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IMPLEMENTING CIRCULAR ECONOMY IN HEALTHCARE – CHALLENGES AND STRATEGIC SOLUTIONS

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Purpose: The study aims to identify and address the key challenges that are faced during the implementation of Circular Economy (CE) for sustainable healthcare.
Design/methodology/approach: This scoping review follows Levac et al.'s (2010) methodological framework, enhanced by Pham (2014) and Tricco (2016), to identify and address relevant literature on challenges and solutions of implementing CE in healthcare. A comprehensive search of SCOPUS, EBSCO, ProQuest, and Web of Science yielded 112 articles (2010 onwards), with 73 meeting inclusion criteria focused on CE challenges and solutions in healthcare. The extracted data were synthesized using a narrative approach to identify key themes and research gaps.
Findings: The study finds key challenges in implementing CE principles in healthcare, including resource depletion, medical waste, energy consumption, emissions, and healthcare inequity. Healthcare's high use of resources and energy results in environmental threats and costs, while significant medical waste contributes to pollution. CE strategies can enhance efficiency, reduce waste, and lower emissions. Overcoming these challenges requires improving resource management, promoting recycling, and ensuring equitable access to sustainable healthcare**.**
Research limitations/implications: Findings may not be universally applicable due to regional variations in healthcare systems and regulations. Rapid advancements in CE and healthcare technologies may have emerged since the review, affecting the relevance. Practical challenges like regulatory hurdles and financial constraints were identified but not exhaustively explored.
Practical implications: By identifying the main challenges in the implementation of CE principles in healthcare, the study provides valuable guidance for policymakers to develop targeted policies addressing resource depletion, waste management, energy consumption and emissions, and equitable access to sustainable healthcare. For healthcare practitioners, the study offers actionable insights for implementing solutions like recycling programs, energy-saving measures, and sustainable procurement practices within their facilities.

Social implications: Promoting CE practices can reduce pollution, minimize healthcare facilities' environmental footprint, and ensure equitable access to sustainable healthcare.
Originality/value. The originality of this study lies in its comprehensive examination of challenges and solutions for implementing CE principles in healthcare. Focusing on the interconnectedness of sustainability, public health, and social equity, this scoping review offers actionable strategies for promoting sustainability in healthcare systems.
Category of the paper: Scoping Review.
Keywords: sustainability, green economy, CE.

1. Introduction

The healthcare industry, despite its essential role in public health, often remains overlooked in research about environmental sustainability and carbon emissions. Healthcare activities contribute significantly to the global carbon footprint, which accounts for up to 5% of total emissions (Leiva, 2023). 25% of the total amount of medical waste - a quantity expected to rise with the world population aging - is hazardous for human beings and for the environment, containing radiological, biological, or chemical threats(Wei et al., 2021). This impact is driven by energy-intensive operations, pharmaceutical production, medical waste disposal, and resource-intensive supply chains (Stadhouders et al., 2019). This is a huge environmental footprint, making it urgent to adopt Circular Economy (CE) principles within the healthcare system.

Implementing CE practices in healthcare is crucial for several compelling reasons. First, it aims to bring down medical waste, which includes vast amounts of single-use plastics and hazardous materials (Chew et al., 2023). By redesigning products to prioritize durability, recyclability, and reuse, healthcare facilities can significantly diminish waste generation and alleviate the burden on landfills (Ramos et al., 2023). Secondly, CE strategies promote efficient resource use by optimizing processes, adopting responsible procurement practices, and managing supply chains sustainably (Moraga et al., 2019). This can lead to reduced resource consumption, lower operational costs, and decreased overall environmental impact.

Furthermore, addressing healthcare's carbon footprint is paramount in combating climate change. Embracing CE principles can help mitigate these impacts by promoting energy efficiency, renewable energy adoption, and sustainable practices throughout healthcare systems (Yaryhina et al., 2021). Additionally, implementing CE initiatives fosters resilience within healthcare by encouraging local sourcing, reducing reliance on single-use materials, and driving innovation towards sustainable healthcare solutions (Dumée, 2022).

Boerdonk et al. (2021) view the CE in healthcare as an economic strategy that proposes innovative ways to transition from the current linear system of consumption to a circular one. By transforming the predominantly linear model into a circular system, the CE offers opportunities for resource optimization and long-term sustainability (Van Boerdonk et al.,

2021a). According to Moreau et al. (2017) the CE is restorative and regenerative by design with an emphasis on always preserving materials products, and components at their maximum usefulness (Moreau et al., 2017). They highlight the concept as a continuous positive development cycle, and this can be applied to healthcare as well – by recycling and reusing more.

Additionally, Haupt et al. (2019) have envisioned CE as a system of production and consumption with low material and energy losses (Haupt et al., 2019). Their definition emphasizes extensive reuse, recycling, and recovery practices to minimize resource depletion and environmental impact.

CE in healthcare is an economic system that aims to eliminate and reduce waste for the reduction of pollution (D'Adamo et al., 2024). CE in healthcare ensures the circulation of products and materials at their highest value, so they do not turn into waste (UNDP, 2023). It involves strategies like smarter product design, longer use, recycling, and regenerating nature, and can be applied at various scales from individual medical products to medical instruments and devices (Molero et al., 2020) The concept of CE in healthcare is the same as that in other industries - the exact opposite of the prevailing linear economy model, which considers that the available resources are abundant and produced goods can be disposed of after being used once. CE in contrast to that, establishes that products can be kept in a cyclic usage to gain maximal utilization – thus preventing excessive waste (Pacheco et al., 2024).

In implementing CE principles in healthcare, several challenges have been highlighted by different researchers. Mehtsun, Hyland, Offodile (2023) have discussed the emissions generated by healthcare energy consumption. The authors state that supply chains in healthcare, including the food and transportation sector, account for up to 80% of total healthcare–associated emissions in the US. It is a challenge to reduce these emissions without compromising the quality of healthcare. Huttin (2023) and Teymourian (2021) have highlighted the effects of healthcare inequity and inequality The authors argue that achieving equal healthcare access under a CE presents significant challenges. This includes affecting the pricing dynamics across primary markets (e.g., with repurposed products), secondary markets (with reused or recycled products), and the interplay between supply and demand.

Regulatory changes from authorities and major tech players, alongside traditional stakeholders in healthcare, could further complicate this landscape. Another challenge is that repurposing medical equipment or drugs for underserved populations via secondary markets can lower prices but also result in price discrimination. D'Alessandro et al. (2024) focuses on challenges including resource depletion in healthcare. The authors conclude that the challenge is attaining sustainability through a CE model, striving for a profitable and sustainable system that advances the economy without resource depletion. This can only be achieved by minimizing resource use and maximizing recycling.

Kandasamy (2022), has pinpointed that medical waste management has followed a linear economy approach for a long time, but it now needs to transition to a CE due to ecological and economic issues associated with the linear model. Overproduction and waste dumping are causing environmental pollution while dwindling raw materials and rising demand are driving up prices and impacting global markets. These challenges are umbrella terms that carry the other challenges that are found during the application of CE in healthcare systems especially post-pandemic (Wuyts et al., 2020).

These challenges were selected in these studies because of their significant impact on sustainability as found by previous research carried out. They have a significant impact on the healthcare sector and the potential for CE principles to address them effectively.

The worldwide medical devices market reached an astounding value of $432 billion in 2020 and is expected to grow to $628 billion by 2028. This has happened with an annual growth rate of 5.4% from 2021 to 2028. This sector of healthcare demands significant resources in terms of mining and energy, typically has a relatively short lifespan, and poses challenges for recycling, leading to a substantial carbon footprint and waste generation (Ivan Idso, 2022). Healthcare facilities use up a large amount of these resources, and their depletion poses environmental threats while leading to increased costs and inefficiencies within the system (Brown, Buettner, Canyon, 2012). Embracing CE strategies can help reduce resource consumption and promote efficiency, mitigating the impact of resource depletion (Tong et al., 2022).

Medical waste generation is another crucial challenge, as healthcare facilities produce large volumes of waste, especially from disposable equipment, medications, and protective gear. This is one of the biggest ways the healthcare sector contributes to the waste pile of the earth (Ekins, Zenghelis, 2021). Consequently, improper disposal methods cause pollution and greenhouse gas emissions on a large scale (Abubakar et al., 2022; D'Alessandro et al., 2024).

CE principles offer solutions by reducing waste generation and encouraging recycling and reuse practices, which can lessen the environmental impact of medical waste (Ranjbari et al., 2022).

Energy consumption and emissions are also major concerns for healthcare facilities, which have high energy usage and resulting emissions. These emissions pose multiple hazards to the environment and the health of humans (Vishwakarma et al., 2023). Application of CE into healthcare can help decrease energy usage which in turn reduces emissions. This aligns with global climate targets and promotes overall sustainability in the sector (Yousefi, Avak Rostami, 2017).

Even though various challenges have been addressed by researchers in the field, none of these research works have presented the challenges all at once. Moreover, there is a need for a solid plan to address and prioritize the various challenges in the healthcare sector, considering how they impact each other. Each healthcare system and region have its unique problems, so we need novel ideas to deal with them effectively. Getting all the key players involved and working together is crucial for moving towards a CE, but there's not enough research on how

to carry this out. Also, there is a lack of good methods to measure and monitor progress, which makes it hard to make informed decisions and compare different CE strategies. By filling these research gaps through teamwork across different fields, we can get a better grasp of the challenges and come up with effective ways to apply CE principles in healthcare. This will help make the sector more sustainable and efficient with resources.

This study aims to find the key challenges in implementing CE principles in the healthcare sector to promote sustainability. Further, the aim is to suggest solutions to all these challenges in this study. The research question that will be addressed is what are the key challenges in implementing CE principles in the healthcare sector, and what strategic solutions can be adopted to overcome these challenges to promote sustainability? These challenges and their solutions will be pinpointed in this paper because they represent crucial areas where efforts to promote sustainability through the implementation of CE. The paper explores the critical barriers to CE adoption in healthcare, as well as proposes corresponding solutions to overcome them and drive sustainable practices in the sector.

2. Methodology

This scoping review follows the methodological framework proposed by Levac et al. (2010) and is further enhanced by Pham (2014) and Tricco (2016). The key steps in the review process are:

1. Identifying the research question.
2. Identifying relevant studies.
3. Study selection.
4. Charting the data.
5. Collating, summarizing, and reporting the results.

A comprehensive search strategy was developed to identify relevant literature from multiple databases, including SCOPUS, EBSCO, ProQuest, and Web of Science. The search terms used a combination of keywords including CE, circular economy, healthcare, healthcare management, sustainability, and their combinations. The search was limited to articles published in English from 2010 onwards. Titles and abstracts of the identified records were screened against the inclusion criteria. Articles that were full-text articles and the author could have access to were then retrieved and assessed for eligibility.

For this analysis, a total of 112 articles were initially scanned from various academic databases and online sources. After a thorough review process, 39 articles were excluded due to reasons such as lack of relevance, not falling into the inclusion criteria, or being conference proceedings. The remaining 73 articles formed the core literature used to identify the key challenges and research gaps in implementing CE principles in healthcare.

The inclusion criteria were:

1. Studies focusing on the challenges faced in implementation of CE principles in the healthcare sector 2010 onwards.
2. Studies examining the challenges and/or solutions for adopting CE practices in healthcare.
3. Peer-reviewed journal articles, and grey literature.

The extracted information was synthesized using a narrative scoping review approach to identify and summarize key themes, patterns, and gaps related to the research question. The synthesis focused on categorizing and describing the various challenges and potential solutions for implementing CE principles in the healthcare sector. All steps in the literature selection process, from initial search to final synthesis, were conducted transparently to ensure the reliability and validity of the findings The synthesis focused on categorizing and describing the various challenges and potential solutions for implementing CE principles in the healthcare sector.

3. Theoretical Background

The adoption of a CE approach in healthcare entails the repair, reuse, reprocessing, and recycling of resources, requiring effective alignment between healthcare and regulatory bodies to ensure the safety and efficacy of reusable devices. Implementing CE strategies in healthcare can significantly reduce environmental impacts, promoting a more sustainable system. The financial savings generated from these practices can be reinvested in improving staff well-being, patient care, and community outreach programs, ultimately enhancing overall healthcare quality (Al-Alawy et al., 2021).

The development of CE in healthcare revolves around two key strategies: transitioning from a linear to a circular system and designing products with their entire life cycle in mind. This approach prioritizes recycling, reusing, and optimizing resources, aiming to preserve materials and components at their maximum utility (Ellen et al.,2012). However, integrating CE principles into healthcare is complex due to challenges such as ensuring medical product safety, navigating regulatory compliance, and managing costs. Overcoming these challenges requires innovative engineering, stringent testing, and regulatory adjustments to balance sustainability with patient safety (Leiva, 2023).

The intersection of CE and healthcare presents a set of complex problems due to the unique characteristics and demands of the sectors. The design and safety considerations of medical products pose substantial threats. When medical devices are designed, only one aspect is kept in mind - the efficacy and efficiency of patient care that they can provide (Altayyar, 2020; Miclăuş et al., 2020). Transitioning towards reusable or recyclable designs must ensure that

these products remain safe and effective for medical use, complying with regulatory requirements that prioritize patient safety above all else (Guzzo et al., 2020). Finding the right equilibrium between sustainability and safety demands inventive engineering, stringent testing procedures, and continuous monitoring to uphold the durability and reliability of medical devices across their lifespan (Haber et al., 2021).

Navigating regulatory compliance is a multifaceted problem when integrating CE practices into healthcare. This makes it very complex. The healthcare sector is governed by stringent regulations aimed at ensuring patient safety (Kwon et al., 2013). Implementing changes to product design, waste management, or supply chain practices must adhere to current regulatory frameworks or involve the development of new standards that support sustainable practices while maintaining patient care and regulatory compliance standards (Al-Alawy et al., 2021).

Cost considerations also make it harder to adopt CE principles within healthcare (WHO, 2017). Healthcare is known for its high financial costs, and any shifts towards sustainable practices must be economically viable. Implementing reusable or recyclable solutions should not significantly increase financial burdens on healthcare providers or patients, necessitating careful cost-benefit analyses and financial planning (Politecnico et al., 2013; Almodhen et al., 2023). Balancing sustainability with affordability requires strategic investments in technology and infrastructure that demonstrate long-term cost savings and environmental benefits, fostering a sustainable healthcare ecosystem without compromising financial stability(Tambor et al., 2015) Although complex, adopting CE principles in healthcare can significantly reduce waste, enhance resource efficiency, and promote sustainability, ultimately benefiting patients and the environment.

4. Results

The healthcare sector, despite its essential role in public health, has a notable impact on global carbon emissions and environmental health. Accounting for up to 5% of total global emissions, healthcare activities contribute significantly to environmental degradation, particularly through the generation of hazardous medical waste, including radiological, biological, and chemical threats. This environmental footprint is exacerbated by energy-intensive operations, pharmaceutical production, medical waste disposal, and resource-intensive supply chains. Consequently, there is an urgent need for the adoption of CE principles within the healthcare sector.

Comprehensive studies related to the challenges of implementing CE in Healthcare are rare. Researchers tend to focus on single challenges such as waste management (Jafarzadeh Ghoushchi et al., 2022; Kandasamy et al., 2022b; Mahjoob et al., 2023), energy consumption (Mehtsun et al., 2023), emissions (Pecchia et al., 2021; Abubakar et al., 2022), and healthcare

inequity and inequality (Huttin, 2023; Teymourian et al., 2021). These all are papers addressing individual healthcare challenges when it comes to the implementation of CE into healthcare but none of them address all of these challenges in one paper. Many studies also focus on other challenges to implementing CE in healthcare supply chains, such as policy, financial, management, social, cultural, and technological barriers (Alfina et al., 2022). Some have also explored challenges to implementing CE in healthcare as analysed from a systems perspective, including infection prevention, behaviours of device consumers and manufacturers, and regulatory structures that encourage the proliferation of disposable medical devices (Basu et al., 2019). Complementary policy- and market-driven solutions are required to encourage systemic transformation in the implementation of CE in healthcare to foster sustainability. (Macneill et al., 2020) However, there is a lack of comprehensive research related to the challenges of implementing CE in healthcare from the individual's perspective. This scoping review addressed all these challenges in one paper.

While implementing CE principles in healthcare, four main challenges have been pinpointed for investigation: resource depletion in healthcare, medical waste generation, energy consumption and emissions, and healthcare inequity and inequality (Samenjo et al., 2023a). These challenges were selected because there is significant research done on them in terms of their impact on sustainability within the healthcare sector and the potential for CE principles to address them effectively. These challenges represent crucial areas where efforts to promote sustainability can have a big impact on CE implementation in healthcare.

There are many challenges found in the implementation of CE principles in healthcare to attain sustainability, during the scoping review. However, four key challenges were pinpointed i.e. resource depletion, medical waste generation, energy consumption, and healthcare inequity as seen in (Figure 1).

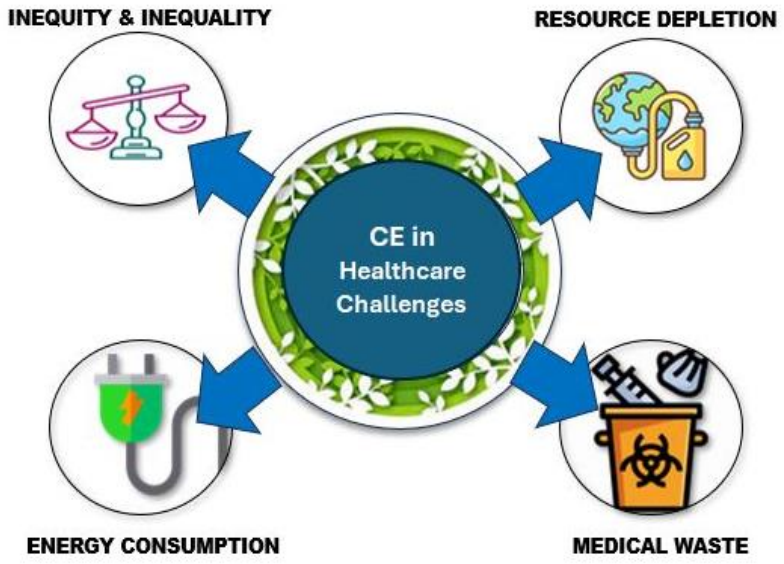

Figure 1. CE in Healthcare Challenges – a Visual Depiction.

Source: Own work.

These were found to be the most significant barriers to CE adoption. To overcome these challenges, it is required that regulatory investments are carried out, along with innovating green solutions and strategic investments to create a sustainable healthcare ecosystem post-pandemic. Following are the results of the scoping review describing each of the challenge in detail and discussing possible solutions to address them.

4.1. Resource Depletion

Resource depletion in healthcare, covering energy, water, medicines, and medical equipment, highlights the need for smart resource use to reduce waste and improve efficiency (EU, 2020). The worldwide medical devices market reached an astounding value of $432 billion in 2020 and is expected to grow to $628 billion by 2028. This has happened with an annual growth rate of 5.4% from 2021 to 2028. This sector of healthcare demands significant resources in terms of mining and energy, typically has a relatively short lifespan, and poses challenges for recycling, leading to a substantial carbon footprint and waste generation (IvanIdso, 2022). Healthcare facilities use up a large amount of these resources, and their depletion poses environmental threats while leading to increased costs and inefficiencies within the system (Brown et al., 2012). Embracing CE strategies can help reduce resource consumption and promote efficiency, mitigating the impact of resource depletion (Tong et al., 2022).

To mitigate resource depletion, regulatory investments are crucial to enforce sustainable practices and provide incentives for resource optimization (Aithal, Aithal, 2023). This can include the implementation of policies that encourage people to practice responsible procurement, The promotion of the use of renewable resources must be also practiced along with a focus on the regulation of healthcare resource extraction in a way that the environmental impact is reduced (Pecchia et al., no date). Other ideas include the development of ecologically friendly materials, thus reducing resource consumption while maintaining quality standards in healthcare (Kondratenko et al., 2023).

4.2. Medical Waste Generation

Medical waste generation is another crucial challenge, as healthcare facilities produce large volumes of waste, especially from disposable equipment, medications, and protective gear. This is one of the biggest ways the healthcare sector contributes to the waste pile of the earth (Ekins et al., 2021). Healthcare facilities are known to produce a variety of waste, including single-use equipment and materials, contaminated materials, and pharma by-products (Dixit et al., 2024) Consequently, improper disposal methods cause pollution and greenhouse gas emissions on a large scale (Abubakar et al., 2022; D'Alessandro et al., 2024). CE principles offer solutions by reducing waste generation and encouraging recycling and reuse practices, which can lessen the environmental impact of medical waste (Ranjbari et al., 2022).

To address this issue, it is vital to work towards the creation of a waste management strategy that prioritizes the reduction of waste along with recycling and reusing it (Lee, Lee, 2022). Healthcare regulatory frameworks need to be focused on mandating the segregation of medical waste and healthcare disposal practices (Najafi, Kohli, 1997). The healthcare sector needs to make investments towards innovation in waste treatment technologies - this may include repurposing and recycling in a way that minimizes the environmental impact while promoting CE principles in healthcare (Tabrizi et al., 2018).

4.3. Energy Consumption

Energy consumption and emissions are also major concerns for healthcare facilities, which have high energy usage and resulting emissions. These emissions pose multiple hazards to the environment and the health of humans (Vishwakarma et al., 2023). Healthcare buildings, vital to societal well-being, present a distinct sustainability challenge due to their continuous operation and stringent hygiene standards, which significantly impact emissions management (Silva et al., 2024). Hospitals demand significantly more thermal and electrical energy compared to other commercial buildings due to their constant operation round the clock, every day of the year. Most of the energy in healthcare is primarily utilized for heating, air conditioning, producing sanitary water, sterilization, laundry, and kitchen services; thus increasing the emissions (Chen-Xu et al., 2024).Application of CE into healthcare can help decrease energy usage which in turn reduces emissions. This aligns with global climate targets and promotes overall sustainability in the sector (Yousefi et al., 2017).

To tackle energy consumption in healthcare, strategic investments are needed to promote energy efficiency and renewable energy adoption (Taleb et al., 2022). Regulatory incentives can also encourage the adoption of energy-saving practices, like upgrading to energy-efficient equipment. This can also include optimizing building designs for natural lighting and ventilation (Lipschutz et al., no date). Furthermore, investing in renewable energy infrastructure, like solar panels and wind turbines, can decrease reliance on fossil fuels and mitigate greenhouse gas emissions (Ramos et al., 2021).

4.4. Healthcare Inequity

There is healthcare inequity and inequality come from the complex supply chains within healthcare that involve numerous stakeholders, making it difficult to trace and manage the environmental impact of products and materials used in medical care (Woromogo et al., 2020). Regulatory and policy barriers often do not prioritize sustainability or those trying to gain access to sustainable healthcare, hindering the adoption of eco-friendly technologies and practices (Aboueid et al., 2023). Public awareness and engagement around healthcare sustainability remain important for fostering support and understanding among patients, and healthcare professionals (Calabrese et al., 2023). It also means that healthcare needs to be made more accessible in terms of sustainable healthcare to everyone in society (Molero et al., 2020).

Addressing healthcare inequity requires regulatory interventions to promote equitable access to sustainable healthcare solutions (Hadjiat, 2023). This includes implementing policies that prioritize sustainability in healthcare procurement and resource allocation, ensuring that underserved communities have access to eco-friendly medical products and services (Sheringham et al., 2022; Haggerty et al., 2020). Moreover, targeted investments in community-based healthcare initiatives and public awareness campaigns can foster sustainability and equity in healthcare provision (Gkiouleka et al., 2023).

The solutions to challenges all have a common objective – that is attaining sustainability through a CE model, striving for a profitable and sustainable system that advances the economy without resource depletion. This can only be achieved by minimizing resource use and maximizing recycling (Kandasamy et al., 2022a) These challenges are umbrella terms that carry the other challenges that are found during the application of CE in healthcare systems especially post-pandemic (Wuyts et al., 2020). These challenges were selected in these studies because of their significant impact on sustainability as found by previous research carried out. They have a significant impact on the healthcare sector and the potential for CE principles to address them effectively (Samenjo et al., 2023).

Overcoming these challenges necessitates a collaborative effort from regulatory bodies, healthcare providers, and stakeholders to prioritize sustainability and innovation in healthcare practices. This involves implementing regulatory investments, fostering green solutions, and making strategic investments to establish a sustainable healthcare ecosystem. However, integrating CE principles into established healthcare systems presents challenges due to the multifaceted nature of the industry. Addressing these barriers requires proactive measures and innovative solutions to ensure the effective and sustainable implementation of CE practices in healthcare.

5. Conclusion

The purpose of this scoping review study was to comprehensively identify and address the key challenges and suggest solutions for the challenges faced during the implementation of CE principles for sustainable healthcare. It sought to explore how CE strategies could mitigate environmental impacts caused by healthcare activities, such as resource depletion, medical waste, and high energy consumption, while promoting efficiency, waste reduction, and equitable access to sustainable healthcare. By examining these challenges and proposing strategic solutions, the study aspired to guide policymakers and healthcare practitioners in developing and adopting CE practices that enhance sustainability within the healthcare sector. For this purpose, a comprehensive scoping review was conducted by carrying out a systematic search of existing literature that fulfilled the criteria of this scoping review. These articles were

analysed and synthesized using a narrative approach to identify key themes and research gaps related to CE challenges and solutions in healthcare.

Incorporating CE practices in healthcare holds promise in addressing numerous challenges. By revamping product designs to prioritize durability, recyclability, and reusability, healthcare establishments can effectively mitigate medical waste, encompassing single-use plastics and hazardous materials. This proactive approach not only curbs waste generation but also mitigates environmental hazards linked to improper disposal. CE strategies advocate for efficient resource utilization via process optimization, responsible procurement, and sustainable supply chain management. This translates into reduced resource consumption, diminished operational expenses, and an overall decline in environmental footprint. Moreover, optimizing resource usage contributes to conserving natural resources for future generations.

Addressing energy consumption emerges as another pivotal aspect where CE practices wield significant influence. Purposeful investments in energy efficiency and the adoption of renewable energy sources can reduce the dependence on fossil fuels, helping in a transition toward cleaner energy alternatives. Through initiatives like optimizing building structures, upgrading equipment, and investing in renewable energy infrastructure, healthcare facilities can reduce their carbon footprint, thereby advancing environmental sustainability. CE practices offer avenues to tackle healthcare inequity by ensuring equitable access to sustainable healthcare solutions. Regulatory frameworks play a critical role in prioritizing sustainability in healthcare procurement and resource allocation, especially for marginalized communities. Directed investments in community-based healthcare programs and public awareness initiatives are essential in fostering sustainability and fairness in healthcare provision.

Integrating CE principles into healthcare operations presents a comprehensive approach to addressing various challenges, encompassing medical waste generation, resource depletion, energy consumption, and healthcare inequity. Addressing healthcare's carbon footprint is critical for combating climate change. Embracing CE principles can help achieve this by promoting energy efficiency, renewable energy adoption, and sustainable practices across healthcare systems. Moreover, CE initiatives foster resilience within healthcare by encouraging local sourcing, reducing dependence on single-use materials, and driving innovation towards sustainable solutions.

There are limitations to this article that need to be addressed. First, there is a strong focus on challenges and research gaps from the perspective of Western or developed countries. This overlooks the unique situations and constraints faced by developing nations or resource-limited healthcare systems. The geographical diversity of these challenges is also not adequately considered. The feasibility of CE strategies in different regions can be significantly influenced by factors such as infrastructure, cultural norms, and legal frameworks. Additionally, without quantitative data and metrics, it's challenging to gauge the relative impact or scale of the identified challenges, as well as the possible economic and environmental benefits of implementing CE principles in healthcare.

To overcome these limitations and improve our understanding of implementing CE principles in healthcare, future research should focus on comparative studies across diverse healthcare systems, including both developed and developing countries. Additionally, exploring effective models for stakeholder engagement and collaboration can help identify the incentives, roles, and responsibilities of different stakeholders in moving towards a CE in healthcare. Bringing together experts from healthcare, environmental science, economics, and policy can give us a deeper understanding of the challenges and help find effective solutions By addressing these research directions, researchers can provide a more actionable understanding of implementing CE principles in the healthcare sector, ultimately promoting sustainability and resource efficiency.

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