



Green Hospital Sustainability Assessment : a Bibliometric Analysis and Future Research Agenda

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Abstract. Health care is the largest consumer of energy and other natural resources because it operates twenty-four hours non-stop and produces a negative impact on the environment in the form of two giga tonnes of CO₂. In ensuring environmental sustainability, hospitals as health care facilities are required to implement green hospitals to reduce negative impacts on the environment. Implementation of green hospitals requires a sustainability assessment model. This study aims to determine the trend of green hospital sustainability assessment publications from 2016-2024 through bibliometric analysis with VOSViewer and Biblioshiny. Bibliometric analysis is a method that can study scientific literature by analyzing and describing large amounts of literature. Publications were retrieved through a Scopus database search until 127 publications were obtained. The VOSViewer program was used to visualize and analyse trends and patterns in the literature. The study results showed that the trend of publications and journals that publish green hospital sustainability assessments has increased from year to year. There are 16 clusters of research themes can be used as an evolution of research themes. Green hospital sustainability assessment with multiple criteria from the triple bottom line dimension and sustainability balance scorecard is new and further research can be done in the future

Keywords: Green Hospital; Assessment; Sustainability

1 Introduction

According to the Intergovernmental Panel on Climate Change, rapid and widespread changes are needed in all aspects of society to limit global warming. It is imperative to transition energy, industry, buildings, transport, and cities to reduce CO₂ emissions from human activities worldwide to reach a net zero target by 2050 [1]. Increasing global energy consumption and its negative impact on the environment is an issue that continues to be discussed by academics and practitioners in the health sector. Hospitals, which are one of the healthcare facilities, are major consumers of energy, leading to increased operational costs, decreased competitiveness, and negative impacts on the environment. Healthcare is the largest consumer of energy and natural resources because it operates twenty-four hours non-stop and produces a negative impact on the environment in the form of two giga tonnes of CO₂ [2]. Indonesia with a high population still needs new hospitals because the ratio of beds to population in Indonesia

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with a high population still needs new hospitals because the ratio of beds to population in Indonesia is 1.21:1,000 population, while the World Health Organisation recommends a ratio of beds to population of 5:1,000 population. Limiting the number of hospitals to reduce CO₂ emissions cannot be done because it will reduce the quality of health of the Indonesian population, the alternative is the necessity to build and develop hospitals holding the concept of green hospitals [3]. Hospital planning in implementing green hospitals is limited by the availability of resources. Budget, human resources, and technology are limited resources in an organization. The operational capability of management is determined by the strategy of allocating the resources owned [4]. One of the obstacles for hospitals in implementing green hospitals is the funding aspect. The costly nature of green building in the initial stage, the high cost of green technology equipment, and the lack of financial motivation were identified as barriers to sustainable construction practices in hospital buildings [5]. Technologies related to green innovation, green building, big data analysis and artificial intelligence are used in supporting the implementation of green hospitals. Green innovation is an important benchmark in green hospital implementation because it can incorporate energy-efficient technologies that minimize pollution and can recycle waste generated by the hospital. Hospitals through green innovation can increase productivity and cost efficiency, creating environmentally friendly services in an effort to support the implementation of green hospitals [6].). Green buildings supported by technology improve the welfare of health workers in the long term, and reduce waiting time and costs incurred by patients [4]. Environmentally friendly human resource management facilitates the implementation of green hospitals, this is due to human resources as a fundamental factor in hospital business processes and has a better understanding and involvement in various activities related to environmental sustainability [7].

Hospitals that can implement sustainable concepts can reduce energy use and waste generation [8]. Healthcare facilities, especially hospitals, have an increasingly important role in the context of urban sustainability. The development of environmentally friendly hospitals is important to create healthy lifestyles that are economically, environmentally, and socially viable, thus realizing sustainable cities (Sahamir, 2017). Eco-friendly hospital design aspires to provide energy savings and a comfortable environment for users through innovative design and eco-friendly techniques. Measures to achieve sustainable hospitals can result in cost savings, increased patient satisfaction, and environmental benefits [9]. Globally, there are already several instruments to assess and measure green building performance, revolutionizing hospital design by using sustainable technologies, energy-efficient systems, and recyclable or renewable resources and materials [10]. There are an estimated 600 green rating systems worldwide [8]. Developed countries have proposed green building evaluation systems to minimize energy consumption and pollution. In some countries, there are still differences in clear and unified definitions related to the sustainability assessment of green hospitals that refer to green buildings. The criteria in assessing and measuring the performance of green buildings in the world consist of, Leadership in Energy and Environmental Design (LEED) initiated by the US Green Building Council and applied in the United States, Building Research Establishment's Environmental Assessment Method (BREEAM) initiated by Building Research Establishment and

applied in the United Kingdom, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) initiated by the Japan Sustainable Building Consortium applied in Japan, Green Star (GS) initiated by Green Building Council Australia applied in Australia, Assessment Standard for Green Building (ASGB) initiated by Ministry of Housing and Urban-Rural Development of People's Republic of China applied in China, Building Environmental Assessment Method (BEAM) initiated by Hong Kong Green Building Council applied in Hong Kong, Green Mark (GM) initiated by Building and Construction Authority applied in Singapore, Green Building Index (GBI) initiated by Greenbuildingindex Sdn Bhd implemented in Malaysia, the Indian Green Building Council (IGBC) initiated Indian Green Building Council implemented in India [11].

In LEED, the significant criteria in sustainability are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, sustainable location, innovation, integrative process, and regional priority. The significant criteria in BREEAM are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, innovation, land use and outdoor environment, waste management, construction project management, transport, and pollution. The significant criteria in CASBEE are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, land use and outdoor environment, and offsite environment. Significant criteria in GS are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, innovation, land use and outdoor environment, waste management, construction project management, and transport. Significant criteria in ASGB are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, innovation, land use and outdoor environment, and construction project management. Significant BEAM criteria are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, sustainable location, and integrative process. Significant criteria in GM are energy efficiency, water efficiency, material efficiency, indoor environmental quality and health and well-being, waste management, climate considerations, and advanced green measures. Significant criteria in GBI are water efficiency, material efficiency, indoor environmental quality and health and well-being, sustainable location, and waste management. The significant criteria in IGBC are energy, water efficiency, material efficiency, indoor environmental quality and health and well-being, sustainable location, and pollution [11]. Two early systems developed were Leadership in Energy and Environmental Design (LEED) and Green Guide for Health Care (GGHC). LEED provides instruments to quantitatively measure building performance, while GGHC is the first specialized instrument that measures the design, construction, operation, and transformation of hospitals that are healthy for people and the environment. In 1996, the Global Green Healthy Hospitals (GGHH) refined the GGHC by adding the concept of sustainability without compromising patient safety or care, which has criteria for buildings, chemicals, energy, food leadership, pharmaceuticals, purchasing, transportation, waste, and water. The GGHC criteria consist of location, water use efficiency, air and energy pollution, materials

and resources, indoor environmental quality, healthy food, green education, green purchasing, reducing contaminants, and green cleaning [8].

The Indonesian Ministry of Health targets that by 2020, all hospitals in Indonesia should have implemented green hospitals. In 2018, the Ministry of Health issued green hospital guidelines that refer to the technical requirements of hospital environmental health, National Hospital Accreditation Standards, Green Building Council Indonesia's green building assessment tool implementation guidelines, as well as relevant laws and ministerial regulations to serve as a reference for green hospital implementation. Not many hospitals have implemented the green hospital concept in Indonesia because some hospitals in Indonesia implement green hospitals by referring to international criteria because they are globally recognized, so there is no sustainability assessment of green hospital implementation. This study aims to determine the publication trends of green hospital sustainability assessment from 2000-2024 through bibliometric analysis.

2 Materials and Methods

The stages of bibliometric analysis begin with determining the purpose and scope of the research then selecting bibliometric techniques, collecting data from the database, carrying out bibliometric analysis and reporting research findings [12]. This research has several stages, starting with identifying articles contained in the Scopus database. Keywords such as "green hospital" "sustainability" "criteria", "mutliaspect" were used to search for titles, abstracts, keywords in research journals published in the Scopus database. The selection of specific keywords is based on the research objectives, namely knowing the trend of green hospital sustainability assessment publications from 2016-2024 through bibliometric analysis. The keywords "green hospital" and "sustainability" are intended so that the search for articles is limited to the scope of sustainability of the green hospital. The keywords "criteria" and "multi-aspect" are intended for the research purpose of assessing the criteria and multi-aspect green hospital. Article searches in this study are assisted by Boolean operators such as AND, OR. This research is also in identifying, filtering, deciding the eligibility of articles, and completing the list of articles to be analysed using the four stages of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyze) [13]. The initial search query in the Scopus database was TITLE-ABS-KEY ("green hospital" OR sustainability AND "criteria" OR "multiaspect") AND PUBYEAR > 2015 AND PUBYEAR < 2025. The following figure 1 presents the study review process in this research.

The search results were then analysed based on document type, trend, subject, country, author, source and year. Articles related to green hospital criteria were taken from 2016-2024 in the Scopus database, while bibliometric analysis used the VOS-Viewer application (version 1.6.19) and biblioshiny. The selection of the time span since 2016 is due to the entry into force of the Paris Agreement which is a milestone in climate change that has an impact on health services, especially hospitals [14]. The results will be analysed descriptively based on the visual results obtained. The selec-

tion of a single database helps reduce errors due to duplication of articles, especially the use of a single database already fulfils scientific principles. Scopus database was chosen because it is the main repository of multidisciplinary peer review articles and is widely used in similar studies. Some duplicated and irrelevant articles were excluded. VOS-Viewer was used to visualise and analyse various trends and patterns in the articles. VOS-Viewer can generate co-authorship, cocitation, and co-occurrence maps, making this software helpful in bibliometric analysis [15]. The findings in bibliometric analysis can be divided into two, namely performance analysis and science mapping. Science mapping consists of citation analysis, co-citation analysis, bibliographic coupling, co-word analysis, co-authorship analysis, network metric, clustering, and visualisation [12].

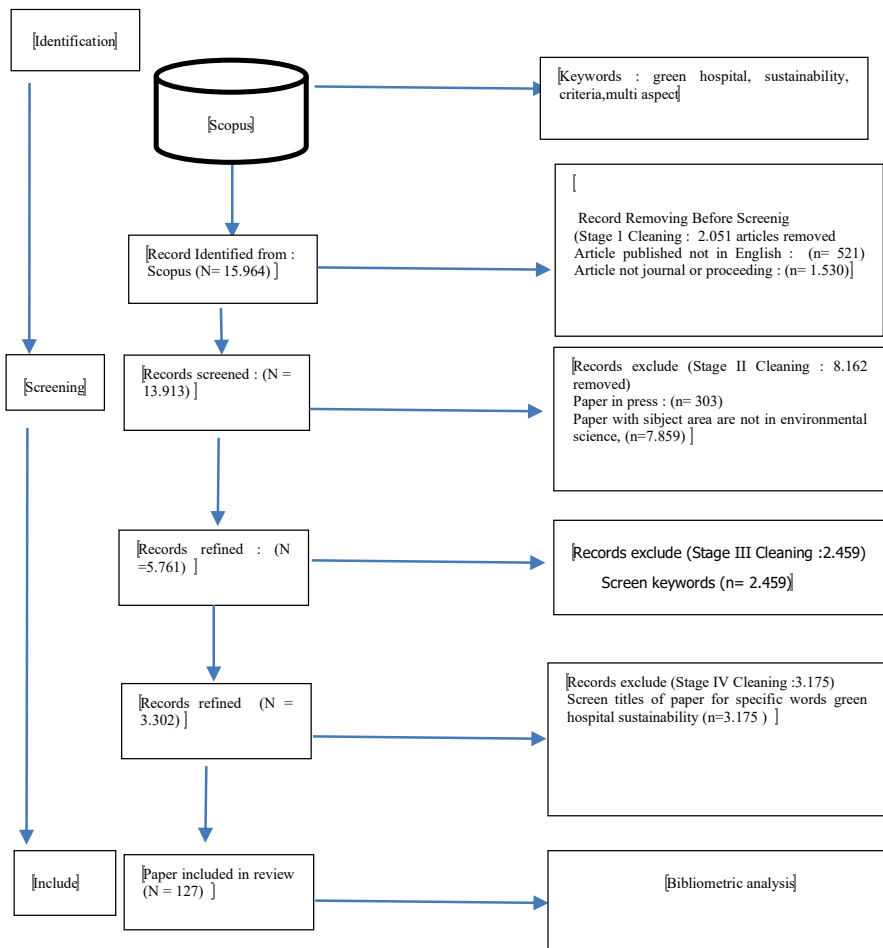


Fig. 1. Bibliometric Process

In addition to using VOS-Viewer, bibliometric analysis in this study also uses biblioshiny which is run using the R Studio application. The csv file obtained from the Scopus database was analysed into the R Studio application. The use of biblioshiny analysis in bibliometric research has not been widely used, this can be a novelty in this study. Analyses that are widely used only use VOSViewer. Research related to the assessment of hospital sustainability based on the implementation of green hospital in its analysis combines VosViewer and biblioshiny. Performance mapping consists of total publications, number of contributing authors, publications as a single author, publications with more than one author, number of active years of publication, number of contributing authors, single author publications, multiple author publications, number of active years of publication, number of citations, average citations, number and proportion of cited publications.

3 Results

3.1 Reasearch Trends and Collaborations

Bibliometrics was developed by Leiden University in the Netherlands and is used to explore and visualize two-dimensional bibliometric networks [13]. After selecting the articles, 127 articles were obtained for bibliometric analysis. The trend of publication from year to year increases can be seen in Figure 2, there is only a decrease in 2024 as many as 16 articles due to calculations starting in May. Sustainability evaluation in the health sector, especially in hospitals, is not as much as in other sectors such as the petroleum industry, banking, and other industries due to the limited sustainability evaluation model [16]. The distribution of journals that publish green hospital sustainability assessment articles is still dominated by Sustainability, Journal of Cleaner Production, International Journal of Environmental Research and Public Health, Sustainable Cities and Society, and Building and Environment. In the 2016-2018 period, there were only publications from the Journal of Cleaner Production, but the journals Sustainability and Building and Environment had just started publishing articles related to green hospital sustainability assessment and were followed by other journals until now. The increase in the number of journals that are published related to green hospital sustainability assessment shows that the research theme has been carried out by many researchers spread in various countries.

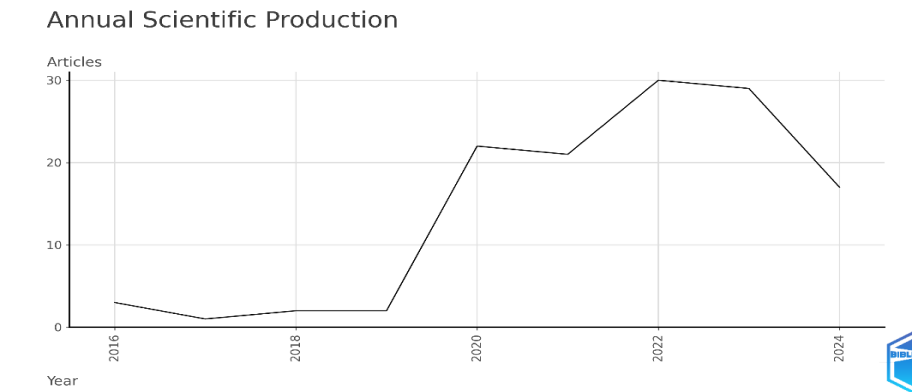


Fig. 2. Publication Trends 2016-2024

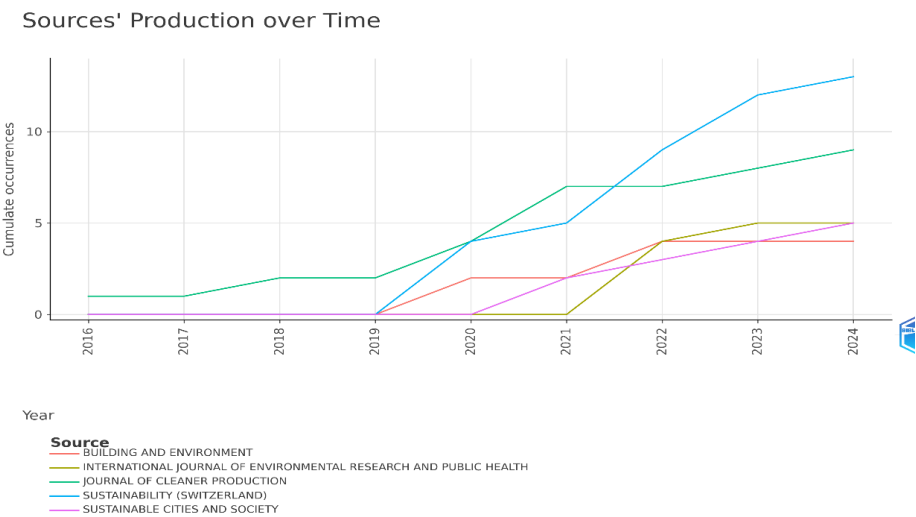


Fig. 3. Distribution of Publications Related to Green Hospital Sustainability Assessment in 2016-2024

The map of the distribution of research collaboration related to the assessment of green hospital sustainability is not only concentrated in developed countries. The distribution map of research collaborations related to green hospital sustainability assessment is not only concentrated in developed countries. An interesting finding is the involvement of Asian countries, especially Southeast Asian countries, this indicates that articles with the theme of green hospitals have been widely published throughout the continent and have become quite important research themes. Southeast Asian countries such as Indonesia and Malaysia have also collaborated with other countries, this is due to the increasing ecological footprint due to the increasing number of hospitals [17]. There is an urgent need for countries conducting research related to green hospitals to overcome the public health crisis as a negative impact of healthcare facilities [18].

3.2 Topic Trend

The biblioshiny analysis resulted in a trend of research topics from 2016-2024 which can be seen in Table 1. Sustainability has the highest frequency of 20 but only until 2023. Meanwhile, energy efficiency from 2020 to 2024 remained consistent with a frequency of 7. Energy efficiency is included in the topic trend until 2024 because the research conducted focuses on reducing the use of increasingly limited energy resources. The large use of electrical energy for the daily operations of hospitals ranging from lighting needs, and air conditioning, to the use of medical devices in twenty-four hours [19]. According to reports in the United States, hospitals consume twice as much energy as other office buildings [20]. Energy consumption is directly proportional to the number of beds, type of service, number of patients and staff, and climate zone. Hospitals in Germany require 17 million mWh for annual heat generation. Malaysia has an average annual electricity consumption of 44,637,966 kWh with air conditioning consuming 65% and lighting consuming 17% of the hourly electricity allocation [19]. Hospitals in Indonesia consume electricity at a high rate of 225 kWh/m² well above Japan's 175 kWh/m² [6]. This shows that the focus of research in that year range is still focused on the environmental and economic dimensions, not yet involving the social and other dimensions. The requirement for sustainability is the integration of all dimensions and the fulfillment of the criteria within them. The determination of the sustainability model, its dimensions, and the criteria that determine it will be seen in the mapping and evolution stages of the research theme.

Table 1. Trend Topic

Term	Frequency	Year (Q1)	Year (Medium)	Year Q3
Green building	5	2020	2020	2023
Green building	5	2020	2020	2022
Sustainability	20	2020	2022	2023
Green hospital	15	2020	2022	2023
Climate change	11	2020	2022	2023
Healthcare	12	2021	2023	2023
Energy efficiency	7	2020	2023	2024
Environment	7	2022	2023	2023

3.3 Science Mapping

Science mapping results from Vosviewer show that green hospital sustainability assessment using a multi criteria analysis approach with sustainability criteria and sustainability indicators in health care facilities is still a novelty because there are still few researchers who use this approach, as shown in Figure 4. Science mapping is followed up with a thematic map using biblioshiny so that sixteen research theme clusters are obtained. The first cluster is ahp, the second cluster is green hospital, the third cluster is sustainability, the fourth cluster is green building technology, the fifth cluster is green hospital, the sixth cluster is bibliometric analysis, the seventh cluster is triple bottom line, the eighth cluster is big data analytics and the ninth cluster is carbon footprint, tenth cluster is healthcare buildings, eleventh cluster is covid 19, twelfth cluster is criteria, thirteenth cluster is green technology, fourteenth cluster is energy management, fifteenth cluster is lifecycle cost analysis, and sixteenth cluster is rating system. Visualisation of science mapping was made to observe the most used keywords by previously published articles [21]. Sustainability in health care facilities, in this case hospitals, will affect public health, thus requiring a conceptual model consisting of environmental, social and economic dimensions [9]. The needs of each country in conducting a green hospital-based hospital sustainability assessment require determining the model used as an approach, determining the dimensions and assessment criteria. A model that combines the concepts of triple bottom line and balanced scorecard produces a sustainability evaluation in hospitals that includes six dimensions, namely environment, social, economy, stakeholders, internal processes, learning and growth [16].

Cluster	Number Keyword	Occurance	Predominant Keyword
			environmental behaviour
Criteria	1	2	Criteria
Green technology	1	2	Green technology
Ahp	3	7	Ahp, healthcare waste management, topsis
Energy management	1	2	Energy management
Lifecycle cost analysis	2	4	Lifecycle cost analysis
Rating systems	3	6	Rating systems, residential buildings, tropical climate

The keywords obtained in mapping science can be used to analyse the evolution of research themes which can be displayed in Figure 5. Based on biblioshiny analysis, the research theme map is divided into four quadrants, namely niche themes, motor themes, emerging or clining themes, and basic themes. The upper right quadrant called motor themes has high density and centrality, while the lower right quadrant called basic themes has high centrality with low density and niche themes located in the upper left quadrant have high density and high centrality and the lower left quadrant called clining themes have low centrality and density [22]. The lower right quadrant called basic themes has high centrality with low density, giving rise to a research cluster related to the sustainability of health care facilities and green hospitals. There are still few studies that raise these themes, so this includes research novelty. In the upper right quadrant, environmental performance, healthcare waste management, ahp and topsis have high research density. Themes located in the right quadrant, namely motor themes and basic themes, are established themes because they show strong scientific evidence [21]. The sustainability of health care facilities requires assessment of criteria using a rating system that contains various approaches in determining dimensions and criteria. Green hospital is not only a vague concept, but must be implemented by hospitals in an area so as to harmonise quality services for the community and be environmentally friendly [23]. Previous research related to green hospitals has focused more on environmental technical matters, not touching other dimensions such as social, economic, stakeholders, internal processes, learning and growth. A model that combines the concept of triple bottom line and balanced scorecard produces an evaluation of sustainability in hospitals that includes six dimensions namely environment, social, economy, stakeholders, internal processes, learning and growth [16]. The focus of previous research still includes barriers to the implementation of green hospitals in terms of investment costs and fulfilment of technical matters from the environmental side [24]. Health care facilities to ensure the achievement of goals in accordance with the SDGs are obliged to carry out a transformation process. Both developed and developing countries need to develop models to ensure their healthcare facilities are functional and sustainable. Transformation is necessary to adapt to various possibilities that occur in the future [25]. The evolution of research themes in the lower right quadrant consisting of sustainable healthcare, energy efficiency, carbon

footprint, and hazardous waste can bridge the research gap related to green hospitals so as to obtain an ideal model of hospital sustainability assessment based on green hospitals towards multi-criteria assessment with an integrated approach of various models.

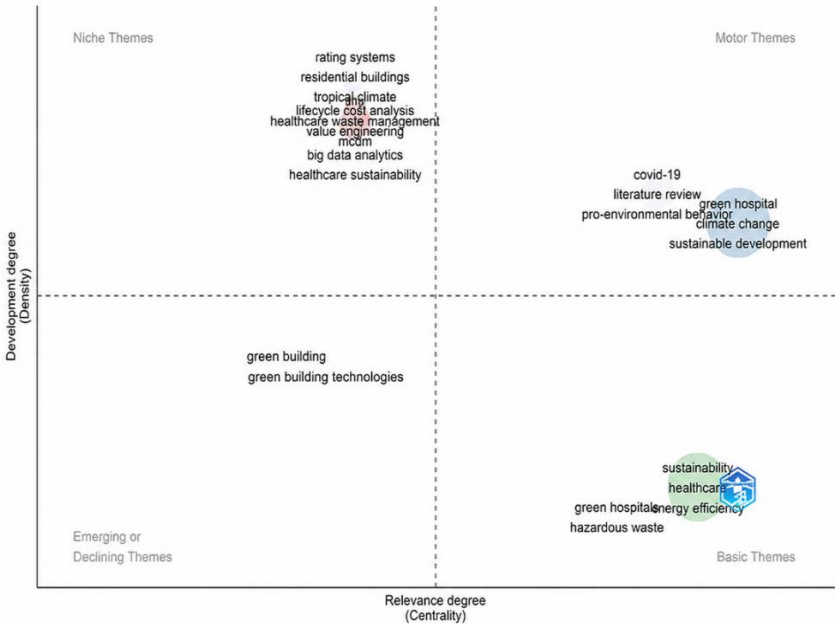


Fig. 5. Evolution of Research Themes

3.5 Sustainable Healthcare

Hospitals, which are one of the health care facilities, are major consumers of energy, leading to increased operating costs, decreased competitiveness, and negative impacts on the environment [2]. Increasing public awareness of environmental stewardship has led hospitals to provide products and services that can reduce risks to the environment. By attracting more patients through environmentally friendly services, hospitals can increase revenue as well as make cost efficiencies [26]. Sustainability in health care facilities, in this case hospitals, will affect public health, thus requiring a conceptual model consisting of environmental, social, and economic dimensions. The environmental dimension has sustainability processes consisting of renewable energy use, waste reduction management, air pollution reduction, soil pollution reduction, water pollution reduction, natural resource conservation, energy efficiency, use of electric transport, sustainable building design, recycling, material use efficiency, and sustainable procurement processes. Innovative implementation of sustainability in healthcare facilities is done to mitigate climate change, conserve natural resources. The implementation status of sustainability innovations can identify healthcare facilities' efforts to respond to climate change. Hospitals can be evaluated on their environmental performance in six dimensions: sustainable management, hospital pollution

management, environmental communication, resource conservation, energy conservation, patient space sustainability and water recycling. Hospital policy makers can identify and improve sustainability dimensions that have low implementation. Human resources are a key factor in the successful implementation of sustainability in hospitals [27]. In the triple bottom line concept, hospitals as health care facilities are required to transform into sustainable health services that can save costs, increase efficiency, provide better care to patients and reduce negative impacts on the surrounding environment [28]. The green hospital measurement system in various countries refers to the Green Building Rating System (GBRS), which is dominated by environmental considerations in the GBRS, while the social and economic dimensions receive less attention. The GBRS used as a reference in measuring green hospitals that are widely used in measurement systems in the world consist of BREEAM, LEED, Green Star, CASBEE, Green Globes, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), VERDE, and Level (s) [29]. Since the reference is the green building rating system, it still focuses on the environmental dimension. Meanwhile, the Triple Bottom Line (TBL) concept has environmental, social, and economic dimensions that have equal importance and must be managed simultaneously [30]. In the triple bottom line concept, hospitals as health care facilities are required to transform into sustainable health services that can save costs, increase efficiency, provide better care to patients and reduce negative impacts on the surrounding environment [28]. Sustainable Balanced Scorecard is formulated based on the Balanced Scorecard with special emphasis on the organisation's sustainability strategy to improve sustainability performance. The Sustainable Balanced Scorecard integrates the three dimensions of sustainability into a system so that it can be measured and can plan more accurately. Assess performance from an economic, social, environmental, internal, learning and growth, and consumer perspective [31]. In Mehra & Sharma's research (2021) research and innovation and local products are significant leverage factors, while circular practices, waste reduction and management, facility design, sustainable procurement, employee satisfaction, economic growth can guide hospital managers and healthcare facility practitioners in achieving hospital sustainability based on green hospital implementation [32]. Research by Brambilla et al. (2022) the highest score was achieved by social quality followed by environmental and organisational quality. The leverage factors are energy management, facility management and technological innovation [33]. Lee's research (2022) shows the leverage factors that contribute to the implementation of green hospitals, the first is the support of top management in setting the vision and mission, building organisational culture so as to provide continuous education and training opportunities. Second, the active role of employees in the green hospital implementation process. Third is the integration of stakeholders to ensure the success of green hospital implementation. The fourth is involving employees who deal with patients directly to reduce waste. Fifth, providing motivation and incentives for employees who play a role in the implementation of green hospitals [34]. The five most important criteria of the sustainability balanced scorecard are efficiency, effectiveness, accessibility, and waste production [16]. The determination of the criteria of each dimension is based on the leverage factors of each dimension, which can be seen in table 3 below.

Table 3. Determination of Criteria for Each Dimension

Dimension	Criteria	Reference
Environment	Waste Production	[16]
Social	1. Accessibility 2. Eco-culture 3. Satisfaction level 4. Development of community participation	[16]
Economy	Efficiency	[35]
Stakeholder	1. Top management support 2. Active role of employees 3. Stakeholder integration 4. Employee engagement reduces waste Motivation and incentives	[34]
Internal Process	1. Effectiveness Local products	[16] [32]
Learning and Growth	1. Research and Inovation Organisational learning	[32] [31]

The Sustainability Balanced Scorecard can integrate environmental, social and economic dimensions into the business strategy of an organisation including healthcare facilities so as to achieve holistic sustainability [31]. The assessment of green hospitals needs to shift from a green building assessment basis to a multi-aspect sustainability analysis by integrating the TBL and SBSC concepts. The linkage of sustainability performance measurement with multiple criteria from each dimension of TBL and SBSC is still a new area for future research.

4 Conclusion

The findings of this study indicate that the trend of publications related to green hospital sustainability assessment and journals that publish has increased from 2016-2024. The global concern of hospitals as health care facilities that have a negative impact on the surrounding environment and the support of stakeholders both internal and external to the hospital that makes the hospital sustainable into the future. This study identified sixteen research clusters from the results of biblioshiny analysis that can be used as the evolution of future research themes. Sustainability research themes with rating systems require dimensions and assessment criteria. Green hospital sustainability assessment with multiple criteria from the triple bottom line dimension and sustainability balance scorecard is new and can be done further research in the future. Energy efficiency criteria, carbon footprint mitigation and hazardous and toxic waste

management are research themes related to green hospital-based hospital sustainability criteria. The contribution of this research is to provide new insights into research related to green hospitals that have not been widely researched globally in the 2016-2024 timeframe involving various models, dimensions and criteria that are integrated with each other. This will accelerate the process of environmentally friendly transformation in the hospital industry, which has now begun to have an awareness of its responsibility to the surrounding environment. Awareness from within the hospital and patients as users of health care facilities. Green hospital-based hospital sustainability assessment will be an integrated hospital performance assessment between interrelated dimensions, resulting in a sustainability value that describes the existing condition of the hospital from various aspects based on the implementation of green hospitals. This assessment is important to be able to maintain the sustainability of the hospital in a time of intense hospital competition today and faced with increasingly complex health problems. Hospitals that are unable to answer future challenges, one of which is environmental impact, will find it difficult to be sustainable.

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