. However, before proceeding with the content analysis of the papers, a descriptive analysis of the corpus was carried out.

The first section examines the distributions related to the year of publication, type of publication, and geographical affiliation of the first author. In contrast, the second section analyzes the citation data.

2.7.1 Years, journals and affiliations

Fig. 6 presents a histogram illustrating the number of papers published each year from 2011 onwards. A notable increase in publications can be observed starting in 2018, reaching its peak during the post-pandemic period (2022-2024). This trend suggests a growing academic and industrial interest in the challenges and solutions related to healthcare supply chain management, likely in response to the issues that emerged during the global health crisis.

The rise in publications after 2020 can be attributed to the need to enhance supply chain resilience, the increasing digitalization, and the adoption of risk mitigation strategies to address potential future health crises.

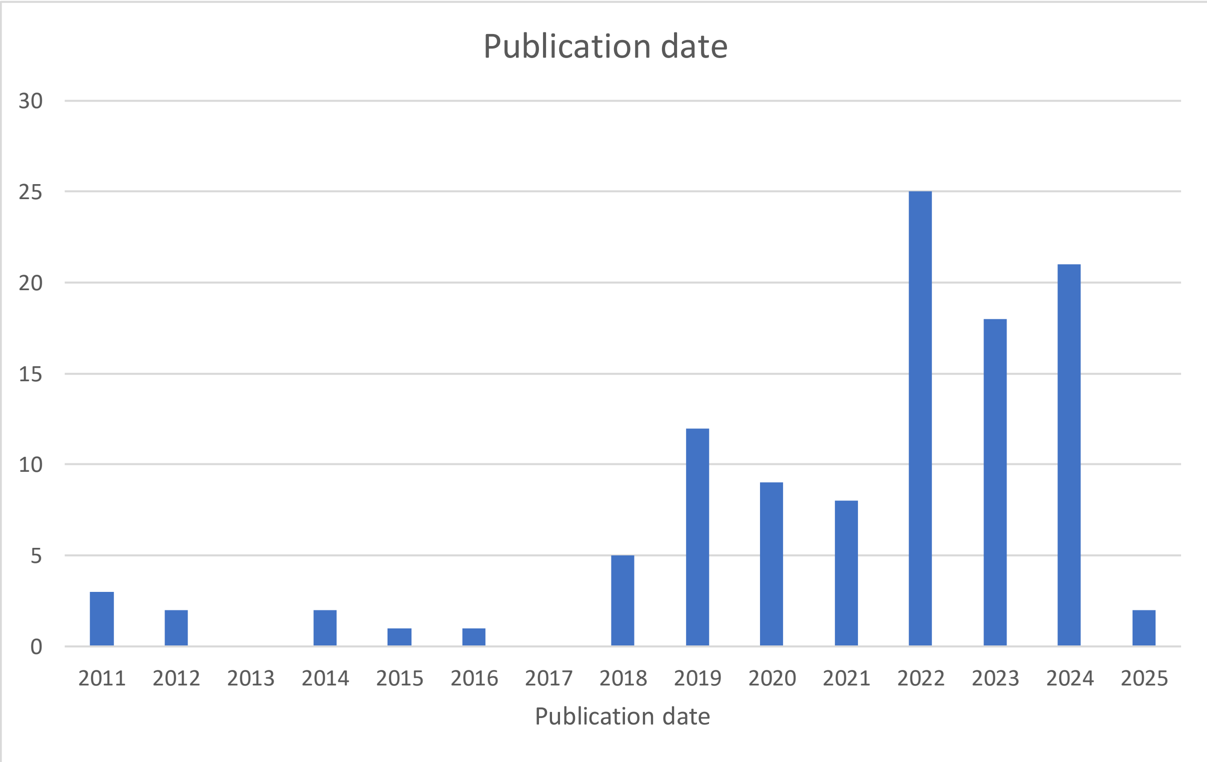

Figure 6: Number of papers published per year

The chart in *Fig. 7* illustrates the distribution of publications selected for this systematic literature review by type. Scientific articles represent the predominant category within the analyzed corpus.

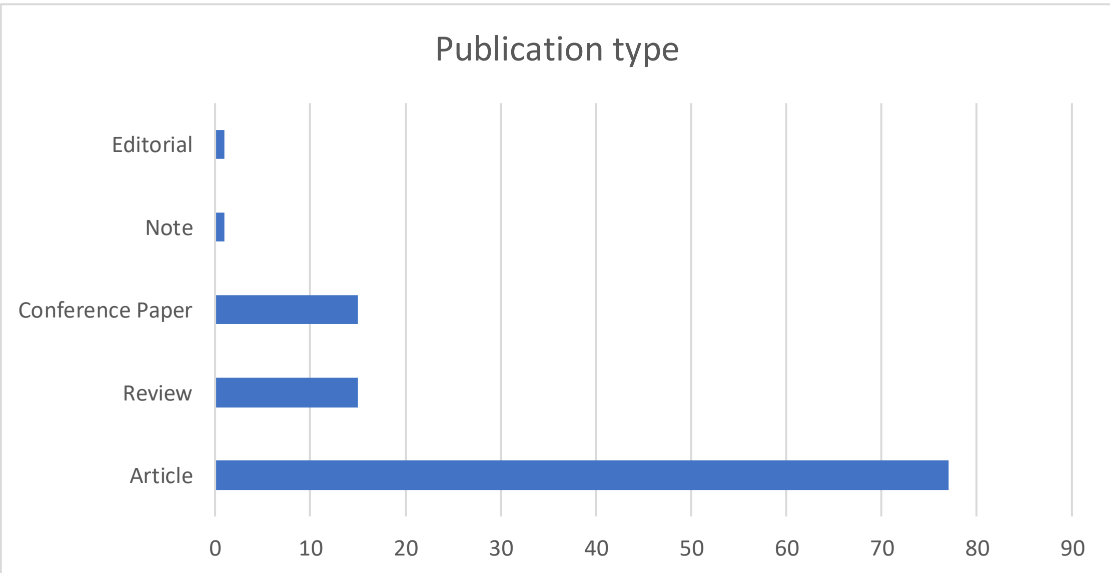

Figure 7: Number of papers per each publication type

This prevalence may be attributed to the fact that journal articles are the most common and widely available form of publication in academic databases such as Scopus, as well as being generally associated with higher standards of reliability and scientific rigor.
These are followed by a smaller proportion of review papers and conference proceedings, while editorials and notes appear only marginally.
Further expanding the analysis, the chart in *Fig. 8* illustrates the distribution of publications based on the country of affiliation of the first author, highlighting a wide geographical diversity.

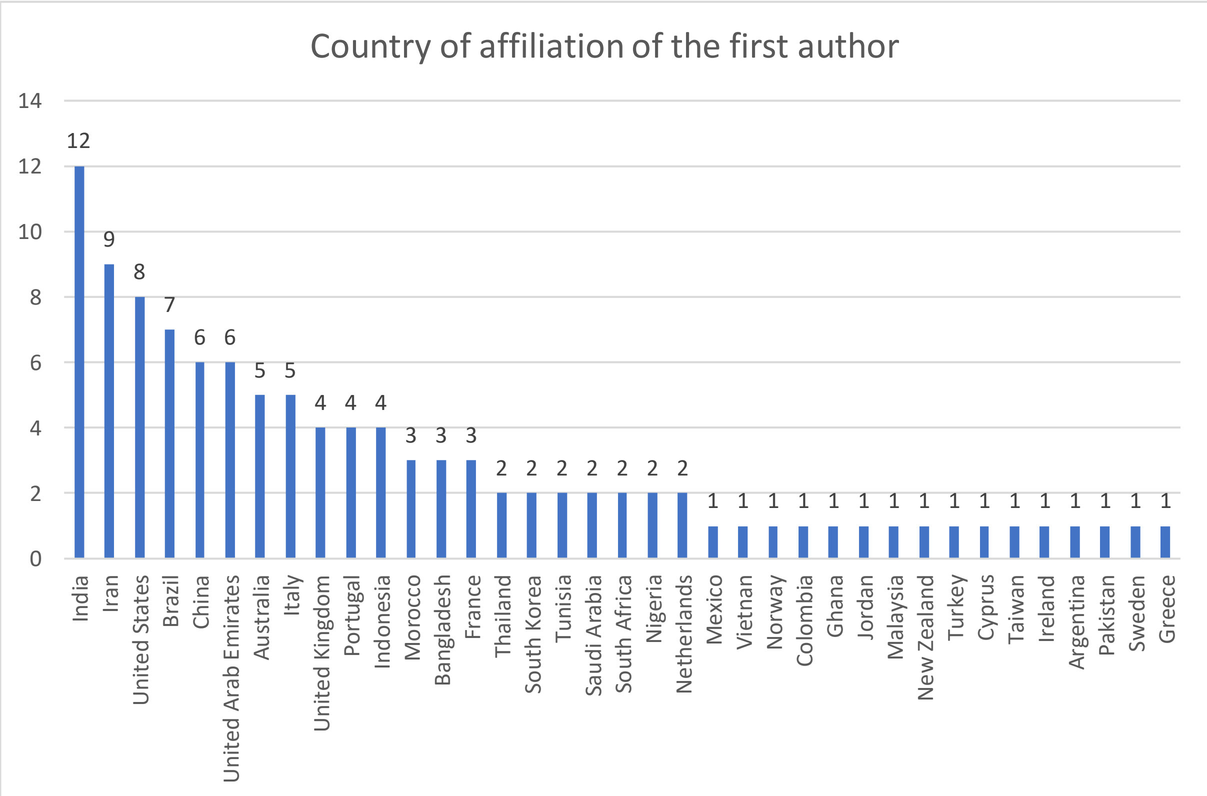

Figure 8: Number of papers per each country affiliation of the first author

India has the highest number of contributions, suggesting a strong interest in pharmaceutical supply chain management. This is followed by Iran, the United States, and Brazil.
However, this figure should be interpreted in the context of countries that invest the most in scientific research. India's predominance can be attributed to its role as a global leader in generic drug and active pharmaceutical ingredient (API) production, as well as the country's growing commitment to research and development in the healthcare sector. The number of publications reflects not only pharmaceutical production volume but also the level of investment in academic and industrial research.
The countries with the highest number of first authors are also among the most active in scientific research and pharmaceutical innovation. The United States, the United Kingdom, and Iran, for example, have well-established research ecosystems and academic institutions

dedicated to developing supply chain solutions. This suggests that scientific output in this field depends not only on the significance of the pharmaceutical sector in a given country but also on the presence of strong research infrastructures and favorable funding policies.

The significant presence of publications from emerging economies highlights a global effort to enhance the resilience of pharmaceutical supply chains, likely accelerated by the challenges posed by the COVID-19 pandemic. However, the number of published studies also depends on the scientific infrastructure and research funding available in different countries. This distribution underscores the importance of international collaboration in optimizing healthcare supply chains and addressing future challenges with an integrated approach. Above all, it highlights that this is a matter of global concern, engaging researchers from various countries in the pursuit of sustainable and resilient solutions.

2.7.2 Citations

Continuing with the analysis of the corpus content, a scatter plot *(Fig. 9)* was created to illustrate the relationship between the publication year of papers and the number of citations received. More recent papers (from 2021 onwards) generally have fewer citations, as they have had less time to be cited. In contrast, papers published before 2020 show greater dispersion, with some exceeding 100 citations and one surpassing 350.

There is a high density of recent papers with few citations, indicating that their impact is still developing. Additionally, in the post-COVID period (from 2021 onwards), there has been an increase in publications, likely driven by the growing interest in pharmaceutical supply chains. This rise has led to a wider distribution of citations, with many articles still in the process of being established in the scientific literature.

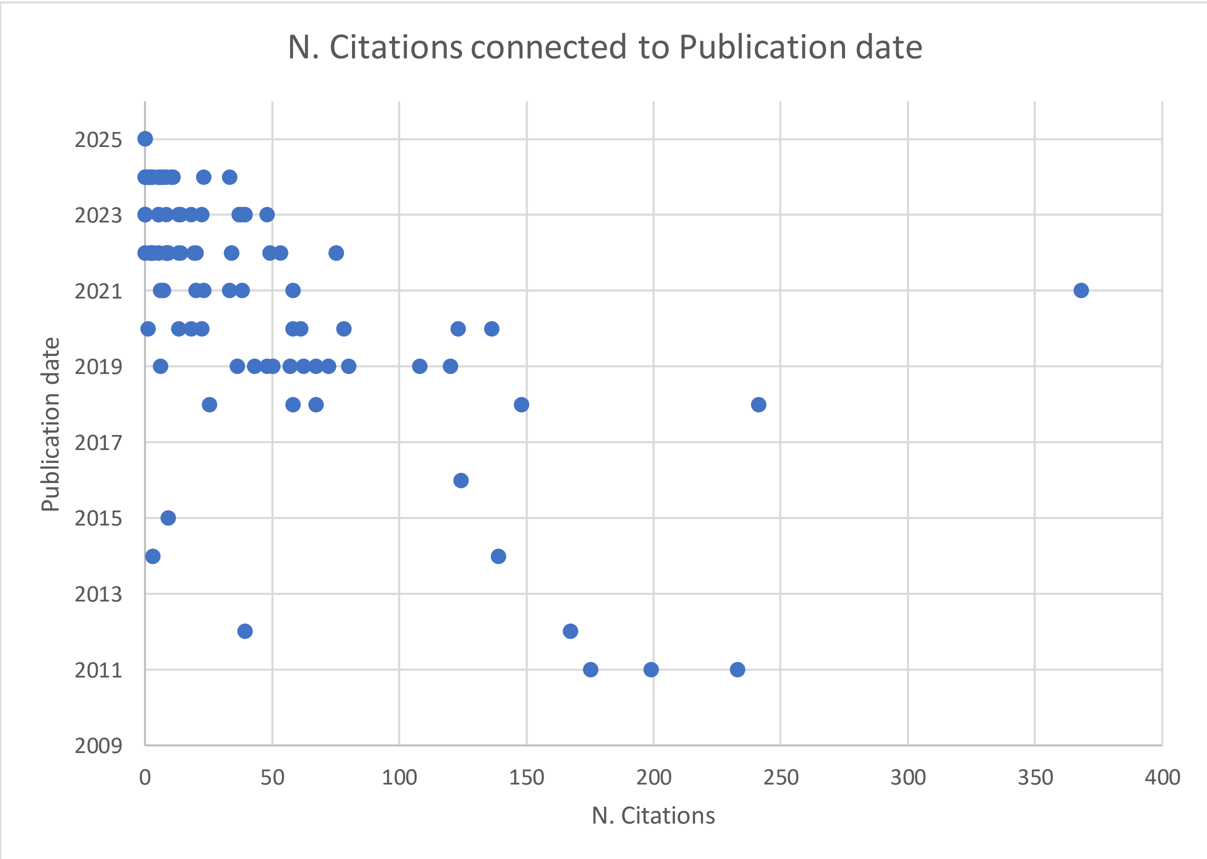

Figure 9: Scatter plot showing the relationship between the number of citations and the publication year

2.8 Analysis of the corpus papers

This section provides an in-depth analysis of the content of the corpus and the selected papers. In the first part, the distribution of adopted methodologies is examined, distinguishing between qualitative, quantitative, and mixed approaches, along with an analysis of their main objectives. Subsequently, the content analysis of the papers is conducted, identifying the key topics associated with the research questions and the main aspects related to them.

2.8.1 Methodologies

For each paper, the applied methodologies were recorded, often including more than one. Additionally, the overall classification of the methodology was specified, distinguishing between qualitative, quantitative, or mixed approaches, with the latter encompassing studies that integrate both qualitative and quantitative elements.

To begin with, *Fig.10* presents a pie chart illustrating the distribution of methodologies used in the analyzed papers. The majority of studies (48%) adopt a mixed approach, combining qualitative and quantitative methods to provide a more comprehensive analysis of the pharmaceutical supply chain. A significant portion of studies (37%) follows a qualitative approach, focusing on conceptual analysis, case studies, and theoretical models to examine strategic and managerial aspects. Finally, a smaller percentage of papers (15%) use a quantitative approach, relying on numerical data, simulations, and mathematical models to analyze the pharmaceutical supply chain in a more structured and measurable way.

After analyzing the overall distribution of methodologies within the corpus, the specific qualitative and quantitative methodologies applied in each paper were identified.

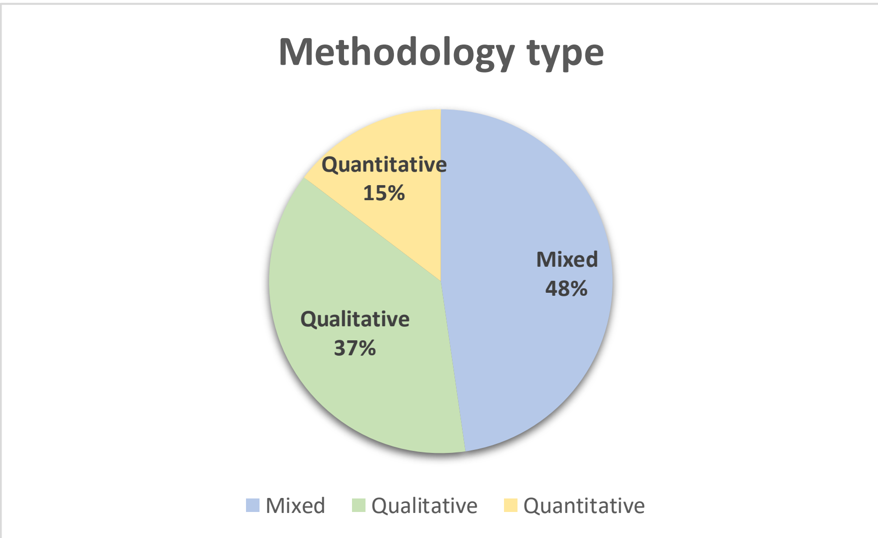

Figure 10: pie chart illustrates the distribution of methodologies used in the analyzed papers

Subsequently, two separate histograms were created for both methodological approaches, illustrating the frequency with which different methodologies were adopted.

The first chart (*Fig. 11*) illustrates the distribution of qualitative methods used in the analyzed papers. Literature review is the most commonly adopted methodology, with the highest number of studies utilizing this approach to synthesize the state of the art and identify key research trends.

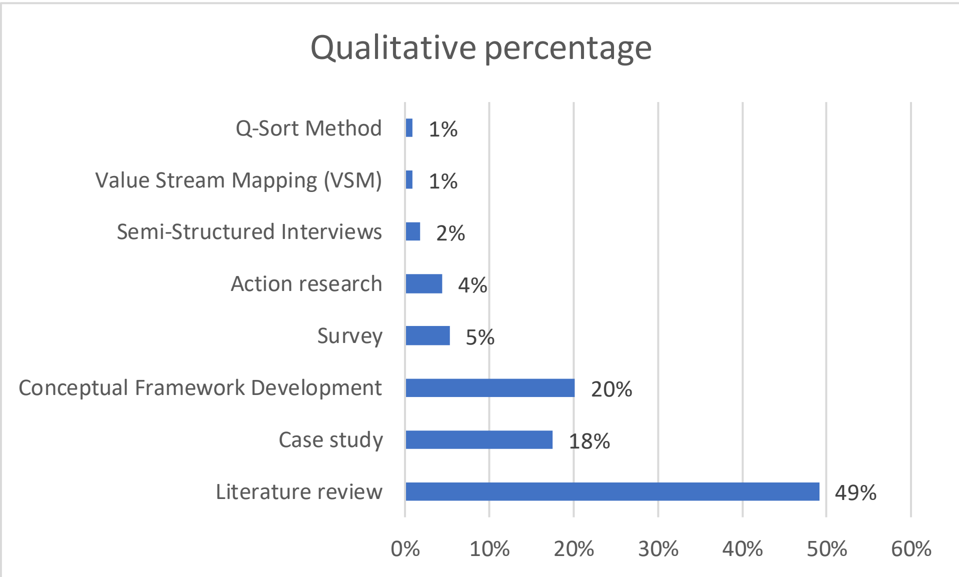

Figure 11: distribution of qualitative methods used in the analyzed papers

The case study method follows, frequently employed to examine specific situations in the pharmaceutical supply chain, providing an in-depth analysis of real-world contexts.

Other qualitative approaches include conceptual framework and conceptual framework development, which are essential for structuring theories and analytical models. Less commonly used methods include survey, action research, Value Stream Mapping (VSM), Q-Sort Method, and semi-structured interviews, which appear in only a limited number of studies.

To gain a deeper understanding of the content and objectives of the analyzed papers, *Table 6* presents a list of all qualitative methodologies identified in the corpus, along with a description of their respective objectives.

Methodology	Objective
Literature review	Synthesizes existing research to provide a comprehensive understanding of a topic.
Case study	Examines a specific instance or organization to gain in-depth insights into real-world applications.
Conceptual Framework Development	Constructs theoretical models to explain relationships between concepts.
Survey	Collects data from respondents to understand opinions, behaviors, or trends.
Action research	Engages in iterative problem-solving within organizations to drive practical improvements.
Semi-Structured Interviews	Gathers qualitative insights through guided yet flexible conversations with participants.
Value Stream Mapping (VSM)	Analyzes and optimizes workflows to improve efficiency and eliminate waste.
Q-Sort Method	Categorizes and prioritizes qualitative data based on participants' subjective judgments.

Table 6: qualitative methodologies and their objectives

Finally, *Fig. 12* presents the chart illustrating the distribution of quantitative methods used in the analyzed papers. The most common method is systematic literature review, adopted to systematically analyze existing literature.

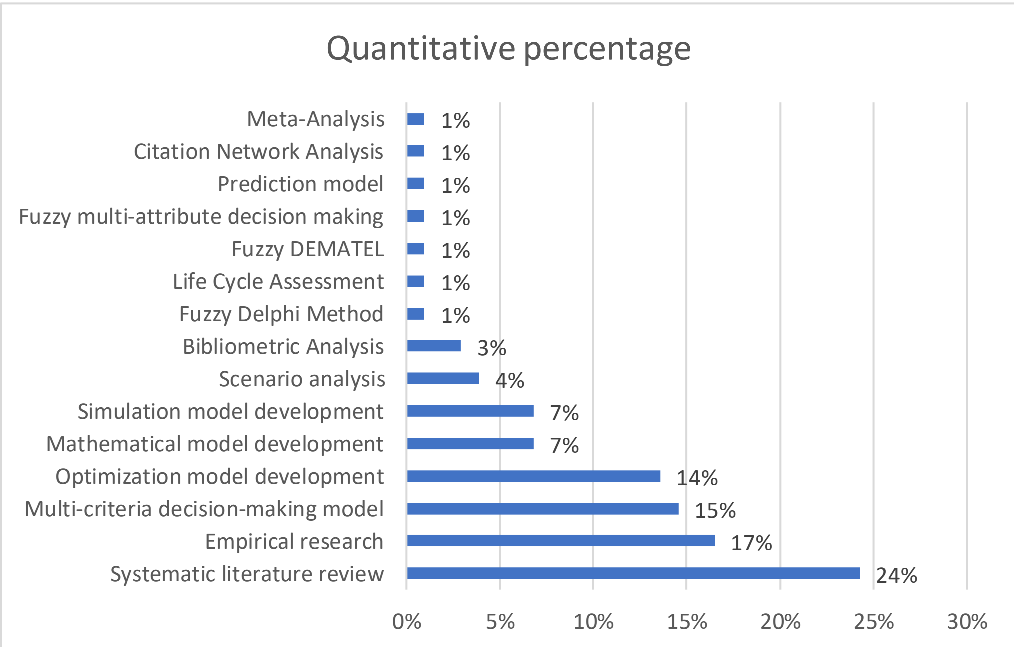

Figure 12: distribution of quantitative methods used in the analyzed papers

Among the other widely used quantitative methods, the multi-criteria decision-making model stands out, commonly applied to support complex decision-making in the pharmaceutical supply chain. Additionally, empirical research relies on questionnaires administered to participants, followed by statistical analysis to interpret the collected data.

Other significantly present approaches include mathematical model development, scenario analysis, and prediction models, highlighting the use of predictive and simulation tools for supply chain management. Less frequently used methods include citation network analysis, Life Cycle Assessment, Structural Equation Modeling (SEM), and Analytical Network Process, which appear in only a limited number of studies.

To gain a deeper understanding of the content and objectives of the analyzed papers, *Table 7* presents a list of all quantitative methodologies identified in the corpus, along with a description of their respective objectives.

Methodology	**Objective**
Systematic literature review	Synthesizes existing research to identify key trends, gaps, and future directions.
Empirical research	Collects and analyzes real-world data to test hypotheses and validate theories.
Multi-criteria decision-making model	Supports decision-making by evaluating multiple criteria simultaneously.
Optimization model development	Develops models to find the most efficient solution to a given problem.
Mathematical model development	Creates mathematical representations of systems to analyze and predict behaviors.
Simulation model development	Simulates real-world scenarios to assess potential outcomes and decision impacts.
Scenario analysis	Evaluates different future scenarios to support strategic planning and risk management.
Bibliometric Analysis	Analyzes academic literature quantitatively to identify research trends and influence.
Fuzzy Delphi Method	Uses expert opinions with fuzzy logic to achieve consensus on complex issues.
Life Cycle Assessment	Assesses the environmental impact of a product or process throughout its lifecycle.
Fuzzy DEMATEL	Identifies and analyzes cause-effect relationships in complex systems using fuzzy logic.
Fuzzy multi-attribute decision making	Enhances decision-making by handling uncertainty in multiple criteria.
Prediction model	Forecasts future trends based on historical data and statistical techniques.
Citation Network Analysis	Examines citation patterns to map knowledge flow and research impact.

Meta-Analysis	Combines findings from multiple studies to derive overall conclusions and statistical significance.

Table 7: quantitative methodologies and their objectives

2.8.2 Specific topics

As previously mentioned in *Section 2.7*, specific topics were identified for each research question. The Excel corpus was then populated with brief descriptions in cases where a paper was relevant to one of the research questions and its associated topics. These descriptions detailed how the paper addressed the specific theme.
In particular, the topics identified for each research question are as follows:

- For the first research question: *Operational topics, Economic topics, Environmental topics, Social topics*
- For the second research question: *Lean principles or tools applied, Type of products, Supply chain process, Identified wastes, Defined actions to reduce or eliminate wastes,* Achieved benefits of Lean application, Limitations of Lean application
- For the third research question: *Social models characteristics, Sustainable models characteristics, Type of products, Supply chain process, Externalities reduced, Benefits of model application, Limitations of model application, Regulations involved*

Whenever a paper addressed one of these topics, the corresponding field was filled with a brief description explaining the article's contribution to that specific theme.
Once all descriptions were completed, specific topics were assigned to each of them to enable a structured categorization. This process allowed for the standardization of information and facilitated statistical analyses, making it easier to interpret the data and identify relevant patterns.
For each identified specific topic, key topics were associated to systematically trace descriptions and facilitate data analysis. The tables (in Appendix) summarize the key topics associated with each specific topics: for the first research question, key topics are presented in *Tables 8, 9, 10*, and *11*; for the second research question, they are included in *Tables 12, 13*, and *14*; for the third research question, they are compiled in *Tables 15, 16, 17, 18*, and *19*.
It should be noted that, with regard to the categories *Type of Products* and *Supply Chain Processes* – relevant to both the second and third research questions – as well as the *Identified Wastes* from the second research question, no dedicated tables have been included.

For the *Type of Products*, it was not necessary to introduce further specifications or subcategories: each product was uniquely identified, and a reclassification was deemed unnecessary. The *Supply Chain Processes* were instead classified according to the SCOR (Supply Chain Operations Reference) model, which defines standard activities in supply chain management by integrating processes, metrics, best practices, and technologies. For the purposes of this research, the following processes were considered:

1. **Plan**: activities related to supply chain planning, including demand forecasting, capacity planning, inventory, and transportation.
2. **Source**: procurement of materials and services from suppliers, including selection, receipt, and payment.
3. **Storage** (instead of "Make"): the term "Storage" was adopted in place of "Make" since production is not the focus of this analysis, which instead concentrates on procurement, storage, and subsequently, product distribution.
4. **Deliver**: all activities related to product distribution, such as order management, warehousing, transportation, and invoicing.
5. **Return**: management of returns, both from customers and to suppliers, involving defective or excess products.

As for the *Identified Wastes*, categorization was carried out based on the 7 Muda, which are the seven types of waste identified in the Toyota Production System. Specifically, the following specific topics were used:

1. **Waiting**: idle time in which people, machines, or materials are waiting for information, tools, or processes.
2. **Transporting**: excessive or inefficient movement of materials or products, which does not add value.
3. **Overproduction**: producing earlier or more than necessary, which results in surpluses and wastes resources.
4. **Inventory**: unnecessary accumulation of raw materials, semi-finished, or finished products, leading to additional costs and space usage.
5. **Motion**: unnecessary movement of people due to poor workplace organization.

6. **Defects / Rework**: non-compliant products that require rework or are discarded, resulting in increased costs.
7. **Process Wastes**: superfluous activities or processes carried out to a higher quality level than required, without adding value.

2.9 Main research trends

The following section presents the results obtained from the Systematic Literature Review. For each research question and related topic analyzed, a chart is provided showing the distribution of related themes, both in percentage terms and absolute values. The bar charts are designed with two vertical axes. The primary axis indicates the absolute number of times each theme is addressed in the corpus, with the value displayed inside each bar. The secondary axis shows the percentage that this number represents out of the total, marked by an orange dot positioned above each bar. This representation allows for a clear and immediate understanding of both the absolute frequency and the relative weight of the themes covered in the analyzed literature.

2.9.1 Research question 1

The first analysis addresses the first research question: What are the operational, economic, environmental, and social aspects of healthcare supply chain management addressed?
The graph below presents all the topics related to this research question. The following sections examine and discuss each topic in detail.

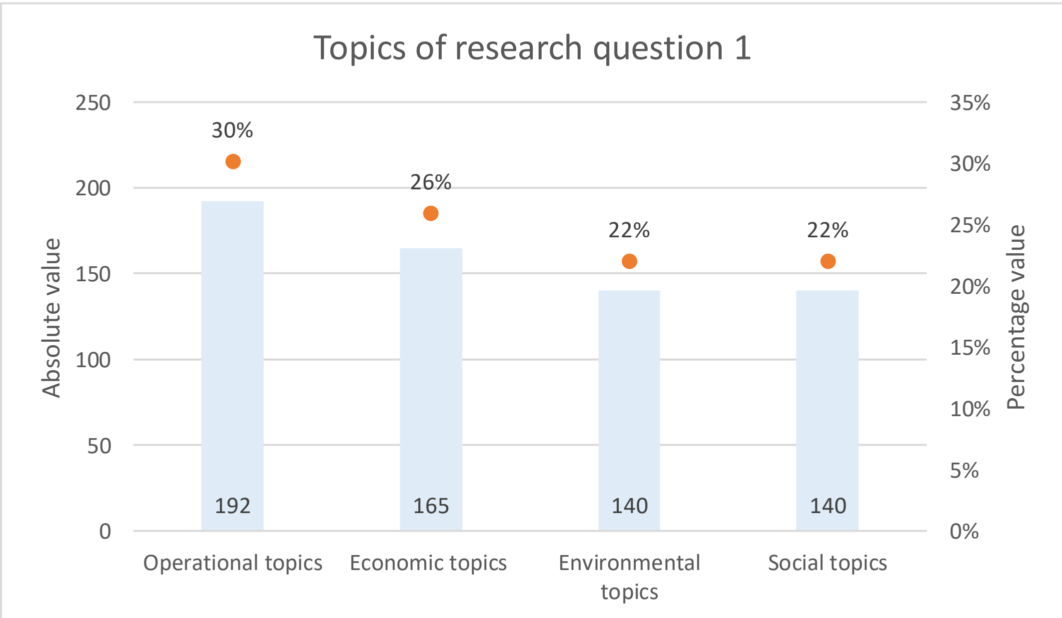

Figure 13: Results of the topics related to the first research question

The graph shows the distribution of Op*erational*, *Economic*, *Environmental*, and *social topics* addressed in the literature related to the healthcare supply chain (HSC). It is clearly observed that *Operational topics* are the most extensively explored (30% out of the total number of topics addressed in the corpus). This trend can be explained by the need, which became particularly evident during the COVID-19 pandemic, to ensure the timely availability of medicines (namely drugs), medical devices, personal protective equipment, and other healthcare materials. This need has driven research to focus on aspects such as resilience, logistics efficiency and operational flexibility (Niloofar Hajipour Machiani *et al., 2025*). The logistics efficiency refers to the capacity of the healthcare supply chain to deliver the right products at the right time and place, while minimizing delays and resource waste. Closely related to this is operational flexibility, which indicates the ability of the supply chain to adapt quickly to fluctuations in demand or supply availability. For example, Hajipour Machiani et al. (*2025*) propose the use of backup warehouses and dynamic reallocation of stock between distribution centers to maintain continuity in the face of demand surges or supply delays. Moreover, since the healthcare sector is highly sensitive to events (including both disruptive crises and more routine fluctuations in demand or supply) that can directly impact the system's ability to deliver care and services, attention to improving operational performance becomes essential to identify concrete and immediately applicable solutions capable of ensuring continuity in healthcare provision.

Economic topics, while significantly represented, are often addressed as a consequence of operational choices. In numerous contributions, the improvement of economic performance, such as cost reduction or efficiency gains, is presented as an indirect result of adopting more effective logistics strategies or implementing digital technologies (Riccardo Aldrighetti, *et al., 2019*). Tools such as artificial intelligence, Internet of Things (IoT), blockchain, and advanced data analytics are increasingly adopted to enhance demand forecasting, real-time inventory tracking, and supply chain visibility. However, it is rare for the economic dimension to constitute the core of the analysis. In the healthcare context, economic sustainability is certainly relevant, but it must constantly be balanced with the need to ensure quality, safety, and efficiency in services, which are generally given priority. Consequently, economic topics play a secondary role compared to the operational ones. *Environmental* and *Social* themes are less debated in the literature, despite the growing interest in environmental sustainability in the healthcare sector. Environmental issues, such as the management of medical waste or the adoption of circular models (Abrar Mahjoob *et al., 2023*), are addressed, as will be seen in the results of Research Question 3, but rarely represent the exclusive focus. They are often accompanied by *Operational* and *Economic* aspects. Similarly, *Social* dimensions, such as corporate responsibility, working conditions, or equity in access to care, receive limited attention, probably due to the difficulty in measuring their impacts and the scarcity of structured data.

Operational topic

The following chart presents the distribution of the specific topics identified within the operational dimension. A detailed discussion of these topics is provided in *Section 2.8.2.*

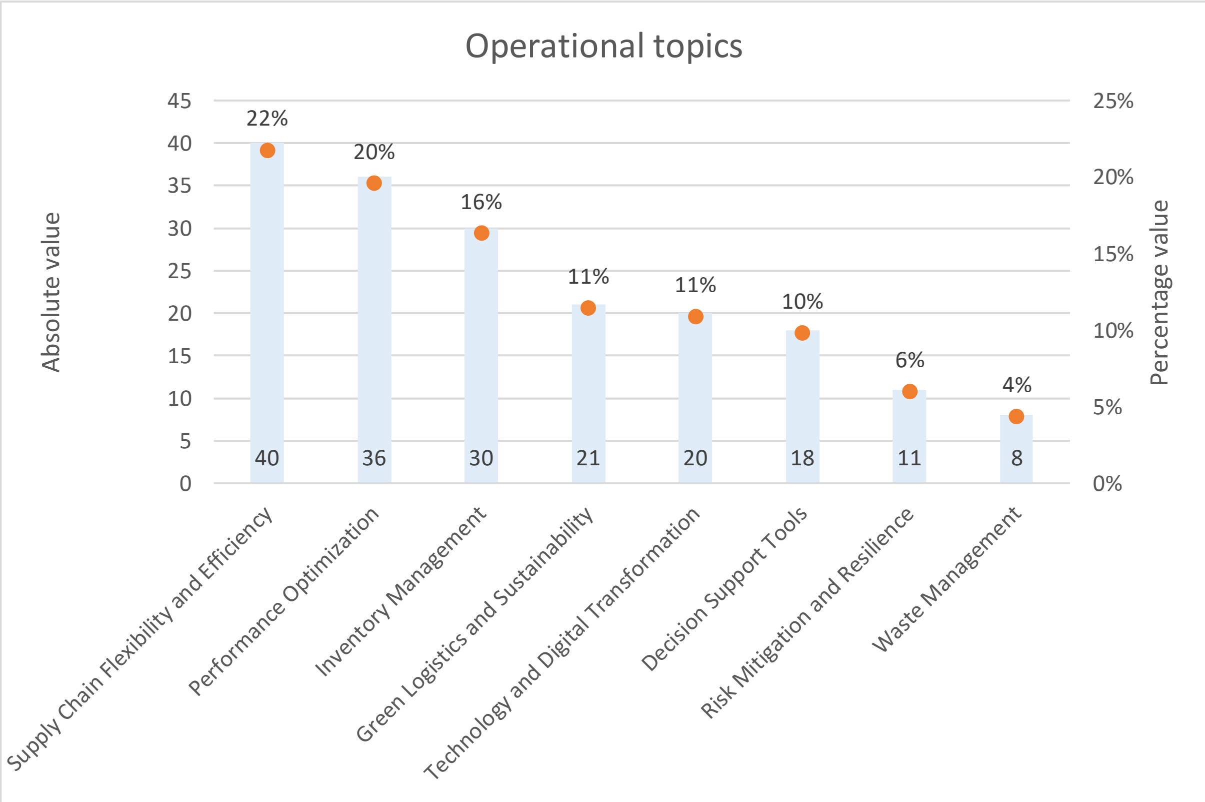

Figure 14: Results of the specific topics related to operational topics

The graph highlights how *Supply Chain Flexibility and Efficiency* is the most frequently addressed operational topics (22% out of the total number of topics addressed in the corpus), reflecting the importance of responsiveness to demand fluctuations and health emergencies. The COVID-19 pandemic made clear the need for more integrated strategies, reduction of bottlenecks, and decentralization of operations to improve supply chain adaptability. Integrated strategies involve better coordination among supply chain actors through shared data and joint planning, for example centralized platforms for PPE procurement. Reducing bottlenecks means addressing critical delays, such as limited warehouse capacity or transport congestion, by optimizing inventory flow. Decentralization, such as distributing stock across regional hubs, allowed for quicker local deliveries and reduced reliance on single points of failure, increasing responsiveness during disruptions. As a result, research has focused on solutions that enhance coordination among supply chain actors, reducing inefficiencies and delays in the distribution of medicines and medical devices (Imene Elhachfi Essoussi, *2015*).

Performance Optimization is also a central topic (20%), as an efficient healthcare supply chain requires continuous improvement methodologies, advanced simulations, and digital technologies. In particular, simulation tools, such as discrete event simulation, are used to model and test alternative operational scenarios, allowing organizations to evaluate the impact of specific strategies on cost, efficiency, and service levels before applying them in real-world settings. Instead, the adoption of artificial intelligence and automation allows for the reduction of operational costs and increased productivity, responding to the growing pressure for faster and more cost-effective healthcare services (Dae HyunJung, *2022*).

Another equally crucial topic is *Inventory Management*, aimed at reducing waste and ensuring the availability of essential products. The use of digitalization, with tools such as blockchain and IoT, is improving traceability and real-time inventory control (Dae HyunJung, *2022*). However, the heterogeneity of healthcare needs and the difficulties in accurately forecasting demand make this topic still open to future developments.

Regarding *Green Logistics and Sustainability*, *Technology and Digital Transformation*, and *Decision Support Tools*, appear in similar percentages in the chart (10–11%). The first topic is discussed in relation to reducing environmental impact through practices such as green procurement, low-emission distribution, and recycling. The COVID-19 pandemic has increased attention to these issues, highlighting the role of green supply chains in strengthening resilience and sustainability (Moustafa Mohamed Nazief Haggag Kotb Kholaif *et al., 2024*)

Technology and Digital Transformation includes the adoption of technologies such as blockchain, IoT, and big data analytics to improve traceability, visibility, and operational efficiency across the supply chain (Dae HyunJung, *2022*). Instead, *Decision Support Tools* refer to simulation models and advanced information systems used to evaluate alternative scenarios and support complex decision-making under uncertainty, ultimately improving efficiency and service quality (Imene Elhachfi Essoussi *et al., 2015*).

Finally, *Waste Management* and *Risk Mitigation and Resilience*, although relevant, receive less attention. *Waste Management* is often included in the broader discussion on sustainability, but it is not an immediate priority for healthcare facilities, which focus on efficiency and operational continuity. *Risk Mitigation and Resilience*, on the other hand, mainly emerge in crisis contexts, but the difficulty in quantifying the benefits of preventive strategies limits their systematic adoption (Gutama Kusse Getele *et al.,2022*).

Economic topic

The following chart presents the distribution, both in percentage terms and absolute values, of the specific topics identified within the economic dimension. A detailed discussion of these topics is provided in *Section 2.8.2*.

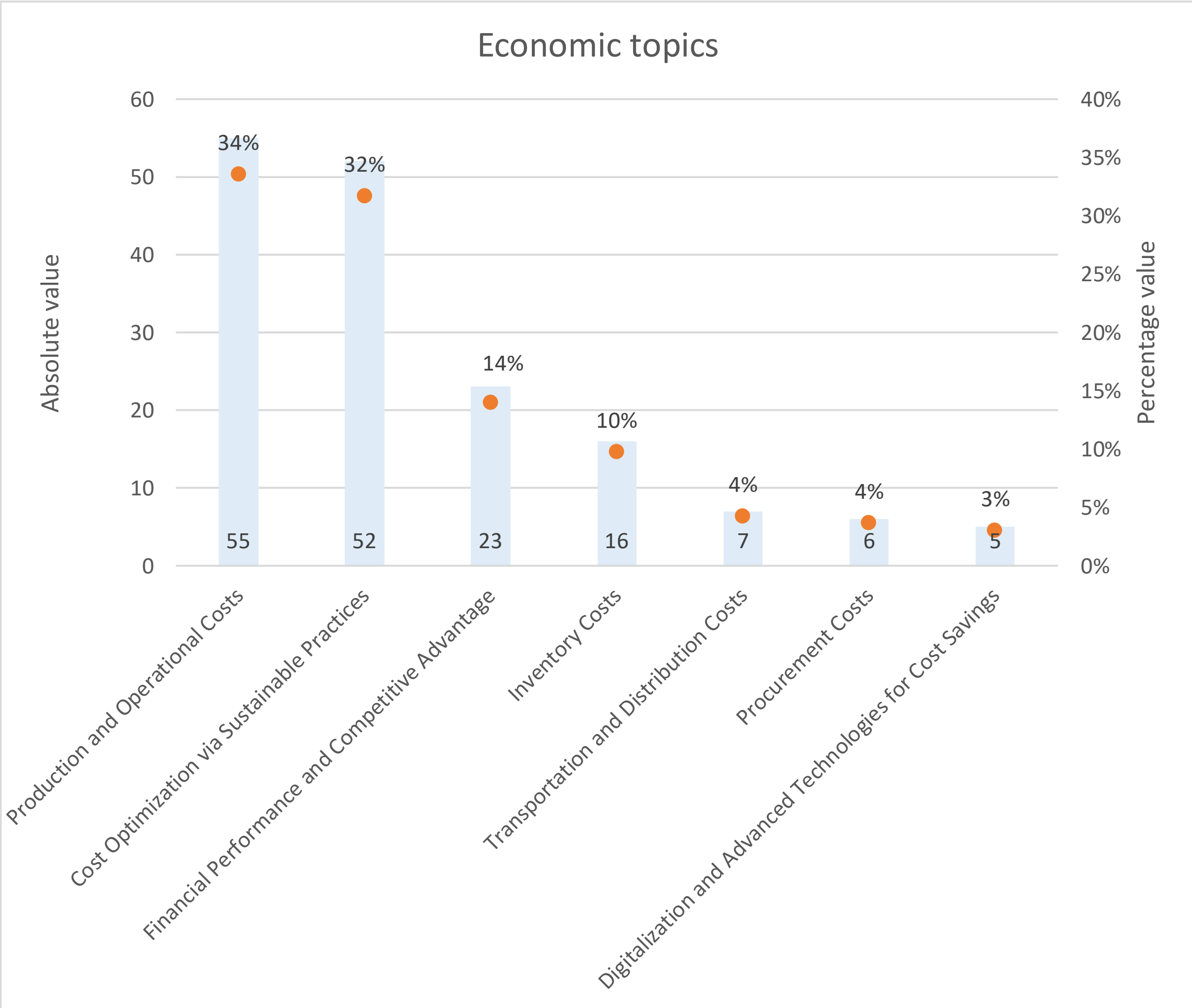

Figure 15: Results of the specific topics related to economic topics

The graph highlights how the most frequently addressed economic topics in the healthcare supply chain are related to *Production and Operational Costs* (34%) and *Cost Optimization via Sustainable Practices* (32%), which together represent the majority of the available literature. This reflects the need to balance operational efficiency with economic sustainability in a sector where resource management is essential to ensure continuous access to medicines and medical devices. The adoption of sustainable practices is increasingly relevant, as reducing waste and optimizing processes allows for cost reduction without compromising service quality.

At an intermediate level, in terms of the number of times they are debated, topics such as *Financial Performance and Competitive Advantages* are found, closely tied to operational

efficiency. A healthcare organization's ability to optimize its operations and reduce costs directly affects its competitiveness and long-term sustainability. In particular, financial risk management strategies and the adoption of innovative business models are increasingly studied to ensure the sector's economic stability (Dae HyunJung, *2022*).
Another relevant topic is *Inventory Costs*, which is connected to the results in *Fig. 14* on operational themes, where inventory management emerged as a key aspect. Inventory optimization is essential to reduce holding costs and ensure the availability of critical products without excess or shortages.
Less frequently addressed topics, such as *Transportation and Distribution Costs*, *Procurement Costs,* and the use of *Digitalization and Advanced Technologies for Cost Savings*, suggest that the literature tends to focus on aspects, such as those mentioned above, that generate a more direct and immediate economic impact for healthcare organizations. In particular, although digitalization is recognized as a key factor for supply chain optimization, its direct impact on cost reduction is still less explored compared to other, more established topics such as *Production and Operational Costs* and *Cost Optimization through Sustainable Practice*. This is likely due to the high initial costs of implementing digital technologies, whose economic benefits are mainly realized in the long term. As a result, compared to other areas that are more tangible and offer quicker returns, digitalization appears to be less frequently addressed in contributions dedicated to cost optimization.

Environmental topics

The following chart presents the distribution, both in percentage terms and absolute values, of the specific topics identified within the environmental dimension. A detailed discussion of these topics is provided in *Section 2.8.2*.

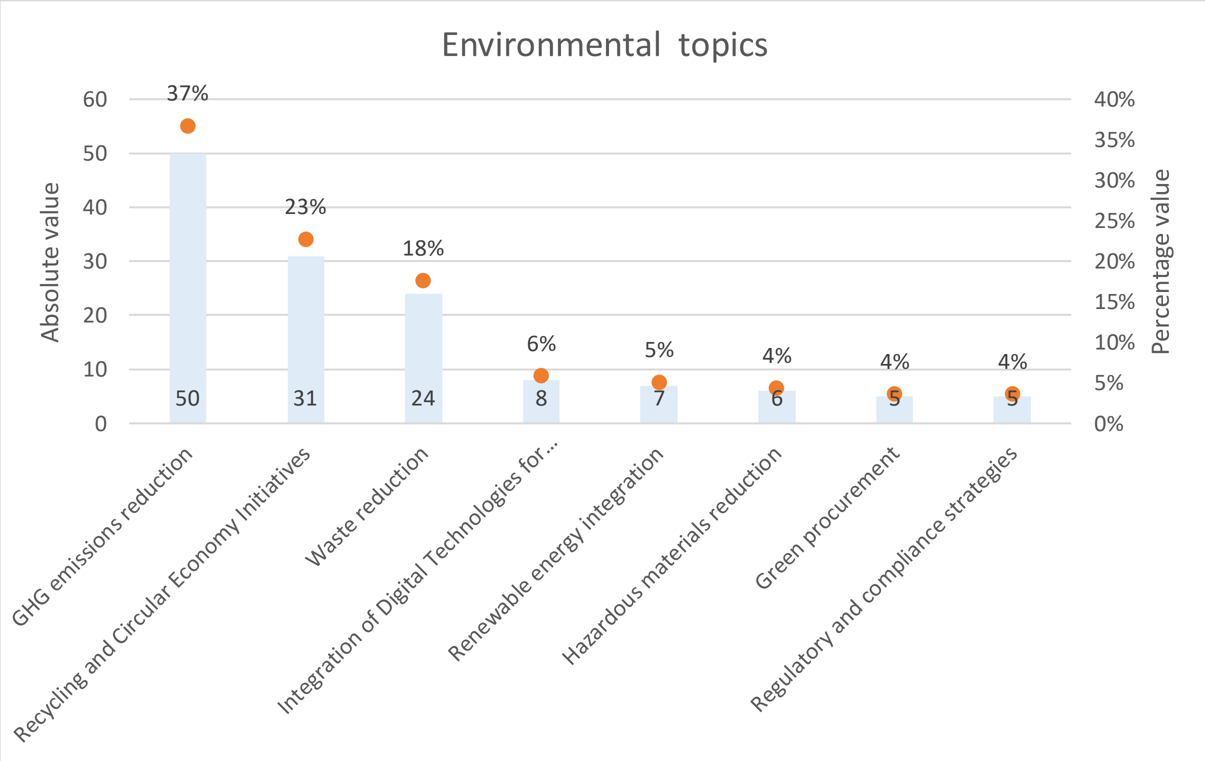

Figure 16: Results of the specific topics related to environmental topics

The graph highlights that the most frequently addressed environmental topics in the literature are G*reenhouse Gas (GHG) Emissions Reduction* (37%), *Circular Economy Initiatives* (23%), and *Waste Reduction*, which together receive the majority of academic attention. In particular, the centrality of the *GHG Emissions Reduction* theme is justified by the fact that the healthcare sector is responsible for approximately 4.4% of global greenhouse gas emissions (Leal Filho *et al., 2024*). The main direct and indirect sources include the production and disposal of medical devices, internal transportation, energy for climate control in facilities, and general resource consumption in care processes, among which the supply chain accounts for up to 71% of emissions, primarily due to the procurement of goods and services, including pharmaceuticals, medical equipment, and food (Leal Filho *et al., 2024*).

Growing awareness of the sector's climate impact has driven research to focus on decarbonization strategies, which include the adoption of sustainable practices, integration of renewable energy (such as solar panels, wind power, and biofuels), and optimization of transportation through AI-based planning systems.

The topic of *Recycling and Circular Economy* also plays a significant role, driven by the need to move beyond the still-prevalent linear approach in the management of healthcare materials. The extensive use of disposable products and the challenges in managing hazardous waste have fueled interest in models of regeneration, material reuse, and reverse logistics (Abrar Mahjoob *et al., 2019*). Specifically, regeneration models refer to systems that aim to restore used or expired products to a usable state, for example through reprocessing of single-use devices by specialized third parties. Material reuse involves the recovery and reintegration of components or raw materials, such as plastics, metals, or fabrics, from used products into the production cycle, reducing the need for virgin resources. Finally, reverse logistics encompasses the infrastructure and processes needed to collect, transport, and reintegrate post-use materials or equipment into the supply chain, either for safe disposal, recycling, or reconditioning.

Closely connected to these topics, *Waste Reduction* has emerged as an area of growing interest, as the waste of unused medicines and devices represents a significant issue both environmentally and economically. For this reason, the literature is increasingly exploring solutions related to the optimization of logistics flows, inventory practices, and the introduction of collection and reuse systems. However, while waste reduction is widely addressed in environmentally oriented studies, especially due to its relevance in mitigating ecological impacts such as pollution, resource depletion, and greenhouse gas emissions, it remains surprisingly underexplored in the operational literature. This limitation is likely due to the fact that research in the operational field has historically focused on process efficiency and performance objectives, often neglecting the integration of sustainability as a strategic metric. As a result, supply chain optimization is frequently pursued based on short-term economic criteria, relegating environmental issues and waste management to a secondary role.

Other environmental topics in the graph, such as the *integration of digital technologies* for sustainability, use of *Renewable Energy Sources*, *Reduction of Hazardous Materials*, *Green Procurement*, and *Regulatory and Compliance Strategies*, are addressed less frequently. This disparity is likely due to the greater operational and technological complexity involved, the high implementation costs, and the limited availability of standardized data, namely consistent and interoperable datasets across healthcare organizations, which are often hindered by system fragmentation, heterogeneous data formats, and strict privacy regulations.

In fact, the approach to environmental sustainability still appears to be strongly focused on emissions and waste, while more advanced strategies, such as technological integration and sustainable procurement, remain in an exploratory phase. An interesting aspect is the presence of the waste concept in both Operational Topics and Environmental Topics, though with different nuances. In the former, the theme is classified under *Waste Management*, emphasizing the operational handling of waste within the healthcare supply chain, including its collection, treatment, and efficient disposal. In the latter, the theme falls under *Waste Reduction*, focusing on minimizing waste production through prevention strategies, process improvements, and resource optimization.

A similar distinction can be observed between *Green Procurement* in Environmental Topics and *Green Logistics and Sustainability* in Operational Topics. *Green Procurement* refers to adopting sustainable purchasing strategies, such as selecting suppliers that comply with environmental standards or sourcing materials with a lower ecological impact. On the other hand, *Green Logistics and Sustainability*, has a broader scope that encompasses the entire supply chain, including procurement, with the goal of optimizing logistics operations to reduce environmental impact. This involves, for example, improving transportation efficiency, reducing emissions, and implementing sustainable logistics practices throughout all phases of distribution and inventory management.

This distinction highlights two complementary perspectives: one operational and managerial, focused on waste handling, and one environmental, aimed at reducing waste generation to minimize the overall ecological footprint of the healthcare supply chain.

Social topics

The following chart presents the distribution, both in percentage terms and absolute values, of the specific topics identified within the social dimension. A detailed discussion of these topics is provided in *Section 2.8.2*

The graph clearly shows that the topic of *Community Engagement* (50%) is the most frequently addressed among the social aspects in literature. The centrality of *Community Engagement* is understandable in light of the growing awareness of the role of healthcare organizations within the social fabric: training programs on sustainability and activating forms of collaboration with local stakeholders (such as NGOs -Non Governmental Organization-, public institutions, or community-based organizations) becomes a concrete way to strengthen trust in the supply chain, improve the effectiveness of interventions, and build more inclusive healthcare systems. Moreover, several studies highlight how active community involvement serves as a strategic lever for the adoption of practices aimed at environmental sustainability and operational efficiency, including those inspired by Lean principles (C. Kanokphanvanich *et al.,2023;* Scavarda *et al., 2019*). This makes the topic particularly relevant in the literature.

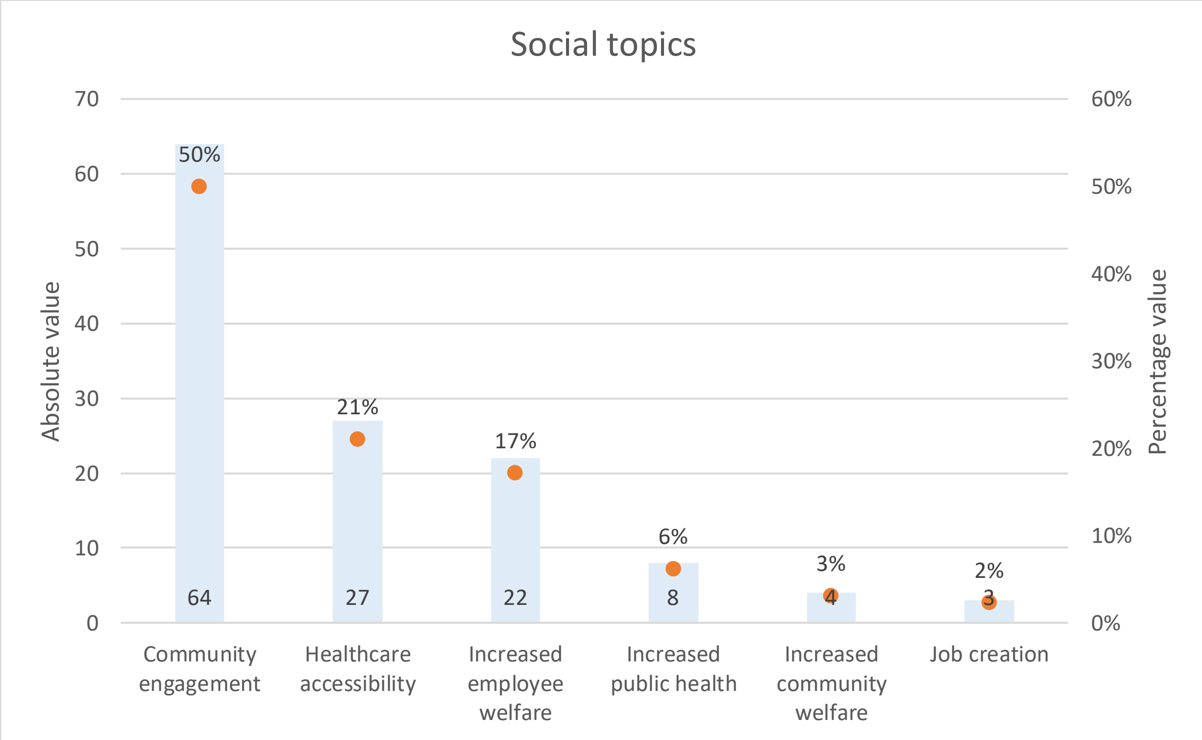

Figure 17: Results of the specific topics related to social topics

Access to Healthcare Services, although not the main topic, strongly emerges in contexts where the public healthcare system is under severe economic or structural pressure, as in many developing countries (Jahre *et al., 2012*). In such cases, ensuring equitable access to care, even through an efficient and well-organized supply chain, is a social priority and a direct indicator of the system's sustainability.

Employee well-being, on the other hand, is mainly addressed in contributions that analyze human capital as a strategic resource: adequate working conditions, safety, and incentive systems are seen as essential elements to improve productivity, reduce absenteeism, and attract qualified personnel within the supply chain (Duong *et al.,2021*).

The less explored topics, such as the *Enhancement of Public Health*, *Collective Welfare*, and *Job Creation*, appear to be marginal. This can be attributed to two main factors: on one hand, the difficulty in systematically measuring the impact of the healthcare supply chain on aggregate variables such as public health or employment; on the other hand, the fact that these effects are often indirect, and therefore less immediately observable or quantifiable in the models analyzed. Furthermore, *Job Creation* or the *Improvement of Public Welfare* are cross-cutting themes that, in the analyzed contributions, are often addressed only incidentally and not as main research focuses.

2.9.2 Research question 2

The second analysis addresses the second research question: How can Lean principles be applied to minimize waste and reduce costs in healthcare supply chains while maintaining quality of care? The graph below presents all the topics related to this research question. The following sections examine and discuss each topic in detail.

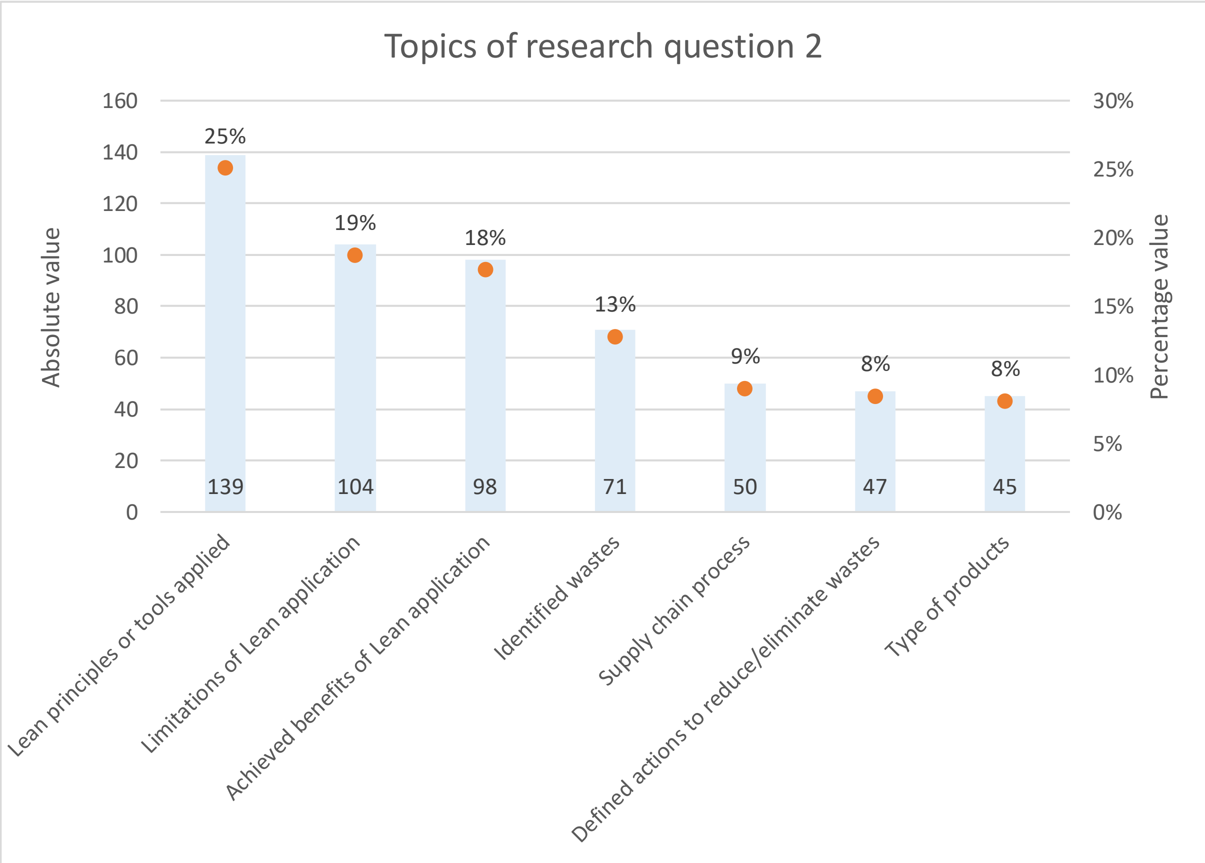

Figure 18: Results of the topics related to the second research question

The graph highlights the main topics addressed in the literature on the Lean healthcare supply chain. The most frequently discussed topic is related to *Lean Principles and The Tools Adopted* (25%). This reflects the need, within the scientific literature, to clarify from the outset the methodological references used in case studies or analyses. Whenever Lean is discussed, it is essential to explicitly state which tools or principles are being applied, such as Value Stream Mapping (VSM), Just-in-Time (JIT), Kanban, 5S, or others (A. Dixit *et al., 2021*; Borges *et al., 2019;* Adeel Akmala *et al.,2020*). The adoption of these tools constitutes the operational foundation through which Lean interventions are implemented and therefore represents a central element within the academic discussion.

Immediately after, with very similar values, are the topics related to the lim*itations* and *Benefits of Lean Application* (19%). These two aspects appear to be strongly interconnected in the literature: on one hand, there is an effort to measure the improvements achieved, such as process optimization, reduced waiting times, or improved quality of care; on the other hand, attention is given to the factors that hinder implementation, such as resistance to change, conflicts between Lean and resilience, or difficulties in integration across departments and systems (Khorasani *et al. 2019*; Akmal *et al., 2020*). Essentially, the literature aims to balance positive evidence with a critical analysis of organizational, cultural, and structural barriers, highlighting that benefits are only realized when these limitations are effectively managed.

In contrast, the least addressed topics concern the *Types of Products* involved in the supply chain and the specific *Actions of Waste Reduction*. Although the latter parts of Lean philosophy, they often do not constitute the central focus of studies, but are instead discussed indirectly, as a consequence of the application of Lean tools. Inventory management, for example, is frequently cited as a lever for improving efficiency, but rarely analyzed in relation to specific product categories, such as medicines, vaccines, or medical devices.

Lean principles or tools applied

The following chart presents the distribution, both in percentage terms and absolute values, of the Lean principles and tools identified through the research.

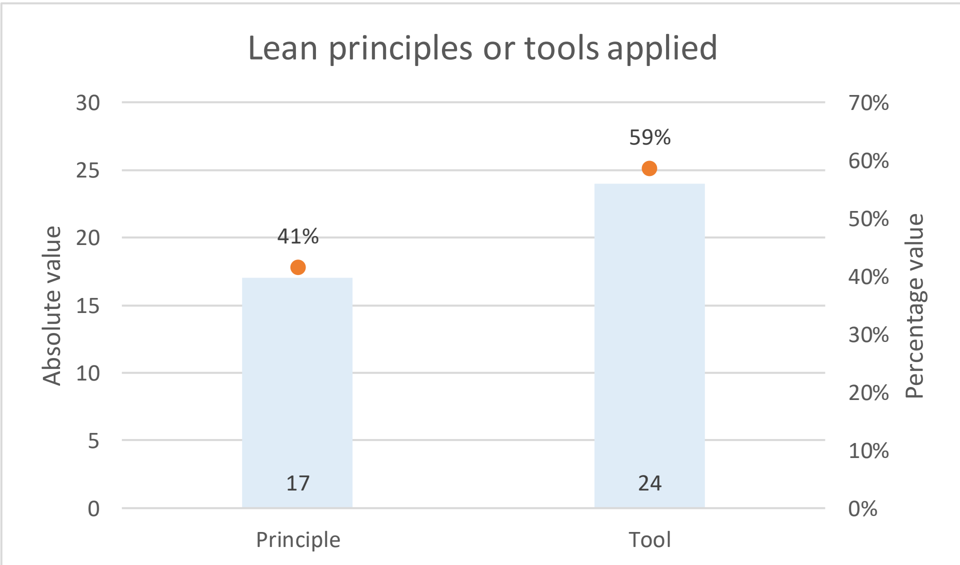

Figure 19: Results of the specific topics related to lean principles or tools applied

The reported chart represents the distribution between *Lean Tools* (41%) and *Lean Principles* (59%) within the analyzed corpus. The analysis shows that *Lean Tools* are the most discussed topic, accounting for 59% of the cases, while *Lean Principles* represent 41%. This suggests that the analyzed literature tends to focus more on practical tools for Lean implementation rather than on the theoretical principles that form its methodological foundation. This distribution can be explained by the fact that, in the healthcare context, Lean adoption is often geared towards solving concrete operational problems rather than achieving a complete cultural transformation (Akmal *et al., 2020;* Li *et al., 2024*). *Lean Tools*, such as Value Stream Mapping, 5S, Kanban, or Kaizen, provide practical and measurable methodologies to optimize processes, reduce waste, and improve operational efficiency. As a result, studies tend to focus on direct applications and tangible outcomes, favoring an approach based on specific tools.

On the other hand, the 41% share dedicated to *Lean Principles* still reflects an interest in the philosophy behind Lean Thinking, such as continuous improvement, patient value focus, and systematic waste reduction. However, since implementing *Lean Principles* requires a profound organizational change and a cultural transformation, it may be more complex to analyze and apply compared to individual tools.

Type of products

The following chart presents the distribution, both in percentage terms and absolute values, of the type of product identified through the research.

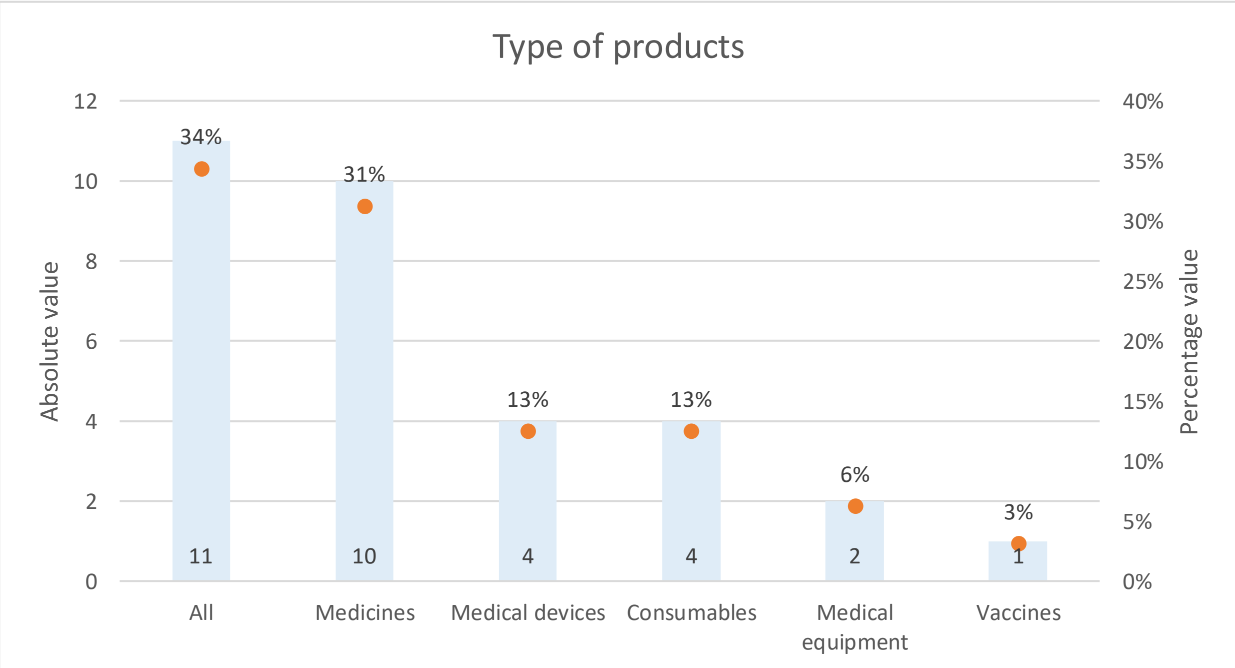

Figure 20: Results of the specific topics related to type of products

The graph shows that most of the literature on the Lean healthcare supply chain adopts a general perspective (*All*), analyzing multiple types of products or addressing the topic without specifying the kind of products considered. Among the specific categories, medicines emerge as the main focus, as their availability directly affects the quality of healthcare services and operational costs. The application of Lean principles to pharmaceutical management aims to optimize inventory and improve distribution, reducing surpluses that could lead to waste and ensuring an efficient supply flow (A. Dixit *et al., 2021*; Dossou *et al., 2020*).

The similar value attributed to *Medical Devices* and *Consumables* can be explained by their comparable nature in supply chain management. Both represent healthcare tools and materials used routinely in hospital settings. *Medical Devices* include diagnostic tools and support equipment, while *Consumables* consist of disposable items such as gloves, syringes, and bandages. While both categories require constant resupply, they are generally less complex to manage than pharmaceuticals, although some medical devices may still be subject to strict regulations, specific storage requirements, or expiration constraints.

Vaccines and *Medical Equipment* are the least addressed topics. *Vaccines* are generally managed through public health programs and government campaigns, with distribution regulated by national and international organizations, making them less relevant in the context of the Lean healthcare supply chain. *Medical Equipment*, on the other hand, differs from other products as it consists of durable goods, such as ventilators, surgical tables, stethoscope, purchased less frequently and subject to maintenance processes rather than dynamic inventory management.

Supply chain process

The following chart presents the distribution, both in percentage terms and absolute values, of the supply chain process identified through the research.

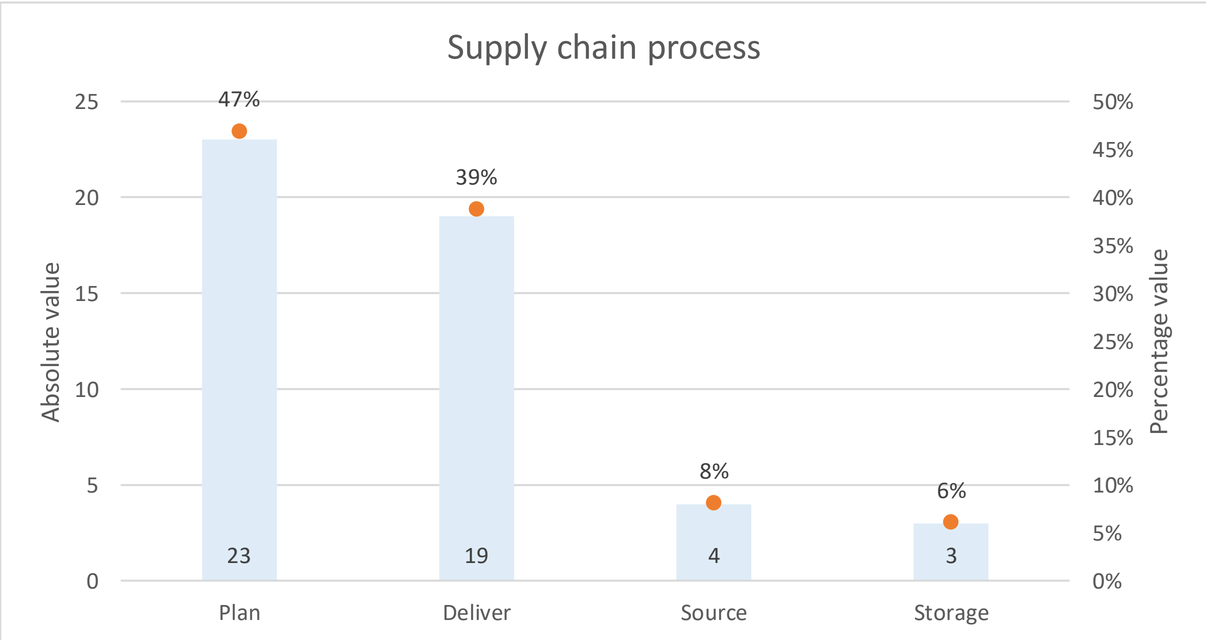

Figure 21: Results of the specific topics related to supply chain process

A detailed discussion of these topics is provided in *Section 2.8.2*.

The graph highlights that the most frequently addressed process in the healthcare supply chain is *Plan* (47%), followed by *Deliver* (39%), while *Source* and *Storage* appear less frequently. This reflects the need for careful and structured management of the healthcare supply chain, which differs from other sectors due to its complexity and criticality.

Plan is a central topic because, in the healthcare sector, demand is often unpredictable, and poor planning can lead to shortages of medicines and medical devices, compromising the delivery of care. Planning is essential to ensure a stable supply, optimize resources, and reduce waste (z M. Almutairi *et al., 2021*).

Deliver is the second most discussed process, as the transportation of medicines and medical devices must comply with strict safety regulations, specific storage conditions, and precise timing to avoid deterioration or delays in patient care. Optimizing the delivery phase is therefore crucial to ensure operational continuity and improve the efficiency of the healthcare supply chain.

By contrast, *Sourcing* and *Storage* are less discussed. *Sourcing*, or the procurement of materials, is often governed by long-term contracts with specific suppliers, making it a less critical aspect compared to planning and delivery.

Identified wastes

The following chart presents the distribution, both in percentage terms and absolute values, of the identified wastes of the healthcare supply chain. A detailed discussion of these topics is provided in *Section 2.8.2*.

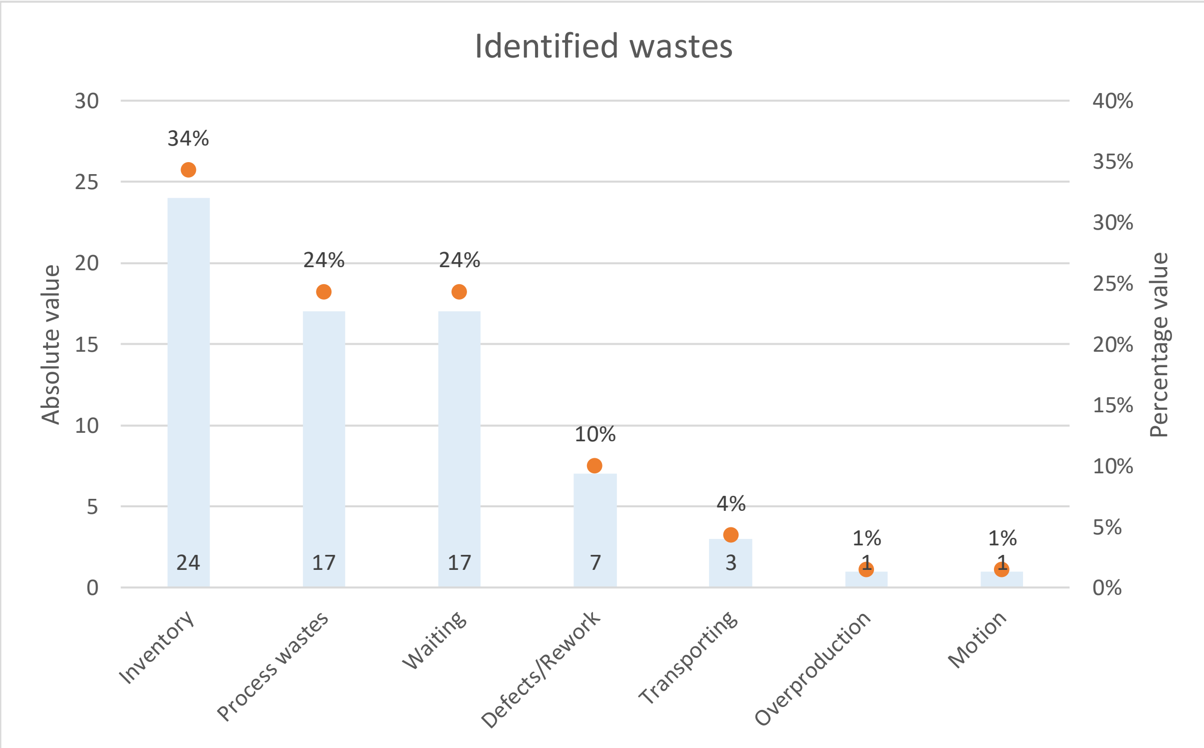

Figure 22: Results of the specific topics related to the identified wastes

The bar chart shows the percentage coverage of the various types of waste in Lean healthcare. The most frequently addressed is *Inventory* waste (34% out of the total number of topics addressed in the corpus), as excess stock represents one of the major challenges in the healthcare sector. *Inventory* management, both within hospitals and in intermediate hubs, directly affects the availability of medicines and the financial sustainability of healthcare facilities, given that pharmaceuticals have specific expiration dates and high obsolescence (Bouchra *et al., 2024*).

This is followed by *Waiting Times* and *Process Waste*, both widely studied for their impact on operational efficiency and service quality. Delays in drug delivery and long *Waiting Times* for patients can generate inefficiencies, increase operational costs, and compromise patient satisfaction. Lean methodologies aim to reduce these wastes by improving workflow, eliminating redundancies, and optimizing the use of available resources (Borges *et al., 2019*).

Process Waste, on the other hand, stems from organizational and operational inefficiencies, such as errors in information management, unnecessary staff movements, and lack of standardization in treatment protocols. These factors can lead to the improper use of resources and increased treatment times, thereby reducing the hospital's ability to manage patients effectively.

In contrast, *Overproduction*, *Transportation* and *Motion* are less frequently addressed in the literature. *Overproduction* is less problematic compared to the manufacturing sector, as the demand for pharmaceuticals is relatively predictable and regulated by strict standards, reducing the risk of excess production. *Transportation* also has a limited impact, since medicines are distributed through stable contracts and planned flows, ensuring efficient stock management and minimizing logistical waste.

Defined actions to reduce/ eliminate waste

The following chart presents the distribution, both in percentage terms and absolute values, of the actions undertaken within the healthcare supply chain, aimed at eliminating or at least mitigating the previously identified types of waste. A detailed discussion of these topics is provided in *Section 2.8.2*.

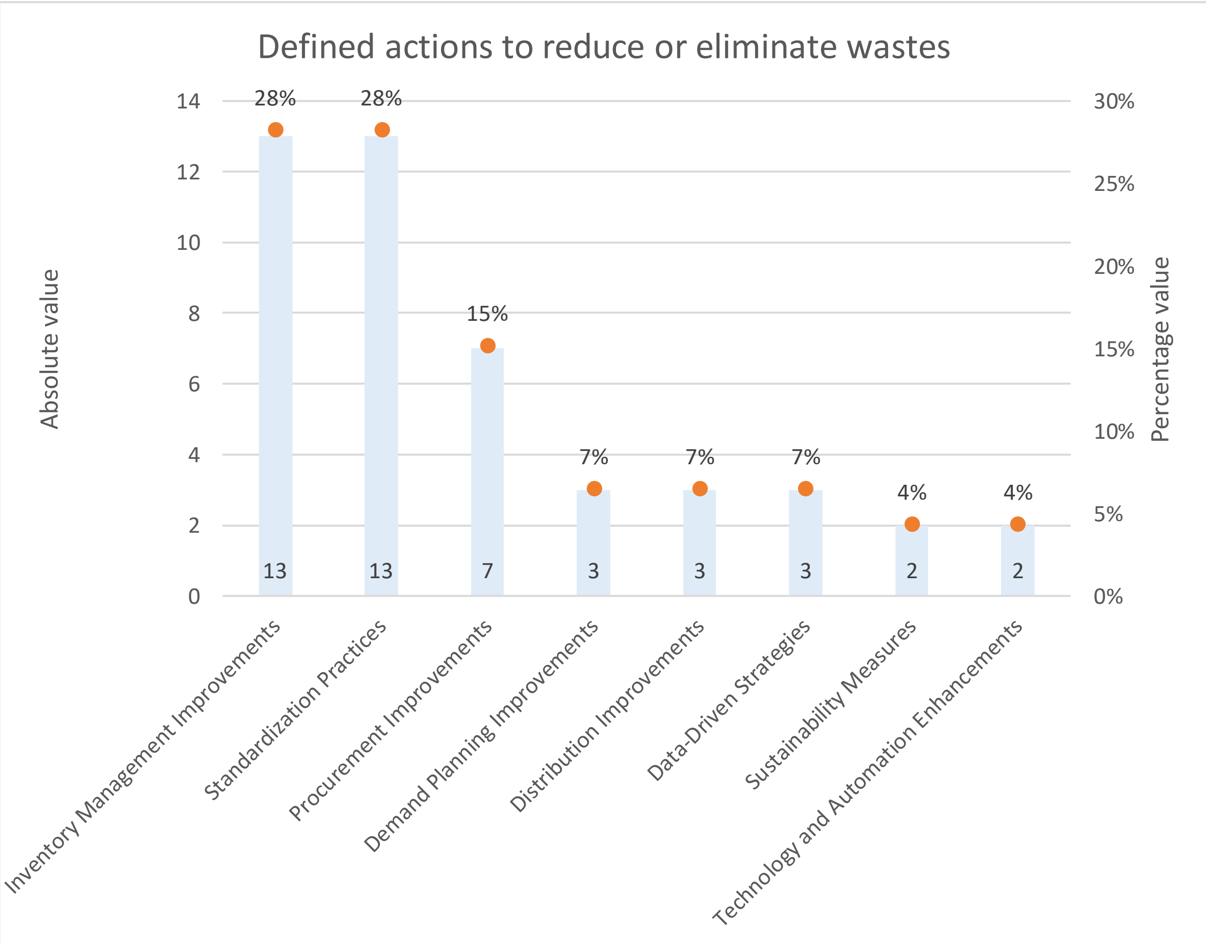

Figure 23: Results of the specific topics related to the defined actions to reduce or eliminate wastes

The chart illustrates the percentages and absolute values of actions adopted to reduce or eliminate waste in Lean healthcare. Among these, *Improving Inventory Management* (28%) emerges as the most significant intervention, in line with previous findings where inventory waste was identified as the most critical issue in the healthcare sector, mainly due to stock accumulation and the management of pharmaceutical expiration dates. However, not in all cases where inventory waste was identified were corrective actions implemented: only in 13 out of 24 occurrences (see *Fig. 22*) was action actually taken to improve the situation. To address this problem, the literature focuses on optimization strategies such as Just-in-Time (JIT) and Kanban, which help maintain appropriate supply levels without excessive accumulation, thus reducing the risk of waste and improving operational efficiency (A. Akmala *et al., 2020*; A. Dixit *et al., 2021*).

Another key aspect highlighted is the *Standardization of Processes* (28%), closely linked to process waste. Standardization helps reduce variability in healthcare procedures, ensuring greater efficiency, quality, and safety for patients. Tools such as Lean Six Sigma and Value Stream Mapping (VSM) are widely used to analyze and optimize workflows, eliminating redundancies and inefficiencies and improving coordination across hospital activities (Dixit *et al., 2021*).

In contrast, aspects such as *Sustainability* and *Technological Automation* are less discussed in the literature as strategies for waste reduction. Environmental sustainability, although an important issue, is often secondary to the primary goal of Lean healthcare, which focuses mainly on eliminating operational waste and improving management efficiency. As for *Technology and Automation*, their use in Lean healthcare is still limited, likely due to the high investment required and the difficulties of integration with existing healthcare systems. As a result, many facilities prefer to rely on established Lean principles and optimization tools rather than adopt advanced technological solutions.

Achieved benefits of lean application

The following chart presents the distribution, both in percentage terms and absolute values, of the benefits achieved through the application of Lean principles in the healthcare supply chain.. A detailed discussion of these topics is provided in *Section 2.8.2.*

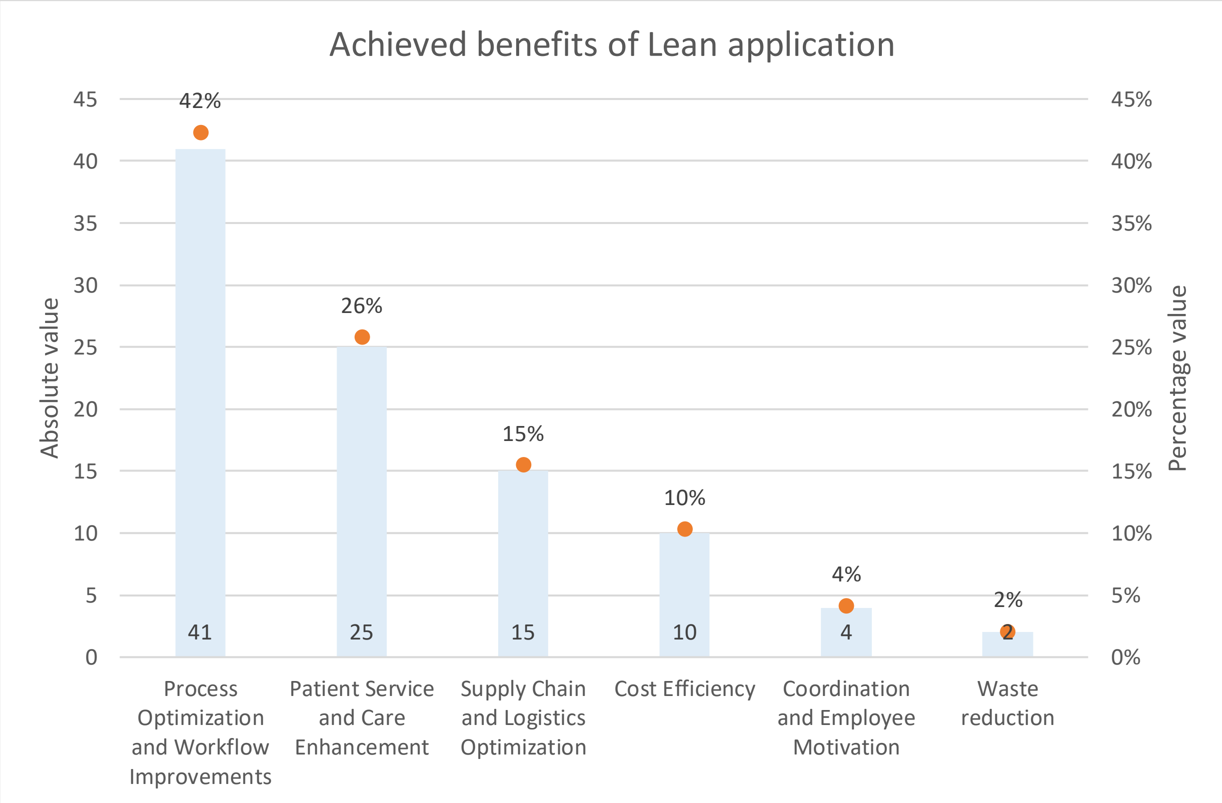

Figure 24: Results of the specific topics related to the achieved benefits of the Lean application

The chart shows the benefits achieved through the application of Lean healthcare, with a focus on *Process and Workflow Optimization* (42%), which is the primary goal of this methodology. Lean aims to improve operational efficiency by reducing waiting times, eliminating redundant activities, and optimizing resource use. The results demonstrate how the actions undertaken (*Fig. 23*) have enabled the achievement of these objectives across the entire supply chain, including hospitals and healthcare facilities, which have achieved significant reductions in operational costs and process times thanks to the adoption of Lean techniques (Bouchra *et al., 2024*).

Process Optimization (26%) also leads to improved service delivery and quality of care. Healthcare services become more timely and organized, reducing clinical errors and increasing patient safety through better resource management and the standardization of protocols (Borges *et al., 2019*).

However, the results related to *Waste Reduction* and *Staff Coordination*, although they are key principles of Lean, appear less evident. Resistance to change in the healthcare sector hinders staff engagement and the improvement of internal communication, making it difficult to achieve tangible benefits in terms of motivation and coordination. Moreover, although Lean was originally developed to reduce waste, this aspect is often considered a side effect of process optimization rather than a benefit measured independently.

Waste Reduction, as highlighted in *Section 2.8,* refers to the elimination of unnecessary resources, the removal of redundant processes, and the optimization of inventory and the supply chain. However, implementing these changes in healthcare is complex: hospitals must maintain safety stock to handle emergencies, making it difficult to push for aggressive inventory optimization. Furthermore, the demand for materials, pharmaceuticals, and staff is highly variable and unpredictable, complicating just-in-time management without risking critical shortages (M. Almutairi *et al., 2021*).

For these reasons, *Waste Reduction* in healthcare is more difficult to implement than in other sectors and is less frequently reported among the main benefits of Lean, as it often results indirectly from process optimization rather than being a standalone objective.

Limitations of lean application

The following chart presents the distribution, both in percentage terms and absolute values, of the limitations encountered in applying Lean practices and tools to the healthcare supply chain. A detailed discussion of these topics is provided in *Section 2.8.2.*

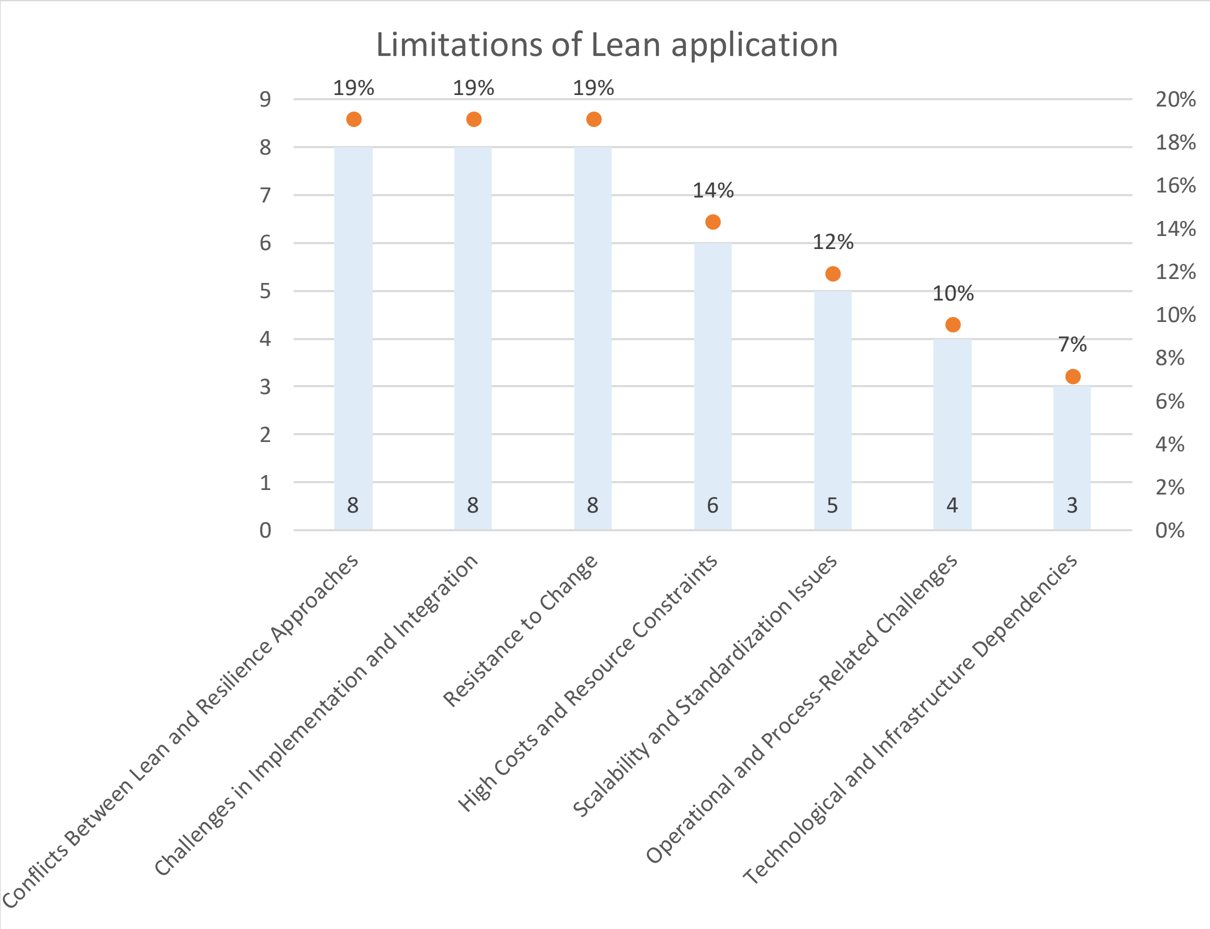

Figure 25: Results of the specific topics related to the limitations of lean application

The chart shows the main limitations of Lean healthcare implementation, highlighting that the primary obstacles are related to *Conflicts Between Lean and Resilience Approaches*, *Implementation and Integration Difficulties*, and *Resistance to Change*, each occurring with equal frequency (19%). This suggests that these challenges are closely interconnected and stem from the same underlying issue: the difficulty of transforming a healthcare system traditionally structured to ensure safety and continuity into a Leaner and more efficient model (N. Alemsan *et al., 2021,* M. Almutairi *et al., 2021*).

The *Conflicts Between Lean and Resilience* arise from the need to balance operational efficiency with flexibility in the healthcare sector. Lean aims to reduce waste and optimize resources, while resilience focuses on the system's ability to adapt to unforeseen changes and ensure service continuity. This tension makes it difficult to adopt Lean strategies without compromising the healthcare system's readiness in emergency situations.

Implementation and Integration difficulties are linked to the complexity of the healthcare sector, which is characterized by highly regulated processes and a fragmented supply chain. Implementing Lean requires alignment among different operational units, a process that often encounters bureaucratic hurdles, a lack of specific skills, and organizational resistance.

Lastly, *Resistance to Change* is another major cause of failure in adopting Lean in healthcare. Organizational culture plays a crucial role: healthcare personnel, accustomed to established procedures, may perceive changes as a risk to the quality of care or as an increase in workload (M. Alali *et al., 2022*). Additionally, the lack of training and incentives for staff reduces engagement with Lean initiatives.

In contrast, *Technological and Infrastructural Limitations* appear less significant, likely because many Lean solutions rely on process improvement methodologies rather than advanced technological innovations. Moreover, while digitalization can support Lean implementation, many techniques such as Value Stream Mapping (VSM) and Kaizen can be applied using traditional tools without requiring substantial technological investment (A. Akmala *et al., 2020*).

2.9.3 Research question 3

The third analysis addresses the last research: How social and sustainable models based on circular economy and on ESG factors/SDGs goals can reduce adverse externalities along the healthcare supply?

The graph below presents all the topics related to this research question. The following sections examine and discuss each topic in detail.

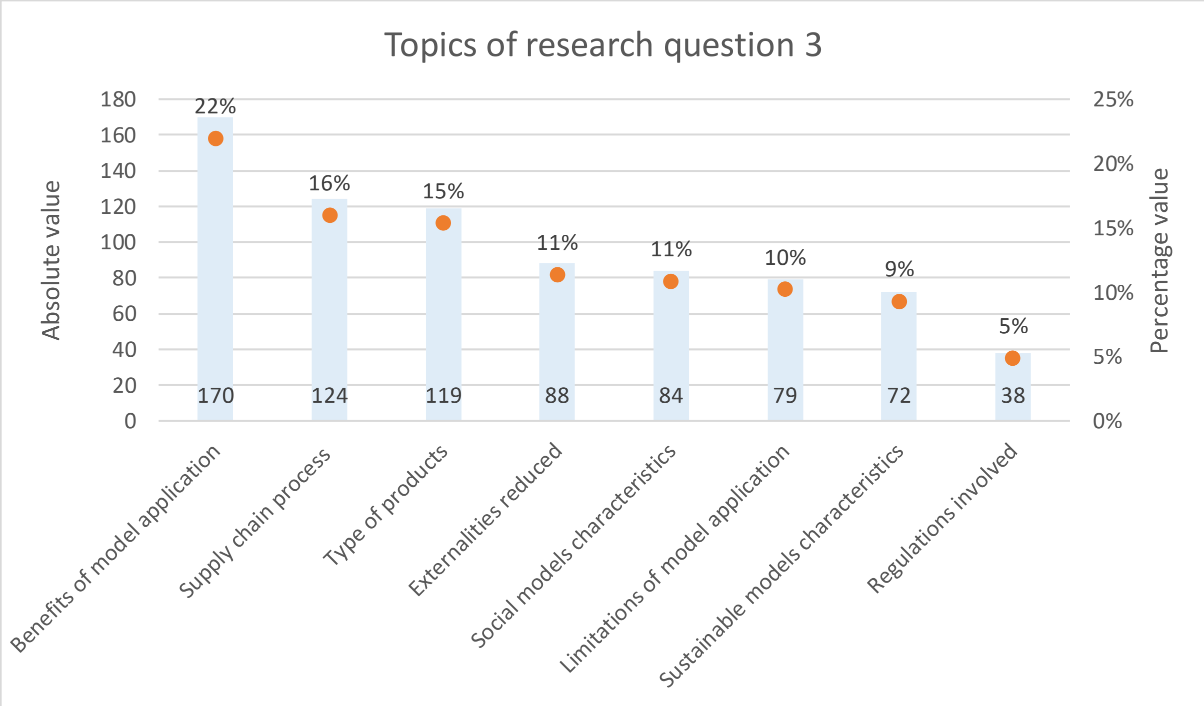

Figure 26: Results of the topics related to the third research question

The chart highlights a clear predominance of the *Benefits of Applied Models* (22%), namely, the various approaches identified through the research, particularly the implementation of Lean tools and practices within the healthcare supply chain, as the main theme in the literature on healthcare supply chain sustainability. This trend reflects a strong orientation in the literature toward the functional and advantageous aspects of sustainability. In particular, numerous studies emphasize cost reduction, as also shown in the chart on economic topics (*Fig. 15*), where the *Cost Optimization via Sustainable Practices* represents the 32% of the total number of topics covered, as well as improvements in efficiency, corporate image, access to new technologies, and increased organizational resilience (A. Mostepaniuk *et al., 2023;* B. Leksono *et al., 2019;* S. Elabed *et al., 2021*). These tangible and measurable elements explain why concrete benefits are the most frequently addressed focus in the analyses.

Themes such as *Environmental Externalities* (e.g., emission and waste reduction), the *social Characteristics of Models*, and *Implementation Limitations* are less explored, likely due to their more difficult nature to measure or standardize in quantitative models (F. Khosravi *et al.,2019;*

M. Azadi *et al., 2023)*. *Regulations*, finally, occupy a marginal position, probably due to their strong geographical variability and the fact that, being rigid and imposed from above, they are not considered variables to be modeled but rather external constraints. For this reason, they are often cited in the literature only to contextualize the study or to support methodological assumptions. However, several studies emphasize their strategic importance as enabling (or limiting) factors in the transition toward more sustainable supply chains.

Social models characteristics

The following chart presents the distribution, both in percentage and absolute terms, of the social model characteristics that emerged from the research.

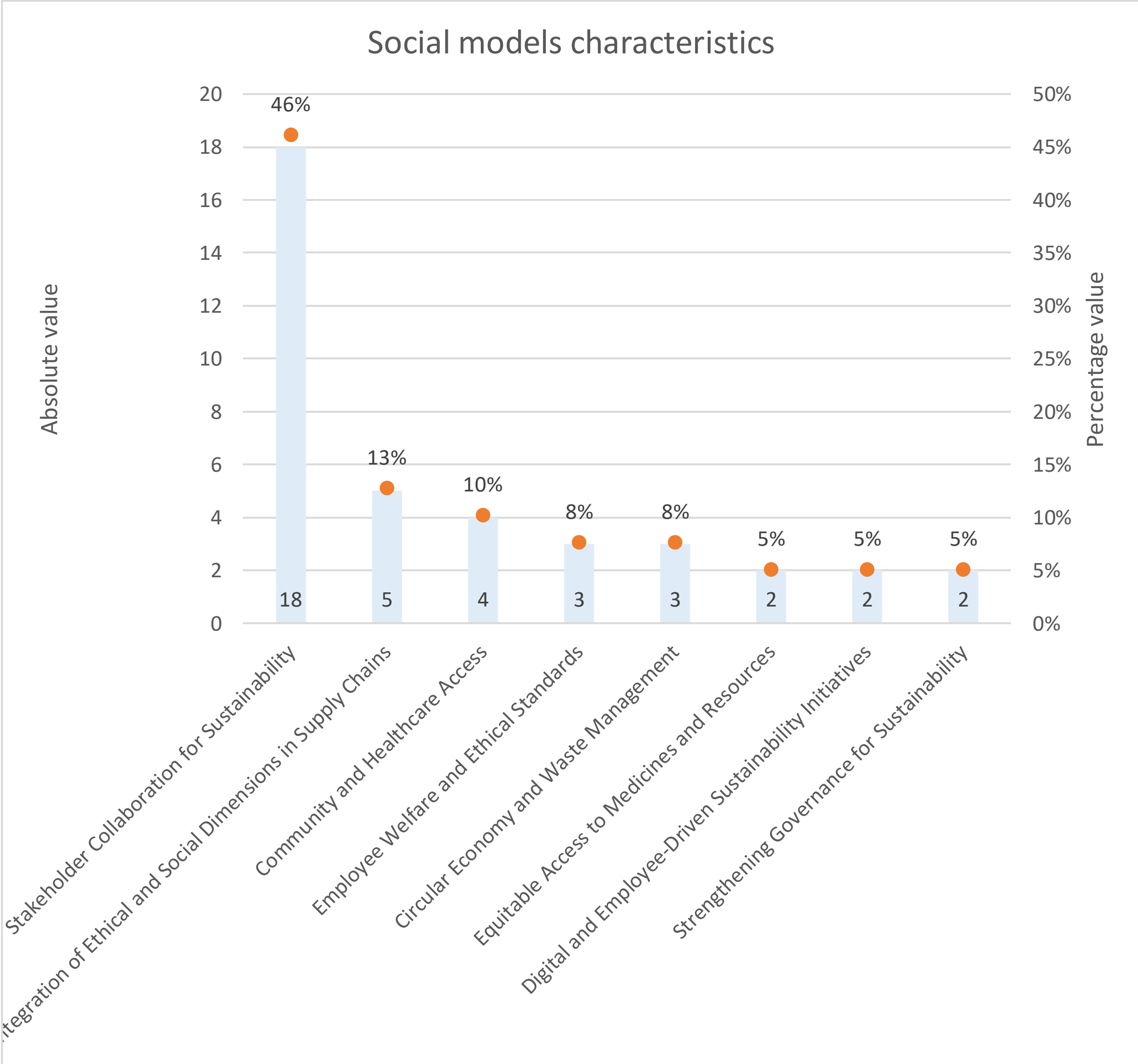

Figure 27: Results of the specific topics related to the social models characteristics

A detailed description of the themes that can be included under the term *Social* is provided in *Section 1.4*, while an in-depth discussion of these topics is presented in *Section 2.8.2.*

The chart on Social Model Characteristics clearly shows that *Stakeholder Collaboration* is the most explored social dimension in the literature on healthcare supply chain sustainability, representing 46% of the total. This predominance can be explained by the central role of multi-stakeholder engagement in addressing the complex challenges of the healthcare sector. Sustainability in healthcare requires a systemic and cooperative approach involving hospitals, suppliers, public institutions, and local communities. Moreover, strong collaboration fosters resilience, trust, and the dissemination of virtuous practices, elements now considered priorities in an increasingly unstable post-pandemic context (M. Hussain *et al., 2018*; F. Khosravi *et al., 2019*).

The lower presence of other topics, all ranging between 13% and 5% of the total themes identified under social model characteristics, reflects a tendency in the literature to address social dimensions more as context or indirect benefits rather than as primary objects of analysis or modeling. For example, equitable *Access to Medicines* or *Staff Well-Being* are considered important topic, but they often lack clear formalization in quantitative models, as they are difficult to measure or standardize.

The limited emphasis on *Employee-Driven Digital Initiatives* or on *Strengthening Governance* can also be attributed to the limited integration of social indicators in existing frameworks, as shown in the study by Faramarz Khosravi et al. (*2019*), which adopts a stakeholder perspective to assess social sustainability, also highlighting a lack of robust metrics.

Sustainable models characteristics

The following chart presents the distribution, both in percentage and absolute terms, of the sustainable model characteristics that emerged from the research.

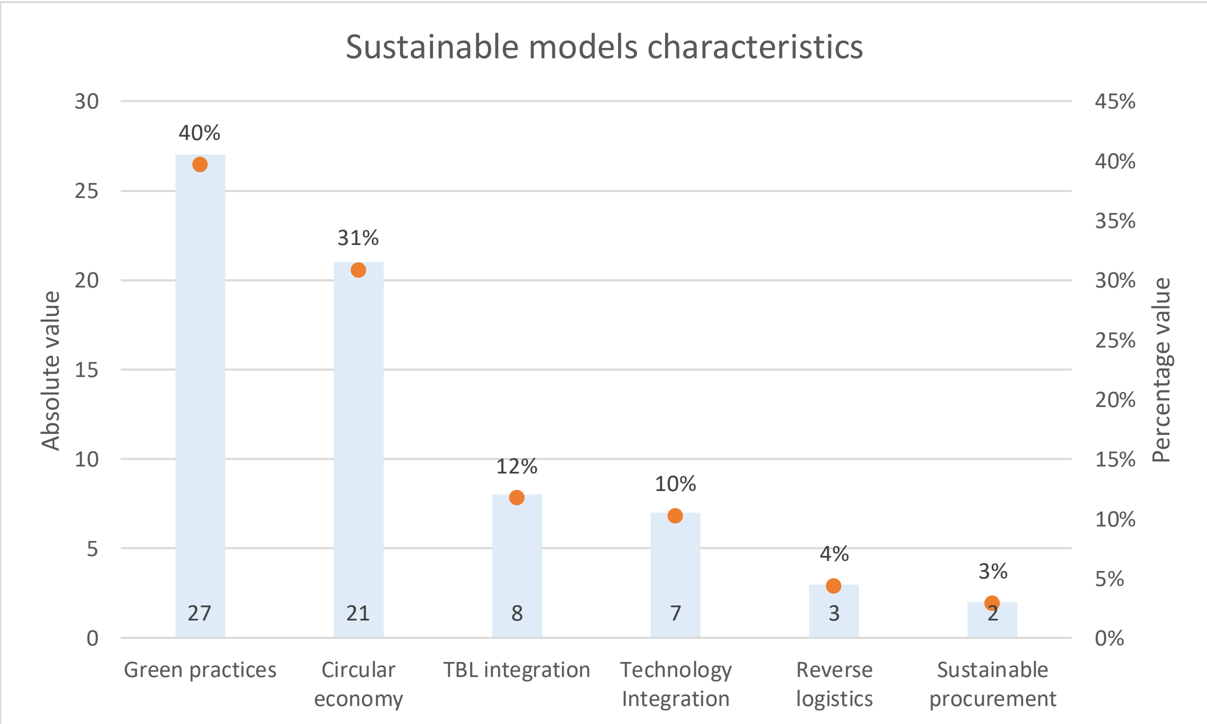

Figure 28: Results of the specific topics related to the sustainable models characteristics

A detailed description of the themes that can be included under the term *sustainable* is provided in *Section 1.3*, while an in-depth discussion of these topics is presented in *Section 2.8.2*.

The chart shows that *Green Practices* (40%) and *Circular Economy* (31%) are the most frequently addressed sustainability characteristics in the literature. This result reflects the growing attention toward reducing environmental impact in a sector that has historically generated high volumes of waste, consumed energy intensively, and handled hazardous materials. Numerous studies highlight how the adoption of *Green Practices*, such as reducing packaging, using recyclable materials, and managing waste sustainably, is considered an immediately actionable measure to mitigate environmental externalities (J. Jemai *et al., 2020*; Y. Lin *et al., 2024*).

At the same time, the *Circular Approach* is seen as a systemic response to the inefficiencies of the linear model, and finds application in initiatives related to recovery, reuse, and the design of closed-loop medical products (K. Nur Alfina *et al., 2024*; B. Straten *et al., 2020*).

There is comparatively less focus on the integration of the *Triple Bottom Line* and *technology*, not because they are less relevant, but because they are more difficult to implement simultaneously. The *TBL approach*, which considers economic, social, and environmental impacts simultaneously, requires sophisticated metrics and advanced governance, which are often not yet mature in healthcare systems. Similarly, *Technological Integration*, while crucial for efficient and traceable management, faces challenges such as interoperability issues, lack of common standards, and cultural barriers to digital adoption (Y. Lin *et al., 2024*).

Finally, the low presence of *Reverse Logistics* and *Sustainable Procurement* can be explained by operational and regulatory challenges. *Reverse Logistics* is complex to implement in healthcare due to safety, sterility, and traceability requirements for materials (K. Nur Alfina *et al., 2024*). *Sustainable Procurement*, on the other hand, requires changes in supplier evaluation criteria and strong institutional support, which is often lacking (C. Schutte *et al., 2022*). Although both topics are relevant, they are still in an early stage of exploration in both the literature and in practice.

Type of products

The following chart presents the distribution, both in percentage and absolute terms, of the most relevant type of products that emerged from the research.

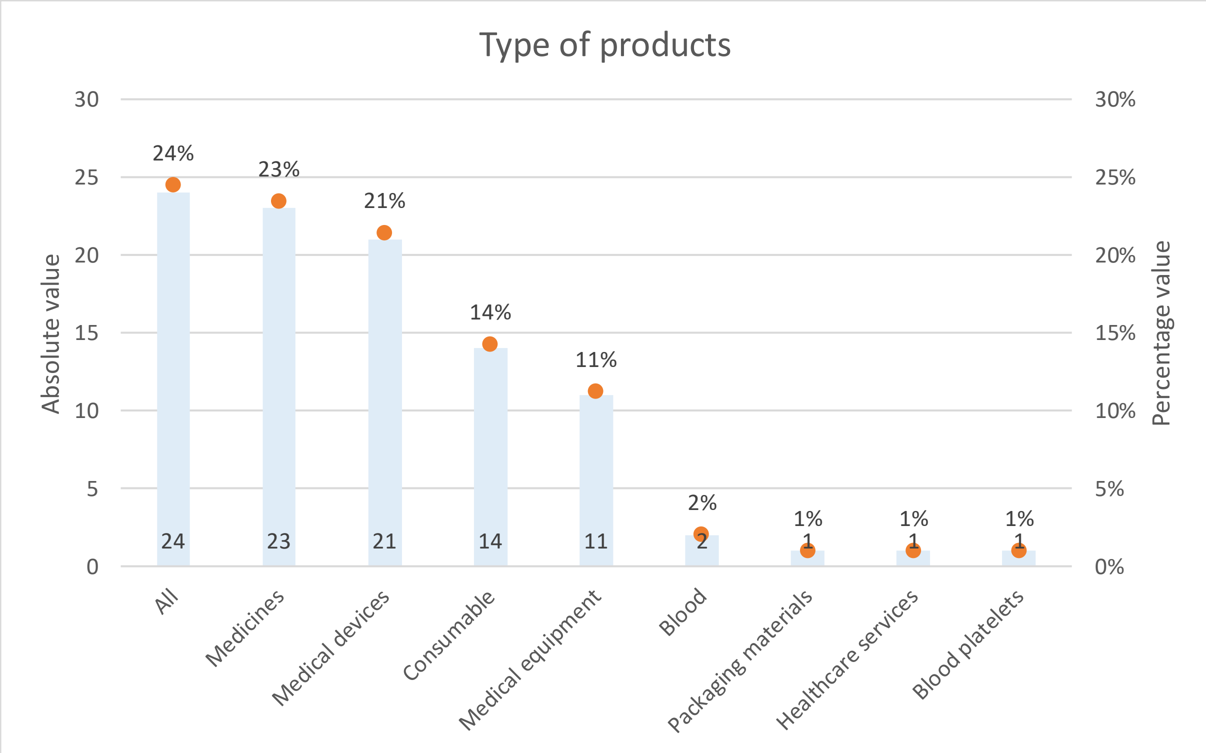

Figure 29: Results of the specific topics related to the type of products

The chart shows that the "*All*" category is the most frequently addressed (24%) in sustainable models of the healthcare supply chain. This category includes all studies that adopt a general approach, simultaneously considering multiple product classes or proposing models that are broadly applicable without focusing on specific categories.

Immediately following, with very similar percentages, are *Medicines* (23%) and *Medical Devices* (21%), which represent the main areas of specific focus. The relevance of these two areas is justified by their economic and operational impact on healthcare systems. *Medicines* are among the highest spending categories and involve significant challenges related to disposal and environmentally impactful production. *Medical Devices*, on the other hand, generate large volumes of waste and present challenges in terms of sterility, reverse logistics, and non-recyclable materials. Numerous studies analyzed propose green or circular strategies specifically in these areas, which are often more regulated and standardized, making modeling and data collection more feasible (K. Nur Alfina *et al., 2024;* S.Elabed *et al., 2021*; K. Sri Suthagar *et al., 2023*).

The categories of *Consumables* and *Medical Equipment* receive comparatively less attention, despite being integral to clinical operations. This may be due to the fragmentation of these categories, the difficulty in tracking their impact along the entire supply chain, or the lower perceived priority compared to high-value medicines and devices. All other categories have minimal impact, being addressed in only one or two papers.

Supply chain process

The following chart presents the distribution, both in percentage and absolute terms, of the healthcare supply chain process that emerged from the research. A detailed discussion of these topics is provided in *Section 2.8.2*

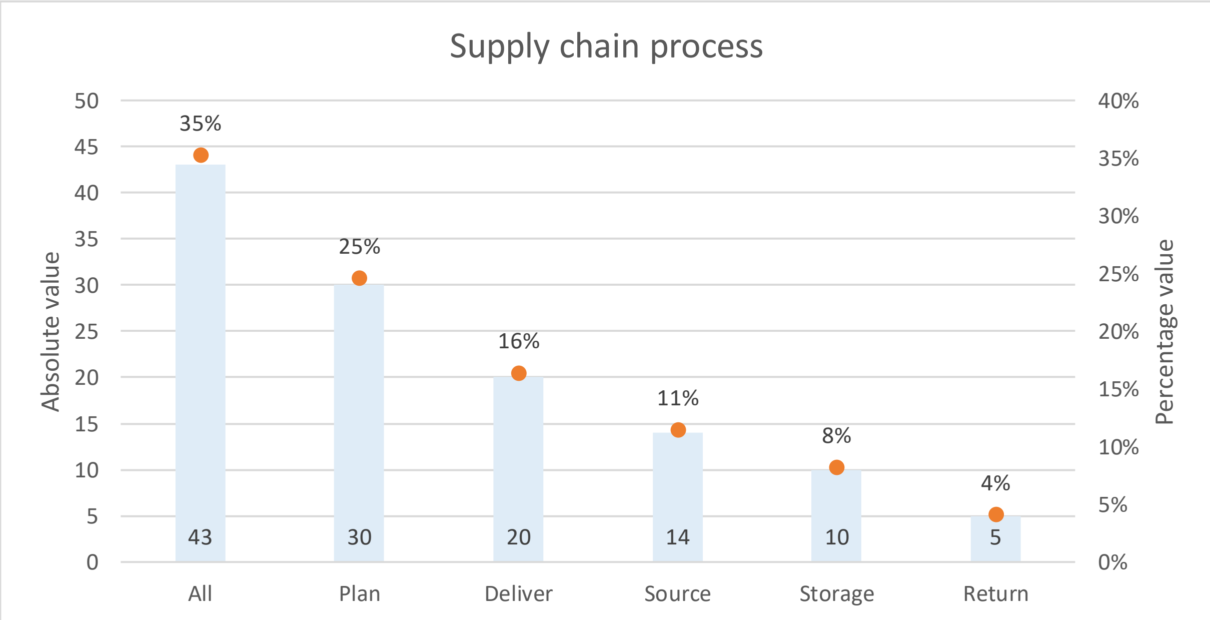

Figure 30: Results of the specific topics related to the supply chain process

The chart shows that the most frequently addressed process in sustainable models is "*All*," confirming the literature's tendency to consider the healthcare supply chain in an integrated way, without focusing on individual phases. This approach reflects the complex and interconnected nature of healthcare systems, where sustainability requires cross-functional coordination across all processes (M. Hussain *et al., 2018*).

Immediately following is *Plan* (35%), which aligns with the fact that sustainability in healthcare demands strategic planning that takes into account environmental, social, and economic constraints. The literature shows that an effective planning phase is crucial for optimizing resources, reducing waste, and increasing system responsiveness (K. Nur Alfina *et al., 2024*).

Next is the *Deliver* (25%) process, which includes the transportation and delivery of healthcare goods, often identified as one of the main sources of emissions and operational inefficiencies.

The interest in this phase is justified by the need to adopt greener logistics practices, especially in the last mile, and by the importance of timely deliveries in healthcare, particularly in critical or emergency contexts (J. Braithwaite *et al., 2024*; K. Sri Suthagar *et al., 2023*).

Finally, the processes *Source*, *Storage*, and *Return* are the least addressed in sustainable models. This limited attention may be attributed to the greater complexity in modeling these phases, especially in the healthcare context. *Sourcing* involves a careful selection of suppliers, which would require sustainability criteria that are still underdeveloped or difficult to apply globally. *Storage* entails challenges related to the management of sensitive, perishable, or hazardous products, which limit the applicability of standardized strategies. Lastly, reverse logistics (*Return*) is rarely addressed because it is difficult to implement in environments where sterility, safety, and traceability are top priorities.

Externalities reduced

The following chart presents the distribution, both in percentage and absolute terms, of the environmental externalities mitigated through sustainability practices, as identified in the research. A detailed discussion of these topics is provided in *Section 2.8.2*

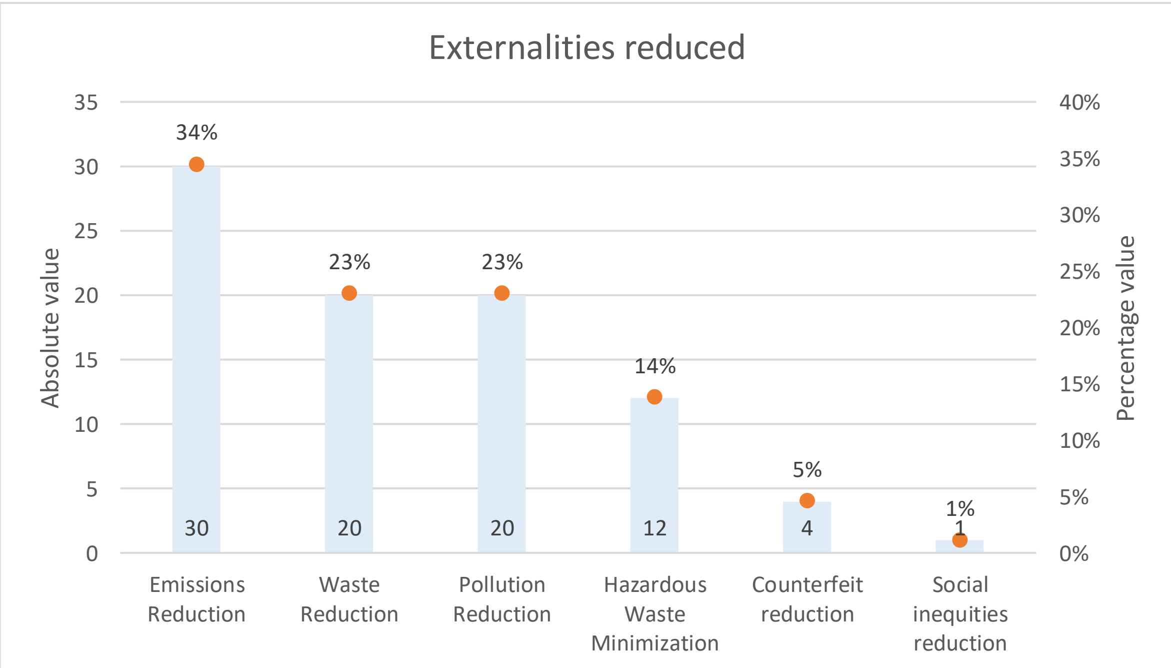

Figure 31: Results of the specific topics related to the externalities reduced

The chart shows that among the externalities addressed in sustainable models, *Emission Reduction* (34%) is the most frequently discussed topic. This result is justified by the fact that emissions, particularly those related to greenhouse gases, represent one of the most significant and easily measurable environmental impacts in the sector. Moreover, the literature increasingly focuses on concrete operational strategies to reduce them. These include logistics optimization using AI systems to reduce mileage, the adoption of renewable energy sources such as solar and biogas in healthcare facilities, and the use of practices such as waste-to-energy, which recovers value from medical waste by generating energy and reducing emissions from incineration (G. Daú *et al. 2019,* Sri Suthagar *et al., 2023*).

Waste Reduction and *Pollution Reduction* (both at 23%) follow in terms of frequency. *Waste Reduction* primarily concerns packaging, disposable materials, and pharmaceutical or medical device waste, areas where circular strategies can be effectively applied (K. Nur Alfina *et al., 2024;* A. Mostepaniuk *et al. 2023*). *Pollution Reduction* is often addressed alongside emissions and waste, and includes actions such as more efficient management of logistics flows and the use of low-impact vehicles, which contribute to the overall reduction of air and noise pollution (J. Jemai *et al., 2020*).

The minimization of *Hazardous Waste* is less frequently addressed because it is more difficult to manage through innovative approaches. It requires complex technologies, significant investment, and strict adherence to healthcare regulations. These challenges limit its inclusion in general sustainability models.

Benefits of model application

The following chart presents the distribution, both in percentage and absolute terms of the benefits resulting from the application of models based on sustainability, green practices, circular economy, reverse logistics, and all other previously discussed themes.

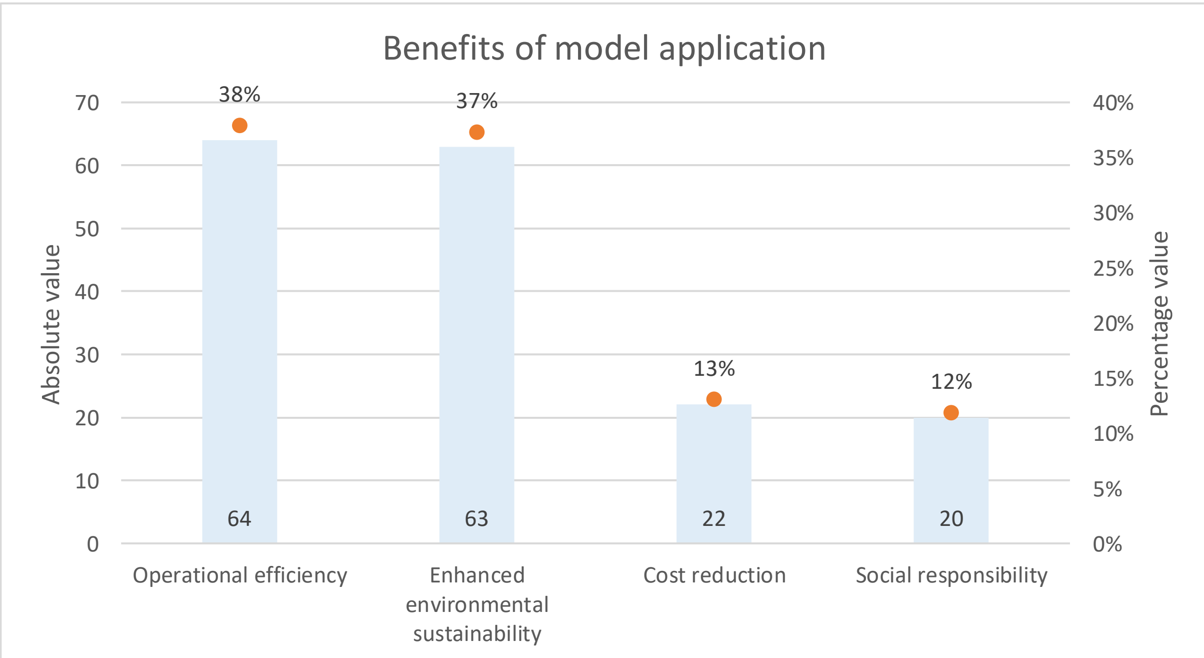

Figure 32: Results of the specific topics related to the benefits of model application

A detailed discussion of these topics is provided in *Section 2.8.2.*

The chart shows the main benefits associated with the application of sustainable models. The strong emphasis on *Operational Efficiency* (38%) reflects the highly complex and fragmented nature of the healthcare supply chain, where sustainable models, especially those supported by digitalization and artificial intelligence, enable the optimization of logistics flows, procurement, and resource utilization (Y. Lin *et al., 2024*). This trend aligns with what emerged in previous charts, where "Plan" and "Deliver" are among the most analyzed processes, and emission reduction is the most frequently addressed priority, all elements that, if well managed, directly contribute to improving system efficiency.

Enchanced Environmental Sustainability (37%) is also a central goal, consistent with the high number of studies addressing the reduction of emissions, waste, and pollution, as shown in the previously discussed chart on externalities (Fig. 31). The adoption of practices such as renewable energy, transport optimization, and smart material management encourages healthcare organizations to integrate environmental criteria into operational processes, generating positive outcomes both in terms of ecological impact and corporate image (J. Braithwaite *et al.,2024*; G. Daú *et al.2019* W. Cristiano *et al., 2024*).

In contrast, *Cost Reduction* and *Social Responsibility* are less emphasized in the models. The former is often overlooked because sustainability is seen more as a long-term investment rather than an immediate cost-saving strategy. The latter, *Social Responsibility*, is less frequently addressed because it is more difficult to model quantitatively and is often viewed as a secondary impact compared to environmental and efficiency goals, as also confirmed by the low percentage dedicated to reducing social inequalities in the externalities chart (*Fig. 31*).

Limitations of model application

The following chart presents the distribution, both in percentage terms and absolute values, of the limitations encountered in applying sustainable practices to the healthcare supply chain. A detailed discussion of these topics is provided in *Section 2.8.2*.

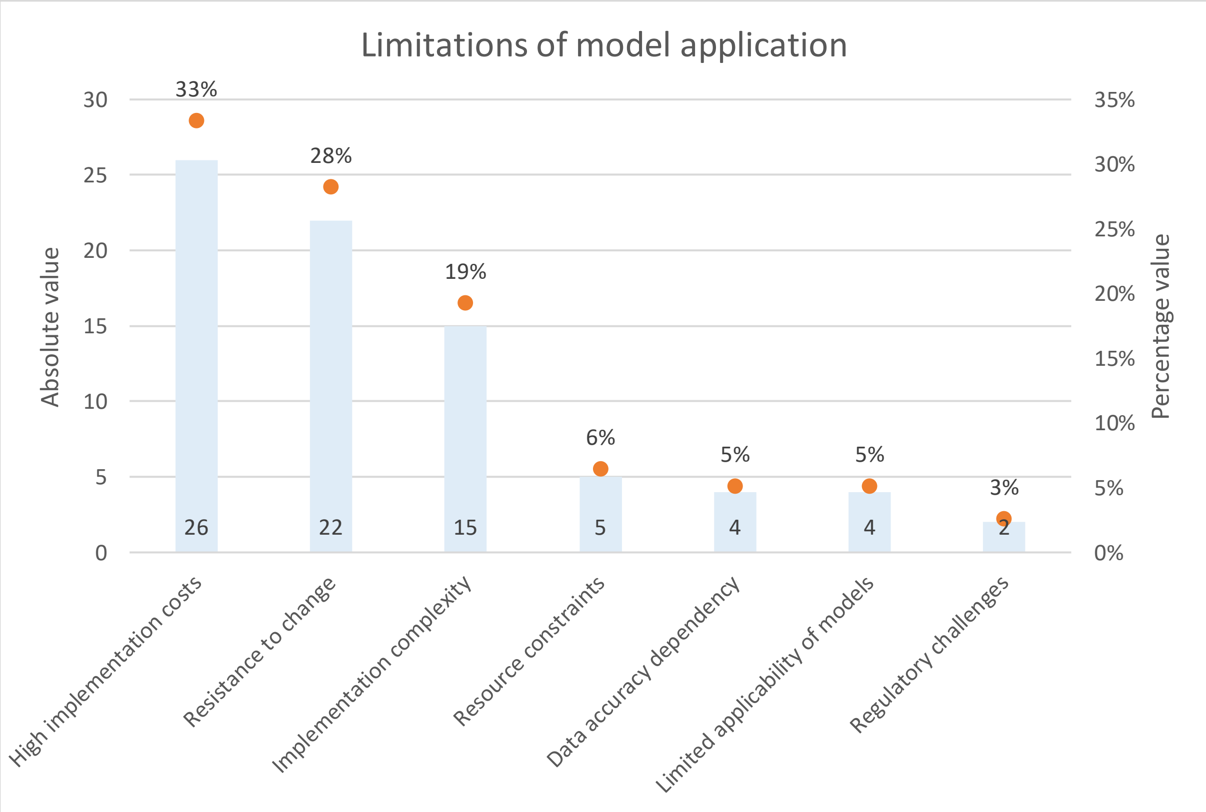

Figure 33: Results of the specific topics related to the limitations of model application

The chart highlights that the main limitations to the application of sustainable models in the healthcare supply chain are the *High Implementation Costs* (33%), *Resistance to Change* (28%), and *Complexity in Application* (19%). These obstacles reflect the highly regulated, fragmented, and resource-constrained context in which healthcare facilities operate. *High Costs* stem from the adoption of advanced technologies, such as logistics digitalization or the integration of renewable energy sources, identified in previous charts as key tools for reducing emissions and increasing efficiency, but which require significant initial investments (K. Nur Alfina *et al., 2022*; G. Bogale Fanta *et al., 2022*).

Resistance to change is linked to the conservative nature of the healthcare sector, where introducing new practices, even if sustainable, implies modifying established routines, overcoming cultural barriers, and training personnel. *Implementation Complexity*, on the other hand, reflects the difficulty of coordinating various actors and processes and translating theoretical models into scalable operational solutions. Moreover, many models are developed in academic settings with simplified assumptions but face obstacles when applied in practice, where real constraints emerge, such as managing clinical emergencies, ensuring interoperability of digital systems, or maintaining continuity of care during the transition to more sustainable practices (K. Nur Alfina *et al., 2022;* Y. Lin *et al., 2024)*.

The lesser barriers, such as *Limited Resource Availability*, *Dependence on Accurate Data*, and *Limited Applicability of the Models*, indicate technical challenges often related to the lack of integrated information systems or the difficulty in adapting models to highly specific contexts. Finally, *Regulatory Challenges* appear marginal, consistent with what emerged in *Fig. 26* among the least addressed themes, such as regulations. Despite their real impact, they are often seen as external constraints that are difficult to model, and thus are rarely included in the frameworks analyzed.

2.10 Main research gaps

Despite the growing academic interest in the healthcare supply chain, the systematic literature review reveals several research gaps that highlight the need for more structured, context-specific, and practically oriented investigations. This section presents a series of research gaps that could be addressed by future studies.

2.10.1 Resistance to change

A first significant gap concerns the lack of structured strategies for change management. The issue of resistance to change is widely cited in the literature, both in relation to the introduction of lean principles and the adoption of sustainable models. As highlighted in *Fig. 25 and 33*, both referring to limitations identified in these two areas, resistance to change appears to be one of the most frequently mentioned factors. However, despite the considerable attention devoted to this issue, there is a noticeable lack of operational proposals that concretely guide the transition process in a progressive and adaptable way within healthcare settings. Numerous studies identify obstacles such as limited staff engagement, lack of training, or rigid organizational structures, but rarely is there a methodological framework capable of addressing these challenges. Future research could fill this gap by proposing change management frameworks specifically designed for healthcare, focusing on phases such as internal listening, progressive training, distributed leadership, and monitoring metrics, in order to support a more conscious and sustainable adoption of innovations.

2.10.2 Methodological Gap

A second gap concerns the methodological approach adopted in the analyzed contributions. As shown in *Fig. 10*, the vast majority of studies in the literature employ a qualitative methodology, while quantitative analyses account for only a small percentage of the reviewed works (15%). Although qualitative methods offer valuable insights, there is a clear need to complement these approaches with quantitative methods capable of validating and generalizing the results. Many of the benefits attributed to lean or sustainable models, such as improved efficiency, waste reduction, or service optimization, are discussed descriptively, but are rarely supported by systematic quantitative data.

The use of quantitative methods would not only help confirm such findings but would also enable more robust cross-sectional analyses, comparisons across different scenarios, and the testing of model applicability in various healthcare contexts. This would support the development of common reference frameworks useful for both research and operational practice, contributing to the dissemination of more replicable and data-driven solutions.

2.10.3 Performance indicators

The third gap is closely linked to the previously identified one, namely the lack of clear and measurable performance indicators, particularly concerning the social dimension. Although aspects such as employee well-being, patient satisfaction, stakeholder collaboration, and equitable access to healthcare services are frequently mentioned, there is a lack of structured metrics capable of quantifying these outcomes. These elements are often treated as desirable side effects rather than as measurable and monitorable objectives. An illustrative example is the topic of community engagement (see Fig. 17), which is the most frequently cited social aspect, yet lacks specific indicators to assess its actual impact. The development of robust social KPIs would enable longitudinal studies capable of tracking evolving trends and evaluating the effectiveness of interventions, thereby bridging the gap between narrative and measurement.

2.10.4 Regulation involved

Another significant gap concerns the limited integration of regulatory references within the models analyzed, a topic that is either insufficiently explored, particularly in relation to sustainability issues, or entirely absent. This shortcoming is evident in various sections of the present analysis, as illustrated by *Fig. 16*, *Fig. 26*, *Fig. 27* and *Fig. 33*. In the reviewed literature, and especially in contributions addressing operational, economic, or Lean Thinking-related aspects, regulatory frameworks are largely overlooked. The few regulations mentioned refer almost exclusively to the Sustainable Development Goals (SDGs), which are used as a general value framework, but rarely accompanied by concrete regulatory references governing healthcare activities in specific national or regional contexts. This highlights a widespread neglect of concrete regulatory analysis, which is instead essential when designing operational models for a highly regulated sector like healthcare. As a result, many proposed models, though theoretically sound, risk being difficult to implement in practice. The lack of regulatory assessment weakens the applicability of such models and limits their external validity, underscoring the need for a closer alignment between operational strategies and legislative constraints.

In conclusion, the gaps identified show that, despite the breadth and growing attention of the literature on healthcare supply chains, important areas of weakness and under-exploration remain, both from a theoretical and practical standpoint. Addressing these gaps represents not only a challenge but also a strategic opportunity for future research. A commitment in this direction could help transform the existing literature into a more useful, operational, and action-oriented body of knowledge, particularly in those contexts where challenges are more complex and resources are more limited.

Conclusion

In this last chapter, it will be discussed the academic and practical implications brought by this thesis, the problems encountered, the limitations of the work and the possible future research that can take place starting from this project's conclusion.

3.1 Academic and practical implications

This work aims to provide a structured analysis of the most relevant scientific literature, with a specific focus on the healthcare supply chain (HSC). To this end, a Systematic Literature Review (SLR) was conducted, supported by both backward and forward snowballing techniques, which led to the identification of a final sample consisting of 109 scientific papers. The selected contributions were thoroughly analyzed, taking into account a variety of aspects in order to identify the main research trends and the still open gaps, which could serve as a basis for future academic investigations.

The results highlight that, although the healthcare supply chain has attracted increasing interest in recent years, it remains a fragmented research area that requires further exploration from different perspectives, in order to provide a more comprehensive understanding of the current healthcare system. In particular, the COVID-19 pandemic has clearly exposed structural weaknesses in healthcare supply chains, thereby offering a favorable context for investigating new organizational, technological, and strategic solutions.

From an academic perspective, this study aims to stimulate further research on topics such as sustainability, the application of lLean principles, and the economic, social, and operational dimensions of the healthcare supply chain, thus contributing to expand and consolidate the existing body of knowledge. The breadth and methodological rigor adopted in the collection and analysis of the contents make this work a potential reference point for future studies in the field.

From a practical point of view, the research provides a clear and up-to-date overview of the HSC, highlighting the main actors involved and the challenges the system is currently facing. Moreover, it offers public and private stakeholders a detailed and up-to-date review of the main actions undertaken, emerging practices, and management models adopted in the healthcare context, thus serving as a useful decision-making support tool to guide strategic and operational choices in a constantly evolving sector.

3.2 Limitations

This research presents some limitations that could be addressed and further explored in future studies. The primary limitation concerns the structure of the analysis itself, which was developed around the three research questions defined at the initial stage. As a result, the entire work focuses exclusively on concepts, themes, and dimensions directly related to these questions, exploring in particular the areas that emerge from them.

However, it is important to note that the healthcare supply chain is an extremely complex system, characterized by a wide range of stakeholders and processes extending throughout the entire value chain. This implies the existence of additional relevant aspects that were not investigated in the present research. Nevertheless, with regard to the specific topics examined, sustainability, lean management, and the operational, economic, and social dimensions of the HSC, the study provides comprehensive coverage, offering a structured and updated overview of the state of the art, which may serve as a valuable foundation for future research that is either broader in scope or more focused on other aspects of the healthcare supply chain.

A second limitation that emerged concerns the availability of scientific contributions during the selection phase. Despite the use of a structured and rigorous process for identifying and screening papers, several potentially relevant articles were not included in the analysis due to limited accessibility. The possible inclusion of these works might have influenced the final results, offering further insights in relation to the three research questions and contributing to an even more comprehensive picture of the current state of the literature in the healthcare sector.

Lastly, the exclusive use of the Scopus database for collecting contributions represents an additional limitation of the research. This methodological constraint may have led to the exclusion of articles published in other academic databases or specialized journals not indexed in Scopus, which could have further enriched and diversified the analysis. A future extension of the study could involve the integration of multiple databases in order to increase the completeness and robustness of the results.

3.3 Future research

Based on these observations, future research could further expand the analysis of topics related to the healthcare supply chain, broadening the scope of investigation and contributing to a more organic overall picture. .As with any systematic literature review, the present study provides a static image of the state of the art, based on the time at which the research was conducted, namely Fall-Winter 2024. Consequently, scientific articles, conference proceedings, and other contributions published later were not included, even though they may offer new evidence or partially revise the results that have emerged. In this perspective, it may be particularly useful to replicate the present SLR in the coming years, updating its contents and integrating the most recent contributions.

A further avenue for future development concerns the addressing of the research gaps identified and discussed in *Section 2.10*. In particular, it would be highly relevant to develop operational strategies for managing resistance to change in healthcare settings, both in relation to the adoption of lean principles and to the integration of sustainable models. Defining concrete approaches and tools could support stakeholders involved in the transition process, making it smoother and more effective.

Finally, another important area for future research relates to the translation of qualitative studies into applicable quantitative models. Integrating descriptive findings with structured empirical data would allow for the comparison of different scenarios and the testing of model effectiveness in diverse healthcare contexts. In particular, this approach could support the development of clear and measurable performance indicators, especially regarding the social dimension. The formulation of robust social KPIs, for example, those related to patient satisfaction, employee well-being, or stakeholder collaboration, would make it possible to monitor evolving trends and objectively assess the impact of implemented strategies.

References

[1]. Abdolazimi, O., Salehi Esfandarani, M., Salehi, M., Shishebori, D., & Shakhsi-Niaei, M. (2023). Development of sustainable and resilient healthcare and non-cold pharmaceutical distribution supply chain for COVID-19 pandemic: a case study. *The International Journal of Logistics Management*, *34*(2), 363–389. https://doi.org/10.1108/IJLM-04-2021-0232

[2]. Acharjya, D., & Dash, M. K. (2024). Sustainability of healthcare supply chain management: a panoramic approach through SLR and bibliometric. *Kybernetes*. https://doi.org/10.1108/K-11-2023-2487

[3]. Akmal, A., Greatbanks, R., & Foote, J. (2020). Lean thinking in healthcare – Findings from a systematic literature network and bibliometric analysis. *Health Policy*, *124*(6), 615–627. https://doi.org/10.1016/j.healthpol.2020.04.008

[4]. Ala, A., Goli, A., Mirjalili, S., & Simic, V. (2024). A fuzzy multi-objective optimization model for sustainable healthcare supply chain network design. *Applied Soft Computing*, *150*, 111012. https://doi.org/10.1016/j.asoc.2023.111012

[5]. Alali, A. M., Abu Al Rejal, H. M., Abu, N. H. B., & Alali, H. (2022). The Impact of Supply Chain Preparedness on Healthcare Service Quality: A Literature Review. *International Journal of Sustainable Development and Planning*, *17*(5), 1425–1430. https://doi.org/10.18280/ijsdp.170506

[6]. Aldrighetti, R., Zennaro, I., Finco, S., & Battini, D. (2019). Healthcare Supply Chain Simulation with Disruption Considerations: A Case Study from Northern Italy. *Global Journal of Flexible Systems Management*, *20*(S1), 81–102. https://doi.org/10.1007/s40171-019-00223-8

[7]. Alemsan, N., & Tortorella, G. L. (2022). Lean and Resilience in Healthcare Supply Chain: A Mediation Analysis. *IFAC-PapersOnLine*, *55*(10), 436–441. https://doi.org/10.1016/j.ifacol.2022.09.432

[8]. Alemsan, N., Tortorella, G., Taboada Rodriguez, C. M., Balouei Jamkhaneh, H., & Lima, R. M. (2022). Lean and resilience in the healthcare supply chain – a scoping review. *International Journal of Lean Six Sigma*, *13*(5), 1058–1078. https://doi.org/10.1108/IJLSS-07-2021-0129

[9]. Alfina, K. N., Chandima Ratnayake, R. M., Wibisono, D., Basri, M. H., & Mulyono, N. B. (2022). Analyzing Barriers Towards Implementing Circular Economy in Healthcare Supply Chains. In *2022 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 827–831). Kuala Lumpur, Malaysia: IEEE. https://doi.org/10.1109/IEEM55944.2022.9989999

[10]. Alfina, K. N., & Ratnayake, R. M. C. (2023). Upstream Healthcare Supply Chain Risk Management in the Implementation of Circular Economy at the Primary Care Level. In *2023 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 0813–0817). Singapore, Singapore: IEEE. https://doi.org/10.1109/IEEM58616.2023.10406400

[11]. Alfina, K. N., Ratnayake, R. M. C., Wibisono, D., Basri, M. H., & Mulyono, N. B. (2025). Prioritizing Performance Indicators for the Circular Economy Transition in Healthcare Supply Chains. *Circular Economy and Sustainability*, *5*(1), 231–276. https://doi.org/10.1007/s43615-024-00436-9

[12]. Alharthi, S., Cerotti, P. R. C., & Maleki Far, S. (2020). An Exploration of The Role of Blockchain in The Sustainability and Effectiveness of The Pharmaceutical Supply Chain. *Journal of Supply Chain and Customer Relationship Management*, 1–29. https://doi.org/10.5171/2020.562376

[13]. Ali, I., & Kannan, D. (2022). Mapping research on healthcare operations and supply chain management: a topic modelling-based literature review. *Annals of Operations Research*, *315*(1), 29–55. https://doi.org/10.1007/s10479-022-04596-5

[14]. Alizadeh, M., Kalantari Khalil Abad, A. R., Jahani, H., & Makui, A. (2024). Prevention of post-pandemic crises: A green sustainable and reliable healthcare supply chain network design for emergency medical products. *Journal of Cleaner Production*, *434*, 139702. https://doi.org/10.1016/j.jclepro.2023.139702

[15]. Allahham, M., Sharabati, A.-A. A., Hatamlah, H., Ahmad, A. Y. B., Sabra, S., & Daoud, M. K. (2023). Big Data Analytics and AI for Green Supply Chain Integration and Sustainability in Hospitals. *WSEAS TRANSACTIONS ON ENVIRONMENT AND DEVELOPMENT*, *19*, 1218–1230. https://doi.org/10.37394/232015.2023.19.111

[16]. Almutairi, Abdulaziz M., Almanei, M., Al-Ashaab, A., & Salonitis, K. (2021). Prioritized Solutions for Overcoming Barriers When Implementing Lean in the Healthcare

Supply Chain: A Saudi Perspective. *Logistics*, *5*(1), 9. https://doi.org/10.3390/logistics5010009

[17]. Almutairi, Abdulaziz Marzouq, Salonitis, K., & Al-Ashaab, A. (2019). A framework for implementing lean principles in the supply chain management at health-care organizations: Saudi's perspective. *International Journal of Lean Six Sigma*, *11*(3), 463–492. https://doi.org/10.1108/IJLSS-01-2019-0002

[18]. Alves, D. D. S., Smek, D. J., Souza, É. F. D., Felizardo, K. R., & Vijaykumar, N. L. (2024). Updating a Systematic Literature Review on Knowledge Management Diagnostics in Software Development Organizations. In *Proceedings of the XXIII Brazilian Symposium on Software Quality* (pp. 125–135). Salvador Bahia Brazil: ACM. https://doi.org/10.1145/3701625.3701652

[19]. Andrighetto, G., Gavrilets, S., Gelfand, M., Mace, R., & Vriens, E. (2024). Social norm change: drivers and consequences. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *379*(1897), 20230023. https://doi.org/10.1098/rstb.2023.0023

[20]. Anser, M. K., Khan, M. A., Nassani, A. A., Abro, M. M. Q., Zaman, K., & Kabbani, A. (2021). Does COVID-19 pandemic disrupt sustainable supply chain process? Covering some new global facts. *Environmental Science and Pollution Research*, *28*(42), 59792–59804. https://doi.org/10.1007/s11356-021-14817-2

[21]. Antonoplis, S. (2024). Studying personality and social structure. *Social and Personality Psychology Compass*, *18*(1), e12932. https://doi.org/10.1111/spc3.12932

[22]. Aronsson, H., Abrahamsson, M., & Spens, K. (2011). Developing lean and agile health care supply chains. *Supply Chain Management: An International Journal*, *16*(3), 176–183. https://doi.org/10.1108/13598541111127164

[23]. Azadi, M., Yousefi, S., Farzipoor Saen, R., Shabanpour, H., & Jabeen, F. (2023). Forecasting sustainability of healthcare supply chains using deep learning and network data envelopment analysis. *Journal of Business Research*, *154*, 113357. https://doi.org/10.1016/j.jbusres.2022.113357

[24]. Baumgärtner, S., & Quaas, M. (2010a). Sustainability economics — General versus specific, and conceptual versus practical. *Ecological Economics*, *69*(11), 2056–2059. https://doi.org/10.1016/j.ecolecon.2010.06.018

[25]. Baumgärtner, S., & Quaas, M. (2010b). What is sustainability economics? *Ecological Economics*, *69*(3), 445–450. https://doi.org/10.1016/j.ecolecon.2009.11.019

[26]. Benzidia, S., Bentahar, O., Husson, J., & Makaoui, N. (2024). Big data analytics capability in healthcare operations and supply chain management: the role of green process innovation. *Annals of Operations Research*, *333*(2–3), 1077–1101. https://doi.org/10.1007/s10479-022-05157-6

[27]. Benzidia, S., Makaoui, N., & Bentahar, O. (2021). The impact of big data analytics and artificial intelligence on green supply chain process integration and hospital environmental performance. *Technological Forecasting and Social Change*, *165*, 120557. https://doi.org/10.1016/j.techfore.2020.120557

[28]. Borges, G. A., Tortorella, G., Rossini, M., & Portioli-Staudacher, A. (2019). Lean implementation in healthcare supply chain: a scoping review. *Journal of Health Organization and Management*, *33*(3), 304–322. https://doi.org/10.1108/JHOM-06-2018-0176

[29]. Bouterfas, B., & Ibn El Farouk, I. (2024). Lean management in public hospital medicines supply chain: a literature review. In *2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)* (pp. 1–8). Sousse, Tunisia: IEEE. https://doi.org/10.1109/LOGISTIQUA61063.2024.10571492

[30]. Braithwaite, J., Smith, C. L., Leask, E., Wijekulasuriya, S., Brooke-Cowden, K., Fisher, G., Patel, R., Pagano, L., Rahimi-Ardabili, H., Spanos, S., Rojas, C., Partington, A., McQuillan, E., Dammery, G., Carrigan, A., Ehrenfeld, L., Coiera, E., Westbrook, J., & Zurynski, Y. (2024). Strategies and tactics to reduce the impact of healthcare on climate change: systematic review. *BMJ*, e081284. https://doi.org/10.1136/bmj-2024-081284

[31]. Campos, J. T. D. G. A. A., Vivas, R. D. C., Ferreira, A. M. S., & Freires, F. G. M. (2020). Operational Decisions and Sustainability: A Brazilian Case of a Drugs Distribution Center. *Sustainability*, *12*(21), 8916. https://doi.org/10.3390/su12218916

[32]. Cristiano, W., De Marchi, C., Di Domenico, K., Punzo, O., Mancini, A., & Mancini, L. (2024). The elephant in the room in greenhouse gases emissions: rethinking healthcare systems to face climate change. A rapid scoping review. *Environmental Sciences Europe*, *36*(1), 24. https://doi.org/10.1186/s12302-024-00839-3

[33]. Daú, G., Scavarda, A., Scavarda, L. F., & Portugal, V. J. T. (2019). The Healthcare Sustainable Supply Chain 4.0: The Circular Economy Transition Conceptual Framework with

the Corporate Social Responsibility Mirror. *Sustainability*, *11*(12), 3259. https://doi.org/10.3390/su11123259

[34]. De Fine Licht, K., & Folland, A. (2025). Redefining ‘sustainability’: A systematic approach for defining and assessing ‘sustainability’ and ‘social sustainability’. *Theoria*, *91*(1), 45–59. https://doi.org/10.1111/theo.12568

[35]. De La Sablonnière, R. (2017). Toward a Psychology of Social Change: A Typology of Social Change. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00397

[36]. De Vries, J., & Huijsman, R. (2011). Supply chain management in health services: an overview. *Supply Chain Management: An International Journal*, *16*(3), 159–165. https://doi.org/10.1108/13598541111127146

[37]. Debnath, B., Bari, A. B. M. M., Haq, Md. M., De Jesus Pacheco, D. A., & Khan, M. A. (2023). An integrated stepwise weight assessment ratio analysis and weighted aggregated sum product assessment framework for sustainable supplier selection in the healthcare supply chains. *Supply Chain Analytics*, *1*, 100001. https://doi.org/10.1016/j.sca.2022.100001

[38]. Denise , O. (2009). Considering sustainability through ethical approaches and their practical application. In *International Symposium on Technology and Society*. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ISTAS.2009.5155906

[39]. Ding, B. (2018). Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains. *Process Safety and Environmental Protection*, *119*, 115–130. https://doi.org/10.1016/j.psep.2018.06.031

[40]. Dixit, A., & Dutta, P. (2024). Critical success factors for the adoption of circular economy in sustainable healthcare waste management. *Clean Technologies and Environmental Policy*, *26*(7), 2181–2201. https://doi.org/10.1007/s10098-023-02712-y

[41]. Dixit, A., Routroy, S., & Dubey, S. K. (2019). A systematic literature review of healthcare supply chain and implications of future research. *International Journal of Pharmaceutical and Healthcare Marketing*, *13*(4), 405–435. https://doi.org/10.1108/IJPHM-05-2018-0028

[42]. Dixit, A., Routroy, S., & Dubey, S. K. (2022a). Analyzing the operational barriers of government-supported healthcare supply chain. *International Journal of Productivity and Performance Management*, *71*(8), 3766–3791. https://doi.org/10.1108/IJPPM-09-2020-0493

[43]. Dixit, A., Routroy, S., & Dubey, S. K. (2022b). Development of supply chain value stream map for government-supported drug distribution system. *International Journal of Quality & Reliability Management*, *39*(5), 1151–1169. https://doi.org/10.1108/IJQRM-12-2020-0399

[44]. Dobrzykowski, D., Saboori Deilami, V., Hong, P., & Kim, S.-C. (2014). A structured analysis of operations and supply chain management research in healthcare (1982–2011). *International Journal of Production Economics*, *147*, 514–530. https://doi.org/10.1016/j.ijpe.2013.04.055

[45]. Droz, L. (2019). Redefining Sustainability: From Self-Determination to Environmental Autonomy. *Philosophies*, *4*(3), 42. https://doi.org/10.3390/philosophies4030042

[46]. DUONG, N.-H., & HA, Q.-A. (2021). The Impacts of Social Sustainability Practices on Supply Chain Performance: Mediating Role of Supply Chain Integration. *Journal of Distribution Science*, *19*(11), 37–48. https://doi.org/10.15722/JDS.19.11.202111.37

[47]. Duque-Uribe, V., Sarache, W., & Gutiérrez, E. V. (2019). Sustainable Supply Chain Management Practices and Sustainable Performance in Hospitals: A Systematic Review and Integrative Framework. *Sustainability*, *11*(21), 5949. https://doi.org/10.3390/su11215949

[48]. Elabed, S., Shamayleh, A., & Daghfous, A. (2021). Sustainability-oriented innovation in the health care supply chain. *Computers & Industrial Engineering*, *160*, 107564. https://doi.org/10.1016/j.cie.2021.107564

[49]. Erjaee, A., Hendiani, S., Moradi, S., & Bagherpour, M. (2022). Healthcare Sustainability Evaluation Using a Hybrid Fuzzy Multi-Criteria Decision-Making Model. *International Journal of Fuzzy Systems*, *24*(2), 1182–1202. https://doi.org/10.1007/s40815-021-01128-4

[50]. Eslamipoor, R., & Nobari, A. (2022). A Reliable and Sustainable Design of Supply Chain in Healthcare Under uncertainty Regarding Environmental Impacts. *Journal of Applied Research on Industrial Engineering*, (Online First). https://doi.org/10.22105/jarie.2022.335389.1461

[51]. Essoussi, I. E. (2015). A performance evaluation of some collaborative inventory management practices in the healthcare supply chain. In *2015 International Conference on Industrial Engineering and Systems Management (IESM)* (pp. 277–284). Seville, Spain: IEEE. https://doi.org/10.1109/IESM.2015.7380171

[52]. Ezeudu, O. B., Ezeudu, T. S., Ugochukwu, U. C., Tenebe, I. T., Ajogu, A. P., Nwadi, U. V., & Ajaero, C. C. (2022). Healthcare Waste Management in Nigeria: A Review. *Recycling*, *7*(6), 87. https://doi.org/10.3390/recycling7060087

[53]. Faggini, M., Cosimato, S., Nota, F. D., & Nota, G. (2018). Pursuing Sustainability for Healthcare through Digital Platforms. *Sustainability*, *11*(1), 165. https://doi.org/10.3390/su11010165

[54]. Fanta, G. B., & Pretorius, L. (2022). Supporting circular economy in healthcare through digital reverse logistics. In *2022 IEEE 28th International Conference on Engineering, Technology and Innovation (ICE/ITMC) & 31st International Association For Management of Technology (IAMOT) Joint Conference* (pp. 1–6). Nancy, France: IEEE. https://doi.org/10.1109/ICE/ITMC-IAMOT55089.2022.10033139

[55]. Getele, G. K., & Ruoliu, X. (2024). Service supply chain risk management in the public healthcare sector. *International Journal of Emerging Markets*, *19*(11), 4259–4285. https://doi.org/10.1108/IJOEM-04-2022-0627

[56]. Glavič, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. *Journal of Cleaner Production*, *15*(18), 1875–1885. https://doi.org/10.1016/j.jclepro.2006.12.006

[57]. Goodarzian, F., Hoseini-Nasab, H., Toloo, M., & Fakhrzad, M. B. (2021). Designing a new medicine supply chain network considering production technology policy using two novel heuristic algorithms. *RAIRO - Operations Research*, *55*(2), 1015–1042. https://doi.org/10.1051/ro/2021031

[58]. Goodarzian, F., Hosseini-Nasab, H., Muñuzuri, J., & Fakhrzad, M.-B. (2020). A multi-objective pharmaceutical supply chain network based on a robust fuzzy model: A comparison of meta-heuristics. *Applied Soft Computing*, *92*, 106331. https://doi.org/10.1016/j.asoc.2020.106331

[59]. Greenfield, P. M. (2018). Studying social change, culture, and human development: A theoretical framework and methodological guidelines. *Developmental Review*, *50*, 16–30. https://doi.org/10.1016/j.dr.2018.05.003

[60]. Hajipour Machiani, N., Taleizadeh, A. A., Toloo, M., & Abedsoltan, H. (2025). Designing a new sustainable healthcare network considering the COVID-19 pandemic:

Artificial intelligence-based solutions. *Expert Systems with Applications*, *260*, 125357. https://doi.org/10.1016/j.eswa.2024.125357

[61]. Hossain, M. K., & Thakur, V. (2022). Drivers of sustainable healthcare supply chain performance: multi-criteria decision-making approach under grey environment. *International Journal of Quality & Reliability Management*, *39*(3), 859–880. https://doi.org/10.1108/IJQRM-03-2021-0075

[62]. Hussain, M., Ajmal, M. M., Gunasekaran, A., & Khan, M. (2018). Exploration of social sustainability in healthcare supply chain. *Journal of Cleaner Production*, *203*, 977–989. https://doi.org/10.1016/j.jclepro.2018.08.157

[63]. Hussain, M., Ajmal, M., Subramanian, G., Khan, M., & Anas, S. (2024). Challenges of big data analytics for sustainable supply chains in healthcare – a resource-based view. *Benchmarking: An International Journal*, *31*(9), 2897–2918. https://doi.org/10.1108/BIJ-06-2022-0390

[64]. Igras, S., Kohli, A., Bukuluki, P., Cislaghi, B., Khan, S., & Tier, C. (2021). Bringing ethical thinking to social change initiatives: Why it matters. *Global Public Health*, *16*(6), 882–894. https://doi.org/10.1080/17441692.2020.1820550

[65]. Islam, A. I. M. J., Rahman, H.-U., Mushfiquzzaman, M., Ali, S. M., Alghababsheh, M., & Moktadir, Md. A. (2025). Sustainability drivers to circular economy integration into the healthcare supply chain to address waste: Implications for net-zero emission. *Journal of Cleaner Production*, *490*, 144742. https://doi.org/10.1016/j.jclepro.2025.144742

[66]. Jahre, M., Dumoulin, L., Greenhalgh, L. B., Hudspeth, C., Limlim, P., & Spindler, A. (2012). Improving health in developing countries: reducing complexity of drug supply chains. *Journal of Humanitarian Logistics and Supply Chain Management*, *2*(1), 54–84. https://doi.org/10.1108/20426741211226000

[67]. Jemai, J., Chung, B. D., & Sarkar, B. (2020). Environmental effect for a complex green supply-chain management to control waste: A sustainable approach. *Journal of Cleaner Production*, *277*, 122919. https://doi.org/10.1016/j.jclepro.2020.122919

[68]. José Rodríguez, M., & Guzmán, C. (2013). Innovation in social economy firms. *Management Decision*, *51*(5), 986–998. https://doi.org/10.1108/MD-08-2012-0538

[69]. Junaid, M., Zhang, Q., Cao, M., & Luqman, A. (2023). Nexus between technology enabled supply chain dynamic capabilities, integration, resilience, and sustainable

performance: An empirical examination of healthcare organizations. *Technological Forecasting and Social Change*, *196*, 122828. https://doi.org/10.1016/j.techfore.2023.122828

[70]. Jung, D. H. (2022). Enhancing Competitive Capabilities of Healthcare SCM through the Blockchain: Big Data Business Model's Viewpoint. *Sustainability*, *14*(8), 4815. https://doi.org/10.3390/su14084815

[71]. Kanokphanvanich, C., Rattanawong, W., & Vongmanee, V. (2023). A New Model for a Sustainable Healthcare Supply Chain Prioritizes Patient Safety: Using the Fuzzy Delphi Method to Identify Healthcare Workers' Perspectives. *Sustainability*, *15*(9), 7123. https://doi.org/10.3390/su15097123

[72]. Kar, S., Mohanty, M. K., & Thakurta, P. K. G. (2024). Efficient healthcare supply chain: A prioritized multi-task learning approach with task-specific regularization. *Engineering Applications of Artificial Intelligence*, *133*, 108249. https://doi.org/10.1016/j.engappai.2024.108249

[73]. Karim, R. A., Kawser, S., Rabiul, M. K., Chowdhury, T., & Murtaza, F. N. Y. (2024). Green supply chain management practices and environmental performance in the healthcare sector: the mediating role of green innovation. *Global Knowledge, Memory and Communication*. https://doi.org/10.1108/GKMC-10-2023-0407

[74]. Kees, M. C., Bandoni, J. A., & Moreno, M. S. (2022). A multi-period fuzzy optimization strategy for managing a centralized blood supply chain. *Socio-Economic Planning Sciences*, *84*, 101346. https://doi.org/10.1016/j.seps.2022.101346

[75]. Kelle, P., Woosley, J., & Schneider, H. (2012). Pharmaceutical supply chain specifics and inventory solutions for a hospital case. *Operations Research for Health Care*, *1*(2–3), 54–63. https://doi.org/10.1016/j.orhc.2012.07.001

[76]. Khlie, K., Serrou, D., & Abouabdellah, A. (2016). The impact of Lean-logistics and the information system on the information flow management within the healthcare supply chain. In *2016 11th International Conference on Intelligent Systems: Theories and Applications (SITA)* (pp. 1–5). Mohammedia, Morocco: IEEE. https://doi.org/10.1109/SITA.2016.7772315

[77]. Kholaif, M. M. N. H. K., Xiao, M., & Tang, X. (2024). Opportunities Presented by COVID-19 for Healthcare Green Supply Chain Management and Sustainability Performance: The Moderating Effect of Social Media Usage. *IEEE Transactions on Engineering Management*, *71*, 4441–4454. https://doi.org/10.1109/TEM.2023.3239504

[78]. Khorasani, S. T., Cross, J., & Maghazei, O. (2020). Lean supply chain management in healthcare: a systematic review and meta-study. *International Journal of Lean Six Sigma*, *11*(1), 1–34. https://doi.org/10.1108/IJLSS-07-2018-0069

[79]. Khosravi, F., & Izbirak, G. (2019). A stakeholder perspective of social sustainability measurement in healthcare supply chain management. *Sustainable Cities and Society*, *50*, 101681. https://doi.org/10.1016/j.scs.2019.101681

[80]. Kumar, M. S., Raut, D. R. D., Narwane, D. V. S., & Narkhede, D. B. E. (2020). Applications of industry 4.0 to overcome the COVID-19 operational challenges. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *14*(5), 1283–1289. https://doi.org/10.1016/j.dsx.2020.07.010

[81]. Kwon, I.-W. G., Kim, S.-H., & Martin, D. G. (2016). Healthcare supply chain management; strategic areas for quality and financial improvement. *Technological Forecasting and Social Change*, *113*, 422–428. https://doi.org/10.1016/j.techfore.2016.07.014

[82]. Laganà, I. R., & Colapinto, C. (2022). Multiple criteria decision-making in healthcare and pharmaceutical supply chain management: A state-of-the-art review and implications for future research. *Journal of Multi-Criteria Decision Analysis*, *29*(1–2), 122–134. https://doi.org/10.1002/mcda.1778

[83]. Leal Filho, W., Luetz, J. M., Thanekar, U. D., Dinis, M. A. P., & Forrester, M. (2024). Climate-friendly healthcare: reducing the impacts of the healthcare sector on the world's climate. *Sustainability Science*, *19*(3), 1103–1109. https://doi.org/10.1007/s11625-024-01487-5

[84]. Lee, S. M., Lee, D., & Schniederjans, M. J. (2011). Supply chain innovation and organizational performance in the healthcare industry. *International Journal of Operations & Production Management*, *31*(11), 1193–1214. https://doi.org/10.1108/01443571111178493

[85]. Leksono, E. B., Suparno, S., & Vanany, I. (2019). Integration of a Balanced Scorecard, DEMATEL, and ANP for Measuring the Performance of a Sustainable Healthcare Supply Chain. *Sustainability*, *11*(13), 3626. https://doi.org/10.3390/su11133626

[86]. Li, X., & Martins, A. L. (2024). Leagility in the healthcare research: a systematic review. *BMC Health Services Research*, *24*(1), 307. https://doi.org/10.1186/s12913-024-10771-0

[87]. Lima, R. M., Dinis-Carvalho, J., Souza, T. A., Vieira, E., & Gonçalves, B. (2021). Implementation of lean in health care environments: an update of systematic reviews. *International Journal of Lean Six Sigma*, *12*(2), 399–431. https://doi.org/10.1108/IJLSS-07-2019-0074

[88]. Luque González, A., Coronado Martín, J. Á., Vaca-Tapia, A. C., & Rivas, F. (2021). How Sustainability Is Defined: An Analysis of 100 Theoretical Approximations. *Mathematics*, *9*(11), 1308. https://doi.org/10.3390/math9111308

[89]. Mahjoob, A., Alfadhli, Y., & Omachonu, V. (2023). Healthcare Waste and Sustainability: Implications for a Circular Economy. *Sustainability*, *15*(10), 7788. https://doi.org/10.3390/su15107788

[90]. Man, L. C., Lin, Y., Pang, G., Sanderson, J., & Duan, K. (2024). Digitalization to achieve greener healthcare supply chain. *Journal of Cleaner Production*, *463*, 142802. https://doi.org/10.1016/j.jclepro.2024.142802

[91]. Manoharan, S., A, S., & K, M. (2023). Study of sustainable supply chain management in the healthcare industry. In *Proceedings of the 2023 6th International Conference on Information Management and Management Science* (pp. 308–314). Chengdu China: ACM. https://doi.org/10.1145/3625469.3625480

[92]. Martin, L., & Cobigo, V. (2011). Definitions Matter in Understanding Social Inclusion. *Journal of Policy and Practice in Intellectual Disabilities*, *8*(4), 276–282. https://doi.org/10.1111/j.1741-1130.2011.00316.x

[93]. Mathur, B., Gupta, S., Meena, M. L., & Dangayach, G. S. (2018). Healthcare supply chain management: literature review and some issues. *Journal of Advances in Management Research*, *15*(3), 265–287. https://doi.org/10.1108/JAMR-09-2017-0090

[94]. McDermott, O., Antony, J., Bhat, S., Jayaraman, R., Rosa, A., Marolla, G., & Parida, R. (2022). Lean Six Sigma in Healthcare: A Systematic Literature Review on Motivations and Benefits. *Processes*, *10*(10), 1910. https://doi.org/10.3390/pr10101910

[95]. Moldan, B., Janoušková, S., & Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, *17*, 4–13. https://doi.org/10.1016/j.ecolind.2011.04.033

[96]. Montesinos, L., Checa Rifá, P., Rifá Fabregat, M., Maldonado-Romo, J., Capacci, S., Maccaro, A., & Piaggio, D. (2024). Sustainability across the Medical Device Lifecycle: A Scoping Review. *Sustainability*, *16*(4), 1433. https://doi.org/10.3390/su16041433

[97]. Moore, J. E., Mascarenhas, A., Bain, J., & Straus, S. E. (2017). Developing a comprehensive definition of sustainability. *Implementation Science*, *12*(1), 110. https://doi.org/10.1186/s13012-017-0637-1

[98]. Mostepaniuk, A., Akalin, T., & Parish, M. R. (2023). Practices Pursuing the Sustainability of A Healthcare Organization: A Systematic Review. *Sustainability*, *15*(3), 2353. https://doi.org/10.3390/su15032353

[99]. Nartey, E. (2024). Management accounting and control, supply chain resilience and healthcare performance under disruptive impact. *International Journal of Productivity and Performance Management*, *73*(6), 1948–1969. https://doi.org/10.1108/IJPPM-01-2023-0009

[100]. Nsikan, J., Affiah, E. A., Briggs, I., & Koko, N. (2022). Sustainable supplier selection factors and supply chain performance in the Nigerian healthcare industry. *Journal of Transport and Supply Chain Management*, *16*. https://doi.org/10.4102/jtscm.v16i0.633

[101]. Pathy, S. R., & Rahimian, H. (2023). A resilient inventory management of pharmaceutical supply chains under demand disruption. *Computers & Industrial Engineering*, *180*, 109243. https://doi.org/10.1016/j.cie.2023.109243

[102]. Paul-Eric, D., Rafael, P., Cristiane, S., & Joao, C. J. (2020). How to use lean manufacturing for improving a Healthcare logistics performance. *Procedia Manufacturing*, *51*, 1657–1664. https://doi.org/10.1016/j.promfg.2020.10.231

[103]. Perroni, M. G., Da Veiga, C. P., Su, Z., Ramos, F. M., & Da Silva, W. V. (2023). Dynamic Equilibrium of Sustainable Ecosystem Variables: An Experiment. *Sustainability*, *15*(8), 6744. https://doi.org/10.3390/su15086744

[104]. Pesqueira, A., Sousa, M. J., & Pereira, R. (2023). Individual Dynamic Capabilities Influential Factors in Blockchain Technology Innovation from Hospital Settings. *WSEAS TRANSACTIONS ON BIOLOGY AND BIOMEDICINE*, *20*, 275–294. https://doi.org/10.37394/23208.2023.20.29

[105]. Petrov, T. (2023). Social Inequility and Sustainable Development. In *2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA)* (pp. 1–3). Varna, Bulgaria: IEEE. https://doi.org/10.1109/ELMA58392.2023.10202527

[106]. Pollock, A., & Berge, E. (2018). How to do a systematic review. *International Journal of Stroke*, *13*(2), 138–156. https://doi.org/10.1177/1747493017743796

[107]. Quarter, J., & Mook, L. (2010). An Interactive View of the Social Economy. *Canadian journal of nonprofit and social economy research*, *1*(1). https://doi.org/10.22230/cjnser.2010v1n1a4

[108]. Rahman, T., & Paul, S. K. (2023). Evaluating Environmental Sustainability Performance in Healthcare Supply Chains Under Demand Surges. In *2023 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 0426–0430). Singapore, Singapore: IEEE. https://doi.org/10.1109/IEEM58616.2023.10406760

[109]. Ramires, F., & Sampaio, P. (2022). Process mining and lean six sigma: a novel approach to analyze the supply chain quality of a hospital. *International Journal of Lean Six Sigma*, *13*(3), 594–621. https://doi.org/10.1108/IJLSS-12-2020-0226

[110]. Redhead, D. (2025). Social structure and the evolutionary ecology of inequality. *Trends in Cognitive Sciences*, *29*(2), 201–213. https://doi.org/10.1016/j.tics.2024.10.013

[111]. Regattieri, A., Bartolini, A., Cima, M., Fanti, M. G., & Lauritano, D. (2018). An innovative procedure for introducing the lean concept into the internal drug supply chain of a hospital. *The TQM Journal*, *30*(6), 717–731. https://doi.org/10.1108/TQM-03-2018-0039

[112]. Rehman, O. U., & Ali, Y. (2022). Enhancing healthcare supply chain resilience: decision-making in a fuzzy environment. *The International Journal of Logistics Management*, *33*(2), 520–546. https://doi.org/10.1108/IJLM-01-2021-0004

[113]. Romdhani, S., Nouaouri, I., Tounsi, J., Gattoufi, S., & Allaoui, H. (2022). Two-echelon Inventory Management for Sustainable Pharmaceutical Supply Chain through Waste Reduction. *IFAC-PapersOnLine*, *55*(10), 1380–1385. https://doi.org/10.1016/j.ifacol.2022.09.583

[114]. Roostaie, S., Nawari, N., & Kibert, C. J. (2019). Sustainability and resilience: A review of definitions, relationships, and their integration into a combined building assessment framework. *Building and Environment*, *154*, 132–144. https://doi.org/10.1016/j.buildenv.2019.02.042

[115]. Ruggerio, C. A. (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of The Total Environment*, *786*, 147481. https://doi.org/10.1016/j.scitotenv.2021.147481

[116]. Samah, M., Salah, O., & El Farouk Imane, I. (2022). A Literature Review on Sustainable Supply chain Management and its Impact on Sustainable Performance. In *2022 14th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA)* (pp. 1–8). EL JADIDA, Morocco: IEEE. https://doi.org/10.1109/LOGISTIQUA55056.2022.9938032

[117]. Sazvar, Z., Zokaee, M., Tavakkoli-Moghaddam, R., Salari, S. A., & Nayeri, S. (2022a). Designing a sustainable closed-loop pharmaceutical supply chain in a competitive market considering demand uncertainty, manufacturer's brand and waste management. *Annals of Operations Research*, *315*(2), 2057–2088. https://doi.org/10.1007/s10479-021-03961-0

[118]. Sazvar, Z., Zokaee, M., Tavakkoli-Moghaddam, R., Salari, S. A., & Nayeri, S. (2022b). Designing a sustainable closed-loop pharmaceutical supply chain in a competitive market considering demand uncertainty, manufacturer's brand and waste management. *Annals of Operations Research*, *315*(2), 2057–2088. https://doi.org/10.1007/s10479-021-03961-0

[119]. Scavarda, A., Daú, G. L., Scavarda, L. F., & Korzenowski, A. L. (2019). A proposed healthcare supply chain management framework in the emerging economies with the sustainable lenses: The theory, the practice, and the policy. *Resources, Conservation and Recycling*, *141*, 418–430. https://doi.org/10.1016/j.resconrec.2018.10.027

[120]. Schutte, C., Niemann, W., & Kotzé, T. (2022). EXPLORING RELATIONSHIP POWER IN SUPPLY CHAIN SUSTAINABILITY PRACTICES: A CASE STUDY OF A SOUTH AFRICAN HOSPITAL GROUP. *South African Journal of Industrial Engineering*, *33*(1). https://doi.org/10.7166/33-1-2209

[121]. Shahzad, M. F., Yuan, J., Shahzad, K., & Huang, Y. (2024). Drivers of green consumption: Ethical ideologies and corporate social responsibility in sustainability awareness. *Sustainable Development*, sd.3238. https://doi.org/10.1002/sd.3238

[122]. Sheykhizadeh, M., Ghasemi, R., Vandchali, H. R., Sepehri, A., & Torabi, S. A. (2024). A hybrid decision-making framework for a supplier selection problem based on lean, agile, resilience, and green criteria: a case study of a pharmaceutical industry. *Environment,*

Development and Sustainability, *26*(12), 30969–30996. https://doi.org/10.1007/s10668-023-04135-7

[123]. Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. *Annual Review of Psychology*, *70*(1), 747–770. https://doi.org/10.1146/annurev-psych-010418-102803

[124]. Singh, P. (2019). Lean in healthcare organization: an opportunity for environmental sustainability. *Benchmarking: An International Journal*, *26*(1), 205–220. https://doi.org/10.1108/BIJ-04-2018-0104

[125]. Stukalo, N., & Simakhova, A. (2018). Global parameters of social economy clustering. *Problems and Perspectives in Management*, *16*(1), 36–47. https://doi.org/10.21511/ppm.16(1).2018.04

[126]. Suhandi, V., & Chen, P.-S. (2023). Closed-loop supply chain inventory model in the pharmaceutical industry toward a circular economy. *Journal of Cleaner Production*, *383*, 135474. https://doi.org/10.1016/j.jclepro.2022.135474

[127]. Suthagar, K. S., & Mishra, U. (2024). Sustainable green circular economic model with controllable waste and emission in healthcare system. *Environment, Development and Sustainability*, *27*(4), 8767–8809. https://doi.org/10.1007/s10668-023-04254-1

[128]. Trendova, K., Nkasu, M. M., Alghamdi, A., & Iqbal, S. (2022). Logistical Challenges of Waste Management Within the Abu Dhabi Healthcare System. In *2022 Advances in Science and Engineering Technology International Conferences (ASET)* (pp. 1–6). Dubai, United Arab Emirates: IEEE. https://doi.org/10.1109/ASET53988.2022.9734958

[129]. Tritos, L., Premaratne, S., & Dotun, A. (2013). Prioritizing lean supply chain management initiatives in healthcare service operations: A Fuzzy-AHP approach. In *2013 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 236–242). Bangkok, Thailand: IEEE. https://doi.org/10.1109/IEEM.2013.6962410

[130]. Ukko, J., Saunila, M., Rantala, T., & Havukainen, J. (2019). Sustainable development: Implications and definition for open sustainability. *Sustainable Development*, *27*(3), 321–336. https://doi.org/10.1002/sd.1904

[131]. Van Straten, B., Dankelman, J., Van Der Eijk, A., & Horeman, T. (2021). A Circular Healthcare Economy; a feasibility study to reduce surgical stainless steel waste. *Sustainable Production and Consumption*, *27*, 169–175. https://doi.org/10.1016/j.spc.2020.10.030

[132]. Vea, E. B., Ryberg, M., Richardson, K., & Z Hauschild, M. (2020). Framework to define environmental sustainability boundaries and a review of current approaches. *Environmental Research Letters*, *15*(10), 103003. https://doi.org/10.1088/1748-9326/abac77

[133]. Viegas, C. V., Bond, A., Vaz, C. R., & Bertolo, R. J. (2019). Reverse flows within the pharmaceutical supply chain: A classificatory review from the perspective of end-of-use and end-of-life medicines. *Journal of Cleaner Production*, *238*, 117719. https://doi.org/10.1016/j.jclepro.2019.117719

[134]. Vishwakarma, A., Dangayach, G. S., Meena, M. L., Gupta, S., Joshi, D., & Jagtap, S. (2024). Can circular healthcare economy be achieved through implementation of sustainable healthcare supply chain practices? Empirical evidence from Indian healthcare sector. *Journal of Global Operations and Strategic Sourcing*, *17*(2), 230–246. https://doi.org/10.1108/JGOSS-07-2022-0084

[135]. Vishwakarma, A., Dangayach, G. S., Meena, M. L., Gupta, S., & Luthra, S. (2023). Adoption of blockchain technology enabled healthcare sustainable supply chain to improve healthcare supply chain performance. *Management of Environmental Quality: An International Journal*, *34*(4), 1111–1128. https://doi.org/10.1108/MEQ-02-2022-0025

[136]. Vogt, M., & Weber, C. (2019). Current challenges to the concept of sustainability. *Global Sustainability*, *2*, e4. https://doi.org/10.1017/sus.2019.1

[137]. Vos, R. O. (2007). Defining sustainability: a conceptual orientation. *Journal of Chemical Technology & Biotechnology*, *82*(4), 334–339. https://doi.org/10.1002/jctb.1675

[138]. Voudrias, E. A. (2018). Healthcare waste management from the point of view of circular economy. *Waste Management*, *75*, 1–2. https://doi.org/10.1016/j.wasman.2018.04.020

[139]. Wang, Z., Huang, L., & He, C. X. (2021). A multi-objective and multi-period optimization model for urban healthcare waste's reverse logistics network design. *Journal of Combinatorial Optimization*, *42*(4), 785–812. https://doi.org/10.1007/s10878-019-00499-7

[140]. Wu, Y. J., Wu, T., & Arno Sharpe, J. (2020). Consensus on the definition of social entrepreneurship: a content analysis approach. *Management Decision*, *58*(12), 2593–2619. https://doi.org/10.1108/MD-11-2016-0791

[141]. Yuksek, Y. A., Afy-Shararah, M., & Salonitis, K. (2023). Data-Driven Environmental Sustainability of Supply Chain for Medical Equipment. *Procedia CIRP*, *120*, 1238–1243. https://doi.org/10.1016/j.procir.2023.09.155

[142]. Zhao, H., Zhou, H., Yuan, C., Huang, Y., & Chen, J. (2015). Social Discovery: Exploring the Correlation Among Three-Dimensional Social Relationships. *IEEE Transactions on Computational Social Systems*, *2*(3), 77–87. https://doi.org/10.1109/TCSS.2016.2517092

[143]. Андреева, Г. М., & Леонтьев, А. Н. (2018). Methodological Problems in the Study of the Psychological Aspects of Social Change. *Психология Журнал Высшей школы экономики*, *15*(4), 646–654. https://doi.org/10.17323/1813-8918-2018-4-646-654

List of visited websites

[1] https://www.farmacista33.it/archivio-news/14142/farmaci-falsi-o-scadenti-oms-1-su-10-nei-paesi-in-via-di-sviluppo.html

[2] https://www.unido.org/our-focus-advancing-economic-competitiveness-competitive-trade-capacities-and-corporate-responsibility-corporate-social-responsibility-market-integration/what-csr#:~:text=Corporate%20Social%20Responsibility%20is%20a,and%20interactions%20with%20their%20stakeholders

[3] https://www.elsevier.com/products/scopus

List of acronyms

AI	Artificial Intelligence
ESG	Environmental, Social and Governance
GHG	Greenhouse Gas
HSC	Healthcare Supply Chain
HSCM	Healthcare Supply Chain Management
IoT	Internet of Things
JIT	Just in Time
KPI	Key Performance Indicator
NGO	Non Governmental Organization
PPE	Personal Protective Equipment
RFID	Radio Frequency Identification
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SDG	Sustainable Development Goals
SEM	Structural Equation Modeling
SLR	Systematic Literature Review
TBL	Triple Bottom Line
WHO	World Health Organization

Appendix

Specific topics	**Key topic**
Supply Chain Flexibility and Efficiency	**Integration of Lean and Agile approaches**: using hybrid strategies to improve responsiveness and reduce waste in the supply chain.
	Bottleneck reduction and process optimization: Identifying and mitigating bottlenecks in distribution flows.
	Decentralized and resilient supply chains: Implementing decentralized processes to enhance adaptability during crises or demand fluctuations.
	Enhanced coordination and supplier collaboration: Improving communication among supply chain actors to reduce delays and inefficiencies.
Inventory Management	**Optimized stock replenishment strategies:** Adopting optimized replenishment strategies to balance supply and demand.
	Integration of digital tools for stock tracking: Utilizing technologies like blockchain and IoT to track and manage inventory in real-time.
	Reduction of expired and overstocked items: Implementing stock rotation methodologies to minimize waste and obsolescence.
	Lean and agile inventory practices: Applying lean inventory management models to minimize unnecessary stock and improve operational efficiency**.**
Risk Mitigation and Resilience	**Real-time monitoring and predictive analytics**: Using AI-driven models and IoT sensors for real-time risk detection and crisis adaptation.
	Supplier diversification for supply chain security: Increasing resilience by reducing reliance on single suppliers.
	Disaster preparedness and contingency planning: Developing emergency plans to address sudden disruptions in the supply chain.
	Closed-loop processes for risk reduction: Implementing systems like reverse logistics for product recollection and reuse to enhance resilience.
Green Logistics and Sustainability	**Reverse logistics for medical waste and expired products:** Implementing reverse logistics strategies, such as recollection and sterilization of single-use medical devices for reuse, to manage waste and obsolete products.
	Circular economy in healthcare supply chains: Adopting circular economy principles, such as refurbishing medical equipment and reprocessing surgical instruments, to reuse and reduce waste.

	Decarbonization strategies in supply chains: Optimizing transportation networks to reduce greenhouse gas emissions.
	Integration of sustainable procurement and resource efficiency: Using sustainable materials, such as biopolymers for medical packaging, and optimizing resources to reduce environmental impact.
Technology and Digital Transformation	**Blockchain for real-time tracking and counterfeit prevention:** Using blockchain to improve security and transparency in the supply chain.
	IoT and smart logistics for real-time visibility: Implementing IoT devices to monitor transport conditions and inventory in real-time.
	AI-powered predictive maintenance for medical equipment: Using artificial intelligence to reduce medical equipment downtime.
	Industry 4.0 technologies for enhanced supply chain visibility: Applying advanced tools to improve management and supply chain efficiency.
Waste Management	**Standardized protocols for waste segregation and disposal:** Optimizing waste management through standardized protocols.
	Integration of IoT for smart waste tracking: Using IoT devices for real-time monitoring of hospital waste.
	Reverse logistics for medical waste processing: Implementing reverse logistics strategies for safe and sustainable medical waste management.
	Circular economy for waste reduction: Applying circular economy models, such as recycling single-use medical plastics into new healthcare products, to reduce waste and increase material reuse.
Performance Optimization	**Lean Six Sigma and process improvement:** Applying LSS methodologies to improve operational efficiency and reduce cycle times.
	Discrete event simulation for performance testing: Using simulations to test recovery policies in case of disruptions.
	Automation and AI-driven workflow optimization: Implementing artificial intelligence and automation to reduce costs and improve productivity.
	Standardization of procurement and distribution: Optimizing procurement processes to reduce delivery times and enhance service quality.
Decision Support Tools	**Predictive analytics for demand forecasting** : Using predictive analytics tools to improve demand and supply management.
	Multi-criteria Decision Making (MCDM) for supplier selection: Applying decision-making models to optimize supplier selection.

	Simulation-based optimization for logistics and inventory management: Using advanced simulations to optimize logistics management.
	Balanced scorecard for healthcare supply chain performance: Implementing KPIs to monitor and improve healthcare supply chain performance.
	Predictive analytics for demand forecasting: Using predictive analytics tools to improve demand and supply management.

Table 8: key topic related to operational topic (first research question)

Specific topics	Key topic
Transportation and Distribution Costs	**Optimization of transport routes:** Reducing costs through AI-driven route planning and vehicle scheduling.
	Multi-modal transportation for cost efficiency: Combining air, road, and rail to minimize distribution expenses.
	Decentralized facility location planning: Strategically positioning warehouses to lower fuel and transit costs.
Inventory Costs	**Stock optimization through digital tools:** AI-driven forecasting to reduce overstocking and stockouts.
	Centralized inventory management: Consolidating storage facilities to lower holding costs.
Procurement Costs	**Supplier selection for cost efficiency:** Choosing vendors based on total cost, reliability, and sustainability.
	Bulk purchasing agreements: Negotiating long-term contracts to stabilize procurement expenses.
	Reverse logistics for procurement savings: Recovering and redistributing surplus stock to cut purchasing costs.
	Reduction of emergency procurement costs: Predictive demand planning to minimize last-minute stock purchases.
Production and Operational Costs	**Lean manufacturing for cost efficiency:** Applying lean principles to eliminate waste and inefficiencies.
	Automated systems for cost reduction: Implementing robotics and AI to optimize production costs, especially in the assembly of surgical instruments, pharmaceutical packaging, and diagnostic equipment.
	Energy-efficient operations: Using renewable energy and smart grids to reduce long-term expenses.
	Green procurement strategies: Sourcing eco-friendly materials at competitive prices.
Cost Optimization via Sustainable Practices	**Waste reduction for cost savings:** Lowering waste disposal costs through recycling and circular economy models, including the recovery of medical plastics, single-use surgical instruments, and pharmaceutical packaging.
Financial Performance and Competitive Advantage	**Cost reduction through supply chain optimization:**Using data-driven insights, such as AI-powered demand forecasting and real-time inventory tracking, to enhance financial sustainability.

	Reduction of compliance and regulatory costs: Avoiding fines through better supply chain governance.
	Revenue generation from circular economy practices: Selling refurbished and recycled materials, such as reprocessed medical plastics, stainless steel surgical tools, and recovered electronic components. Companies in the medical device reprocessing and pharmaceutical waste management sectors are typically involved.
	Improved financial sustainability through resilience strategies: Balancing cost efficiency with disruption management.
Digitalization and Advanced Technologies for Cost Savings	**Blockchain for secure and efficient transactions:** Reducing fraud and inefficiencies in procurement.
	AI-driven demand forecasting: Enhancing procurement accuracy and minimizing waste.
	Automation in warehousing and inventory: Cutting labor and operational expenses through robotics.

Table 9: key topic related to economic topic (first research question)

Specific topics	**Key topic**
GHG Emissions Reduction	**Optimized transport logistics:** Reduction of CO_2 emissions through AI-driven route planning.
	Renewable energy adoption: Use of solar panels, wind energy, and biofuels in supply chain operations.
	Decarbonization strategies: Reduction of Scope 1, 2, and 3 emissions via sustainable practices.
Procurement Costs	**Medical waste recycling:** Recovery and reuse of materials from medical devices and pharmaceuticals.
	Reverse logistics for circularity: Collection, refurbishing, and redistribution of medical equipment.
	Integration of eco-innovative materials: Use of recycled plastics, biodegradable components, and sustainable packaging.
Waste Reduction	**Minimizing waste through better stock rotation**: Reducing material waste by optimizing inventory management and avoiding product obsolescence.
	Reduction of medical waste through reuse, remanufacturing, and recycling initiatives: Extending the lifecycle of healthcare equipment and supplies to minimize waste generation.
	Reduction of waste through accurate forecasting and allocation of medical resources: Preventing excess production and unnecessary stock by improving demand planning.
	Lean practices contribute to waste reduction: Implementing lean methodologies to eliminate

	inefficiencies in the healthcare supply chain and reduce resource wastage.
Green Procurement	**Supplier selection based on environmental standards:** Prioritization of ISO 14001-certified vendors.
	Eco-friendly material sourcing: Preference for biodegradable and recyclable raw materials for the production of medical devices, pharmaceutical packaging, and hospital supplies. This includes using plant-based bioplastics for syringes, recycled polymers for protective equipment, and compostable materials for single-use items to reduce environmental impact.
	Sustainable packaging solutions: Minimization of non-recyclable plastics and excess packaging.
	Promotes green procurement by prioritizing eco-certified suppliers and sustainable materials: Encouraging the selection of environmentally responsible vendors and products.
Integration of Digital Technologies for Sustainability	**Big Data for sustainability optimization:** AI-driven resource efficiency and waste reduction.
	IoT-enabled waste tracking: Smart monitoring for better segregation and disposal of medical waste.
	Blockchain for green supply chains: Ensuring transparency in sustainable sourcing and emissions reporting.
Hazardous materials reduction	**Minimization of hazardous waste**: Reduction of toxic and infectious waste through safe disposal and recycling methods
	Prevention of contamination: Proper treatment of pharmaceutical and healthcare waste, including expired medications, chemical byproducts, and infectious materials, to prevent soil and water pollution. This includes implementing advanced filtration systems, controlled incineration, and safe disposal protocols to mitigate environmental risks.
	Reduction of hazardous chemicals: Transition towards safer, eco-friendly materials in medical supply chains
Renewable energy integration	**Solar-powered medical devices**: Use of solar-powered oximeters and diagnostic tools to reduce reliance on fossil fuels
	Renewable energy adoption in healthcare logistics: Integration of solar, wind, and biomass energy in transportation and facility operations
	Green energy in supply chain: Decarbonization efforts through renewable energy-powered production and storage systems
Regulatory and Compliance Strategies	**Environmental compliance standards**: Adoption of ISO 14001 and other green certifications in supplier selection

	Regulatory adherence for waste management: Implementation of strict guidelines for hazardous medical waste disposal
	Sustainability policies in procurement: Supplier selection based on eco-friendly standards and waste minimization practices

Table 10: key topic related to environmental topic (first research question)

Specific topics	**Key topic**
Healthcare accessibility	**Enhanced access to healthcare technologies through frugal engineering**: Developing low-cost medical devices like pupillometers and ReMotion Knee prostheses for underserved regions.
	Equitable distribution of medical resources: Strategic placement of healthcare facilities and donation programs to ensure accessibility for marginalized populations
	Emergency healthcare support: Establishment of efficient blood supply networks and optimized distribution of life-saving medicines
	Enhanced healthcare service delivery in rural areas: Strengthening medical supply chains to ensure timely delivery of critical healthcare products.
Job creation	**Employment opportunities in healthcare logistics**: Creation of jobs through the establishment of new facilities, including production sites and recycling centers
	Sustainable job growth: Green logistics and waste management hubs generating employment in circular economy initiatives
	Workforce development through healthcare sustainability: Training programs in recycling, reverse logistics, and remanufacturing processes
	Involves local cooperatives in recycling activities: Generating jobs by integrating community-based organizations into waste management efforts.
Increased community welfare	**Healthier communities through sustainable healthcare**: Implementation of eco-friendly healthcare practices to reduce environmental risks and improve public health
	Strategic location of disposal sites: Placement of waste management facilities away from densely populated areas to minimize health hazards
	Community engagement in sustainability: Inclusion of local cooperatives in recycling and waste management projects
Increased public health	**Reduction of health risks from hazardous waste**: Implementation of safer disposal and recycling practices for medical waste

	Improved safety through green healthcare services: Sustainable healthcare supply chains reducing exposure to harmful materials
	Strengthening healthcare infrastructure: Investment in facilities and logistics systems to improve public health responses
	Reduction of health risks from hazardous waste: Implementation of safer disposal and recycling practices for medical waste
Increased employee welfare	**Enhanced workplace safety**: Reduction of worker fatigue through optimized task sequencing and ergonomic designs
	Healthcare and well-being initiatives: Promotion of health-focused workplace policies and employee assistance programs
	Fair working conditions: Implementation of structured welfare programs to ensure equitable treatment of employees
	Reducing workload inefficiencies through lean practices: Minimizing administrative burdens and optimizing workflows to improve job satisfaction.
Community engagement	**Educational initiatives for sustainability**: Training programs for employees and local communities on waste management and energy efficiency in the healthcare supply chain. These initiatives focus on optimizing resource use, reducing medical waste through proper segregation and recycling, and promoting energy-saving practices in hospital operations and logistics.
	Collaboration with local institutions: Engagement with non-profits, educational organizations, and government agencies for public health awareness campaigns
	Strengthening engagement with local stakeholders: Collaborating with health organizations, non-profits, and government agencies to promote social sustainability.

Table 11: key topic related to social topic (first research question)

Specific topics	**Key topic**
Inventory Management Improvements	**Stock rotation improvement**: Implemented better stock rotation to reduce expired products and optimize resource utilization.
	Kanban implementation: Adopted Kanban for real-time inventory tracking to minimize overproduction and understocking.
	Vendor Managed Inventory (VMI): Used VMI to align stock levels with demand, preventing excess accumulation.
	Cross-docking: Reduced storage time and accelerated distribution by streamlining inventory flow.

Demand Planning Improvements	**Advanced forecasting techniques**: Implemented data-driven forecasting to align supply with demand and reduce waste.
	Improved demand accuracy: Applied analytical models to enhance demand precision and prevent stock fluctuations.
Procurement Improvements	**Optimized supplier communication**: Improved supplier engagement to reduce unnecessary administrative tasks.
	Purchase order consolidation: Combined multiple product requests into fewer purchase orders to streamline procurement.
Distribution Improvements	**Cold chain logistics enhancement**: Improved cold storage processes to reduce spoilage and ensure product quality.
	Procurement and delivery optimization: Used real-time data tracking and lean tools to minimize inefficiencies.
	Direct shipment implementation: Reduced unnecessary product movements by shipping directly from warehouses to testing labs.
Standardization Practices	**Lean process streamlining**: Implemented standardized workflows to reduce delays and improve response times.
	Use of Value Stream Mapping (VSM) to identify bottlenecks: Standardizes processes by mapping each stage of the supply chain, identifying inefficiencies, and ensuring a uniform and replicable workflow.
	Application of lean tools for process optimization: Techniques such as Just-In-Time (JIT) and flow management contribute to standardization by eliminating variability in production and distribution times, ensuring predictable and consistent flows.
	System-wide adoption of Lean Thinking (LT) principles: Large-scale implementation of Lean Thinking ensures that operational procedures remain uniform across departments, preventing the transfer of inefficiencies and promoting structured, repeatable management practices.
Technology and Automation Enhancements	**Hospital Information Systems (HIS) integration**: Implemented HIS for real-time updates and improved data accuracy.
	Automated logistics solutions: Used intelligent conveyor and Automated Intelligent Vehicles (AIVs) to optimize storage and transportation.

Table 12: key topic related to Defined actions to reduce or eliminate wastes (second research question)

Specific topics	Key topic
Waste Reduction	**Minimization of unnecessary resources**: Reduced overuse of materials and streamlined procurement to lower waste levels.
	Reduction of redundant processes: Identified and eliminated inefficient steps in workflows to optimize performance.
	Optimization of material usage: Implemented better inventory and supply chain strategies to minimize excess materials.
Cost Efficiency	**Reduction of inventory costs**: Lowered stock expenses by implementing efficient inventory management techniques.
	Optimized operational expenses: Minimized financial waste by refining resource allocation and procurement strategies.
	Higher financial outcomes: Achieved cost savings that improved overall profitability and budget management.
	Minimization of errors-related costs: Reduced expenses associated with inaccurate data, procurement, and logistics.
Supply Chain and Logistics Optimization	**Faster delivery of medical supplies**: Implemented logistics strategies to accelerate supply distribution.
	Improved supply chain visibility: Enhanced tracking and monitoring of inventory and procurement processes.
	Enhanced stock management practices: Applied automated inventory control to optimize stock levels.
	Reduction of unnecessary inventory levels: Minimized excess stock to prevent waste and improve efficiency.
Patient Service and Care Enhancement	**Reduced patient waiting times**: Accelerated admissions, diagnostics, and treatment to improve patient experience.
	Improved service levels for patients: Increased the quality and reliability of patient care services.
	Timely availability of medicines: Enhanced supply chain coordination to ensure critical medicine availability.
	Enhanced clinical quality and safety: Improved treatment standards and reduced the risk of errors in patient care.
Process Optimization and Workflow Improvements	**Enhanced operational efficiency**: Improved system workflows, reducing inefficiencies and increasing productivity.
	Reduction in lead times: Shortened process durations across healthcare and logistics operations.
	Streamlining of workflows: Eliminated bottlenecks and redundancies to improve overall process performance.
	Better resource allocation: Optimized staff, equipment, and material distribution for maximum efficiency.
Coordination and Employee Motivation	**Improved collaboration among hospital departments**: Strengthened interdepartmental communication to enhance workflows.

	Enhanced employee motivation: Increased staff engagement through better organizational structures and incentives.
	Better organization of work environment: Implemented lean workspace strategies for more effective task management.
	More effective resource utilization: Improved scheduling and role distribution to maximize employee productivity.

Table 13: key topic related to Achieved benefits of Lean application (second research question)

Specific topics	**Key topic**
Operational and Process-Related Challenges	**Lack of empirical validation**: The limited availability of real-world case studies and quantitative evidence restricts the applicability of lean models in diverse healthcare settings, making it difficult to assess their effectiveness and adaptability.
	High dependency on manual labor: Operational efficiency can become more variable when lean processes rely heavily on manual labor. For example, in the healthcare supply chain, excessive reliance on manual inventory management can lead to delays, stockouts, or misplacement of critical medical supplies, reducing the overall efficiency and responsiveness of the system.
	Difficult integration with sustainability goals: Aligning lean practices with environmental sustainability is complex. For example, reducing excess inventory in hospitals can lower waste but may conflict with eco-friendly procurement strategies that favor bulk purchasing to minimize packaging and transport emissions.
Conflicts Between Lean and Resilience Approaches	**Trade-off between waste reduction and resilience**: Lean minimizes waste, but reducing buffers can compromise the ability to respond to unexpected events.
	Increased vulnerability to disruptions: Without adequate resilience measures, lean systems can become more fragile during crises.
	Resistance to integrating resilience principles: The need to balance efficiency and redundancy often creates conflicts between different business strategies.
	Limited adaptability during severe disruptions: The reduction of buffers and safety stock can make it difficult to manage sudden emergencies.
Challenges in Implementation and Integration	**High complexity of implementation**: The correct application of lean requires high coordination and a systematic approach.
	Difficult standardization across facilities: The diversity of healthcare systems makes it challenging to implement uniform processes.

	Integration with healthcare supply chain: Poor compatibility between lean and current hospital supply chain management practices, such as centralized inventory management, just-in-time (JIT) procurement, vendor-managed inventory (VMI), and batch ordering. These traditional approaches often prioritize cost efficiency and bulk purchasing over lean principles of waste minimization and continuous flow.
	Dependence on stakeholder commitment: The success of lean implementation heavily depends on the active involvement of all relevant stakeholders.
Resistance to Change	**Cultural resistance to Lean implementation**: Employees tend to resist the structural changes imposed by lean practices.
	Lack of awareness or training: Resistance often stems from a lack of knowledge about lean methodologies.
	Discomfort with new workflows: Healthcare professionals may oppose modifications to established workflows.
	Dependence on employee training: Continuous training is essential but is often overlooked or undervalued.
High Costs and Resource Constraints	**High initial investment**: The initial costs of training and implementation can be prohibitive for many healthcare facilities.
	Limited adoption in resource-constrained settings: The adoption of lean is often challenging in environments with limited resources.
	Lack of skilled personnel: The shortage of qualified personnel reduces the long-term sustainability of lean practices.
Technological and Infrastructure Dependencies	**Reliance on robust IT infrastructure**: Implementing data-driven improvements, such as real-time monitoring and automated workflows, requires advanced digital systems and network capabilities.
	High dependency on technology for lean adoption: Tools like Hospital Information Systems (HIS), Enterprise Resource Planning (ERP), and digital inventory tracking are essential for integrating lean methodologies effectively.
	Challenges in digital transformation: Many healthcare facilities struggle with outdated IT infrastructure, limiting the adoption of automation, predictive analytics, and AI-driven decision-making.
	Integration barriers with existing systems: The successful implementation of lean often requires compatibility with current healthcare technologies, such as electronic health records (EHRs) and supply chain management software, which may not always align with lean principles.

Scalability and Standardization Issues	**Limited scalability in complex settings**: The applicability of lean is reduced in hospitals with complex structures and high interdependencies.
	Fragmented implementation across departments: The partial adoption of lean across different departments reduces its overall effectiveness.
	Lack of standardization in Lean Six Sigma: The absence of standardized practices limits the full potential of Lean Six Sigma.
	Challenges in adapting to hospital size variations: Differences in hospital sizes hinder the uniform integration of lean.

Table 14: key topic related to Limitations of Lean application (second research question)

Specific topics	**Key topic**
Employee Welfare and Ethical Standards	**Safe working environments**: Ensured workplace safety to protect employees' health and well-being, such as enforcing strict hygiene protocols in hospitals, providing adequate protective equipment for healthcare workers, and implementing ergonomic measures to reduce physical strain in medical facilities.
	Fair labor conditions: Implemented ethical labor practices in wages and working conditions, such as ensuring fair pay for nurses and hospital staff, enforcing regulated working hours to prevent burnout, and promoting equal opportunities regardless of gender or background.
	Human rights and ethics: Promoted human rights and social responsibility to support local communities, such as ensuring access to essential medicines in underserved areas, establishing ethical sourcing policies for medical supplies, and supporting healthcare initiatives that provide free or affordable treatments for vulnerable populations.
Community and Healthcare Access	**Enhanced healthcare access**: Improved healthcare services in underserved areas to reduce inequalities.
	Community engagement: Fostered local community involvement in healthcare and social initiatives, such as organizing free health screenings in rural areas, promoting vaccination awareness campaigns, and collaborating with local organizations to provide mental health support programs.
	Equitable access to medicines and resources: Ensured fair access to medicines and healthcare resources to minimize disparities.
Stakeholder Collaboration for Sustainability	**Cross-sector collaboration**: Encouraged cooperation among hospitals, suppliers, and public institutions to enhance sustainability.

	Improved transparency: Increased data sharing among stakeholders to build trust and supply chain efficiency.
	Ethical and environmental goals alignment: Ensured that stakeholders' objectives aligned with social and environmental sustainability.
	Systems-thinking approach: Integrated holistic strategies to address healthcare challenges with multi-stakeholder involvement.
Integration of Ethical and Social Dimensions in Supply Chains	**Ethical supplier relationships**: Applied ethical criteria in supplier selection and supply chain management.
	Social responsibility in sourcing: Incorporated social and ethical considerations into procurement decisions.
	Stakeholder inclusion in decision-making: Engaged patients, suppliers, employees, and governments in strategic decision-making.
Equitable Access to Medicines and Resources	**Health and safety prioritization**: Focused on ensuring workers' health and safety while improving equitable access to essential medicines.
	Stakeholder collaboration: Encouraged partnerships between healthcare providers, policymakers, and suppliers to enhance resource distribution.
	Minimization of expired medicine risks: Implemented strategies to reduce patients' exposure to expired or ineffective medications.
Circular Economy and Waste Management	**Shared sustainability goals**: Built a collaborative network among suppliers, manufacturers, and hospitals to reduce waste.
	Reverse logistics systems: Optimized donation and recycling processes to minimize environmental impact.
	Development of circular economy frameworks: Designed circular models to implement sustainable resource management in healthcare.
Strengthening Governance for Sustainability	**Collaborative culture**: Fostered a culture of continuous improvement and shared accountability among employees and management.
	Regulatory alignment: Ensured coordination between hospitals, businesses, and regulatory bodies to enhance sustainable governance.
	Sustainability frameworks in healthcare: Developed governance strategies to strengthen sustainability in healthcare systems.
Digital and Employee-Driven Sustainability Initiatives	**Integration of digital tools for sustainability:** Adoption of data-driven technologies and employee engagement strategies to enhance environmental and social sustainability in healthcare supply chains.

Table 15: key topic related to social models characteristics (third research question)

Specific topics	Key topic
TBL integration	**Triple Bottom Line (TBL) approach**: Balances economic, social, and environmental goals to drive sustainability in supply chain decisions.
	Sustainability pillars integration: Incorporates environmental, economic, and social dimensions into supply chain management.
	Equitable healthcare supply chains: Ensures fair access to essential medical resources in underserved areas.
Circular economy	**Waste reduction through recycling**: Promotes recycling and reuse of materials like metals, plastics, and medical waste.
	Closed-loop supply chain practices: Focuses on remanufacturing, reuse, and refurbishment of medical equipment and devices.
	Resource recovery strategies: Implements waste-to-energy technologies and upcycling initiatives to enhance environmental sustainability.
	4Rs framework (Reduce, Reuse, Recycle, Recover): Prioritizes resource efficiency and product lifecycle extension.
Green practices	**Eco-friendly materials and renewable energy**: Encourages the use of sustainable materials and clean energy sources such as solar and wind power.
	Waste minimization: Reduces packaging waste and optimizes inventory management to decrease environmental impact.
	Green logistics and procurement: Implements sustainable transportation, supplier selection, and production methods.
	Carbon footprint reduction: Focuses on minimizing emissions through energy-efficient systems and pollution control technologies.
Reverse Logistics	**Recovery of used medical equipment**: Implementing reverse logistics strategies to collect and refurbish medical devices, such as syringes and single-use surgical instruments, reducing waste and costs.
	Reintegration of pharmaceutical products: Managing the return and redistribution of unused or expired medications through proper disposal or repurposing initiatives.
	Sustainable waste management: Establishing reverse logistics networks for medical waste, including recycling processes for plastics and metals from medical disposables.
Sustainable Procurement	**Supplier certification programs**: Encourages sourcing from eco-friendly and ethical suppliers.

	Green procurement strategies: Integrates sustainability criteria into purchasing decisions to reduce environmental impact.
	Ethical sourcing: Ensures fair labor practices and minimizes the ecological footprint of procurement processes.
Technology Integration	**Circular economy transition with Industry 4.0**: Uses IoT, AI, and digital solutions to enhance sustainability in healthcare supply chains.
	Lifecycle analysis for impact assessment: Evaluates environmental footprints across the supply chain to optimize sustainability efforts.
	Telemedicine and smart logistics: Reduces emissions through digital healthcare solutions and optimized transport systems.
	Extended Producer Responsibility (EPR): Encourages manufacturers to develop reusable and low-impact products.

Table 16: key topic related to Sustainable models characteristics (third research question)

Specific topics	**Key topic**
Waste Reduction	**Minimized environmental impact from waste**: Reduced waste generation through material recycling, sustainable production, and optimized inventory control.
	Reduced resource waste: Improved patient flow and data management to decrease unnecessary resource consumption.
	Enhanced workflow efficiency: Streamlined operations to minimize waste and associated costs.
	Lower medical waste generation: Adoption of circular economy models to recycle and reuse materials.
Emissions Reduction	**Lower greenhouse gas (GHG) emissions**: Optimized transportation and energy-efficient processes to reduce carbon footprints.
	Fuel-efficient logistics: AI-driven route optimization and local sourcing to decrease transportation-related emissions.
	Renewable energy adoption: Use of solar, wind, and biofuels to power healthcare operations sustainably.
	Waste-to-energy solutions: Plasma gasification, carbon capture, and energy recovery to minimize emissions from medical waste.
Pollution Reduction	**Better waste segregation and disposal**: Implementation of eco-friendly packaging and sustainable waste management.
	Minimized environmental impact of hazardous waste: Reduced contamination from improper pharmaceutical and medical waste disposal.

	Compliance with environmental standards: Adoption of ISO 14001 and other green policies to improve sustainability.
Hazardous Waste Minimization	**Reduction of toxic waste**: Decreased hazardous waste from medical disposables like needles and syringes.
	Improved disposal methods: Implementation of sealed bins and high-temperature incineration to prevent contamination.
	Mitigated environmental hazards: Enhanced waste segregation and recycling to minimize pollution risks.
	Lower risk to human health: Ensured proper disposal of infectious and chemical waste to protect communities.
Counterfeit medicines reduction	**Lower fraud risks in medical supply chains**: Improved tracking systems to prevent counterfeit drugs.
	Serialization for better traceability: Enhanced digital monitoring to verify the authenticity of medicines.
	Reduced inefficiencies from fake products: Ensured secure distribution channels to maintain pharmaceutical quality.
Social inequities reduction	**Better healthcare access for underserved communities**: Improved collaboration between suppliers, governments, and healthcare providers.

Table 17: key topic related to Externalities reduced (third research question)

Specific topics	Key topic
Enhanced environmental sustainability	**GHG Emissions Reduction**: Implementing renewable energy sources like solar, wind, and geothermal power in healthcare facilities and optimizing transportation routes using low-emission vehicles and carbon offset strategies to lower overall carbon footprints.
	Waste Minimization: Establishing hospital-wide recycling programs, reverse logistics for used medical devices, and incorporating biodegradable materials into packaging and medical supplies to limit environmental contamination.
	Sustainable Procurement: Selecting eco-friendly suppliers that adhere to environmental certifications (e.g., ISO 14001) and prioritizing the use of green-certified materials to reduce the carbon footprint of sourced products.
	Circular Economy Integration: Encouraging reuse, remanufacturing, and refurbishment of medical equipment to extend product lifecycles, reduce reliance on virgin raw materials, and cut down on unnecessary waste generation.
Cost reduction	**Reduced Waste Disposal Costs**: Lowering expenses by implementing advanced waste segregation, recycling programs, and sustainable disposal methods that reduce landfill and incineration fees.

	Efficient Inventory Management: Minimizing excess stock and expired medical supplies through predictive analytics, automated stock rotation, and just-in-time (JIT) inventory practices to prevent over-ordering.
	Reverse Logistics Savings: Cutting costs by refurbishing, sterilizing, and reusing medical equipment instead of purchasing new items, reducing procurement expenses and environmental impact simultaneously.
	Process Optimization: Enhancing workflows through automation, AI-driven demand forecasting, and lean methodologies that streamline labor-intensive operations and reduce unnecessary expenditures.
Social responsibility	**Improved Stakeholder Collaboration**: Encouraging transparency and trust through real-time data sharing among hospitals, suppliers, and regulatory bodies, improving decision-making and accountability.
	Increased Healthcare Access: Strengthening supply chain networks to guarantee the availability of medicines and critical healthcare supplies in underserved regions, reducing disparities in medical treatment.
	Employee Welfare and Safety: Ensuring fair wages, ethical labor conditions, and enhanced workplace safety measures to protect healthcare workers and supply chain personnel.
	Community Engagement: Supporting corporate social responsibility (CSR) initiatives like sustainability training programs, local employment opportunities, and public health education campaigns to create long-term societal benefits.
Operational efficiency	**Streamlined Inventory Management**: Utilizing AI-driven forecasting, blockchain-based tracking, and digital twins to monitor stock levels in real time, preventing stockouts and reducing holding costs.
	Enhanced Decision-Making: Applying data analytics and machine learning models to procurement planning, allowing for better cost predictions, reduced waste, and improved supply chain agility.
	Improved Resilience: Strengthening supply chain agility through redundancy planning, dual sourcing strategies, and dynamic risk assessment to mitigate disruptions caused by global crises or local shortages.
	Automation and Digitalization: Implementing robotic process automation (RPA), IoT-enabled tracking systems, and cloud-based logistics management platforms to optimize supply chain visibility and minimize human errors.

Table 18: key topic related to Benefits of model application (third research question)

Specific topics	Key topic
Resource constraints	**Limited funding and infrastructure**: Developing regions struggle with poor infrastructure, lack of financial resources, and workforce shortages.
	Dependence on external funding: Implementation relies heavily on financial support and technological advancements.
Implementation complexity	**Variability in application**: Different regions face challenges in adapting models due to diverse healthcare structures and regulatory frameworks.
	Integration of advanced technologies: Requires skilled personnel and complex system coordination for AI, big data, and smart logistics.
	Coordination across stakeholders: Aligning diverse priorities in healthcare supply chains increases complexity.
High implementation costs	**Expensive infrastructure investments**: High costs for implementing circular economy models, Industry 4.0 technologies, and renewable energy systems.
	Financial barriers in sustainable initiatives: Initial setup and maintenance costs for green technologies and smart waste management are often prohibitive.
	Regulatory compliance costs: Establishing closed-loop supply chains and reprocessing systems requires significant financial resources.
Resistance to change	**Stakeholder reluctance**: Resistance from hospital management, suppliers, and employees due to lack of technical expertise or awareness.
	Challenges in adoption of green practices: Organizational pushback against sustainability-oriented changes, including recycling and waste recovery programs.
	Limited participation in new initiatives: Dependence on stakeholder buy-in for circular economy and reverse logistics programs.
Data accuracy dependency	**Reliance on accurate forecasting**: Demand prediction errors can lead to inefficiencies in inventory management and resource allocation.
	Challenges in waste quantification: Inaccurate data on medical waste production affects optimization efforts in recycling and disposal.
Regulatory challenges	**Gaps in legal frameworks**: Lack of clear policies for reverse logistics, circular economy integration, and sustainability practices.
	Government dependency: Need for regulatory support and incentives to encourage the adoption of sustainable healthcare models.

Limited applicability of models	**Restricted generalization**: Models may not be adaptable to all geographic and institutional contexts due to variations in healthcare infrastructure.
	Sector-specific constraints: Some sustainable practices, like circular economy models, are less applicable to non-perishable healthcare products, such as MRI machines, surgical instruments, and hospital beds. Unlike single-use medical supplies, these durable assets have longer life cycles and require specialized refurbishment or disposal processes, limiting their integration into standard recycling frameworks.

Table 19: key topic related to Limitations of model application (third research question)