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Review

Exploring Circular Economy Practices in the Healthcare Sector: A Systematic Review and Bibliometric Analysis

Carlotta D'Alessandro [1,*], Katarzyna Szopik-Depczyńska [2], Małgorzata Tarczyńska-Łuniewska [3], Cecilia Silvestri [4] and Giuseppe Ioppolo [1]

1 Department of Economics, University of Messina, 98121 Messina, Italy; giuseppe.ioppolo@unime.it
2 Department of Business Management, Institute of Management, University of Szczecin, 71-004 Szczecin, Poland; katarzyna.szopik-depczynska@usz.edu.pl
3 Department of Econometrics and Statistics, Institute of Economics and Finance, University of Szczecin, Mickiewicza 64, 71-101 Szczecin, Poland; malgorzata.tarczynska-luniewska@usz.edu.pl
4 Department of Economics, Engineering, Society and Business Organization, University of "Tuscia" of Viterbo, 01100 Viterbo, Italy; c.silvestri@unitus.it
* Correspondence: carlotta.dalessandro@unime.it

Abstract: The healthcare sector produces 2 gigatons of CO_2. To address this impactful trend and contribute to the Sustainable Development Goals (SDGs), the adoption of circular economy (CE) practices could represent a strategic target. In this context, the present article provides a systematic and bibliometric literature review of CE practices applied in the healthcare sector by considering the collected case studies. This study aims to analyze the state of the art in CEs in the healthcare sector in order to identify CE practices in healthcare, examining how they contribute to sustainability goals and the critical issues in their implementation. A final selection of 36 articles from reputable databases, Web of Science and Scopus, was obtained and analyzed using VOSviewer. By systematically examining these papers, the study investigates the key CE practices implemented within the healthcare sector and their respective areas of application, which help the broader mission of achieving SDG 12, and also, to a lesser extent, SDG 9. Although the research criteria impose some limitations, this study offers a comprehensive review of successful circular practices adopted in the healthcare sector while shedding light on existing gaps and providing valuable insights for relevant stakeholders.

Keywords: healthcare sector; bibliometric analysis; systematic analysis; circular economy; CE practices

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1. Introduction

Nowadays, humanity is facing several challenges; among the many, climate change is one of the most pernicious, threatening clean air, safe drinking water, sufficient food, and secure shelter. As we look ahead to the period between 2030 and 2050, climate change is expected to have a grave impact, resulting in an estimated annual increase in deaths of approximately 250,000, predominantly caused by malnutrition, malaria, diarrhea, and heat stress [1]. It is worth noting that the health sector, which bears the responsibility of safeguarding human well-being, has also made substantial contributions to the climate crisis in recent decades [2]. According to the Healthcare Without Harm (HCWH) Annual Report in 2022, if the healthcare sector were a country, it would be the world's fifth largest producer of greenhouse gas (GHG) pollution [3]. In an international comparative analysis using analogous information taken from a selection of 36 OECD countries at various points in time, it was noted that in 2014, the healthcare sector was accountable for emitting 2 gigatons of CO_2, equivalent to 4.4% of the global ecological footprint [4]. Therefore, scientists have stressed that quality amelioration strategies are indispensable for sustainability [5]. Sustainability is perceived as an equilibrium between the social, environmental, and economic aspects of society and the planet as a whole [6].

To enhance environmental sustainability, solutions such as a complete life cycle inventory database for medical devices and drugs, reform of contagion check standards that guide the practical use of single-use disposable devices, implementation of consolidated sustainability operation measures at the medical level, and more national research financial support are needed [7]. Examples that boost social sustainability are domiciliary telemedicine; emerging technologies to ensure accessibility to and the availability of healthcare and ensure patient satisfaction; customized treatments exploiting 3D printing technology; financing expensive drugs for global use; sustainable health training as an approach to achieve sustainability; and improved personnel recruitment [8].

Finally, research, development, and reductions in costs are some of the strategies to achieve economic sustainability; furthermore, energy safeguarding, recycling, sourcing, training programs, and employability, despite covering environmental and social aspects, also contribute to the promotion of economic sustainability [8].

In this context, the United Nations General Assembly (UN) took a significant step in September 2015 by endorsing the 2030 Agenda for Sustainable Development, which encompasses 17 SDGs. The SDGs call upon nations to collaborate with the purpose of diminishing economic disparities and safeguarding the planet for peace and peoples' well-being [9]. Addressing the environmental impact of the healthcare sector and reorienting its practices towards long-term sustainability can play decisive roles in achieving the overarching goals of the 2030 Agenda for Sustainable Development, ultimately contributing to a high quality of life for both present and future generations.

Moreover, the European Union's (EU) effort to achieve circularity and become more sustainable led to the creation of the Green Deal, a policy developed to reach zero GHG emissions and carbon neutrality and protect human health by 2050 [10,11]. In pursuit of this goal, EU countries have collectively vowed to achieve a reduction in emissions of no less than 55% by 2030 in contrast to the emission levels recorded in 1990 [10]. In order to actively support the fulfillment of the SDGs and address the environmental challenges arising from the healthcare sector, the transition to a CE, considered an emerging and innovative paradigm, holds significant promise as a viable solution. In this economic framework, the central emphasis is on reducing resource consumption and managing environmental consequences [12]. Further, as reported in [13], the shift towards a CE is the requirement for reaching sustainability. A CE is an interdisciplinary topic that encompasses several fields of expertise, with the objective of banding together the enhancement of ecological well-being and financial growth for sustainable ecological development [14]. Indeed, the CE seems to encompass a diverse array of ideas and principles, making it more akin to an umbrella concept. The CE draws inspiration from a variety of sources, including concepts like Cradle to Cradle, Industrial Ecology, Biomimicry, Performance Economy, Blue Economy, Natural Capitalism, and Industrial Capitalism, among others [15]. From this perspective, the implementation of CE strategies in the healthcare sector could represent a response to the growing environmental threats. In fact, a CE primarily aims to reduce pollution and waste while simultaneously generating economic benefits [16], and is built on the suitable and ecological utilization of resources [17]. Moreover, a CE plays a pivotal role in guiding economic development towards sustainability, representing a sustainable profitable system in which the economy improves; it is disconnected from the consumption of resources thanks to the reduction in use and recycling of natural resources [18]. Reaching a CE predominantly means ensuring the reduction in the environmental effects of production and the efficient reuse and recycling of products, developing community interventions to adapt customer behavior to CE requirements [16]. For all the above reasons, the healthcare sector, and in general, all types of institutions, can support positive environmental policies [19].

Furthermore, researchers contend that the transition towards circularity is closely connected with the digitalization transformation [20]; Industry 5.0, conceived to use man's originality expertise in cooperation with intelligent and precise apparatus, is designed to enhance customer satisfaction [21]. In this sense, Industry 5.0 is facilitating the individualized tracking of essential health metrics, such as monitoring blood pressure and blood sugar levels, and offering customized medical care [21]. Likewise, green innovation or eco-innovation can be helpful in preserving environmental management, as it is a method focused on the development of novel advancements in production and technology, all while striving to mitigate environmental hazards, such as pollution and adverse impacts stemming from the exploitation of resources [22].

This method is commonly associated with the triple bottom line concept, which encompasses social, environmental, and economic operations [23]. Due to the huge environmental impacts of the healthcare sector, and the consequent necessity to achieve sustainable development, the purpose of this paper is to comprehend how the sector embraces circularity, identifying the most representative CE practices implemented in the sector.

Indeed, reference [24] demonstrates the existence of untapped sustainability opportunities that have not been thoroughly investigated yet.

In this context, a CE could be considered as a pathway to advance specific SDGs, for example, encouraging facilities to assume more responsible and sustainable practices (Goal 12) [25].

Up to now, the existing body of literature has been more focused on the depiction of singular practice, mainly implemented for healthcare waste management (HWM). While the circularity topic is currently researched within the sector, the categorization of existing practices is necessary and requires attention; none of the analyzed papers present a comprehensive overview of the above-mentioned practices. To achieve this goal, this paper addressed the following research questions:

RQ1: What is the state of the art in a CE implemented in the healthcare sector?

RQ2: What are the main areas of CE practices applied to the healthcare sector?

Following this Introduction, Section 2 presents a description of the literature review method applied, Section 3 underlines the main findings of the study, Section 4 critically examines the results, and finally, in the last section, the conclusions with the main outcomes are summarized, defining future outlooks.

2. Materials and Methods

The present section details the methodology employed for the literature review in this study, which involved both a systematic review and a bibliometric analysis. A systematic literature review involves "replicable, scientific, and transparent procedures to collect all related publications and documents that fit pre-defined inclusion criteria to answer a specific research question" [26]. Instead, a bibliometric analysis is the identification of emerging patterns in articles and a journal's impact, the examination of collaborative networks, and the investigation of the knowledge landscape within a particular field as documented in the existing literature [27]. A combination of both methodologies was proposed to obtain coherent, trustworthy, and robust research.

Sample selection was performed following the specifications suggested by the PRISMA protocol [28]. The systematic literature review was conducted to obtain a global view of the CE practices implemented in the healthcare sector. Figure 1 illustrates the comprehensive research method to provide transparency and allow readers to understand the methodology used to ensure the appropriateness and quality of the sources included in the study.

First, the study objectives, questions, keywords, inclusion and exclusion criteria, and databases were developed. Scopus and Web of Science (WoS) were used concurrently as main sources through the employment of chosen keywords in the title, abstract, and keywords of publications according to the Boolean operators "OR" and "AND". The preference for these two sources was to ensure the inclusion of peer-reviewed articles. These articles, found in reputable journals, are considered high-quality studies, and their relevance and significance were verified [29].

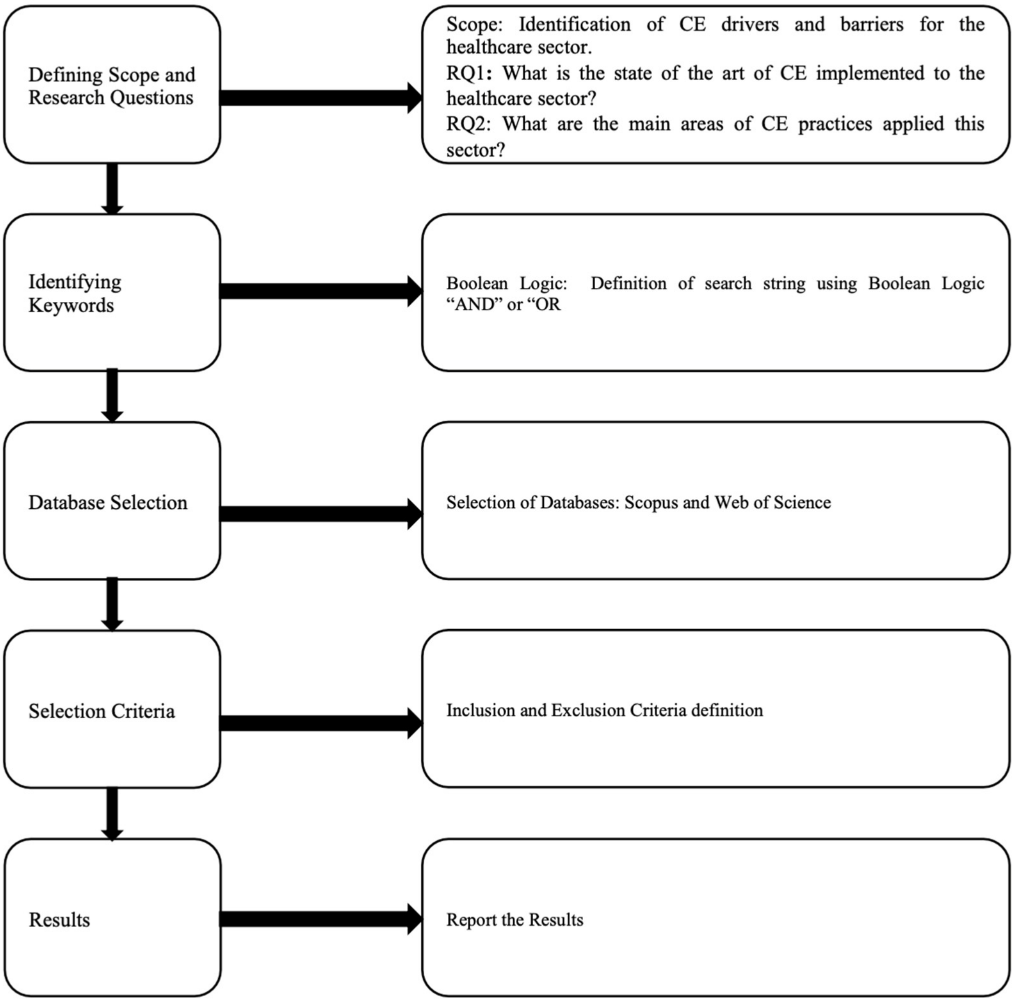

Figure 1. Methodological framework (Source: authors).

The search queries used to conduct the search are available in Table S5 in the Supplementary Materials.

Paper collection was conducted in January 2023; thus, potential forthcoming publications were not taken into account. Afterwards, inclusion (I) and exclusion (E) criteria were defined to evaluate the studies (see Table 1). In addition, articles presenting CE practices applied in multiple sectors were included if and only if one of the sectors analyzed is the healthcare sector, and only data regarding this were extracted.

Table 1. Selection criteria of the sources (Source: authors).

Inclusion Criteria	Exclusion Criteria
(a) Articles must be written in English	(a) Not aligned with the purpose of the study
(b) Accordance with the forward-looking perspective of the studies regarding circularity in the healthcare sector	(b) Inadequacy of information
(c) Main sector of application is healthcare	(c) If the document is a Conference paper; Conference Proceeding; Review; or Book Chapter
(d) Must present CE practices applied to the healthcare sector to face environmental challenges	

In the beginning, the above research strategy initially allowed the identification of a total of 324 articles: 203 from Scopus and 121 from WoS. The two results were merged in Microsoft Excel for Mac, Version 16.80. License Microsoft 365 to carry on the screening process (as shown in Figure 2). The PRISMA flowchart in Figure 2 enables readers to gain a comprehensive understanding of the systematic approach utilized for the identification and analysis of the literature, thereby reinforcing the credibility and reproducibility of the study's findings.

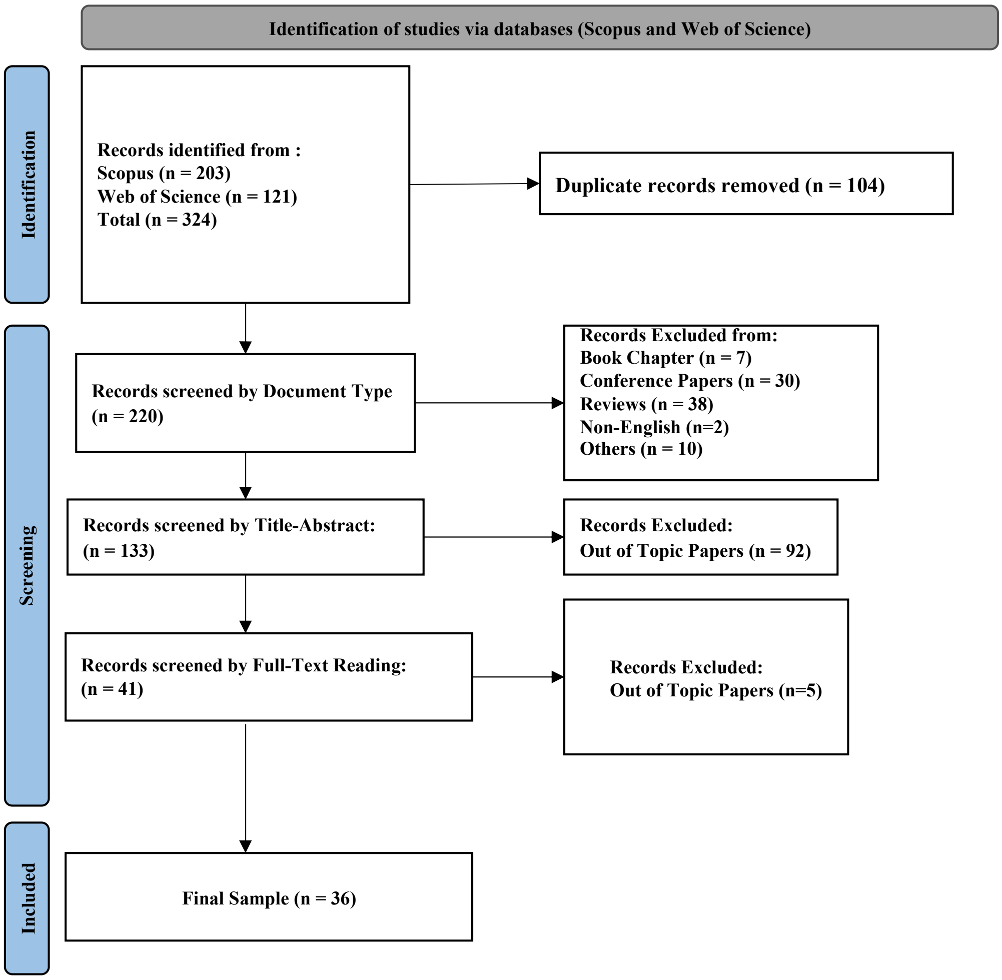

Figure 2. PRISMA flowchart.

The corresponding literature was analyzed to eliminate copies and all non-relevant documents, resulting in an initial sample of 220 articles. The residual articles were screened by considering the document type, excluding conference proceedings, book chapters, reviews, non-English language papers, and others. Thus, 133 articles were screened by taking into account titles and abstracts, not including papers that were off topic, reducing the number of articles to 41.

Later, the full text of these articles was downloaded in order to investigate it. This final screening process permitted the exclusion of five articles, leading to a total of 36 works.

While no temporal constraints were imposed in this analysis, papers deemed pertinent to the study's objectives could not be located preceding the year 2016, as delineated in Section 3.1.

From these 36 studies, the following types of data were extracted and analyzed: bibliometric data such as keywords, the journal and year of publication, subject areas, and geographical location of CE practices. Further, data concerning the practices (particularly their areas of application within the healthcare sector), benefits, and limitations were collected. Bibliometric data were represented in a network map, while the systematic review results were condensed into tables and charts.

Identification of CE Practices and Areas of Application

This section focuses on the practices gathered in the sample and emphasizes the specific areas in the healthcare sector where circular practices have been implemented. Table 2 provides an illustration of the categorization of these practices and their application areas.

Table 2. Classification of CE practices and areas of application (Source: authors).

CE Practice	Area of Application	Example
R-strategies: Analyze how to mitigate operating room (OR) waste through recycling and reuse possibilities. Reusing medical items, after thorough cleaning, decontamination, and sterilization, has shown potential in various areas, e.g., textiles (table covers, gowns, and facemasks), consumables (syringes and single-use plastic trays), and packaging. Recycling by optimizing the sorting process. Reuse options have emerged as the best solution [30].	HWM: It aims to identify and promote waste reduction and safe healthcare waste management, implement regulations to meet global standards, and raise awareness of safety practices [31].	Explore how waste can be minimized in large hospitals via eight observations and five expert interviews. Lowering medical waste cuts both financial and environmental costs [30].
Technology involvement: Clinical climate informatics can lead healthcare decarbonization efforts towards achieving net-zero emissions, minimizing electronic waste, advocating responsible resource management, and realizing environmental sustainability [32].	HSI: It develops awareness about CE strategies' importance to employees, patients, and all the actors involved in healthcare processes [33].	Involvement with relevant stakeholders to increase the awareness of environmental problems and foster change. Optimized algorithms, shared cloud computing resources, low-consumption CPUs, and telemedicine can be implemented to reduce energy consumption. Data analysis can be used to optimize work processes, procurement, and procedures, thus reducing supply waste [32].
Design opportunities: Tracks all materials entering and leaving intensive care through an MFA. The primary environmental footprint is from everyday materials instead of materials designated for specific therapies such as non-sterile gloves, isolation gowns, bed liners, surgical masks, and syringes, giving support to a shift to a circular system in intensive care [34].	Medical devices and supplies: It embraces a wide range of objects and substances, including instruments, apparatuses, implements, machines, materials, medical, or surgical items that are consumable, expendable, disposable, or non-durable for a medical purpose [35].	Application of a Material Flow Analysis (MFA) allows for an assessment of the environmental impacts of key product groups, including weight, carbon footprint, agricultural land occupation, and water usage [34].
Stakeholder involvement: Healthcare stakeholders demonstrate the capability to enact sustainable supply chain management practices and wield substantial influence in elevating the organization's sustainable performance and maintaining a heightened awareness of sustainability [36].	HSC: The healthcare supply chain sector, a significant contributor to worldwide greenhouse gas emissions, is linked to organizational factors, including forging partnerships, delineating roles and responsibilities, and coordinating and managing interface processes [37].	Examination of supply chain strategies aimed at achieving a circular economy within the Indian healthcare sector. Empirical research involving 145 healthcare organizations reveals the hidden connections of stakeholder involvement, sustainable supply chain practices, sustainable performance, and the circular economy in the sector [35].

Table 2. *Cont.*

CE Practice	Area of Application	Example
	HT: It incorporates actions to enhance consciousness about healthcare treatment to reduce carbon footprints [38].	LCA analysis to measure the carbon footprint of breast surgical treatment, revealing less environmental impacts for telehealth visits [38].
	HCP: It covers actions for the proper management of construction processes to ensure the control of CO_2 emissions [39].	Recommendations for sustainable materials in order to enhance environmental protection [39].

3. Results

In this section, we present the main outcomes of our academic literature review, discussing the data obtained from the bibliometric analysis and the relevant practices of circularity implemented in the healthcare sector.

3.1. Bibliometric Analysis

A bibliometric analysis was conducted using VOS viewer Version 1.6.18 to cluster emerging fields related to the chosen topic. The analysis also examined connections among publications and keywords to identify strengths and gaps in the topic and publications. In particular, in the 36 selected papers, the correlations between the keywords used by the top authors were determined through a co-occurrence network map (Figure 3).

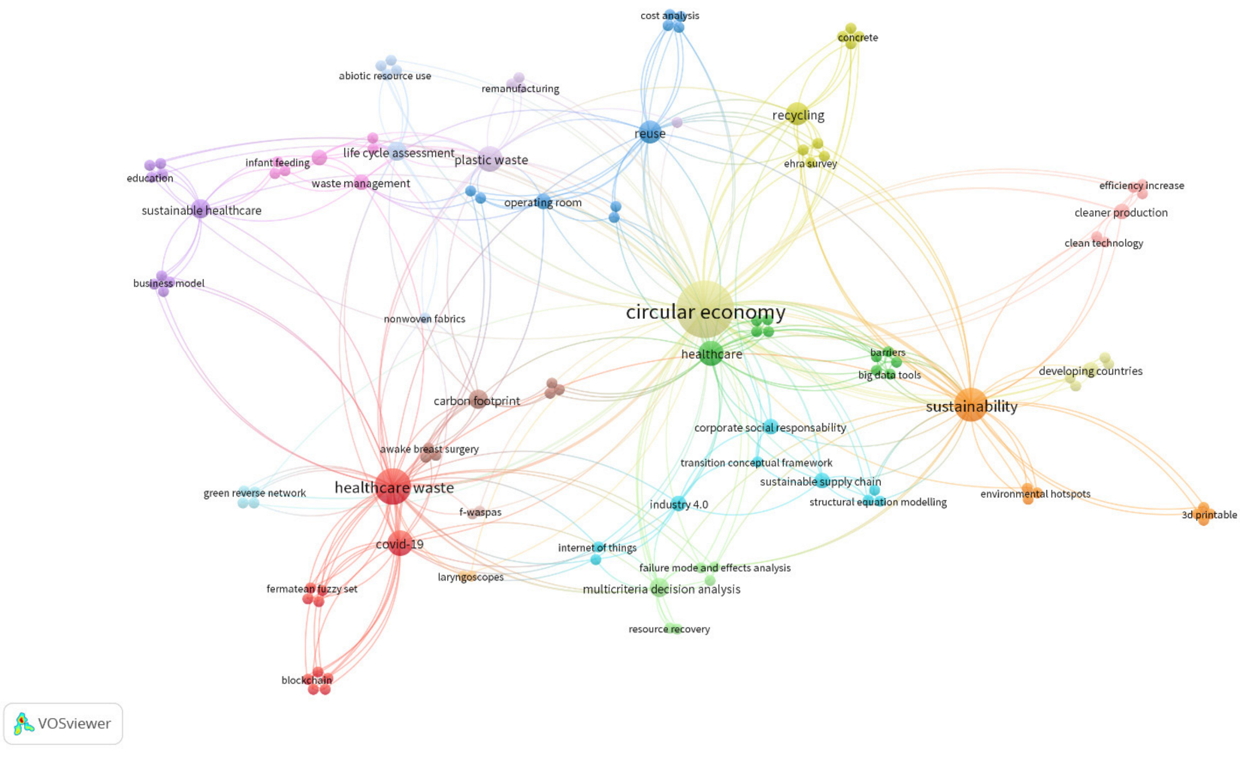

Figure 3. Co-occurrence network map (Source: authors).

The thickness of the lines in the map indicates the strength of the correlations between the nodes (keywords). This strength is calculated by tallying the number of publications where the two keywords appear together. A total of 122 fixed keywords were tested in order to standardize the topics. Of the 122 items in the network, 117 items were connected to each other. The resulting network graph presents clear connections among the investigated keywords, grouped in colored clusters. The most frequently occurring keywords in the study are "circular economy", "healthcare waste", "sustainability", and "plastic waste".

Specifically regarding "plastic waste" and "healthcare waste", they appeared connected with "life cycle assessment". Additionally, the network analysis revealed a connection between the issue of "plastic waste" and "remanufacturing", as they appeared in the same cluster (liliac). Furthermore, there is a correlation between "operating rooms" (ORs) and "reuse" (blue cluster). Similarly, the keyword "Industry 4.0" occurs many times and is linked to the repeated keyword "Internet of Things", and also connected to "sustainable supply chain", to which technologies and the keyword "stakeholder involvement" (light blue cluster) were interconnected, aiming at the achievement of circularity. Moreover, the keywords "waste management", "single-use plastic", and "decontamination" are consistently grouped together (purple cluster). Lastly, "recycling" and "reprocessing" practices are strictly interconnected with a CE (grouped in the dark yellow cluster). Further, to inspect the progress of implementation of CE practices in the healthcare sector, the final group of 36 papers was analyzed by year and considering the journal of publication, as shown in Figure 4. This provides a snapshot of the scholarly activity and the dissemination of knowledge regarding the subject matter.

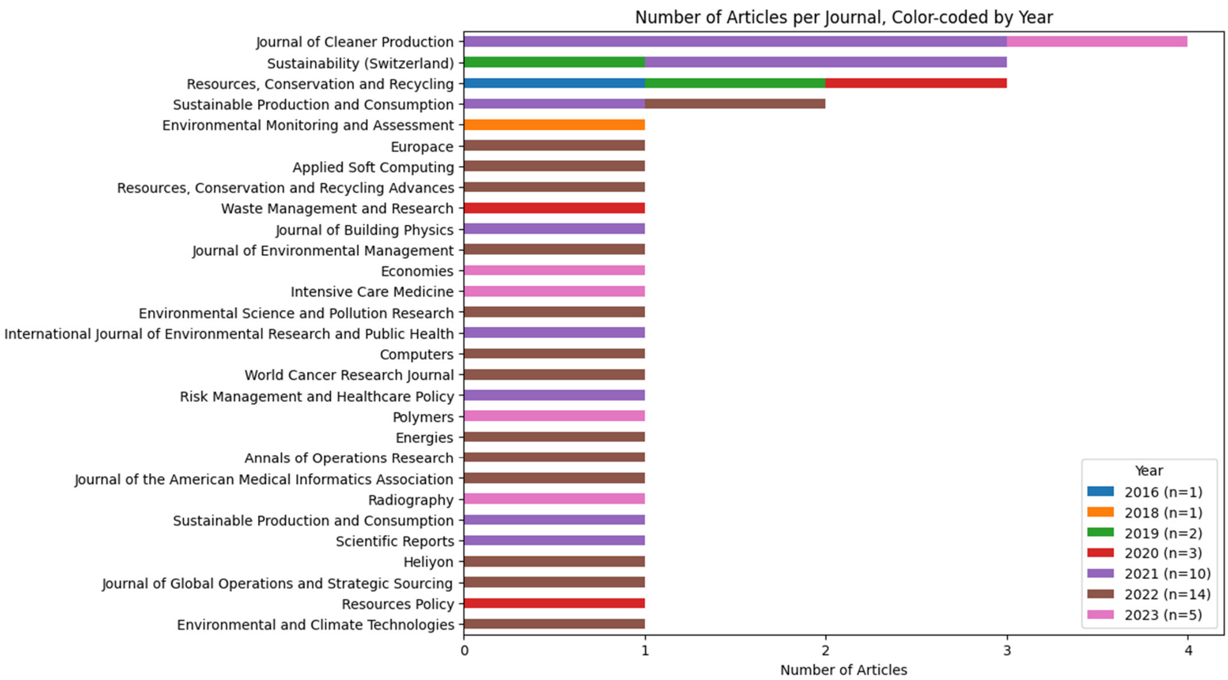

Figure 4. Count of articles distributed per year and by journal.

The first of these works was published in 2016 [40]; prior to 2021, there were only seven publications [40–46], but there was an explosive increase in that year [30,33,37,39,47–52]. Moreover, fourteen publications were recorded in 2022 [32,36,38,53–63], while in 2023, there were only five [34,64–67]. Additionally, the figure illustrates the distribution of articles among different scientific journals, considering the distribution by year as described. Importantly, this study was conducted in early 2023, which accounts for the relatively low number of articles retrieved for this year. The *Journal of Cleaner Production* (JCP) emerges with the highest publication count, with three articles in 2021 [33,47,52] and the most recent one in 2023 [66]. Starting with Resource, Conservation, and Recycling, the first publication on this subject was in 2016 [40]. Subsequently, two more articles were published in 2019 [45], and the most recent one was published in 2022 [56]. Moving on to Sustainability, it has received growing attention from 2019, as evidenced by reference [42]. However, in 2021, there was a decline in this interest, marked by the publication of the last two identified articles on the topic, which are [30,49]. Similarly, the *Journal of Sustainable Production and Consumption* received scholarly interest, as evidenced by the presence of two articles published in both 2021 [50] and 2022 [55], underscoring a commitment to this subject matter. Conversely, the remaining journals published only one paper delving into CE practices, with a particular focus on their implementation within the healthcare sector.

Furthermore, from an examination of research areas per journal, in addition to 15 subject areas of interest emerging, a clear focus on the environment in the subject area emerges, as "Environmental Sciences" is the prevailing area (27.40%), followed by "Engineering" (15.07%), "Medicine" (9.59%), "Economics, Econometrics and Finance" (8.22%), "Business, Management and Accounting", "Computer Science", and "Social Sciences" (6.85%). The other areas with minor relevance are displayed in the Supplementary Materials in Table S3. Finally, the analysis illustrates how publications are distributed geographically by country according to the context in which the studies were conducted.

The outcomes showed that significant contributions were made by the Netherlands (six publications) [33,34,50–52,62], followed by India (five works) [36,46,47,54,56], Spain [39,65], and Iran (two articles) [57,58]. Additionally, the analysis revealed that two articles did not specify the country (indicated as "Not Specified" countries) [32,48], while four articles were labeled as "Multiple countries", due to their reliance on surveys and questionnaires that were administered in more than one country [40,43,53,67]. The Supplementary Materials contains information on the other geographical areas with minor contributions in Table S1.

This examination demonstrates how Europe has made substantial contributions (58%), while Asia (22%) has been increasingly interested in transitioning from the conventional linear model to the implementation of CE practices in the healthcare sector. On the other hand, South America has made fewer contributions (6%), while 11% of contributions did not specify any continent or country.

3.2. Classification of CE Practices

This systematic analysis focuses on examining the well-studied CE practices within the healthcare sector, as documented in the literature, to evaluate their benefits and challenges. It involves classifying and analyzing the CE practices discussed in the collected articles (as shown in Figure 5).

To categorize CE practices in the healthcare sector, several practices were identified in the literature, including recycling, reuse, reprocessing, refurbishment, and recovery, which collectively constitute 47% of the strategies applied within the sector. These practices fall under the established categorization of "R-strategies". They are designed to mitigate the depletion of natural resources and reduce material consumption, all while actively attempting to minimize waste generation [49]; they include refusal, repair, remanufacture, reuse, repurpose, refurbishment, recycling, and recovery. In the hierarchy of circular strategies, "refusal" stands out as the most impactful, whereas "recovery" ranks as the least impactful [34]. Other practices designated as "technology involvement" underscore the role of technology in healthcare processes as a strategy to promote circularity (20%). The primary aim of healthcare waste technologies is to minimize the potential risks associated with waste. These technologies include thermal, chemical, irradiative, and biological treatment methods, alongside mechanical treatment technologies, and they serve as the primary methods of waste management [63]. The research has also identified other circular strategies, such as the redesign of products and processes to consider their end-of-life fate. These strategies, known as "design opportunities", account for 25% of the total practices identified.

Lastly, the familiarity and awareness of customers, particularly patients, and employees are considered potential drivers of CE adoption, representing a significant portion (8%), termed as "stakeholder involvement".

Categorization of Areas of Application

The analysis of the full text reveals several areas within the healthcare sector where CE practices have been applied, categorizing them by geographical areas. These findings are summarized and presented in Figure 6, providing an overview of the prevalence and distribution of CE practices across different categories within the healthcare sector and the geographical areas of their implementation.

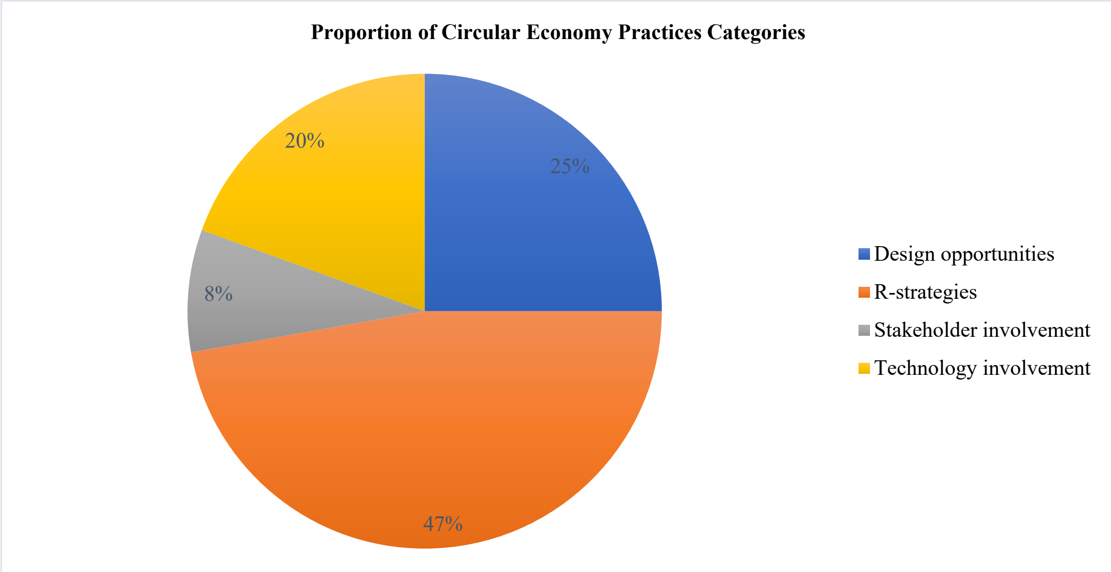

Figure 5. Classification and quantification of CE practices, according to the systematic analysis conducted by the authors.

Notably, HWM has received significant attention from scholars (39%). From this assessment, it emerges that the geographical area more interested in this category is Asia, with three articles originating from India [47,54,56], two from Iran [57,58], one from Pakistan [41], and another from Vietnam [59]. Following Asia, Europe also shows a significant interest in the category, with two articles on CE practice for waste management in the Netherlands [50,52], one in Belgium [30], one in Turkey [61], and another in Latvia [63].

Further, another important area of application has been identified, medical devices and supplies (39%), which encompasses a wide range of practices involving apparatus, tools, implants, in vitro reagents, and disposable or semi-disposable elements used individually or in combination for medical purposes. The focus on practices related to the circular use of devices and supplies is most pronounced in Europe, with three studies conducted in the Netherlands [34,51,62] and two articles spanning multiple countries, labeled as "Multiple Countries" [40,53]. Furthermore, individual studies in this category are located in various European countries, including the United Kingdom [55], the Czech Republic [64], Ireland [45], Spain [65], Denmark [66], and Germany [49]. Moreover, one work within this area does not specify a geographical region and has consequently been categorized as "Not Specified" [48].

Additionally, CE practices implemented in the supply chain have also been identified and are classified under the healthcare supply chain (HSC) category, although there are fewer publications than other areas (8%). The three publications focused on the HSC were conducted in Turkey [37], India [36], and Brazil [42]. Likewise, another category, given the healthcare stakeholder involvement (HSI) label, accounts for 8% of academic interest. These practices, related to the involvement of healthcare stakeholders, workers, and patients, are only addressed in a paper conducted in the Netherlands [33], in a study conducted in "Multiple Countries" [67] and in a study with no specified geographical area [32]. In conclusion, the final two areas in which CE practices were employed were categorized and designated as healthcare treatment (HT) and healthcare construction processes (HCPs). Academic attention was directed towards HT with a total share of 3%, with research conducted in Italy [38]. Meanwhile, HCPs, also representing 3% of the sample, are linked to a study conducted in Spain [39].

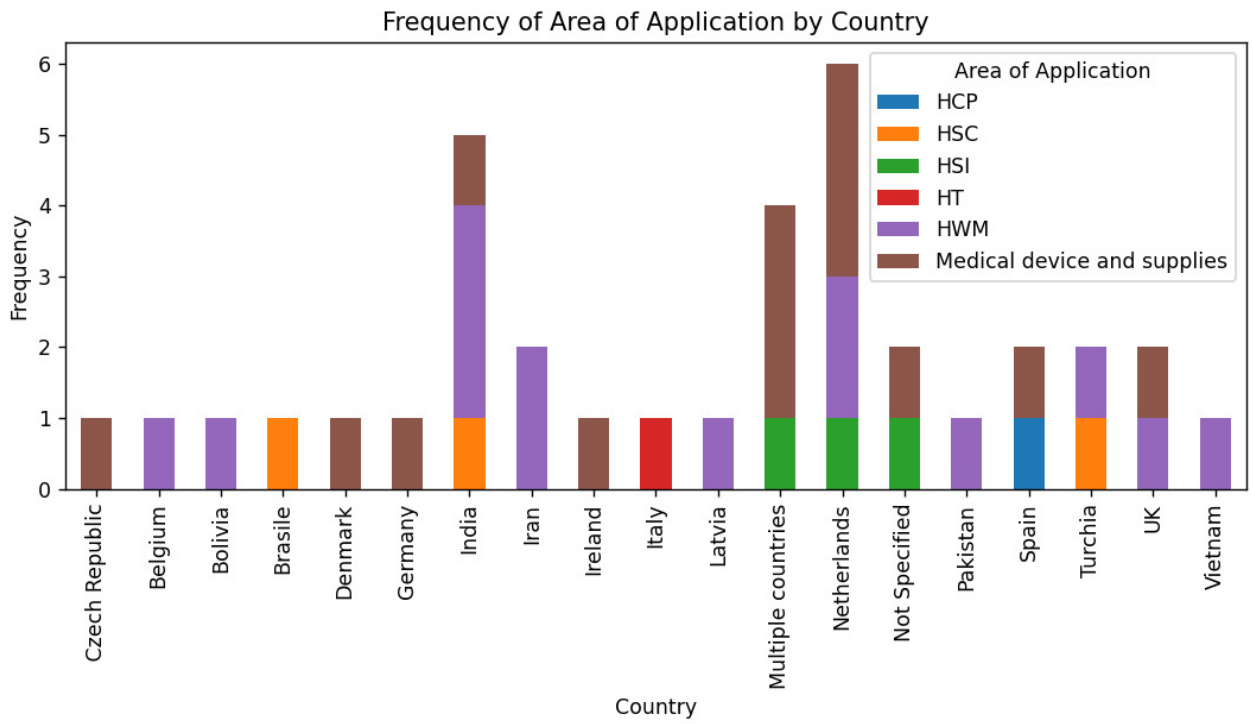

Figure 6. Frequency of CE practices distributed per category and country of application.

4. Discussion

The bibliometric analysis has outlined that the CE concept applied to the healthcare sector as a relatively recent development, as the first article in the collected sample was published in 2016; however, from 2021 to now, the increasing number of articles shows the growing interest of researchers on this topic, with a specific focus in Europe. In this regard, the analysis of keyword occurrence underscores the prevalence and interconnectedness of sustainability and healthcare waste within a CE. Remarkably, keywords such as "remanufacturing" are linked to the plastic waste issue, as it can be considered a solution to the plastic problem. Specifically, following an evaluation of the mechanical recycling of clinical plastic waste for secondary plastic recovery, it becomes evident that incorporating a design that considers the environment in the initial stages of plastic production is essential. This ensures the feasibility of post-use segregation and remanufacturing and enables the assembly and disassembly of material components as needed, thereby extending product life cycles indefinitely [60]. Further, it is evident that ORs are responsible for generating huge amounts of waste, suggesting that the implementation of reusable solutions could serve as a viable remedy [30]. Similarly, the connections between "waste management", "single-use plastic", and "decontamination" keywords can be attributed to the substantial usage of single-use plastic products in this sector, which ultimately leads to waste. Particularly, potential strategies for addressing this issue encompass several options, such as reducing the demand for single-use bottles, exploring alternative solutions for eliminating them, encouraging manufacturers to address product design [45], and motivating policymakers to implement consistent labeling systems for the recycling of materials and the enhancement of waste management and to implement collaborative efforts and assistance systems to achieve sustainable resource management [45].

Furthermore, the analysis of the subject area of the 28 journals in which articles were published clearly marked the close correlation with environmental science; in that light, the sector's profound link to the environment becomes evident, in addition to medicine, engineering, and business and accounting.

Moreover, in line with the co-occurrence analysis, the field of medical devices and supplies was highly prominent, together with the HWM area. Articles on the former were concentrated in Europe, and the latter in Asia.

Nevertheless, we aim to delve further into the assessment of CEs within the healthcare sector by comprehensively outlining all the practices that have been identified in this research. Particularly, the practices identified are categorized as an "R-strategy", considered a pivotal solution to mitigate environmental harm and its associated costs. These practices encompass the use of reusable medical devices [64]. For example, while reusable gynecological speculums have a negative environmental impact during the disinfection and sterilization phase due to the use of ethylene oxide or detergents, this impact is comparatively lower than that of disposable medical devices [64]. Despite this, a notable limitation arises from the preferences of physicians and patients, who often opt for disposable devices [64]. Further, an analysis has been conducted to assess the value of used laryngoscopes [40], with the aim of restoring the intrinsic value of materials. Achieving increased circularity in the management of used laryngoscopes lies in the sourcing of these devices; however, more efficient communication between relevant departments and staff involvement are necessary. One prominent application of reprocessing is the steam sterilization of medical equipment, particularly face masks. Notably, reprocessed masks exhibit a reduced carbon footprint compared to disposable masks, as indicated by the findings of a life cycle analysis (LCA) performed in [51]. A LCA is a methodological approach that evaluates the environmental impact of a product or service throughout its entire life cycle, from raw material extraction to disposal [68,69].

Moreover, the collected sample allowed the identification of the emergence of "design opportunities" practices. A prime example is presented by the development of 3D-printable bioresorbable materials for orthopedic implants (such as bioactive ceramics and bioinert ceramics), which not only reduce waste but also utilize less material during the manufacturing process. However, the limitation posed by 3D-printable bioresorbable materials lies in their sensitivity to repeated stress, which confines their use to small bones [46]. Another example involves designing a circular healthcare business model; gowns integrating nonwoven polyester exhibited worse environmental consequences in comparison to their counterparts composed of nonwoven polypropylene. A circular economy model centered on non-sterile polypropylene gowns holds the potential to slash carbon emissions given the increased usage of these gowns [65].

Further, "technological involvement" has been delineated as a new CE practice area. In fact, emerging technologies could play an important role in strengthening and accelerating the transition into a more circular and sustainable healthcare sector. Indeed, the introduction of technologies such as blockchain technology in [59], even if it is only the first trial of substituting traditional waste treatment processes with this technology, represents a potential solution to the production of waste in order to foster sustainable development. From this perspective, smart waste management is a strategic approach that leverages advanced technologies to guarantee a reduction in medical waste generation [59].

CE strategies identified in the sample also provide a clinical informatics framework designed to mitigate healthcare's contributions to environmental pollution and climate-related effects [32] and to adopt big data [37] to obtain social, economic, and environmental benefits. The framework proposed in [32] can play a fundamental role in promoting the contribution of health information technology (IT) in enhancing environmental sustainability and the betterment of planetary health in healthcare settings. However, the high costs for the implementation of these technologies [37] in this sector represent a major limitation, due to which their application is still a slow process. Finally, the last CE practice area identified was termed "stakeholder involvement", which foresees stakeholder engagement as essential for achieving the common goal of mitigating negative environmental impacts and lowering carbon emissions for the shift toward a CE [37].

Subsequently, in this study, we attempted to provide a categorization of the application areas of the aforementioned circular practices. "HWM" is the first identified area, which aims to promote the reduction in healthcare waste, with a focus on sustainable development as one of its guiding principles [31]. Studies concerning this aspect were concentrated in Asia. The majority of practices for HWM encompass recycling strategies; this offers clear benefits within the CE framework for the preservation of natural resources and reducing the need for extracting new materials. From this standpoint, reuse and recycling processes can contribute to reducing the costs caused by the extraction and processing of natural resources, minimizing healthcare waste. For example, as stated in [60], the reuse, or recycling, if the reuse process is not feasible, of plastic waste could ensure the transition toward a CE. Moreover, ORs are liable for 33% of the waste generated in a hospital [30].

In [30], reusing strategies were introduced to manage waste generated in ORs, registering benefits that extend beyond mere financial savings and leading to a decrease in the environmental impacts. Further, refurbishment and repair were identified as practices to enhance circularity. Refurbishment, for the revitalization of obsolete products and their transformation to align to contemporary standards, alongside the repair strategy, is an optimal solution to avoid waste and costs linked to its disposal [50]. However, ref. [50] evaluated the viability of implementing a circular approach for repurposing discarded medical instruments and stainless-steel waste within hospital settings, ultimately showing that repairing and refurbishing surgical instruments, rather than replacing them with new ones, hold the greatest potential for cost reduction and environmental benefits.

This study focuses on "medical devices and supplies", an area of significant scholarly interest, possibly driven by the positive impacts associated with their circular utilization. In particular, practices falling into this category are primarily classified as an "R-strategy", as possible solutions to manage environmental risks and their related expenses. To address these issues, it is imperative to enhance interdepartmental communication and increase staff involvement.

Thus, the area labeled "HSC" encompasses the reduction in overall resources needed to provide the required level of customer service by increasing product availability, decreasing the time taken for order processing, and simultaneously lowering costs. It is apparent that, for the overwhelming bulk of global greenhouse gas emissions within the HSC, the application of big data technologies is crucial for optimizing the healthcare supply chain [37].

Despite this, a lack of studies in this area was noted; however, the sustainable management of the supply chain could be useful to foster circularity and reduce environmental impacts and the creation of waste by enhancing collaborative partnerships with healthcare professionals.

Likewise, the HSI is another delineated area, including stakeholder, patient, and employee value and involvement, more focused on the social dimension of sustainability, which receives attention from European academics. Establishing familiarity and awareness among human resources engaged in healthcare processes could lead to circularity [37]. Ref. [67] emphasizes the importance of raising awareness among therapeutic radiographers/radiation therapists regarding the several facets of integrating a CE into healthcare, for example, "sustainable transportation", "eco-conscious procurement", "innovative hospital architecture", "efficient food processing", "water conservation", "energy sustainability", and "effective waste control". However, it could be interesting to consider the importance and also the point of view of other relevant actors involved in healthcare processes, like non-specialized figures such as manufacturers, managers, administrators, cooks, and cleaning attendants, to provide a more comprehensive perspective. Stakeholder engagement practices have been acknowledged as essential for achieving the common goal of becoming sustainable [66]; indeed, employees are also responsible for the consumption and separation of products, while producers could redesign medical devices and products to improve end-of-life solutions that can be reused [66]. Nevertheless, there is a lack of adequate training for patients and workers on circular practices. In this sense, a significant obstacle to the implementation of a CE within this sector arises from healthcare workers and professionals having a limited awareness of environmental issues due to insufficient human resources capabilities [37]. It is crucial to enhance their understanding to minimize the environmental consequences of their actions, while also considering the economic outcomes.

Finally, the last two areas identified in this study, which garnered less interest, are HT and HCPs. Although little attention from academics is focused on these subjects, these two areas represent fundamental aspects of the healthcare sector, as their proper management can ensure the reduction in or at least the control of CO_2 emissions [38,39]. To reduce environmental pollution due to treatment, the use of telemedicine is considered a CE solution [38]; instead, in [39], they show that concrete and steel are the most polluting materials. Therefore, by paying more attention to these identified practices, we can unlock the potential for positive environmental, economic, and social outcomes in the healthcare sector.

For example, in [49], the potential of reusing disposed medical devices and stainless-steel waste is demonstrated, while the possibility of cost-cutting in repair and recycling is considered, a new base for surgical waste management is produced, and long-term environmental benefits are actualized. The study indicates that the environmental benefits increase as the collection rates of catheters rise [49]. Further, in [56], it is shown that pharmaceutical blisters (PBs) ground into a powder form and incorporated into concrete, partially substituted with sand, with the aim of recycling PB waste and preserving natural aggregates, could represent a potential solution to fulfil sustainable development goals [56].

Another research work shows that reusable masks create 80–90% less waste than single-use face masks, and have up to 11-fold lower climate change impacts [55]. Moreover, the calculation of the ecocentric value of embodied energy in healthcare waste, performed in [41], proves the value of 100% waste recycling, which can help mitigate the costs of extracting virgin resources. An analysis of intelligent and sustainable technologies within healthcare facilities found that they can contribute to cost savings and enhance staff comfort [42]. Lastly, attention on the social dimension could lead to educational programs that can empower professionals to adjust their practices for greater environmental sustainability [67]. Additionally, the implementation of adaptive treatment methods, such as 3D printing technology [46] or telemedicine [38], contributes to enhancing social sustainability. While the majority of studies tend to emphasize environmental considerations, it is important to recognize that the implementation of circular practices in healthcare holds the potential to not only enhance economic sustainability but also yield positive social impacts. To summarize, the effective management of various categorized areas within healthcare organizations can lead to significant progress in building a more sustainable sector, reducing environmental impacts and fostering a healthier future for both people and the planet.

Hence, these CE practices are a cohesive framework for reorganization at the system level, and by using innovation and creativity, they can pave the way to a constructive and regenerative economy [70]. Consequently, by addressing barriers associated with sustainability in the healthcare sector, CE practices, promoting sustainable resource management and elimination of waste and pollution, hold a crucial role in meeting the SDGs [71]. Although there is not a distinct and specified elucidation of the realized benefits with regard to the SDGs, the identified practices appear to align to SDG 12: Responsible production and consumption. This involves achieving sustainable management and productive utilization of natural resources, as well as substantial waste reduction through prevention, reduction, recycling, and reuse. Additionally, some of these practices [32,37,38,59,63] could be in harmony with SDG 9: Industry, innovation, and infrastructure. SDG 9 emphasizes the modernization of infrastructure industries to make them sustainable, promoting a higher efficiency of resource use and encouraging the adoption of clean and environmentally friendly technologies and industrial processes, making them reliable, sustainable, and resilient.

Despite the growing interest in this topic, the absence of an established classification of CE practices hinders the development of circular healthcare businesses, as does the lack of appropriate behavioral, regulatory, and policy guidance. These recognized practices could be useful for the sector's relevant stakeholders. Thereby, it is recommended to implement managerial, policy, and theoretical measures that support sustainable development initiatives in the healthcare sector, ensuring the effective management of environmental, social, and economic outcomes throughout the process. In this sense, the primary objective of CE practices is to reduce resource consumption, waste production, emissions, and energy depletion [72], while simultaneously promoting social and economic growth; thus, the potential of employing a CE as a vehicle to advance certain SDGs has been suggested [73].

Further, the connection between Industrial Ecology (IE) and a CE is incontrovertible, since IE was denominated as a science of a CE, and central IE tools, such as LCAs or Material Flow Analyses (MFAs), have been gradually implemented within the sustainable CE framework [74]. However, a limited application of IE tools in contrast to other analyses found in the sample, for instance, Multi-Criteria Decision Analyses (MCDAs) and fuzzy theory, [58,61,63], was registered. LCAs were performed in five studies [39,49,51,55,65]; in contrast, only one study was identified that utilized an MFA to evaluate material flows within the healthcare sector [34]. An MFA focuses on managing and quantifying the stocks and flows of substances or materials within a specific system and serves to provide control and measurement over material movement across various stages [75].

Material Flow Analysis or Substance Flow Analysis could be a useful tool for sustainability assessment since it admits in parallel, evaluating environmental and socioeconomic subsystems, together with an analysis of resource utilization [76].

However, it is important to note that research in the field of circular practices within the healthcare sector is still in its early stages, and there are limited scientific studies on this topic.

This broader exploration not only enriches the understanding of circular practices in the healthcare sector but also bolsters commitment to achieving the SDGs, ultimately leading towards a more sustainable and patient-centered healthcare sector.

5. Conclusions

Through a systematic analysis and an in-depth examination of the relevant literature, this study has provided valuable insights into the implementation of CE practices in the healthcare sector, highlighting the pressing need to transform the sector into a more sustainable and circular one aligned with the SDGs. By presenting an overview of the current state of CE practices based on a bibliometric and systematic review, this research contributes to the advancement of sustainability in healthcare.

The increasing interest in CE practices within the healthcare sector reflects a growing focus on sustainability, particularly regarding waste management and resource consumption.

Specifically, the adoption of "R-strategies" addresses reducing waste, prolonging the usefulness of materials, and promoting circularity. Practices falling under "design opportunities" aim to redesign products and processes with attention on the final impact to reduce resource consumption and waste. "Technology involvement" practices are required to improve efficiency and innovation in the healthcare sector, sustaining economic growth and creating a sustainable infrastructure. Lastly, "stakeholder involvement" practices are fundamental for promoting CE adoption through collaboration. All these practices align to both Sustainable Development Goal 12: Responsible Production and Consumption and Sustainable Development Goal 9: Industry, Innovation, and Infrastructure. Although the specific benefits realized in relation to these SDGs are not explicitly outlined, some authors suggest that the proposed research could be a significant focal point in the Agenda for 2023.

Furthermore, these strategies have been applied in various healthcare areas, including HWM, medical devices and supplies, the HSC, HSI, HT, and HCPs.

The framework proposed in this article provides a comprehensive understanding of existing CE practices and offers valuable insights for future studies and applications.

It is important to acknowledge that this study has certain limitations. Firstly, the chosen keywords and database used may have resulted in the exclusion of relevant studies, as the literature on CEs within the healthcare sector is expanding rapidly. Nevertheless, this work represents an original contribution by the authors and represents progress in advancing circularity within the healthcare sector. These outcomes could be significant for the relevant stakeholders seeking to adopt the principles of a CE.

However, further research on CE practices in the healthcare sector should not be limited to qualitative approaches like this study. It is essential to integrate the findings of this review with quantitative IE methods in order to analyze and assess environmental risks more comprehensively. This will provide a more robust and global perspective for future research endeavors. In conclusion, the outcomes contribute to the existing body of knowledge on a CE in healthcare and pave the way for future studies that combine qualitative and quantitative approaches for a more holistic understanding of the environmental impacts and risks associated with healthcare practices.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16010401/s1: Table S1: Dataset; Table S2: Scheme codes; Table S3: Subject Areas; Table S4: Keywords; Table S5: Search queries.

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Abbreviations

The following abbreviations were used in this manuscript:

SDGs	Sustainable Development Goals
CE	Circular Economy
HWM	Healthcare Waste Management
HSC	Healthcare Supply Chain
HSI	Healthcare Stakeholder Involvement
HT	Healthcare Treatment
HCP	Healthcare Construction Process
OR	Operating Room
PB	Pharmaceutical Blister
IE	Industrial Ecology
LCA	Life Cycle Assessment
MFA	Material Flow Analysis

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