



**GLOBAL RESEARCH TRENDS IN SCIENTIFIC PUBLICATIONS ON CARBON
FOOTPRINT IN THE HEALTHCARE SECTOR: A BIBLIOMETRIC ANALYSIS
BASED ON THE WEB OF SCIENCE DATABASE**

**SAĞLIK SEKTÖRÜNDE KARBON AYAK İZİ ÜZERİNE BİLİMSEL
YAYINLARIN KÜRESEL EĞİLİMLERİ: WEB OF SCIENCE VERİTABANI
ÜZERİNDEN BİBLİYOMETRİK BİR İNCELEME**

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Abstract

This study aims to map the general structure of the literature on carbon footprint in healthcare and guide future research by analysing 108 academic publications published in the Web of Science database between 1975 and 2024 using bibliometric methods. The data obtained from the search, conducted in August 2024 using "carbon footprint" and healthcare-focused keywords, was evaluated using VOSviewer software for citation analysis, keyword network, and temporal trend visualization. The analysis findings reveal that the number of publications has increased significantly since 2007 and reached its peak in 2024. The United States (25 publications), the United Kingdom (22), and Australia (11) made the most contributions, respectively. The University of Sydney (8 publications) and the University of London (7 publications) were among the most productive institutions, while Frontiers in Public Health (6 publications) and BMJ (5 publications) were identified as the most prominent journals in terms of publications. An examination of the disciplinary distribution reveals that the fields of public health and environmental sciences (55 publications in total) dominate the literature. According to the citation analysis, the most influential authors are Forbes McGain (374 citations, 3 publications) and Arunima Malik (374 citations, 3 publications). The most cited article is Tennison et al.'s (2021, 347 citations) study assessing the carbon footprint of the UK National Health System (NHS). Keyword analysis revealed that "carbon footprint" (34 repetitions, 147 link strength), "climate change" (9 repetitions, 36 link strength), and "carbon emissions" (7 repetitions, 28 link strength) emerged as key concepts, with themes such as "telemedicine" and "green hospitals" showing rising trends in the post-pandemic period. Consequently, the findings reveal that carbon footprint research in healthcare has a



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multidisciplinary structure. It is important to establish both interdisciplinary and international collaborations and conduct more comprehensive studies to increase the resilience of the health sector to climate change. However, the findings are limited to English-language articles indexed in Web of Science, and by nature, bibliometric methods provide limited insight into the depth of the literature.

Keywords: healthcare services, carbon footprint, bibliometric study, VOSviewer

Öz

Bu çalışma, 1975–2024 yılları arasında Web of Science veri tabanında yayımlanan 108 akademik yayını bibliyometrik yöntemlerle analiz ederek, sağlık hizmetlerinde karbon ayak izi konusundaki literatürün genel yapısını haritalamayı ve gelecekte yapılacak araştırmalara yol göstermeyi amaçlamaktadır. 2024 yılının Ağustos ayında “carbon footprint” ve sağlık hizmetleri odaklı anahtar kelimeler kullanılarak yürütülen tarama sonucunda elde edilen veriler, VOSviewer yazılımı aracılığıyla atıf analizi, ortak kelime ağı ve zamansal eğilim görselleştirmeleriyle değerlendirilmiştir. Analiz bulguları, yayın sayısının 2007 yılından itibaren belirgin bir artış gösterdiğini ve 2024 yılında en yüksek seviyesine ulaştığını ortaya koymaktadır. Bu konuda, ülke bazında en fazla katkı sırasıyla Amerika Birleşik Devletleri (25 yayın), Birleşik Krallık (22) ve Avustralya (11) tarafından yapılmıştır. En üretken kurumlar arasında University of Sydney (8 yayın) ve University of London (7 yayın) öne çıkarken, *Frontiers in Public Health* (6 yayın) ve *BMJ* (5 yayın) yayınlarda en çok öne çıkan dergiler olarak belirlenmiştir. Disiplin dağılımı incelendiğinde halk sağlığı ve çevre bilimleri alanlarının (toplam 55 yayın) literatürde daha baskın olduğu görülmektedir. Atıf analizine göre, en etkili yazarlar Forbes McGain (374 atıf, 3 yayın) ve Arunima Malik’tir (374 atıf, 3 yayın). En çok atıf alan makale ise Tennison ve diğerlerinin (2021, 347 atıf) İngiltere Ulusal Sağlık Sistemi’nin (NHS) karbon ayak izini değerlendirdikleri çalışmadır. Anahtar kelime analizinde “carbon footprint” (34 tekrar, 147 bağlantı gücü), “climate change” (9 tekrar, 36 bağlantı gücü) ve “carbon emissions” (7 tekrar, 28 bağlantı gücü) temel kavramlar olarak ön plana çıkmış, pandemi sonrası dönemde “telemedicine” ve “green hospitals” gibi temaların yükselen eğilimler gösterdiği saptanmıştır. Sonuç olarak, elde edilen bulgular sağlık hizmetlerinde karbon ayak izi araştırmalarının çok disiplinli bir yapıya sahip olduğunu ortaya koymaktadır. Sağlık sektörünün iklim değişikliğine karşı direncinin artırılması için hem disiplinlerarası hem de uluslararası iş birliklerinin yapılması ve daha kapsamlı çalışmaların yürütülmesi önemli görülmektedir.

Anahtar Kelimeler: sağlık hizmetleri, karbon ayak izi, bibliyometrik çalışma, VOSviewer

INTRODUCTION

Today, climate change and global warming represents one of the most urgent and complex crises in human history. Impacts such as depletion of natural resources, increased greenhouse gas emissions, increased frequency of natural disasters, and decreased biodiversity have not only led to a limited environmental imbalance but have also profoundly impacted healthcare systems, as well as all sectors (Bolan et al., 2024; Özkan, 2024). According to the World Health Organization (WHO), climate change causes millions of premature deaths and illnesses each year. Events such as environmental pollution, floods, droughts, and extreme heat waves strain healthcare infrastructures and pave the way for the spread of infectious diseases (Karliner et al., 2020; Tennison et al., 2021). Studies on measuring the carbon footprint related to climate change have become a common ground for many disciplines. This demonstrates the breadth of the issue and the magnitude of its impacts.

The healthcare sector finds itself in a paradoxical position regarding the increase in greenhouse gas emissions and climate change. While health systems operate with the mission of protecting public health, the sector’s service delivery activities—such as energy consumption, medical waste generation, supply chains, and clinical operations—account for approximately 4–5% of global greenhouse gas emissions (Karliner et al., 2020; Tennison et al., 2021; Pichler et al., 2019).

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Hospitals and clinics are among the institutions with a high carbon footprint due to intensive energy use and waste production (Lau et al., 2024; Lokmic-Tomkins et al., 2022). International strategies such as the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Agreement mandate that the healthcare sector reduce these emissions, and a green healthcare transformation is seen as key to ensuring both environmental sustainability and long-term public health (Hamilton et al., 2021; Karliner et al., 2020; Lokmic-Tomkins et al., 2022; Strange et al., 2023). As in all areas, the healthcare sector needs to be resilient to climate change, and within this framework, a transformation that contributes to environmental sustainability and develops strategies for low carbon emissions is needed.

This transformation will not only enhance operational efficiency but also ensure the integration of health policies into the broader framework of climate justice (Rafetti et al., 2024). Developing comprehensive strategies, generating evidence-based knowledge, and identifying trends and trajectories within the literature are essential to achieving these objectives. In this regard, bibliometric studies can map scientific output, facilitate interdisciplinary collaboration, and inform future research directions. Although the carbon footprint literature in healthcare has gained considerable momentum since the 2000s, it still remains in an early developmental stage. While initial studies predominantly concentrated on estimating emissions from national health systems—such as hospital-based assessments in the United States and the United Kingdom—more recently, particularly under the influence of the Covid-19 pandemic, topics such as remote consultation, digitalization, and telehealth have become linked to carbon emissions and have emerged as significant areas of academic inquiry (Tennison et al., 2021; Holmner et al., 2014).

Tennison and colleagues (2021) conducted a pioneering study assessing the carbon footprint of the UK National Health Service (NHS), demonstrating the effectiveness of various emission reduction strategies. Similarly, studies by Holmner et al. (2014) and Lokmic-Tomkins (2022) have focused on examining and comprehensively mapping the carbon impacts of digital health interventions. However, the limited scope of existing bibliometric analyses and the inadequacy of thematic mapping specific to the health sector clearly reveal a research gap in this field. In this context, mapping temporal and geographical trends on a global scale and establishing connections among studies from different disciplines is of considerable importance. Although most research directly concentrates on emission sources—such as energy use, transportation, logistics, and waste, there remains a need for a more holistic perspective (Karliner et al., 2020; Pichler et al., 2019). Accordingly, bibliometric methods can guide researchers toward emerging areas of inquiry by revealing the development of the field and the patterns of collaboration through citation networks and keyword mapping.

METHODOLOGY

Purpose and Significance of the Study

Academic interest in the environmental impacts of healthcare services has increased steadily in recent years. This study aims to elucidate the implications of the concept of the *carbon footprint* for the healthcare sector and to identify research trends in this field, thereby examining the interaction between carbon footprint and healthcare services. Within this framework, articles published in the international literature on the carbon footprint in the healthcare sector between 1975 and 2024 were analyzed according to a set of specific parameters.

Reducing the carbon footprint of the healthcare sector has become a critical requirement for ensuring environmental sustainability and for mobilizing urgent action against the global climate crisis. Minimizing the environmental impact of hospitals and other healthcare institutions will

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support the sector in achieving its sustainability objectives and generate long-term positive outcomes for public health. In this context, the present study provides a comprehensive overview of the field by defining the scope and depth of the literature, paving the way for future strategic directions in environmental sustainability in healthcare, and contributing meaningfully to the understanding of the current knowledge base.

Data Collection Methods

The data used in this study were retrieved from the Web of Science database in August 2024. The Web of Science platform was selected for the bibliometric analysis because it is one of the most widely used databases and offers practical advantages for data extraction (Yang et al., 2013). A search strategy was developed in Web of Science using the following query: TI = (("carbon economic" OR "carbon footprint" OR "carbon pricing" OR "carbon burden" OR "net zero carbon") AND ("health" OR "medicine" OR "medical" OR "hospital" OR "healthcare" OR "public health" OR "epidemiology" OR "environmental health" OR "health economics" OR "health outcomes" OR "public health policy" OR "health system" OR "global health" OR "health services research"))

The selected time frame covers the years 1975–2024. It is expected that applying the same search strategy at different points in time may produce varying results. These variations stem from the continuous updating of the Web of Science database and the ongoing expansion of the scholarly literature in this field (Liu et al., 2013). In this search, the document type was restricted to articles, and only publications written in English were included. The search returned a total of 108 academic publications, all of which were included in the bibliometric analysis.

Each publication indexed in the Web of Science database contains extensive information, including the year of publication, authors, affiliations, title, abstract, source, subject categories, and references. In this study, a bibliometric analysis was conducted on publications related to the carbon footprint of healthcare services indexed in Web of Science. The analysis examined several dimensions, including the number of publications, patterns of author collaboration, journals publishing research on the carbon footprint of healthcare services, geographical distribution of the studies, levels of inter-institutional collaboration, citation and co-citation structures, subject categories, and keyword occurrences.

Analysis of the Study

In this study, VOSviewer software (VOSviewer, 2018), which is freely available and open-access, was used to analyze and visualize relationships among authors, countries, co-citations, and terms. The main types of bibliometric networks include citation networks, co-citation networks, bibliographic coupling networks, keyword co-occurrence networks, and co-authorship networks.

The density map generated in VOSviewer is used to visualize the concentration of publications, authors, or citations within a specific scientific field, as well as their relationships with one another. The colors on the map represent varying levels of density: yellow indicates the strongest connections or the highest citation density, whereas green and blue represent weaker connections. The size of the circles reflects the frequency with which a term appears in titles and abstracts; larger circles signify a higher frequency of occurrence. The distance between terms indicates the strength of their relationship, with shorter distances representing stronger conceptual connections. The interdependence of terms is determined by how frequently they co-occur in titles and abstracts (Rodrigues et al., 2014).

Citation analysis is an effective method for evaluating science and technological development. The method assumes that prior studies contain foundational concepts that contribute to scientific

advancements. However, frequent citation does not necessarily indicate the importance of a document (Akhlaki and Hanapi, 2023). Citation analysis provides multiple insights into a research field. First, this method helps identify the authors and publications that contribute most significantly and effectively to the field. Additionally, it can reveal information sharing and communication networks among authors. Finally, examining the relationships between cited and citing documents reveals how a field evolves over time (Pournader et al., 2020; Gundolf and Filser, 2013).

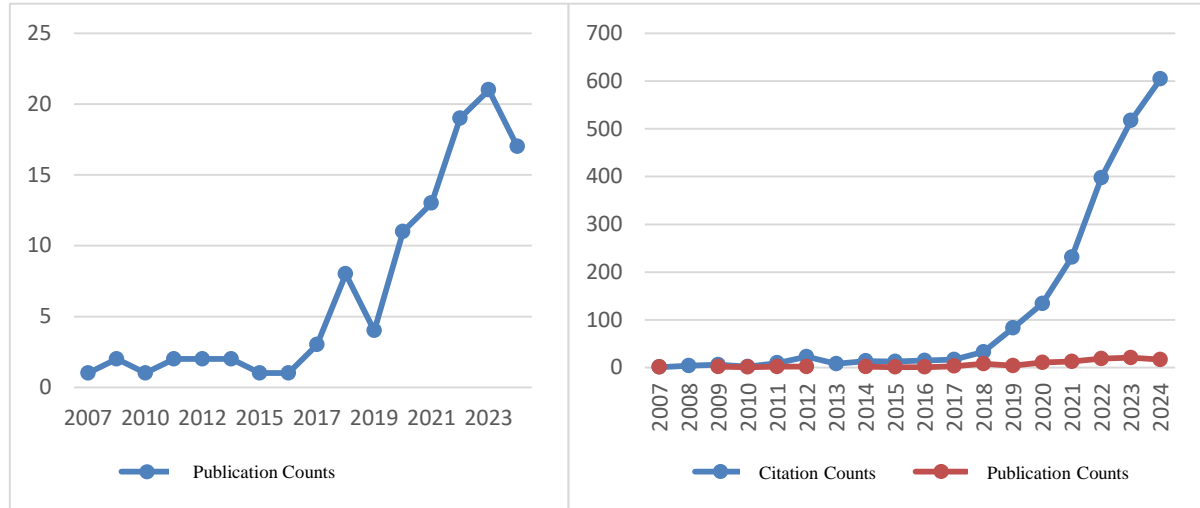
This study employed bibliometric analysis, using data extracted from the Web of Science (WoS) Core Collection. Within the scope of the analysis, citation patterns related to the theme “*Carbon Footprint in Healthcare*” were examined at the levels of authors, documents, sources, institutions, and countries. Additionally, to identify the conceptual structure and thematic evolution of the field, temporal keyword trend analysis and co-keyword network analysis were performed. VOSviewer was used to map concepts with strong relationships for each type of analysis. Keyword popularity and trend changes over time were analyzed using color scales.

Approval of Ethical Committee: Ethical committee approval is not required for this article.

RESULTS

This section systematically presents the data obtained from the bibliometric analysis. The findings reveal patterns of productivity, the collaborative structure of the research field, and key areas of conceptual focus within the literature.

Figure 1: Publication Years and Citation Counts of Publications Related to Carbon Footprint in Healthcare Services



According to Figure 1, the first study on the carbon within the healthcare sector dates back to 2007. Although scholarly interest has fluctuated over time, the topic has gained renewed attention in recent years. While citation counts in this field remained relatively low during the initial stages of research, they began to rise substantially after 2018.



Table 1. Publication Numbers by Country

Countries	Publication Numbers
USA	25
United Kingdom	22
Australia	11
Spain	8
Canada	8
China	7
Germany	5
France	4
Netherlands	4
New Zealand	4

According to Table 1, the United States ranks first in terms of the number of publications on the carbon footprint in the healthcare sector, with a total of 25 studies. It is followed by the United Kingdom with 22 publications and Australia with 11 publications.

Table 2. Publication Numbers by University (Top 10)

No	Universities	Publication Numbers
1	University of Sydney	8
2	University of London	7
3	Harvard University	4
4	Johns Hopkins University	3
5	Universidad De Extremadura	3
6	University College London	3
7	University of British Columbia	3
8	University of Melbourne	3
9	University of Oxford	3
10	Australian National University	2

According to Table 2, the University of Sydney ranks first among the top ten universities publishing on the carbon footprint in the healthcare sector, with a total of eight publications. The University of Sydney and the University of London contribute more extensively to this field compared to the other institutions on the list, while Harvard University ranks third with four publications. The Australian National University completes the list with two publications. Overall, the ranking is dominated by universities from the United States, Australia, and the United Kingdom, suggesting that these countries place considerable emphasis on research at the intersection of health and sustainability.



Table 3. Distribution of Publications by Journal (Top 10)

No	The Title of the Journal	Publication Numbers
1	Frontiers In Public Health	6
2	BMJ British Medical Journal	5
3	Journal of Climate Change and Health	4
4	Lancet Planetary Health	3
5	Age and Ageing	2
6	BMJ Open	2
7	Medical Journal of Australia	2
8	Environmental Health Perspectives	2
9	European Respiratory Journal	2
10	Frontiers In Ecology and The Environment	2

According to Table 3, the most active journal publishing on the carbon footprint in the healthcare field is *Frontiers in Public Health*, with a total of six publications. *BMJ-British Medical Journal* ranks second with five publications, followed by the *Journal of Climate Change and Health* with four publications.

Table 4. Distribution by Field of Study

Work Field	Number
Public Environmental & Occupational Health	29
Environmental Sciences Ecology	26
General Internal Medicine	18
Health Care Sciences Services	13
Science Technology Other Topics	8
Engineering	7
Surgery	4
Business Economics	3
Dermatology	3
Medical Informatics	3

Table 4 shows that, when examining the distribution of Web of Science categories by research discipline in the healthcare field, the connection between environmental issues and health becomes particularly prominent. The categories receiving the highest number of citations are Public, Environmental & Occupational Health, Environmental Sciences & Ecology, and General & Internal Medicine. These findings demonstrate a distinct multidisciplinary orientation in the study of the carbon footprint.

Table 5. Authors with the Most Citations and Publications (Top 10)

No	Author Name	Number of Citations	No	Author Name	Number of Publications
1	McGain, Forbes	374	1	McGain, Forbes	3
2	Malik, Arunima	374	2	Malik, Arunima	3
3	McAlister, Scott	346	3	Sehgal, Ashwini R.	2
4	Ashby, Ben	300	4	Singh, Mamta K.	2
5	Boyd, Richard	300	5	Sánchez-Barroso, Gonzalo	2
6	Eckelman Matthew	300	6	García Sanz-Calcedo, Justo	2
7	Hamilton, Ian	300	7	Keefe, Sarah O.	2
8	Oreszczyn, Tadj	300	8	Rosenbach, Misha	2
9	Owen, Anne	300	9	Jayakrishnan, Thejus	2
10	Romanello, Marina	300	10	Wise, Jacqui	2

Table 5 presents the top ten authors with the highest number of citations and publications on the carbon footprint in the healthcare field. Forbes McGain and Arunima Malik stand out as the most influential authors, each receiving 374 citations and producing three publications, making them the most cited and most prolific contributors in this research area.

Table 6. Most Cited Studies (Top 10)

Author	Publication Year	Publication Name	Number of Citations
Tennison et al.	2021	Health care's response to climate change: a carbon footprint assessment of the NHS in England	347
Malik et al.	2018	The carbon footprint of Australian health care	316
Chung and Meltzer	2009	Estimate of the carbon footprint of the US health care sector	258
Holmner et al.	2014	Carbon footprint of telemedicine solutions-unexplored opportunity for reducing carbon emissions in the health sector	123
Rizan et al.	2021	The carbon footprint of waste streams in a UK hospital	90
Nansai et al.	2020	Carbon footprint of Japanese health care services from 2011 to 2015	86
McAlister et al.	2022	The carbon footprint of hospital diagnostic imaging in Australia	79
Wu, R.	2019	The carbon footprint of the Chinese health-care system: an environmentally extended input-output and structural path analysis study	69
Khan et al.	2022	The impact of carbon pricing, climate financing, and financial literacy on COVID-19 cases: go-for-green healthcare policies	50
Bousema et al.	2020	Reducing the carbon footprint of academic conferences: the example of the American society of tropical medicine and hygiene	48

Table 6 presents the authors and key details of the ten most frequently cited studies on the carbon footprint in healthcare. The most cited publication is the study by Tennison et al. (2021), titled “Health care's response to climate change: a carbon footprint assessment of the NHS in England,” which has received 347 citations. This study assesses the carbon footprint of the UK healthcare system within the broader context of climate change mitigation efforts. The second most cited article is “The carbon footprint of Australian healthcare,” published by Malik et al. (2018), in which the authors evaluate the environmental impact of the Australian healthcare system in terms of its total carbon emissions.

Figure 2. Keyword Occurrence Frequencies and Total Link Strengths Based on Temporal Trend and Co-Word Network Analysis

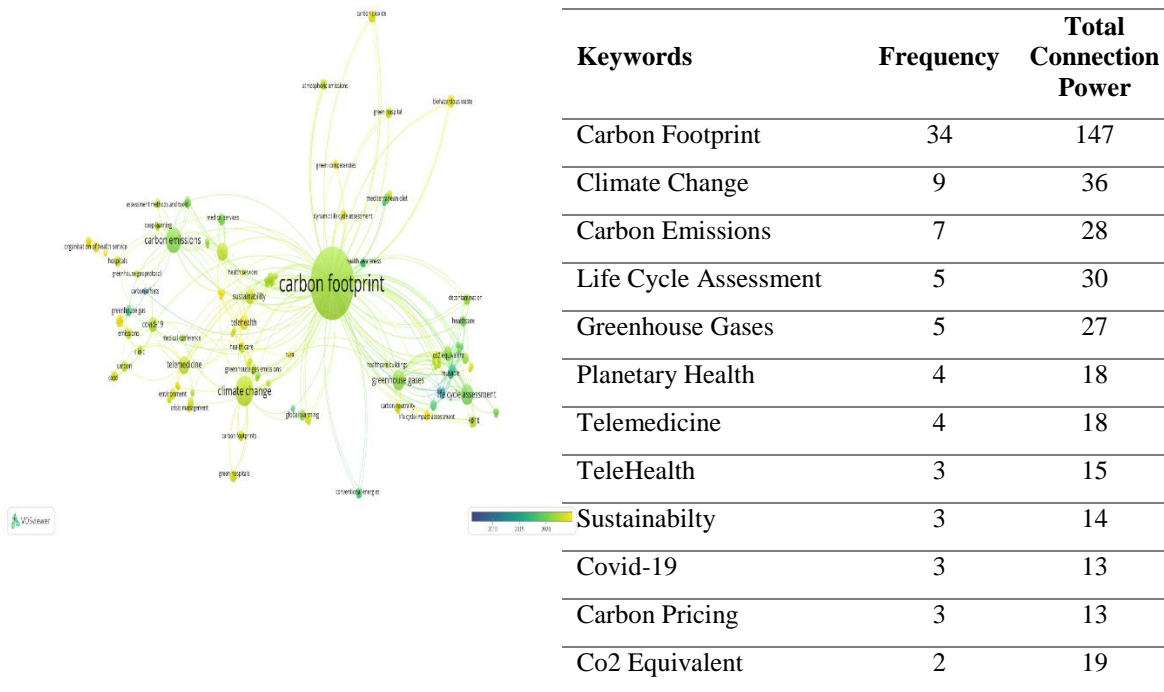


Figure 2 illustrates the thematic structure and temporal evolution of research regarding the carbon footprint within the healthcare sector. Large clusters indicate that concepts such as carbon footprint, climate change, carbon emissions, and greenhouse gases are long-standing and dominant themes. Specifically, *Carbon Footprint* occupies the most central position, demonstrating the highest connection density within the network. The color-coded, ranging from dark blue to yellow, reflects the chronological progression of keywords from pre-2010 to post-2020. Earlier (pre-2010) research (blue tones) predominantly features terms like *carbon dioxide*, whereas recent (2018-2022) contributions (yellow and light green tones) highlight keywords such as *telehealth*, *sustainability*, *life cycle assessment*, *COVID-19*, *biohazardous waste*, and *carbon neutrality*. The emergence of new terminology reflects a notable shift in scholarly focus, driven by the transformative effects of the COVID-19 pandemic and an intensified interest in environmentally sustainable healthcare practices. This shift is further evidenced by keywords such as *Greenhouse Gases* and *Green Hospitals*, which point to strategic initiatives aimed at mitigating the environmental footprint of healthcare services. Quantitatively, *Carbon Footprint* ranks highest with 34 occurrences and a total link strength of 147, followed by *Climate Change* (9 occurrences) and

Carbon Emissions (7 occurrences). Additionally, keywords like *CO2 Equivalent*, while less frequent, maintain strong conceptual relevance as evidenced by their high link strength. Overall, the network underscores both the enduring conceptual anchors of the field and its evolving trajectory shaped by global developments.

Table 7. Keywords Most Closely Associated with Major Keywords in the Co-Word Network Analysis

Keywords	Related Keywords
Carbon Footprint	Climate Change, Carbon Emission, Telehealth, Life Cycle Assessment, Health Care, Global Warming, Telemedicine, Co2 Equivalent
Climate Change	Carbon Footprint, Carbon Emissions, Telehealth, Health Care, Green Hospitals
Carbon Emissions	Carbon Footprint, Climate Change, Telehealth, Digital Healthcare

Table 7 shows the most important keywords identified through the common word network analysis, highlighting the terms most closely associated with carbon footprint, climate change, and carbon emissions. In addition to having strong interconnections among themselves, these three keywords also exhibit meaningful conceptual relationships with terms such as telehealth and healthcare.

DISCUSSION AND CONCLUSION

Although the number of studies on the carbon footprint in the healthcare sector fluctuated between 2007 and 2016, it has increased steadily since 2017. After a brief decline in 2019, publication output continued to rise, reaching 23 studies in 2023. Citation counts have also shown a consistent upward trend since 2015, increasing from 13 citations in 2015 to 604 citations in 2024. One of the contributing factors to this growth may be the heightened global awareness of the healthcare sector's carbon footprint, particularly following the adoption of international environmental policies such as the Paris Climate Agreement after 2015.

While about half of the publications on carbon footprints have been published in the UK and the US, a different trend emerges among universities. The highest number of publications were made at universities in Australia (13) and the UK (13). The fact that the universities producing the most publications are in different countries shows that knowledge production and publication platforms vary. In terms of global publishing, the US and the UK can be said to be central to publications on carbon footprints.

The fact that most publications on carbon footprint have appeared in prestigious journals in public health and medicine shows that this topic is not only the domain of environmental sciences but also of health sciences, which are taking an interest in the carbon footprint issue. The fact that a clinically focused journal (BMJ) ranks second supports this view. Looking at the distribution of publications by discipline, it can be said that carbon footprint is an interdisciplinary topic. The presence of fields such as engineering and information technology among the top ten fields indicates that digital solutions are being sought to reduce carbon footprint. It shows that other fields are at least as important as environmental sciences in reducing carbon emissions.

Cott McAlister, Ben Ashby, Richard Boyd, Matthew Eckelman, Ian Hamilton, Tadj Oreszczyn, Anne Owen, and Marina Romanello are also among the top ten most cited authors, despite not being among the top ten most productive authors. In other words, these scholars have received a substantial number of citations despite contributing relatively few publications. This suggests that



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their works serve as foundational references within the field and have generated a wide-reaching academic impact.

When examining the most cited studies on healthcare services and the carbon footprint, it becomes evident that some investigations address the healthcare sector as a whole, whereas others concentrate on specific components of healthcare, such as particular services, practices, or operational processes. Studies by Chung and Meltzer (2009), Malik et al. (2018), Wu (2019), Nansai et al. (2020), and Tennison et al. (2021) assessed the carbon footprint of entire national health systems. In contrast, Holmner et al. (2014), Rizan et al. (2021), and McAlister et al. (2022) focused on discrete elements of healthcare delivery, providing more detailed evaluations of specific services or practices.

The study conducted by Tennison et al. (2021) on the UK National Health Service (NHS) represents one of the most comprehensive carbon footprint assessments within the healthcare sector. The authors evaluated greenhouse gas emissions from 1990 to 2019 using up-to-date data, as part of the NHS's long-standing efforts initiated in 2008 to reduce its carbon footprint. The study also proposed a methodological framework that can serve as a model for tracking and monitoring carbon reduction strategies in healthcare systems worldwide.

Malik et al. (2018) measured the carbon footprint of the Australian healthcare system and quantified the sector's share of total national carbon emissions. Their findings indicated that hospitals and pharmaceutical products constitute the primary contributors to the healthcare sector's carbon footprint. The authors recommended expanding the use of carbon-efficient practices and strengthening preventive healthcare services in order to reduce the environmental impact of healthcare delivery. Similarly, Chung and Meltzer (2009) calculated the total carbon footprint of the U.S. healthcare sector using data from 2007 and assessed the environmental consequences of healthcare services. Their study revealed that hospitals and prescription drugs accounted for the largest proportion of greenhouse gas emissions within the U.S. healthcare system. Furthermore, the authors emphasized the potential of telemedicine as an effective tool for reducing carbon emissions, arguing that it should be viewed not only as a remedy for geographical or logistical constraints but also as an essential component of routine healthcare delivery.

When examining studies that focus on specific areas of healthcare services, the literature largely centers on applications related to telemedicine, hospital waste management, and hospital imaging services. Holmner et al. (2014) assessed the potential of telemedicine to reduce carbon emissions associated with patient and healthcare worker travel by comparing video-based telemedicine consultations with traditional in-person appointments. Their findings indicate that telemedicine produces 40 to 70 times fewer carbon emissions than face-to-face consultations and remains a more environmentally sustainable alternative even for short travel distances of only a few kilometers. Moreover, the study highlights that telemedicine is a powerful tool for reducing carbon emissions in healthcare and should be regarded not only as a solution to geographical or logistical barriers but also as an essential component of routine healthcare delivery.

Rizan et al. (2021) examined the waste streams of three hospitals in the United Kingdom to determine the carbon footprint associated with hospital waste and to compare the environmental impacts of different waste management approaches. Their findings showed that recycling produces the lowest carbon footprint, whereas high-temperature incineration results in the highest carbon footprint among the evaluated methods. In addition, the study found that clinical, anatomical, and medical waste constitute the waste categories with the highest carbon footprint in hospitals, underscoring the need for improved waste segregation and more sustainable waste management practices within healthcare facilities.

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McAlister et al. (2022) conducted a life cycle assessment of five commonly used imaging modalities—chest X-ray, mobile chest X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound—at two university hospitals in Australia to determine the carbon footprint associated with diagnostic imaging. The study found that ultrasound and mobile chest X-ray have the lowest carbon footprints, whereas MRI has the highest carbon footprint among the evaluated methods. Additionally, the authors identified that energy consumption from devices left in standby mode represents a significant source of emissions. Based on these findings, the researchers recommend minimizing unnecessary imaging procedures, selecting lower-emission imaging methods when clinically appropriate, and ensuring that devices are powered off when not in use as effective strategies for reducing carbon emissions in healthcare services.

Khan et al.'s (2022) study, which examines the impact of carbon pricing, climate finance, and financial literacy on COVID-19 cases, initiates an important discussion on the role that green health policies may play in the post-pandemic period. This example illustrates that the relationship between the carbon footprint and healthcare services is becoming increasingly complex. Earlier carbon footprint studies in the healthcare sector primarily focused on calculating direct and measurable physical or technical emission sources such as energy consumption, hospital waste, and supply chain-related emissions. However, studies published in the 2020s have begun to address the carbon footprint not only through direct emissions but also by integrating broader variables such as economic policy instruments, healthcare financing models, social determinants, and pandemic-related dynamics. Components of economic and social policies such as carbon pricing, climate finance, and green health policies—are now being incorporated into analyses of the healthcare sector's environmental impact. In other words, the central research question is no longer limited to “How much energy do hospitals consume, and how does this contribute to their carbon footprint?” but has expanded to include more holistic considerations such as “Which financing mechanisms can reduce the carbon footprint of the healthcare system?”

The diversity of the most cited studies demonstrates that carbon emissions in the healthcare sector are multidimensional and must be addressed at multiple levels—national, institutional, and service-based. Such comparative analyses are essential for evaluating the effectiveness of different approaches and practices within health policies and for informing them about the development of global solutions. These studies can be regarded as comprehensive and pioneering work that have laid the foundational groundwork for the field.

The association of the carbon footprint concept with terms such as climate change, carbon emissions, telehealth, life cycle assessment, and healthcare demonstrates that the environmental impacts of the health sector are being addressed in a multidimensional and increasingly integrated manner. The connection of carbon footprint with life cycle assessment and carbon dioxide equivalent indicates a growing academic emphasis on systematically measuring the contribution of healthcare activities to carbon emissions and their broader environmental impacts. Moreover, key terms such as life cycle assessment and carbon dioxide equivalent point to methodological approaches that directly support the development of strategies for reducing carbon footprints. Similarly, the presence of keywords such as green hospitals and sustainability highlights the increasing focus on sustainability-oriented transformation initiatives within healthcare institutions. These terms suggest that policies related to energy efficiency, waste management, and carbon neutrality in hospital buildings will become increasingly prominent in the coming years, reflecting a shift toward more environmentally responsible models of healthcare delivery.

On the other hand, the prominence of sustainability among high-impact terms indicates a growing awareness of sustainability-oriented practices and policies within the healthcare sector. This trend



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reflects an increasing interest in sustainable healthcare services and policies, as well as a rising frequency of related discussions in the academic literature. This development suggests that healthcare services have substantial implications not only for human health but also for environmental health and environmental sustainability.

It is also noteworthy that digital health applications such as *telehealth and telemedicine* are associated with carbon footprint and carbon emissions. This highlights that digital health applications have the potential to reduce the carbon footprint of healthcare services and contribute to sustainable healthcare. In addition to these concepts, the association of terms such as *hospitals and medical services* with carbon footprint indicates an increase in academic interest in the environmental impacts of the healthcare sector, greater consideration of the healthcare sector in academic discussions on environmental sustainability, and an increasing focus on the impact of healthcare services on climate change. The emergence of topics such as *biohazardous waste and carbon neutrality* in recent years is indicative of the growing interest in the ecological impacts of healthcare services, waste management in healthcare, and carbon neutrality strategies.

The presence of the COVID-19 concept in the tables and network map demonstrates that the pandemic has made the relationship between healthcare systems and environmental impacts more visible. As in many other sectors, the increasing digitalization of healthcare during the pandemic contributed to heightened awareness of the sector's carbon footprint and related emissions.

The key terms that stand out in the analysis highlight the multidimensional nature of research on the healthcare sector and carbon footprints. These concepts primarily encompass tools used to measure environmental impacts (e.g., CO₂ equivalent, life cycle assessment) as well as terms that reflect the cause-and-effect relationships between climate change and healthcare (e.g., climate change, greenhouse gases, planetary health). In addition, digital health services and sustainability-related discussions—such as telemedicine, telehealth, sustainability, and COVID-19 which gained significant momentum during the pandemic, point to emerging and current trends in the healthcare sector's engagement with carbon footprint issues.

In short, carbon footprint research in the context of healthcare services is emerging as a multifaceted field that encompasses a wide range of subtopics, including climate change, greenhouse gas emissions, life cycle assessments, and digital health applications. In this regard, it is expected that themes such as green hospitals, carbon neutrality, environmentally responsible health policies, and the expansion of digital health services will become increasingly prominent in the academic literature in the coming years, particularly from an interdisciplinary perspective. Moreover, future research is anticipated to place greater emphasis on developing sustainable health policies and reducing the environmental impact of healthcare systems, contributing to a more holistic understanding of sustainability in health.

In conclusion, the increasingly interdisciplinary structure of carbon footprint research in healthcare demonstrates a clear shift from early studies focusing on direct measurements -such as energy consumption and waste management- to more comprehensive and strategic areas, including life cycle assessment, digital health solutions, green hospital initiatives, carbon neutrality, and environmentally oriented health policies. The demonstrated effectiveness of telemedicine and other digital applications in reducing emissions further highlights digitalization as a critical tool not only for improving accessibility but also for advancing environmental sustainability. However, for the field to progress holistically, research efforts must extend beyond high-income countries and address the significant data gaps in low- and middle-income settings. Future studies should employ standardized, comparative methodologies to evaluate the carbon impacts of different diagnostic and therapeutic processes and to examine the environmental implications of carbon pricing, green

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financing mechanisms, and health policy decisions. Advancing research in these directions will strengthen the capacity of health systems to respond to climate change and support the development of healthcare systems that are more sustainable, environmentally responsible.

This study has methodological limitations. First, the analysis is restricted to English-language articles indexed in the Web of Science Core Collection, which may exclude studies published in other databases such as Scopus and PubMed, as well as those written in other languages. The use of specific keywords may have led to the omission of some relevant studies on the carbon footprint in healthcare services. By nature, bibliometric analysis does not allow for a detailed evaluation of the content-related, theoretical, or contextual depth of the literature. Additionally, due to the evolving nature of the Web of Science database, applying the same search strategy at different points in time may yield varying results, representing a time-dependent limitation of the study.

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