environments

Systematic Review

Advancing Environmental Sustainability in Healthcare: Review on Perspectives from Health Institutions

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Abstract: Hospitals play a key role in promoting sustainable and healthy living. Few studies have taken this perspective into account. Therefore, we explored the role of hospital institutions in the development and implementation of sustainability strategies linked to the provision of health services. Applying the PRISMA guidelines, we conducted a systematic review of the PubMed, Scopus, CINAHL, PsycINFO and Web of Science databases and the references of the resulting articles in Mendeley Desktop v1.19.8. Articles peer-reviewed between 2016 and 2023 were eligible if they analyzed sustainable healthcare, activities derived from services provided and professional involvement. From the 27 articles that constituted the final sample, two themes were identified: (a) environmental sustainability in healthcare and (b) involvement of healthcare professionals in environmental sustainability. Proposals for sustainable actions to reduce the environmental impact of healthcare related to the use of natural resources, sustainable food, sustainable transport and waste management were reviewed. The role of healthcare workers, their attitudes and perceptions of sustainability and global health improvement were investigated. Reducing health pollution involves addressing excessive or inappropriate consumption of resources and minimizing the environmental footprint of healthcare activities. The different contexts reveal the heterogeneity of the sustainability interventions existing in the healthcare industry, both in terms of subject matter and in terms of the number of publications from each country.

Keywords: development strategies; green hospital; healthcare sector; sustainable development

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1. Introduction

The World Health Organization (WHO) has declared that climate change presents a threat to human health in terms of death and illness from increasingly extreme weather events, such as heatwaves, storms and floods; the disruption of food systems and an increase in vector-borne diseases. Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year from undernutrition, malaria, diarrhea and heat stress alone. Furthermore, it is undermining many of the social determinants of

good health, such as livelihoods, equality, access to healthcare and functioning of health systems and social support structures [1]

Healthcare and, more specifically, hospitals, play a crucial role in contributing to environmental deterioration, since they generate pathological, pharmaceutical, chemical and radioactive waste, posing significant health risks [2]). Health activities in Western countries such as Canada emit thousands or millions of tons of greenhouse gases and other pollutants each year, which has resulted in the annual loss of 23,000 disability-adjusted life years [3].

The future quality of health services in terms of climate resilience and environmental sustainability is directly related to support health systems to leapfrog to cheaper, cleaner and more reliable solutions, while decarbonizing high-emitting health systems [1].

Some strategies to mitigate the environmental and health impact generated by the provision of health services are being carried out in several dimensions. Firstly, it is worth highlighting the modernization of facilities with new technologies and the design and construction of ecological hospitals through thermal (electrical energy savings and solar protection), acoustic (patient comfort and no noise pollution) and lighting strategies (i.e., openings in building facades) [4]. Several studies have determined that the introduction of elements to provide greater interior thermal comfort (i.e., an increase in relative humidity) reduces the load on air conditioning systems [5,6]). In fact, the results of the first study reflected that increasing indoor relative humidity by 10% reduced the cooling load and energy consumption by 24.9% in green hospitals compared to conventional hospitals.

Secondly, the implementation of sustainable measures can be driven by political and management commitments. In fact, new business models are emerging for pharmaceutical companies, where innovation is a key element in improving sustainable development, especially in the field of green technologies [7]. To achieve this, regulatory frameworks and management plans as well as awareness among managers and health professionals are necessary. Results from several studies show that the corporate responsibility of a proactive manager or leader with high environmental values positively influences (39%) the pro-environmental behavior of healthcare professionals [8,9]). In addition, various authors support training in sustainable development, climate change or gas emissions, among others, to increase knowledge that can be reflected in the clinical practice of health professionals, in the generation of scientific data and in the proposal of new policies [10,11]

Finally, healthcare sustainability science also explores dimensions of resource consumption and environmental emissions associated with healthcare activities. Previous studies have shown that some proposals include the inclusion of new forms of care, such as telemedicine, which would contribute to a reduction in carbon emissions [12,13], the development of life cycle inventory databases for medical devices and drugs and revision of infection control standards driving non-evidence-based uptake of single-use disposable devices [14]. More simply, health education can itself be an ally of sustainability. In this way, advising more physical activity in parks, bicycling or walking, as well as reducing the consumption of prepared foods not only encourages more healthy active lifestyles but could also help reduce air pollution and the use of plastics.

Reducing pollution from healthcare involves addressing excessive or inappropriate consumption of resources and minimizing the environmental footprint of healthcare activities. Efforts to achieve these measures will result in higher-value care and better population health [15]. Therefore, given the active role that hospital institutions must develop to achieve global health and the direct relationship between sustainability initiatives and the well-being of the population, this work aims to explore the role of hospital institutions in the development and implementation of sustainability strategies linked to the provision of health services.

2. Materials and Methods

2.1. Study Design

A systematic review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [16] (Supplementary Materials) was conducted using five electronic databases: PubMed, Scopus, CINAHL, PsycINFO and Web of Science. The searches were performed by two researchers independently between December 2023 and January 2024, using the following Boolean expression, slightly adapted for each database: ("green hospital" OR "healthcare sector" OR "healthcare institution*" OR "sustainable hospital*") AND ("agenda 2030" OR "eco-friendly" OR "pro-environmental" OR "sustainable development" OR "sustainability development goals" OR "sustainability strategy" OR sustainab*).

2.2. Inclusion and Exclusion Criteria

Articles were included if they investigated sustainability issues related to healthcare and were (a) peer-reviewed articles published between 2016 and 2023 and (b) quantitative, qualitative or mixed-design studies. No language restrictions were applied. Articles were excluded if they were editorials, conference proceedings, opinion essays, literature reviews or books or if they did not address environmental sustainability in the healthcare sector. Studies that focused on policies and regulations regarding health environmental sustainability, as well as sustainability measures applied to health infrastructures, were also excluded.

2.3. Study Selection and Data Extraction

After the search, 1575 publications matching the search criteria were included as references in the software Mendeley Desktop v1.19.8. The screening procedure was carried out by two researchers independently, aiming to identify relevant studies based on the inclusion and exclusion criteria. First, duplicate publications were removed (n = 548); then, the reviewers screened 1027 articles by title and abstract. Two hundred and twenty-four full-text articles were screened by two researchers, and if there was a disagreement, another reviewer was consulted. After reading the full-text articles, our final sample included 27 studies. The flowchart is included in Figure 1.

Finally, the following items were extracted for each study: authors, country, year of publication, study objective, research design, sample characteristics and major findings (Appendix A). The summary tables were thoroughly reviewed by all reviewers independently, with critical discussions of the extracted data.

To develop the themes for this systematic review, a thematic analysis approach was used [17]. Two reviewers involved in the searches, screening, article evaluation and data extraction organized descriptive labels, focusing on emerging or persistent concepts and similarities or differences in the role of hospital institutions in the development and implementation of sustainability strategies linked to health service delivery. The coded data from each paper were examined and compared with the data from all the other studies. Finally, the different categories were gathered (grouped) into the following two themes: (a) environmental sustainability in healthcare and (b) engaging health professionals in environmental sustainability.

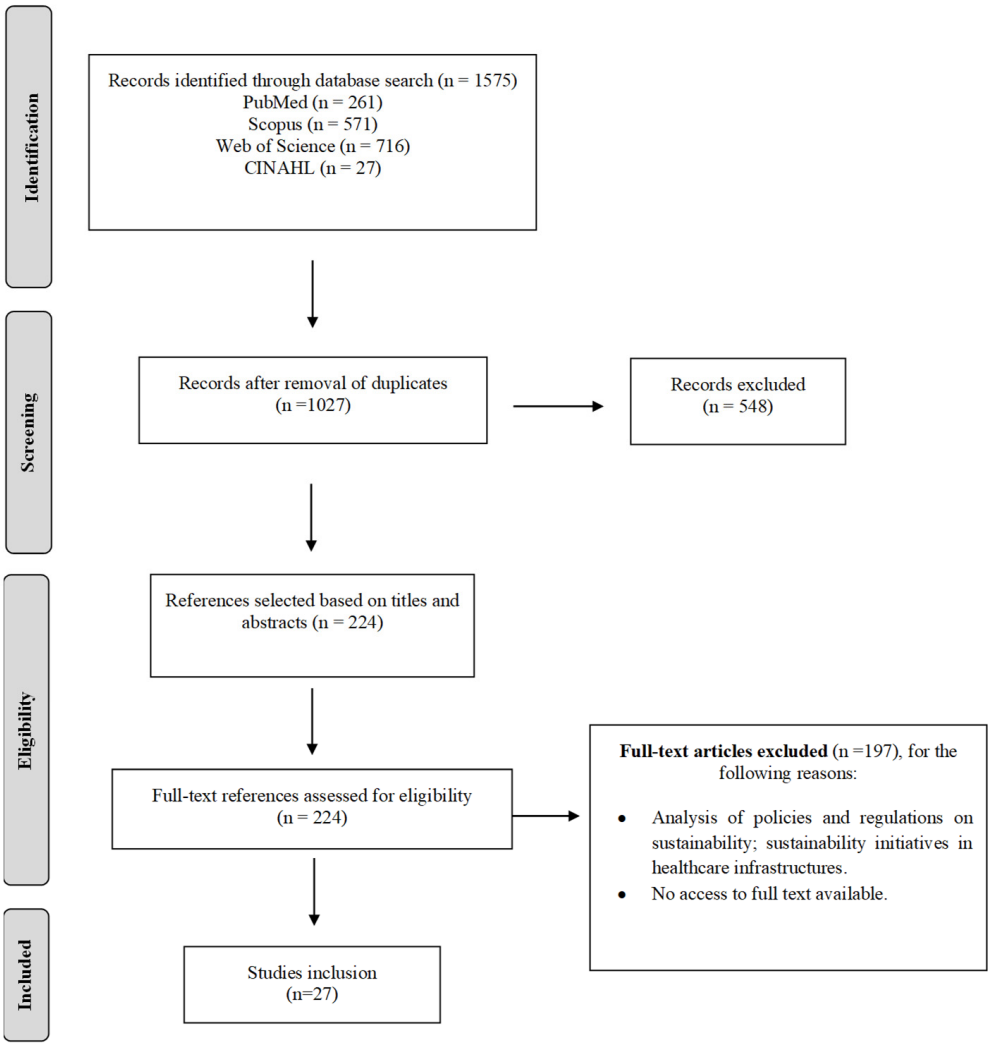

Figure 1. Flowchart for article selection in this systematic review. From Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit www.prisma-statement.org (accessed on 10 June 2024) [16].

3. Results

The results below show the main characteristics of the studies included in this review, as well as a qualitative analysis of the content based on the themes established by the authors.

Characteristics of the Included Studies

A total of 27 articles were included in the final step of the systematic review; 70% of them were published in the last three years (n = 19). Seventy percent of the studies were conducted in Europe and Asia (n = 10; 37% and n = 9; 33%), followed by the Americas (n = 4; 14%) and Australia (n = 2; 8%).

Most of the articles selected for this review investigated sustainability strategies in healthcare systems (n = 14; 51.8%). In addition, some publications focused on analyzing environmental damage caused by healthcare activity and identified facilitators and barriers to the implementation of sustainability measures (n = 9; 33.3%), and some addressed the role of healthcare professionals in the implementation of these measures (n = 8; 29.6%). Most studies' respondents were healthcare workers from public hospitals (n = 15; 68%), of those studies, four (18%) included management and leadership profession-

als. Other participants were medical students, food chain staff and health industry workers (n = 3; 13%). The full characteristics of the selected studies are shown in Appendix A; a scheme (Figure 2) reflecting the dynamics of environmental impact of medical activities and proposed measures to reduce such impact, as well as a qualitative analysis of the results, are presented below.

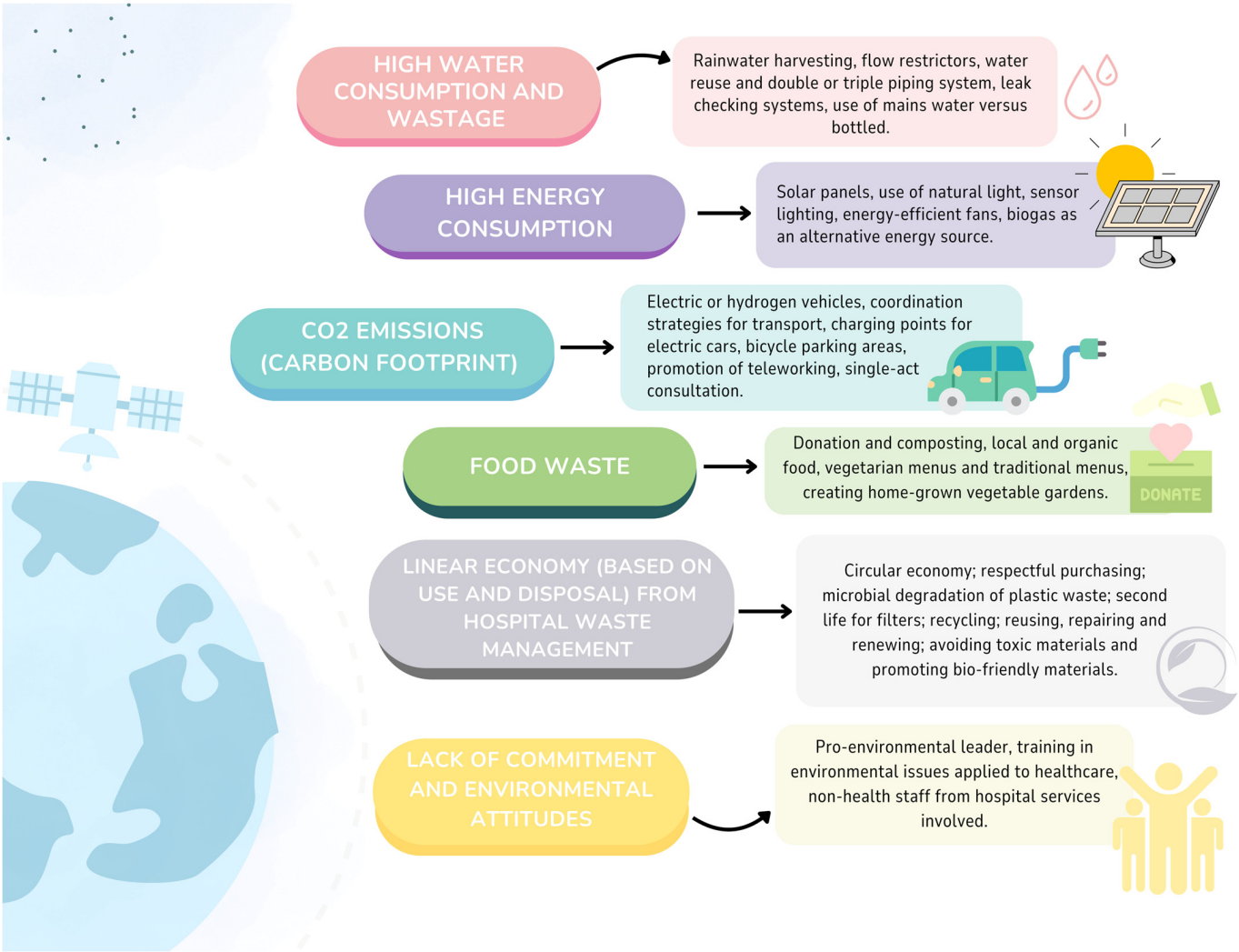

Figure 2. Dynamics of environmental impact of medical activities and measures to reduce it.

Theme 1. Environmental sustainability in healthcare

The detection of a greater environmental impact of the activities of healthcare institutions has been linked to air conditioning; the use of electromedical material for diagnosis; surgical procedures; pharmaceutical products and single-use products such as sterile gloves, gowns, masks or syringes, as well as the transfer of patients themselves to receive healthcare [18,19]. Based on analyses of these forms of damage, various actions in favor of sustainable healthcare stand out.

Promoting sustainable practices in the use of energy and natural resources and in reducing the carbon footprint: Using solar panels and natural light, sensor lighting, energy-efficient fans, biogas and biodiesel, rainwater collection and water treatment were different strategies implemented to achieve a reduction of up to 30% in hospital consumption [20]. Other measures also stand out: checking for leaks in the piping system, using flow restrictors, recycling water and using a double or triple piping system (cold water, hot water and

reticulation of non-potable water) [21]. Finally, a study also showed that patient care procedures such as anesthesia could in-corporate climate benefits in pediatrics [22].

Encouraging sustainable transport: Some hospitals have opted to use electric or hydrogen vehicles instead of diesel, create a transport coordination role, install charging points in parking lots for electric cars and create better and larger bicycle parking areas. In addition, the promotion of teleworking has been analyzed as a measure to limit travel and pollution, and to this end, awareness of the importance of sustainable transport for staff and patients has been promoted [23] This is also helped by single-act consultations, where the patient is seen by all professionals involved on the same day (decreasing transport and therefore up to 35% of emissions) [24].

Sustainable food: On the one hand, this review highlights the waste of food in health services and the need to create measures to avoid food waste, such as the reduction of waste by reusing both edible and inedible waste (i.e., donation) [25] and composting. On the other hand, the consumption of local and organic food is encouraged [25,26], as well as implementing vegetarian menus and traditional menus, creating home-grown vegetable gardens [26] and using mains water instead of bottled water in canteens [21]. As an example, the cost of bottled water consumption in a hospital canteen for about 200 people is about €14,000. In contrast, the installation of a microfiltration system in the drinking water supply network plus the water consumed would cost €2800, which would translate into savings of around €11,200 per year [21].

Adopting sustainable practices in waste management: According to some authors [21,27], one hospital produces about 10.58 kg/person/month of non-hazardous waste and 5.26 kg/month of potentially infectious waste. Of this, 62% is not segregated (40% textiles, 20% paper, 17% plastic). It is therefore necessary to promote the separation of waste in order to recycle; promote respectful purchasing (i.e., avoiding composite packaging of needles reduces unsorted waste by 3%); encourage a change in clinical practice to reduce the use of materials [21,28].; reuse, repair and renew (bases of the circular economy) [29]; avoid toxic materials and promote bio-friendly materials and renewable sources [28].

Currently, the linear economy (based on use and disposal) is the most widespread [27]. Achieving a circular economy will require measures such as changes in protocols; staff training; clear instructions from companies on how to recycle material after use; smaller and more recyclable packaging [21,27] or promotion of the segregation of waste in a way that allows its subsequent reuse. A proposed example of creating strategies that include members of society in the functioning of the hospital circular economy consists of cooperatives that allow citizens to take charge of the segregation and sorting of materials, so that they can use them to create recycled objects such as purses, bags or packages, which they can then display or sell at a craft fair [30].

Another specific strategy contemplates microbial degradation as the most sustainable and economical option for the treatment of plastic waste [31] or the possibility of giving a second life to dialysis filters, which can be used as water filters [25]

Theme 2. The involvement of healthcare professionals in environmental sustainability

The studies included in this review have analyzed different attitudes and perceptions of health professionals towards sustainability as well as factors that influence them.

Deng et al. [8] observed that healthcare staff with pro-environmental values significantly tended to favor reducing hospitals' carbon footprint through actions such as the rational use of energy, switching off electrical equipment that is not being used or using recyclable materials. According to Xu et al. [32], the figure of a pro-environmental and sustainability-minded leader could have an influence of around 40% on workers. In addition to this, this leader figure also had a mediating character between the pro-environmental attitudes of healthcare workers and corporate social responsibility in 47% of cases [8], high-

lighting the positive moderation of female leaders [33]. Another study states that a leader with strong environmental values favors better management of energy expenditure by workers during their clinical activity. For example, up to 90% of the costs of air conditioning can be reduced [9].

In this way, knowledge acquired through training is highlighted as a key factor [8,34–36], which can be extrapolated to future professionals, that is, nursing and medical students. As an example, students from a medical school in Bristol were sent to a SusQI (sustainability in quality improvement) workshop, with the aim of identifying challenges in translating knowledge into practice. Institutional inertia was found to affect their confidence in suggesting changes, and only a minority perceived sustainable healthcare as more than their professional role [37].

Despite the interest of healthcare providers in promoting sustainable measures, several perceived barriers were mentioned, of which the following should receive particular attention: lack of interest on the part of the healthcare facility, difficulty and effort involved in implementing strategies, cost and lack of training [26,27,38]. Regarding renewables, they mentioned that the major impediment to increasing the supply of renewables consisted of the limitations due to the state-level electricity contract and the prices/costs of renewables [39]. However, decreasing the environmental footprint, improving community health, reducing costs, composting and involving non-health staff from other hospital services are perceived as enablers.

4. Discussion

To evaluate the contribution of this review, an analysis of existing similar works was conducted beforehand. The review of other systematic review studies did not reveal a perspective equivalent to that addressed in this work, which has focused on offering a comprehensive literature review to provide a broad perspective on the current state of knowledge, specifically centered on the attitude of healthcare institutions towards implementing environmental care measures within their organizations and the importance of the involvement of healthcare professionals in the application of such measures. This review paper specifically aims to synthesize the state of knowledge concerning the role of hospital institutions in the development and implementation of sustainability strategies related to healthcare service delivery and reducing pollutant emissions such as chemical, radioactive or greenhouse gases and other harmful substances. It also explores the extent to which hospital management prioritizes environmental harm reduction through facility design, technology adoption and the influence of an environmentally oriented organizational culture within the healthcare sector.

Although certain reviews have addressed issues related to the role of healthcare managers, such as those by van Schie [40] and McCauley et al. [41], these studies lack the broad, synthesizing approach undertaken in this review. The systematic reviews published in recent years, although abundant, primarily focus in most cases on environmental improvements in the management of specific healthcare services, such as surgery [42], radiology [43], gastroenterology [44] or radiology departments [45].

Regarding the included works, it is noteworthy that 70% of the papers included in the review were published in the last three years, predominantly in Europe, indicating the cultural influence underlying the prevalence of such policies. Furthermore, the reviewed literature reveals no controversies or opposing viewpoints regarding the necessity of implementing measures to improve hospital management practices. However, while studies such as those of Barbero and Pallaro [25], Cakmak and Yol [46] and Dagenais et al. [38] highlighted the importance of organizational involvement, others, such as that of Boussuge-Roze et al. [27], revealed that healthcare professionals surveyed across

42 countries perceived a lack of interest from the hospitals (59%) and insufficient training (37%) in the implementation of new procedures. The relevance of programs involving staff in environmental care is underscored by other systematic literature reviews with a narrower focus on specific services, such as the review by Huo et al. [47], which pertains to surgical services.

An intriguing aspect regarding potential areas for knowledge expansion lies in the economic evaluation of the benefits derived from implementing waste reduction strategies and improving environmental management in healthcare facilities. While the reviewed studies mention economic advantages, including those from a circular economy perspective, no comprehensive economic analysis supporting these claims has been conducted. This topic is only partially addressed in the literature review conducted by Davies et al. [48].

Implications for Clinical Practice

The results of this study provide a starting point to help create a model for healthcare facility management that contributes to global health and the development of green hospitals. For nurses, in particular, this review is a call to action within the decision-making competencies of the management bodies of healthcare institutions and health systems. Considering the breadth of services offered by nurses, proposals for environmentally sustainable healthcare can emerge. Furthermore, the results highlight the need for sustainability training from academic to continuing education courses and multidisciplinary collaborative work.

Another implication would be the possibility of involving other managers and policymakers in refining regulations that motivate the environmental participation of the centers, that is, that the people who provide healthcare would have the political and regulatory support needed to contribute to the achievement of the 2030 Agenda.

Finally, we must address the implications for citizens. Firstly, by reducing environmental pollution and promoting the use of preventive and health-promoting practices, sustainable practices can help prevent disease and improve the quality of life of the population. Secondly, reducing resource consumption and improving efficiency in service delivery can make health services more accessible and affordable to society. Lastly, reducing energy and water consumption contributes to a healthier and safer environment. In other words, the implementation of sustainable healthcare systems has important implications in terms of improving the quality of healthcare, reducing healthcare costs and environmental impact and promoting a culture of sustainability.

5. Limitations

The present review has some limitations that should be highlighted. It is possible that not all available information has been found, as many hospital sustainability initiatives or approaches may be part of hospital policies, regulations and/or projects that have not been disseminated at a scientific level. However, very broad descriptors and five electronic databases were applied to ensure the greatest number of available resources. A broader review of the gray literature, as well as a review of calls for projects and data from ministries related to health and the environment or from healthcare organizations or systems themselves, would likely be productive in future lines of research. Finally, although this work highlights the assessment of unexplored aspects of the problem, it has the limitations of a review, that is, the absence of proven novelties. To this end, this group of authors, as part of the SUSTAinsHealth project, is carrying out interviews with a qualitative approach regarding environmental sustainability strategies in the health sector that could be replicated in different countries.

6. Conclusions

The health system is increasingly adopting 'green' hospital services, which emphasize the environmental and social impacts of institutional operations. Hospitals play a pivotal role in evaluating and mitigating the environmental footprint of healthcare activities. This study identified a range of sustainable initiatives grounded in a circular economy framework, encompassing sustainable practices in energy and natural resource use, eco-friendly transport solutions, sustainable food procurement and comprehensive waste management strategies. Furthermore, the findings underscore the critical role of committed leadership and the pro-environmental attitudes of managers and healthcare professionals, which act as catalysts to foster more sustainable and environmentally conscious healthcare practices. This highlights the necessity of integrating environmental stewardship into the strategic and operational frameworks of healthcare systems, positioning hospitals as key players in promoting ecological sustainability within their communities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments12010009/s1.

Author Contributions: Conceptualization, B.B. and R.d.-D.-C.; methodology, B.B.; formal analysis, B.B. and M.G.-C.-C.; investigation, B.B., J.M.P.-J., M.G.-C.-C., M.R.-A., A.P.S., S.T.F. and F.J.R.M.; resources, B.B., J.M.P.-J., M.R.-A., A.P.S., S.T.F. and F.J.R.M.; data curation, B.B. and R.d.-D.-C.; writing—original draft preparation, B.B., R.d.-D.-C., J.M.P.-J., M.G.-C.-C., M.R.-A., A.P.S., S.T.F. and F.J.R.M.; writing—review and editing, B.B., R.d.-D.-C., J.M.P.-J., M.G.-C.-C., M.R.-A., A.P.S., S.T.F. and F.J.R.M.; supervision, B.B. and R.d.-D.-C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available upon request from the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Results of the Systematic Review.

Reference	Objective	Methodology	Main Findings	Theme
Abhilash, 2022 [31] (India)	To analyze the means of treatment and/or disposal of plastic waste in the hospital setting during the COVID-19 pandemic.	Qualitative narrative analysis of degradation methods for plastic polymers.	The microbial degradation of plastic waste (degradation of plastic polymers and production of bio-based polymers) was found to be the most cost-effective and least ecotoxic method compared to other methods such as chemical disinfection; dissolution of plastic polymers to recover pigments or other polymers and thermal processes, most notably pyrolysis (use of thermal energy to break the chemical bonds in polymers).	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Barbero and Pallaro, 2017 [25] (Italy)	To discuss the potential of applying a systemic design (SD) approach for sustainable healthcare.	Qualitative study using a systemic design (SD) approach	The SD methodology is presented for enhanced material and energy production processes in the healthcare industry, thus reducing energy expenditure. Several examples of the use of this system include "communication design" (e.g., raising awareness about local food consumption, improving the circular economy, and protecting the environment), "NUF portable filters" (reusing dialysis filters to purify water in other low-income countries), "recovery of hospital food waste" (preventing food waste generation and promoting its reuse in hospitals by educating staff and users) and "eco-dialysis" (exploring the relationship between the components of dialysis devices to optimize material and energy flow, thus creating an efficient and sustainable system adapted to patient needs).	Environmental sustainability in healthcare
Boussuge-Roze et al., 2022 [27] (Various countries)	To investigate the current practice and expectations of European cardiac electro-physiology (EP) centers in terms of environmental sustainability, with a focus on EP catheters.	Quantitative study (online survey) Sample: N = 278 public hospital workers from 42 countries. Gender: 76% men Average age: 43 years.	A total of 72% of the healthcare professionals surveyed say that a linear economy of disposable catheters and packaging is still in place. Possible solutions include changes through protocols, educating professionals, clear instructions from companies after use of the material for recycling, reusing catheters after the necessary regulatory measures and using recyclable and smaller packaging. Overall, 82% of respondents showed interest in performing sustainable work, identifying the main barriers as the lack of interest from the hospital (59%), the complexity of the measures (48%), the effort required to change practices (47%), cost (33%) and lack of training (37%).	Engaging health professionals in environmental sustainability
Burch and McGain, 2021 [39] (Australia)	To identify points of view of healthcare leaders about the carbon footprint, sources of energy and barriers in the field of health.	Qualitative study (interviews) Sample: N = 13 Victorian public healthcare chief executive officers	Most participants acknowledged the importance of climate change and were cognizant of its negative impact. In addition, they had a consensus regarding the significant role of leadership in prompting environmental sustainability in the health public sector. Currently, however, support for renewable electricity is, for the most part, an aspiration and not perceived as a priority, although electricity accounts for 7% of total carbon emissions in Australia. The main perceived barriers to increasing renewable energy supply were limitations due to state-level electricity contracts and the costs of renewable energy resources.	Engaging health professionals in environmental sustainability

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Cakmak and Yol, 2019 [46] (Türkiye)	To create awareness of optimizing energy while maintaining quality in the provision of health services in medical devices.	Quantitative study calculating the energy density of hospital equipment. Sample: N = 1 hospital in Turkey	The medical devices that consume the most energy were radiological imaging, angiography, nuclear medicine, biosafety cabinets, autoclaves, incubators and operating rooms. The majority of this consumption was due to laser devices. Large medical imaging equipment accounted for 38% of the hospital's energy consumption, followed by nuclear medicine at 15%. Energy-saving strategies include reducing standby power levels, using hibernation and shortening startup times on high-power devices.	Environmental sustainability in healthcare
Carino et al., 2021 [26] (Various countries)	To explore the perspectives of hospital food supply chain staff on sustainable practices in food provision, identifying existing barriers and enablers and gathering recommendations for future implementation of sustainable foodservice practices.	Qualitative (semi-interview structure) Sample: N = 46 participants from across the food supply chain for patients Gender: 65% women	Strategies were identified to achieve sustainable food services, such as purchasing organic and local food, composting, vegetarian menus, use of traditional foods and creation of vegetable gardens. Innovation, education of society and environmental professionals and the creation of government regulations were highlighted as facilitators for sustainable food practices. Barriers included strict infection control standards and requirements, restrictions in current waste disposal contracts and the lack of a food sustainability policy.	Environmental sustainability in healthcare
Cockrell et al., 2022 [13] (USA)	To evaluate the environmental impact of implementing telehealth.	Quantitative (Retrospective cohort study at a pediatric surgical care center) Sample: N = 60,773 face-to-face meetings and 10,626 telehealth meetings	The incorporation of telehealth in preanesthesia and pediatric surgery clinics resulted in significant reductions in CO_2 emissions. Telehealth resulted in 1477 patient-km saved and a 312-ton reduction in CO_2 emissions. It was also shown that the greater the distance from home to the hospital, the greater the use of telehealth.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Dagenais et al., 2022 [38] (Canada)	To analyze the barriers and facilitators to implementing sustainable menu practices (SMPs) in Quebec healthcare institutions.	Qualitative study (interviews) Sample: N = 17 foodservice managers from healthcare institutions	The barriers encountered were perceived to a greater extent than the facilitators. These include the complexity of implementation due to the lack of adaption to all institutional contexts, which is related to the lack of support from these organizations and the perception of high cost. This highlights the need for greater collaboration and communication between all actors in the hospital food system. The highlighted facilitators include a reduction in the ecological footprint, contribution to improving community health, the possibility of composting, cost reduction, a reduction in subcontracting, centralization of the kitchen and the involvement of kitchen staff in sustainable development.	Environmental sustainability in healthcare
Deng et al., 2022 [8] (Pakistan)	To examine the relationship between a hospital's corporate social responsibility (CSR) initiatives and employees' pro-environmental behavior with the mediating effect of environmentally specific transformational leadership (ESTL).	Quantitative study (self-administered survey) Sample: N = 239 employees of the Lahore Hospital (39% position) leadership and 66% between 1 and 5 years of work experience). Gender: 58.39% men Age: 89% between 22 and40 years	Leaders embracing environmental sustainability and CSR have a transformational role and significantly influence the pro-environmental attitudes of healthcare workers (manifested as pro-environmental behavior, or PEB), thus facilitating the development of sustainability measures. The ESTL not only directly influences PEB but also acts as a mediator between the PEB and CSR of healthcare workers in 47% of cases. Furthermore, a positive relationship was observed between altruistic values and greater involvement of staff in the initiatives. Thus, the promotion of these values through training was recommended.	Engaging health professionals in environmental sustainability
Eckelman et al., 2018 [3] (Canada)	To estimate the life cycle emissions and associated environmental impacts and secondary health damage produced by the Canadian healthcare system.	Qualitative study Economic–environmental–epidemiological analysis to compare medical expenses with emissions of greenhouse gases and other pollutants.	Greenhouse gas emissions in the Canadian health industry are mainly due to hospital activities, pharmaceutical products and medical services. Canadian healthcare activities accounted for 33 million tons of greenhouse gas emissions and more than 200,000 tons of other pollutant emissions, resulting in an estimated annual loss of 23,000 disability-adjusted life years due to exposure to these pollutants.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Fang et al., 2022 [34] (China)	To review the experiences acquired in nosocomial environments around the world related to healthcare waste management.	Quantitative study (survey) Sample: N = 416 Hospital workers and managers in Shanghai.	A key factor in achieving sustainable waste management is environmental education of staff. Other strategies include conducting an orderly environmental inventory, planning and executing the placement of materials with reuse of everything possible, reducing wastage of energy (turning off electrical appliances when not in use, rational use of air conditioning) and materials and reducing power systems (electrical, thermal, etc.).	Environmental sustainability in healthcare
Geethika and Devi, 2022 [20] (India)	To measure the ecological costs, using carbon foot-printing and operational costs, of a 250-bed multi-specialty hospital with basic green hospital compliance.	Mixed study Participant observation, discussion groups and data obtained from the hospital database. Sample: N = 250-bed multi-specialty hospital	The service with the highest cost and energy consumption (up to 80%) for any hospital is air conditioning. The factors that generate the largest carbon footprint during hospital practices are electricity consumption (17,000 tons of CO_2/year) and the biomedical waste generated (723 tons of CO_2). Some sustainable ecological tools that have been used are as follows: - Use of solar energy (145 solar panels) and natural light; - Combined heat and power system; - Low-consumption ceiling fans; - Motion-sensor lighting; - Local suppliers; - Use of biogas and biodiesel; - Rainwater harvesting and on-site water treatment. These measures reduced the hospital's operating costs by 30%.	Environmental sustainability in healthcare
Hunfeld et al., 2023 [19] (Netherland)	To perform a material flow analysis in an academic intensive care unit and to obtain information on mass, carbon footprint, agricultural land occupation and water usage and to determine so-called "environmental hotspots" in the ICU.	Mixed study Material flow analysis by combining data analysis, measurements, desk research and interviews with staff members Sample: N = 1 ICU at Erasmus MC hospital in Rotterdam (56 mixed surgical and non-surgical beds)	The environmental impact per patient admitted to the ICU was 17 kg of solid waste, 12 kg of CO_2 eq, 300 L of water use and 4 m^2 of agricultural land occupation per day. Five single-use products were identified as the elements with the greatest environmental impact in terms of resource use and waste generation: non-sterile gloves, isolation gowns, bed protectors, surgical masks and syringes (including packaging).	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Irianti, 2016 [29] (Australia)	To gain information about methods and technology used in hospital waste management that can be adopted by Indonesian hospitals.	Qualitative study In-depth interviews and observation Sample: Hospital personnel of HWM practices in The Royal Brisbane and Women's Hospital (Australia).	The proposed hospital waste management is based on the division of waste into four groups (clinical, cytotoxic, recyclable and general waste) and focuses on the incorporation of the '3 Rs' (reduce, recycle and reuse), the segregation of sources, color-coded collection to minimize the production of medical waste and the development of a leadership figure to minimize illnesses and accidents related to waste management.	Environmental sustainability in healthcare
Marsden et al., 2021 [37] (United Kingdom)	To evaluate a training workshop on improving sustainability for clinical practice.	Qualitative study (5 focus groups) Sample: N = 17 third-year medical students at Bristol Medical School who participated in a SusQI (sustainability in quality improvement) workshop	Although the workshop motivated students and gave them skills they wanted to use in the future to improve quality, they expressed that there were multiple barriers to translating what they had learned into actual practice. Thus, although the workshop was successful in restructuring students' perceptions of sustainability, it was not enough, as some students were constrained by the social and cultural contexts of their clinical practice settings. Medical students who applied their learning to the clinical workplace were internally motivated and self-determined but needed time and opportunities to complete projects. Other students were cautious about disrupting established hierarchies and practices or were frustrated by institutional inertia. These barriers impacted their confidence in suggesting or achieving change. A minority saw sustainable healthcare as beyond their professional role.	Engaging health professionals in environmental sustainability
Narayanan et al., 2022 [22] (UK)	To compare the differences in the carbon footprint of inhalational anesthesia and total intravenous anesthesia (TIVA) when used in children.	Quantitative study Mathematical simulation models to compare four pediatric anesthesia techniques in children weighing 5, 10, 20, 30, 40 and 50 kg	TIVA with propofol and remifentanil had a smaller carbon footprint during a typical 60 min anesthetic process (1.26 kg of carbon dioxide equivalents [CO_2 eq] for a 20 kg child) than IV induction. followed by maintenance by inhalation (2.58 kg CO_2 eq) and inhalation induction and maintenance (2.98 kg CO_2 eq). Inhalation induction followed by IV maintenance alone had a lower carbon footprint than inhalation induction and maintenance when used in longer procedures (>77 min for children 5–20 kg; >105 min for children 30–50 kg). All in all, IV anesthesia had climate benefits in pediatrics. However, when used after inhalation induction, the benefits were only achieved in longer procedures.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Peng et al., 2022 [9] (Pakistan)	To improve the energy-specific pro-environmental behavior (EPEB) of hospital employees in an environmentally specific servant leadership (ESL) framework.	Quantitative study Surveys where the variables ESL, EPEB, GSE and GPOS were measured by adapting items from different sources Sample: N = 316 healthcare professionals. Sex: 63% males Age: between 22 and 65 years	The statistical results of the study showed that a servant leadership style with high environmental values (i.e., leaders who prefer environmental benefits to economic ones) has a positive influence on pro-environmental behavior specifically related to energy use by healthcare professionals during the performance of their duties, as employees learn from their leadership and improve their attitudes toward the environment due to the greater perception of support from the organization for implementing ecological initiatives (for instance, without this influence, the energy consumption due to air conditioning increases by 90%). Similarly, the energy consumption behavior of hospital employees improved due to different organizational factors, including leadership style and support for green initiatives.	Engaging health professionals in environmental sustainability
Power et al., 2021 [24] (Ireland)	To estimate the carbon footprint of a single intravitreal injection in a hospital-based intravitreal service.	Quantitative study Calculation of greenhouse gas emissions using the hybrid lifecycle analysis technique (Data on materials procurement, patient travel to and from the hospital and building energy use were used for this calculation)	The carbon emissions associated with an intravitreal injection were 13.68 kg CO_2 eq. This equates to 82,100 kg CO_2 eq annually per ophthalmological service. - Patient journeys: 10.49 kg CO_2 eq per injection (77% of emissions); - Materials procurement: 2.54 kg CO_2 eq (19%); - Building energy use: 0.65 kg CO_2 eq (4% of total emissions). Several aspects were identified that could help reduce emissions, such as bilateral injections on the same day, which would reduce emissions by 35% (less patient travel). Eliminating items considered dispensable from injection packs (povidone–iodine forceps, hand towels, 2 mL syringe, etc.) would reduce emissions by approximately 0.56 kg per injection, i.e., an annual saving of 3360 kg CO_2 eq for an average hospital. No savings were identified in energy use.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Puška et al., 2022 [23] (Bosnia and Herzegovin)	To suggest a model for the selection of healthcare waste incinerators in secondary healthcare institutions in Bosnia and Herzegovina.	Qualitative study Study in four phases: selection of experts to create a questionnaire to evaluate incinerator alternatives, establishing the weight of the criteria selected in the previous phase, ranking of incinerators and sensitivity analysis and examination of the results. Sample: N = 3 experts examined 6 incinerators	Based on fuel consumption and environmental impact, alternative A2 (I8-M50) best meets the objectives, followed by alternative A1 (I8-M40). Small incinerators have less impact on the environment than larger ones because they consume less fuel and destroy less waste. Their community acceptance is better; they take up less space and are less expensive compared to large incinerators. They can also be installed in populated areas because they do not generate significant air pollution. The study showed that the most important criterion according to the experts' assessment is the technical criterion, followed by the economic and environmental criteria, with the social criterion (acceptance of the incinerator by the community) being the least important.	Environmental sustainability in healthcare
Ryan-Forgarty et al., 2016 [36] (Ireland).	To explain and evaluate a systems-based action framework designed to create synergies between both regulatory requirements and voluntary initiatives, supported by government agencies and NGOs, so as to best meet environmental impact mitigation objectives.	Qualitative study Review of programs and actions on waste management and energy consumption. Sample: Cork University Hospital Programs: Green Campus; Eco-Schools; EPA Green Health; Global Network of Green Hospitals Healthy; Public Sector Energy Efficiency Program	This implementation resulted in the mitigation of existing impacts and a commitment to continuous improvement. Environmental education programs, especially action- and reward-based programs, proved successful in providing a systematic approach that facilitates environmental action and education. The researchers acted as advisors and highlighted the seven steps of the program, namely, creating an environmental committee, conducting an environmental study, developing an action plan, monitoring and evaluation (using sustainability indicators), reporting and engagement, linking to on-campus learning and developing a green charter (to ensure continuity).	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Simpson et al., 2022 [35] (United Kingdom)	To scope, identify and appraise the effectiveness of proposed actions relevant to air quality across all areas of operational management at the Queen Elizabeth Hospital Birmingham.	Mixed study Semi-structured interviews and questionnaire to score 79 actions identified in the qualitative phase Sample: 32 experts in areas of interest for the project	The actions with the greatest impact on improving air quality were as follows: - Improve the efficiency of activities that are executed remotely; - Create the role of transportation coordinator to help reduce the impact of employee travel and transportation; - Convert the fleet to electric or hydrogen fuel to replace diesel trucks and vans; - Establish real optimal levels of teleworking and guide the sustainable use of transport to establish new habits; - Implement 'auto-off' periods for non-essential information technology equipment; - Incorporate sustainability into procurement processes by rewarding low-impact and low-emission supply chains; - Install charging points for electric vehicles in the parking lot; - Evaluate the capacity of bicycle courier logistics; - Collect patient and visitor travel data through registration systems; - Integrate sustainable transportation into the patient mindset; - Create and promote a 'sustainability in health management' module with the education department; - Create more and better secure bicycle storage.	Environmental sustainability in healthcare
Scavarda et al., 2019 [30] (Brazil)	To analyze the central sterilization department and the storage of materials in the health supply chain in a Brazilian private health institution and propose a management framework.	Literature review and analysis of the supply chain of materials that make up surgical kits in a healthcare institution (observing the processing of approximately 400 surgical kits from 50 hip arthroplasty surgical procedures). Sample: private health institution in Rio de Janeiro with 200 beds and 11 operating rooms	The proposed healthcare supply chain management framework addresses four materials. It advocates strategies to sell cardboard for packaging to recycling cooperatives, which could save USD 132,000 at the end of one year. Paperboard also provides craftsman cooperatives with other possibilities for conversion into several other products, such as earring, bracelet and necklace boxes. In relation to plastics, a reduction in their use is encouraged, including incineration, reducing the release of toxins. Furthermore, the sale of plastic may reduce the costs of nonwoven sterile barrier systems, thereby allowing reverse logistics of these products to be implemented in the supply chain.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Vaccari et al., 2017 [21] (Italy)	To examine approaches to more sustainable management of waste and water consumption in a healthcare facility.	Quantitative study Sample: N = 1, Gardone Val Trompia Hospital in Brescia, Italy.	Some of the highlighted proposals are as follows: - Technological practices: modification of plants or supply procedures. - Behavioral practices: changing staff and patient water usage habits (i.e., using fresh water instead of bottled water in the dining room). - Healthcare solid waste management: the hospital produces 10.58 kg/person/month of non-hazardous waste and 5.26 kg/month of potentially infectious waste. A high level of unsorted waste was observed (62%), mainly textiles (40%), paper (20%) and plastics (17%). Given the high consumption of paper and plastics, there is a possibility of recovering their value provided they can be segregated, waste can be selectively collected, and recycling is increased. On the other hand, efforts must be made to change clinical practices by using fewer materials and incorporating the use of environmentally friendly materials.	Environmental sustainability in healthcare
Vishwakarma et al., 2022 [28] (India)	To investigate the relationship among the indicators of stakeholder involvement, sustainable supply chain practices, sustainable performance and the circular economy and its effect on attaining sustainability at large.	Quantitative study Questionnaires to identify SHSCP, HSI, SHP and CHE practices. Sample: N = 145 participants (60.68% hospital staff and 39.32% healthcare industry stakeholders)	A positive relationship was confirmed among the circular economy, the supply chain, the participation of people interested in healthcare and sustainability measures (statistically significant relationships between HSI and SHSCP; HSI and SHP; SHSCP and SHP; SHSCP and CHE and SHP and CHE. Some of the proposals include repairing, reusing and renewing resources; reducing biomedical waste and the use of toxic materials; extending the useful life of products; and making greater use of bio-friendly products and renewable sources. In addition, the circular economy was promoted as a mechanism to streamline consumption and increase digitalization.	Engaging health professionals in environmental sustainability

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Wei et al., 2021 [33] (China, Pakistan and Romania)	To reduce the environmental footprint of a hospital by promoting its employees' environment-specific behavior via corporate social responsibility (CSR) and ethical leadership (EL).	Quantitative study Survey Sample: N = 489 staff surveys from the hospital (61.76% health workers and 38.24% general administration) Gender: 56.85% men Age: 42.55% from 20 to 30 years, 46.01% from 31 to 50 and 11.6% over 50	The respondents confirmed that they were motivated to participate in different activities related to environmental behavior in response to the commitment to corporate social responsibility (CSR) by this organization ($\beta 1 = 0.426$; $p < 0.05$). Therefore, to reduce the environmental footprint of institutions, policies are needed that redefine the CRS of institutions, and they need to understand the importance of CRS. A positive relationship was observed between EL and CRS ($\beta 2 = 0.388$; $p < 0.05$), as well as between EL and employee pro-environmental behavior ($\beta 3 = 0.32$; $p < 0.05$). An ethical leader must communicate to the employee the importance of improving the environmental footprint. The overall environmental performance of organizations is enhanced through the voluntary commitment of their employees. In the presence of such leadership, employees increase their environmental commitment to a higher level, stimulating their pro-environmental behavior ($\beta 4 = 0.128$, $p < 0.05$). Finally, both male and female leaders positively moderated the indirect relationship between CSR and pro-environmental behavior, but this moderation was stronger among female leaders.	Engaging health professionals in environmental sustainability
Weisz et al., 2020 [18] (Austria and Germany)	To identify areas for sustainability improvement in healthcare systems and break down carbon emissions attributable to this care.	Quantitative study Multi-regional input–output analysis for carbon emissions by healthcare providers. Sample: healthcare systems in Austria and Germany	Austria's healthcare carbon footprint was 6.8 million tonnes of CO_2 in 2014 (14% less than in 2005, thanks to the use of renewable energy). Hospitals contributed 32% of emissions, with 48 tCO_2 per bed per year. Emissions were mainly produced by purchases of medical goods and services (36%), pharmaceuticals (19%) and energy consumption (31%). CO_2 emissions from patient transport also increased by 15%, demonstrating the need for improved planning. The six main areas of intervention in sustainability are direct energy use, product alternatives, prevention of inefficiencies in the health system (e.g., rational use of pharmaceuticals), changes in medical treatments, changes in national planning of health service delivery and transformation of the healthcare system towards promotion.	Environmental sustainability in healthcare

Table A1. *Cont.*

Reference	Objective	Methodology	Main Findings	Theme
Xu et al., 2022 [22] (Pakistan)	To analyze the attitude and the pro-environmental behavior (PEB) of healthcare professionals through corporate social responsibility (CSR) and green organizational practices in the health sector of an emerging economy.	Quantitative study Survey Sample: N = 441 health professionals Sex: 58% men (256) and 42% women (185) Age: from 18 to 65 years	CSR activities were shown to positively influence employees' pro-environmental behavior ($\beta1 = 0.493$; $p < 0.01$) and promote the adoption of green practices in organizations ($\beta2 = 0.362$; $p < 0.01$). Furthermore, the results indicated that the implementation of green organizational practices fosters employees' green behavior ($\beta3 = 0.183$; $p < 0.01$). Healthcare professionals with pro-environmental, altruistic values favor a reduction in the carbon footprint of a hospital ($\beta4 = 0.276$, $p < 0.01$) through actions such as rational energy use, turning off electrical equipment when not in use and using recyclable and reusable materials. Therefore, it was suggested that the hospital re-evaluate its hiring procedure to select these types of professionals, as they will help the hospital's sustainability to a greater extent. Similarly, HE demonstrates the importance of personal values and the corporate responsibility of managers to be proactive in environmental sustainability.	Engaging health professionals in environmental sustainability

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