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The Interplay Among Digitalization and Environmental Sustainability in Healthcare: A Systematic Literature Review

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Abstract

Background: Digital health technologies promise to reduce healthcare's environmental impact while potentially enhancing access to care. However, digitalization implies an intensification in energy use. Although institutions are pushing for the sector's digital transformation, change is difficult due to the complex relationship between digitalization and sustainability.

Objective: This systematic review illustrates how scientific literature examines the interaction between digital technologies and environmental sustainability in healthcare.

Methods: The authors used the PRISMA model to identify 2,494 papers by initially searching the main scientific literature databases. After pairing, 38 papers were used for the review.

Results: The analysis of the selected papers demonstrates that digital technologies generally improve healthcare's environmental sustainability. However, the interplay between digitalization and environmental sustainability remains far from resolved, with several emerging issues requiring further research. From a policy perspective, the growing weight of environmental considerations in healthcare practice is prompting a rethinking of healthcare personnel's professional development.

Conclusions: Healthcare systems are notoriously energy-intensive, with hospitals and related infrastructure among the most resource-intensive facilities in the world. If implemented strategically, digitalization can optimize resource allocation, reduce redundancies, and streamline processes, thereby reducing healthcare's environmental footprint.

Keywords: digital health, carbon footprint, literature review, health management

1. Background

As climate change escalates, its multiple impacts on human health are becoming increasingly evident. Rising temperatures, extreme weather events, and environmental disruptions are exacerbating a wide range of health risks, including respiratory illnesses, vector-borne diseases, and psychological distress (Smith et al., 2015; Watts et al., 2018; NIEHS, 2024). Paradoxically, while these challenges require expanding and improving healthcare infrastructure, the healthcare sector remains a significant contributor to environmental degradation, accounting for substantial CO^2 emissions and ecological impacts. Data have confirmed that the healthcare sector significantly contributes to global greenhouse gas (GHG) emissions, accounting for approximately 4% of worldwide CO_2 emissions, with peaks of 10% in the United States (Bortoluzzi et al., 2022; Eckelman et al., 2016).

Emissions generated by health systems can be grouped broadly into two main categories. The first is linked to elements and solutions used for therapies and clinical activities, such as medicines, therapeutic gases, and waste management solutions (Dhillon & Kaur, 2015). The second category is linked to tools, processes, and elements that surround a therapeutic process, e.g., patients' and professionals' travel, facility management and conditioning, and administrative and bureaucratic activities (Bhopal et al., 2021).

In recent years, the healthcare sector has undergone a significant digital transformation that aims to enhance patient care and improve efficiency (Holmner et al., 2012). The increasing adoption of digital technologies in healthcare poses positive and negative implications for the environment (Sun et al., 2023). To address this major challenge, both organizations and policymakers must adopt sustainable practices that account for digital transformation's environmental impact as awareness of environmental sustainability grows.

This dual role of healthcare as both a responder to and driver of climate change underscores the urgent need for systemic rethinking. A transition to more environmentally sustainable healthcare models is essential to mitigate this inherent contradiction and align health systems development with broader climate resilience goals (WHO, 2018). Recent research on this topic has grown rapidly. Previous reviews have demonstrated that digital technologies applied to health systems can play an important role in mitigating climate change. However, to the best of our knowledge, digital technology's real-world impact on sustainability remains largely underexamined, and comprehensive reviews that connect specific digitalization processes with system-wide environmental and clinical outcomes are required (Rahimi-Ardabili, Magrabi, & Coiera 2022; Purohit et al., 2021; Lokmic-Tomkins et al., 2022).

This systematic review aims to illustrate the interplay between digital technologies and environmental approaches in health services.

In this context, this paper aims to: 1) contextualize the twin transition toward digitalized and sustainable healthcare; 2) identify the most prominent organizational, policy, and management issues of environmental sustainability in healthcare; and 3) highlight emerging themes in the literature stemming from previously identified issues. The paper concludes with policy recommendations to align digital innovation with environmental goals.

2. Methods

Considering that contributions to climate change and digital health research are relatively new and diverse, often with preliminary results, a systematic review was conducted to map the literature, characterize typical research methods and topics, and indicate emerging themes in this field.

2.1 Search Strategies and Study Selection

This systematic literature review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (Tricco et al., 2018). The literature search was conducted in October and November 2023 without selecting a specific time frame.

The following terms were used as index terms or free-text words: *digitali**; *smart*; *sustainab**; *carbon*; *greenhouse*; *footprint*; *healthcare*; *health care*; and *hospital*.

During the identification phase (Figure 1), the search strategy was conducted in three main databases—PubMed, Scopus, and Web of Science—yielding an original list of 2,494 articles. From these, 795 duplicates were removed before the screening phase.

During the screening phase, we developed inclusion and exclusion criteria together. Methodological choices and uncertainties related to article selection were discussed and resolved through an iterative process (Figure 1). Papers were excluded if any of the following criteria applied to them:

- protocols, opinion papers and commentaries, book chapters, and conference abstracts.
- papers that presented single technological solutions for specific healthcare problems, such as new smart textiles for bandages (Yagi et al., 2014).
- papers that mentioned healthcare as an example or case (e.g., hospitals as an example of smart buildings, listed alongside other examples (Liaqat et al., 2021).
- papers that discussed digitalization exclusively as impacting other dimensions of sustainability, e.g., economic sustainability (Moro-Visconti et al., 2020).

Although they contained some combinations of our search terms, these papers were not aligned with the review's aims.

Through the title/abstract screening, 1,631 papers were removed. Out of the remaining 68, one was excluded because its full text was not available in English.

After a full reading of the resulting papers, 32 more were excluded because at least one of the following criteria applied to them:

- paper not related to carbon footprints
- paper related only to green infrastructures without digitalization in healthcare
- paper not related to environmental sustainability

Four articles were added after being identified through citation searches of the 67 previously identified articles, bringing the total to 39. We then discovered that one paper was retracted in late 2024, so we removed it, leaving a final total of 38 (Figure 1). Appendix A lists the 38 papers.

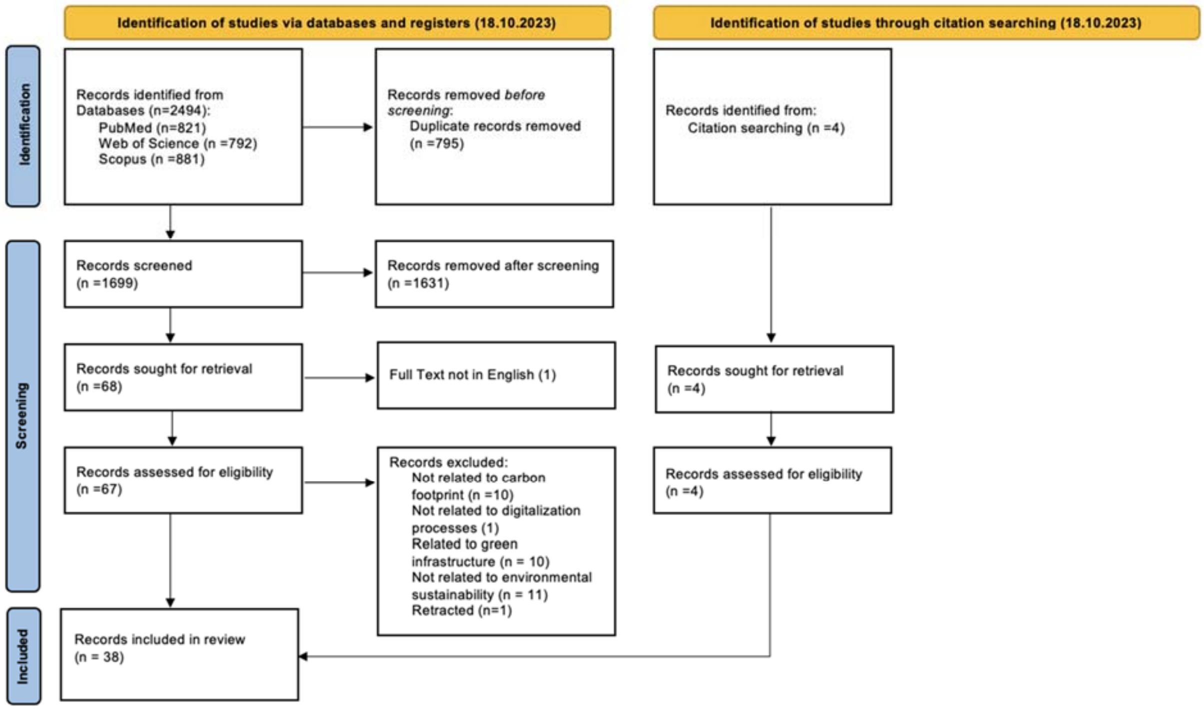

Figure 1. PRISMA flowchart

2.2 Data Extraction and Analysis

One author extracted data—including titles, authors, abstracts, and publication years—from the included articles and entered them into a spreadsheet.

The analysis of the remaining papers followed a two-step process. First, we autonomously read and categorized the papers through a set of characteristics:

1) Type of paper (review, empirical paper, policy paper, or position paper). This characteristic was used to include/exclude papers from the twin transition analysis in Table 1.

2) Unit of analysis (patient, unit, hospital, city/municipality, or healthcare system)

3) The paper's geographic location (Europe, the Americas, Asia, Africa, or Oceania)

4) Digital tools adopted in the innovative healthcare process (e.g., Internet of Things [IoT], wearables, apps, infrastructure, or AI)

Each author independently coded the papers based on the aforementioned categories. The results obtained were discussed iteratively during several meetings until a consensus emerged. Furthermore, each author independently engaged with the results, seeking trends and emerging themes in the analyzed papers. A new round of discussions enabled convergence on a few emerging themes relevant to policymakers and institutions operating in the healthcare context.

3. Results

The results from our analysis were structured around the identified papers' general features (Section 3.1), a characterization of the results from previous and partly overlapping reviews (Section 3.2), identification of the elements of interplay between digitalization processes and environmental sustainability efforts in the empirical papers from our sample (Section 3.3), and the description of a few emerging themes stemming from the literature (Section 3.4).

3.1 Included Studies' Characteristics

Classifying the papers by year of publication, most (29 out of 38) were published starting in 2020, with a peak in 2023.

Examining the papers by publication type, we decided to adopt 5 non-mutually exclusive categories. In this regard, our papers include 2 theory-building papers, 24 empirical research papers, 9 review papers, 2 position papers, and 4 policy papers. It should be noted that, after a long discussion, the authors could not reach an agreement on 3 papers. The papers of Linstadt et al. (2020), Park and Cha (2023), and Verdejo Espinosa et al. (2021) were assigned to more than one category.

While examining the unit of analysis, we identified five broad categories of papers. A few were excluded (theoretical/position papers), and a few more were counted in more than one category. Patients are the focus of five papers. The clinical practices of specific ward- and hospital-unit levels are examined in 11 papers. Digitalization at the hospital level was investigated in 11 papers, whereas 5 examined digitalization at the city/municipality level. Finally, 11 papers examined the healthcare system as a whole.

Regarding geographic location, only 14 of the 38 papers specified it. Most were rooted empirically in the Americas (six) and Europe (four), with three conducted in Asian countries and just one in Oceania. No papers were conducted in Africa.

Considering the digital tools analyzed in the selected papers, most referred to IoT/wearable devices (10) and infrastructure (9), while a few focused on apps (2). It should be noted that the papers of Alazab et al. (2022) and Moncho et al. (2022) were assigned to more than one category, as their contributions span multiple types of digital tools.

3.2 Findings from Previous Reviews

We took our cue from recent reviews, such as Rahimi et al. (2022), Gan et al. (2019), Purohit et al. (2021), and Lokmic-Tomkins et al. (2022), which provide a range of perspectives on the environmental impact of specific subsectors of healthcare systems. Beyond these reviews, the broader literature includes empirical and conceptual studies that focus on particular dimensions of this interplay. For example, some studies have examined the effects of digital innovations on telemedicine (Lokmic-Tomkins et al., 2022; Purohit et al., 2021; Holmner et al., 2014), while others have addressed the environmental impact of specific devices or highlighted hospitals as green or polluting buildings (Wyssusek et al., 2019; Dhillon & Kaur, 2015), at times framing healthcare facilities as contributors to climate change.

Some literature reviews, while analytically examining specific subsets of care services, emphasized the limitations of addressing only part of the pollution issue in care systems, portraying care systems as genuine pollution ecosystems (Purohit et al., 2021; Dhillon & Kaur 2015).

Gan et al. (2019) noted that healthcare systems—particularly Western ones—are embedded in a complex set of factors, and that their existence impacts several resources and systematically pollutes the environment. In their scoping review, they identified several thematic areas, including energy use, waste generation, and disaster preparedness. But what is interesting to highlight here is an attempt to point out the substantial inconsistencies in these debates, which are still approached with significant patchiness and weak systematization.

Lokmic-Tomkins et al. (2022) reviewed evaluation models to assess the environmental sustainability of a digital health intervention but found no standardized methods or validated tools.

Rahimi et al. (2022) considered mitigating factors to reduce energy consumption, including digitizing processes to reduce travel and training practitioners during this new phase of health system development. Following the track of the use of new technologies to support this process, Rahimi et al. (2022) identified the data-driven approach as the principal support for studying environmental impact. As the research string highlighted, this perspective also characterizes our work, in that technological dynamics can be viewed from multiple perspectives and interpreted in different ways (Vishwakarma et al., 2023).

Purohit et al. (2021) also conducted a literature review on the link between digital health and carbon emissions. Their work did not embrace the full spectrum of digital health solutions, as their focus was specifically on telemedicine. Even with this tight focus, this study also confirmed digital technologies' positive role in reducing carbon emissions.

3.3 Digitalization Processes and Environmental Sustainability at a Crossroads

In Table 1, we propose a classification of empirical papers that discuss the interplay between digitalization and environmental sustainability in healthcare. To map the papers in our population, we cross-referenced the descriptions of the digitalization processes in healthcare proposed in each paper with the environmental sustainability dimensions they might impact.

Digitalization processes have been characterized by adapting the excellent analytical tool proposed by Rahimi-Ardabili et al. (2022). They break down digitalization in healthcare into six main processes: data sensing and monitoring; electronic data capture; modeling for forecast generation and decision support for human (professional) decision-makers; and communication devices. We decided to combine data sensing and monitoring, and modeling and decision support into two processes, as they perform similar stages. While these pairs operate at distinct stages of the digital workflow—data sensing and monitoring at the data collection stage, and modeling and decision support at the analysis and decision-making stage—the empirical papers in our sample consistently addressed them in combination. Maintaining separate categories would have resulted in sparse and poorly differentiated entries in Table 1. This consolidation is therefore an analytical response to how the reviewed literature frames these processes and does not imply functional equivalence between them.

Environmental sustainability dimensions are characterized by the polluting effects of GHG emissions, both associated directly with clinical practices and energy production and consumption related to ancillary processes (e.g., transportation emissions related to patients and professionals traveling to receive and provide care) (Pickles et al., 2024), and polluting effects of waste disposal and water usage (Dhillon & Kaur, 2015; Romanello et al., 2023).

In Table 1, we explicitly distinguish energy production from consumption and its effects from clinical practice-specific GHG emissions and transportation-related GHG emissions, given their magnitudes and importance for policy considerations (Moncho-Santonja et al., 2022).

Many extant studies have examined a specific interaction in depth, such as the interaction between waste and sensing, as a combined tool to selectively activate biogas generators (Alotaibi et al., 2019). Similarly, Kumar et al. (2008) highlighted the potential of electronic systems, such as electronic data interchange (EDI), to improve the efficiency and accuracy of hospital supply chains. They emphasized the importance of breaking down any barriers in the use of data, codes, and sensors, such as Radio Frequency Identification (RFID) technologies, to push manufacturers toward unified processes and tools.

A second group of papers examined the deployment of digital technologies to optimize energy generation and consumption in healthcare to reduce GHG emissions. IoT-driven systems, such as those highlighted by Verdejo Espinosa et al. (2021) and López et al. (2023), enhance energy optimization in healthcare and smart cities, aligning with the Sustainable Development Goals. Tuysuz and Trestian (2020) emphasized green IoT technologies that reduce energy consumption in communication networks. Meanwhile, retrofitting strategies for hospital buildings, as discussed by Silenzi et al. (2018), use dynamic simulations to optimize energy use. Finally, Zhang et al. (2020) demonstrated how IoT/wearable devices, supported by deep learning, enable sustainable healthcare for elderly patients. Together, these studies underscore the pivotal role of energy-efficient innovations in minimizing environmental impact and advancing sustainability.

Similarly, several studies examined the interaction between transport-related GHG emissions and digitalization in several diverse scenarios. For example, Callaway et al. (2014) demonstrated how microgrid energy systems can replace traditional diesel generators in disaster medical responses, thereby reducing CO^2 emissions by integrating renewable energy sources, such as solar power and advanced battery storage. Similarly, Borges de Oliveira and De Oliveira (2022) underscored the importance of sustainable systems in reducing energy consumption and emissions in the healthcare supply chain and identified digitalization as a strategic driver in this segment. Likewise, Salehi-Amiri et al. (2022) examined IoT and real-time data capture as tools to optimize vehicle routing in home healthcare, thereby reducing distances traveled and transportation costs while minimizing CO^2 emissions. This approach integrates data-driven decision-making to adapt to dynamic demand and enhance logistics efficiency.

Examining the redesign of clinical activities more directly, Moncho-Santonja et al. (2022), demonstrated telemedicine's impact on rural health systems, quantifying reductions in patient travel distances, which result in substantial savings in GHG emissions. Similarly, Woolen et al. (2023) examined eco-design strategies for energy-intensive medical equipment, such as Magnetic Resonance Imaging (MRI) scanners, leveraging operational data to implement energy-saving modes. These energy optimizations contribute to broader healthcare sustainability goals. Generally, all activities involving digital data transmission help reduce ICT CO^2 emissions. The need for an integrated model that combines technologies (e.g., IoT, wearables) with novel service planning methodologies (e.g., telemedicine, teleconsultation) in rural areas, along with innovative data-driven decision-support systems, as proposed by Woolen et al. (2023), is paramount.

In contrast to the considerable attention given to GHG emissions, waste, and energy in the literature, water is a relatively neglected subject (Table 1). We found no studies linking digitalization and water use reduction. However, researchers corroborated the assertion that reducing water use is feasible (Jehle et al. 2008; Kagoma et al., 2012; Wyssusek et al., 2019). Furthermore, these studies highlighted the paucity of attention devoted to sorting waste in climate-sensitive context, both to prevent potential contamination and to support more meticulous regulation of its use.

To sum up, the literature has identified digitalization as a significant transformative force to help healthcare systems transition to more environmentally friendly processes. However, its integration into facility design and service provision within the field remains underdeveloped, though examining this literature has helped us identify a few trends with game-changing potential in the interplay between digitalization and environmental sustainability in healthcare. We labeled these trends as "emerging themes" in Section 3.4, highlighting their potential ability to foster profound changes at the policy, organizational, and managerial levels.

Table 1. Empirical papers from the review discussing the interplay between digitalization and environmental sustainability in healthcare

		Sustainability dimensions				
		Waste	**Energy**	**Greenhouse emissions: Transportation**	**Greenhouse emissions: Clinical**	**Water**
Categories according to Rahimi-Ardabili et al. (2022)	**Sensing/ monitoring**	Alotaibi et al., 2019	Tuysuz & Trestian, 2020 López et al., 2023 Silenzi et al., 2018 Alotaibi et al., 2019 Zhang et al., 2020	Callaway et al., 2014	Alotaibi et al., 2019	
	Electronic Data Capture	Kumar et al., 2008	Tuysuz & Trestian, 2020 Woolen et al., 2023	Salehi-Amiri et al., 2022 Woolen et al., 2023	Woolen et al., 2023	
	Modeling/ Decision support	Kumar et al., 2008 Alotaibi et al., 2019	Callaway et al., 2014 Alotaibi et al., 2019	Salehi-Amiri et al., 2022 Callaway et al., 2014 (Moncho-Santonja et al., 2022)		
	Communication	Kiang & Behne, 2021	Woolen et al. 2023	(Moncho-Santonja et al., 2022) Kiang & Behne, 2021	Park & Cha, 2023 Zhang et al., 2020	
	Artificial intelligence		Sekhar, et al., 2023 Lopez and al., 2023		Sekhar, et al., 2023	

3.4 Emerging Themes

Growing awareness that macro-level healthcare systems and micro-level clinical activities can have significant environmental consequences has increased scholarly attention to the interplay between environmental transitions and digitalization processes. In the previous section, we outlined the scope of this interplay. Here, we identify and briefly discuss emerging themes in the literature, characterizing each in terms of its policy, organizational, and/or managerial implications.

Telemedicine as a tool to reduce health-related carbon emissions

An important recent research line has focused on the positive effects that the diffusion of telemedicine can have on carbon emissions (Holmner et al., 2014). Specifically, the balance between an increase in emissions due to the introduction of telemedicine techniques and the relative infrastructure, and the reduction in emissions from eliminating travel associated with in-person visits has been described as overwhelmingly positive (Purohit et al., 2021), providing an important policy indication in favor of telemedicine. This is particularly true in contexts where patients need to travel farther to access care (e.g., rural areas) (Moncho-Santonja et al., 2022). From an organizational point of view, important contributions to this literature stream come from technical papers detailing conditions under which specific tools can be deployed to make telemedicine more accessible, such as IoT (Tuysuz

& Trestian, 2020) and digital twins (Alazab et al., 2022), within the so-called Healthcare 4.0 platform (Sekhar et al., 2023).

The green hospital

Research on the effects of pollution generated by buildings has a long history in sustainability studies (Chwieduk, 2003), and in recent years, digitalization's potential effects on buildings have produced a steady stream of papers described as the "smart buildings" literature (Buckman et al., 2014). More recently, hospitals have become a new focus within this wider stream (Dhillon & Kaur, 2015; Gan et al., 2019), as they share the same concerns and proposed solutions as other "energivorous" buildings. However, they also have specific features that can be addressed through appropriate management of digitalization processes, such as reducing paper consumption for internal information circulation. Thus, although the green hospital literature aligns with the smart buildings literature, its health management implications have only been hinted at.

Greening clinical practices

A new trend in the literature, emerging at the crossroads of digitalization and sustainability in healthcare, has been described as "greening clinical practices" (Wyssusek et al., 2019). The idea shared by these contributions is very simple: Whereas much attention has been devoted to the hospital as a vehicle for emissions reduction related to the supply of health services, far less attention has been given to clinical practices themselves, at least until very recently. Many contributions from scholars in the medical sciences underscore a new awareness of the importance of conducting clinical activities sustainably, with obvious managerial and clinical consequences. Many of these studies have underestimated the importance of integration between digital data management processes and clinical processes to reduce carbon footprints in emergency rooms (Linstadt et al., 2020), operating rooms (Pradere et al., 2023), dermatological practices (Niebel et al., 2023), and in the administration of anesthesia (Kalmar et al., 2022). They also emphasized the importance of integrating smart procurement of disposable materials into clinical practice (Al-Hadithy et al., 2023). This growing body of literature has benefited from increased awareness raised by a few position papers outlining proper conduct in several medical disciplines regarding practice-specific problems (Bortoluzzi et al., 2022; Kiang & Behne, 2021), which have helped develop the idea that every specialist needs to become involved in sustainability. At the policy and systemic levels, this literature stream clearly implies the need to integrate environmental sustainability into professionals' training practices and curricula.

Artificial intelligence

The use of AI algorithms is spreading rapidly, with important organizational and managerial consequences. For example, they are used in logistics to optimize routes and minimize fuel consumption (Salehi-Amiri et al., 2022). Remote work and remote care also benefit from AI through predictive scheduling and remote monitoring tools that reduce unnecessary diagnostic procedures and patient travel (Zhang et al., 2020; Woolen et al., 2023). Similarly, AI can enhance water management systems, helping detect leaks and optimize water use in sterilization and other hospital processes.

Even if the literature on the impact of AI on healthcare is still in its infancy, it already offers a complex picture of the transformative power of AI, both at the organizational and managerial level, with the revision of procedures and clinical practices to help reduce the strain on resources, and at the policy level, highlighting the implications of a more pervasive introduction of AI in clinical practice.

Healthcare expansion and vicious circles

A powerful, partly counterintuitive, and potentially disruptive emerging theme has examined the general causal link between healthcare investments and pollution. This literature stream's general goal is to understand the impact of pollution on healthcare expenditures. Generally, it has been found that climate change and pollution provoke higher healthcare expenditures (e.g., Anwar et al., 2022). An interesting theoretical evolution from this literature stream is the hypothesis that healthcare expenditures and related polluting activities have adverse environmental effects, both directly through pollution (Rai et al., 2023) and indirectly through increased emissions. This idea of a vicious circle kick-started by health-related expenditures seems to be a promising avenue of research, specifically if properly linked with growing evidence of rapid increases in healthcare investments tied to other grand challenges, such as the aging population in developed countries (Li et al., 2020) or pollution's adverse effects on health.

4. Discussion

The healthcare sector significantly contributes to pollution and carbon emissions. Major challenges require a comprehensive approach that combines environmental stewardship, technological innovation, and a commitment to equitable healthcare delivery. By aligning digital transformation efforts with Sustainable Development Goals (SDG), healthcare organizations can work toward a more sustainable and inclusive future.

This review aimed to summarize the literature at the crossroads of digital health and the environmental impact of healthcare by identifying key emerging organizational, policy, and managerial themes.

4.1 Organizational Issues

In analyzing the findings, the first contribution concerns the use of digitalization as a strategic tool for process reorganization. The analyzed studies revealed a serious delay in linking digitalization's benefits to actions that can help reduce CO2 emissions in hospitals and health systems more broadly. Furthermore, it is evident that research on GHG emissions has proliferated, yet each empirical study has been closely tied to local systems and contextual choices, creating a gap between theoretical evidence and its implementation in organizational practice (Dhillon & Kaur, 2015).

4.2 Policy Issues

As noted earlier, healthcare plays a critical role within the United Nations' SDG 3, but it also requires the diffusion of a comprehensive sustainability concept. The need to balance environmental, social, and economic dimensions to achieve sustainable development is an accepted tenet, but one that has mostly been neglected in practice.

A second contribution concerns tools that can help curb healthcare's environmental impact. Among the tools examined, many—such as apps, IoT, wearables, and infrastructures—have been combined to provide telemedicine services. Telemedicine plays a crucial role in supporting environmental sustainability as an effective way to provide healthcare services while minimizing the impact from mobility/travel and aligning with broader sustainability goals (e.g. Purohit et al., 2021).

AI algorithms are increasingly impacting several domains. They are used to optimize delivery routes and schedules, thereby reducing fuel consumption and emissions within supply chains (Salehi-Amiri et al., 2022). They are also used in predictive scheduling and remote monitoring tools, thereby enhancing other practices, such as telemedicine, and increasing the scope for remote work and remote care, further cutting emissions (Zhang et al., 2020; Woolen et al., 2023).

4.3 Managerial Issues

Third, the review clarifies how the integration of environmental considerations into healthcare providers' strategic decisions remains lacking. The healthcare sector faces significant challenges in addressing GHG emissions due to its complexity, focus on immediate patient care, and reliance on energy-intensive operations. Activities such as diagnostic imaging and logistics are major contributors to emissions, yet sustainability often takes a back seat to patient outcomes and operational efficiency (Woolen et al., 2023). Limited awareness of healthcare's environmental impact, coupled with insufficient policy support and financial barriers, hinders progress further (Salehi-Amiri et al., 2022; Moncho-Santonja et al., 2022). Furthermore, the lack of robust data collection systems to track emissions prevents the identification of targeted reduction strategies (Borges de Oliveira & De Oliveira, 2022). To overcome these barriers, the sector needs to promote a cultural shift that views environmental health as an integral part of care delivery.

Fourth, in addressing sustainability challenges in healthcare, healthcare professionals play a key role (Vishwakarma et al., 2023), particularly in their ability to use AI and IoT systems effectively. The integration of digital tools into clinical practice has significantly transformed how healthcare professionals work, enhancing efficiency and accuracy and improving patient care. However, it has also introduced entirely new challenges for healthcare professionals, including increased training needs and continuous learning. Many professionals lack the technical expertise needed to fully utilize these tools, creating a significant gap in their readiness for digitalization. However, given the complexity of their roles and the depth of their knowledge and experience, systems need to be genuinely user-friendly and aligned with workflows to reduce resistance to adoption and increase awareness. Yang et al. (2020) emphasized that clinicians often focus on immediate patient outcomes, so that sustainability efforts may not be a priority unless linked to improved care quality. Furthermore, according to Xue et al. (2021), a systematic picture of the need to reduce GHGs is lacking, starting with institutional support, cultural behavior (Moncho-Santonja et al., 2022), and leading by example in the effectiveness of their roles (Woolen et al., 2023).

Finally, it is quite evident that once actions are implemented, the reduction in environmental impact is significant, and the efficacy of sustainable healthcare becomes substantial. Silenzi and colleagues (2018) demonstrated that implementing smart technologies, such as automated thermal controls and optical fiber lighting, could reduce energy consumption by up to 30%, thereby significantly lowering operational costs and emissions. These systems enabled real-time adjustments based on usage patterns, reducing energy waste while maintaining comfort levels. Quantification demonstrated potential energy savings of 20–25% with automated, data-driven systems (Xue et al., 2021; Yang et al., 2020).

5. Conclusions

The two emerging positions from our review can be summarized as follows. On one hand, digitalization has an immense potential to transform healthcare systems into more energy-efficient and sustainable entities. However, the current landscape is fragmented across regions, driven by varying levels of economic development and infrastructure readiness. While some initiatives and pilot projects are promising, these efforts remain limited in scale, scope, and impact.

On the other hand, healthcare systems are notoriously energy-intensive, with hospitals and related infrastructure among the most resource-intensive facilities in the world, thereby potentially aggravating environmental conditions that may negatively affect health and well-being. Paradoxically, improvements in healthcare quality may result in higher emissions, increased energy consumption, and greater resource use, thereby worsening public health.

While it is true that, if implemented strategically, digitalization processes can help curb GHG emissions and other pollution sources, a clear roadmap has yet to emerge. From a policy perspective, raising awareness among healthcare professionals and fully integrating environmental goals in healthcare institutions are good starting points.

To date, coordination and data-driven approaches in healthcare remain insufficient. Many healthcare systems described in the examined research papers remain siloed, with limited interoperability and integration of digital solutions.

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Authors' contributions

Dr. RL, Prof. DP, Prof. MZ, Dr. AZ were responsible for study design and methodology. Dr. RL, Prof. DP and Prof. MZ were responsible for data collection. Dr. RL, Prof. DP, Prof. MZ, Dr. AZ drafted the manuscript and revised it. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. List of 38 Papers Selected for the Review

Papers
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