JRIIE Journal of Research Innovation and Implications in Education
Center for Research Implications & Practice

Website:www.jriiejournal.com ISSN 2520-7504 (Online) Vol.9, Iss.1, 2025 (pp. 113 - 131)

Mapping the Knowledge Base on Sustainable AI: A Systematic Review

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Abstract: *The rapid progress of Artificial Intelligence has sparked substantial concerns about its environmental impact, especially regarding the significant energy usage and carbon emissions involved in training and deploying large models. The field of sustainable AI has emerged as a vital area of research, focused on creating AI technologies that strike a balance between performance and environmental and social responsibility. The PRISMA approach was applied to select documents of the study. The study used the following research algorithm phrases: ((“sustainable AI” OR “green AI” OR “eco-friendly AI” OR “energy-efficient AI” OR “low-carbon AI” OR “environmentally conscious AI” OR “sustainable artificial intelligence” OR “climate-conscious AI”) AND (“sustainability applications” OR “green technology applications” OR “environmental solutions” OR “climate applications” OR “ecological applications”)) to narrow down the search in the Scopus database and identify relevant records. The study employed VOSviewer software, and analysis was performed on 853 articles, enabling the identification of network expansion, significant contributors, the intellectual framework, the most extensively studied subject, and areas necessitating further examination. The result highlighted some new key areas such as “energy efficiency,” “internet of things,” “carbon footprint,” “ethical behavior,” “generative AI,” “large language models,” “cloud environment,” “energy-efficient software,” “edge-cloud computing,” “computing-in-memory,” and “blockchain technology,” suggesting the existence of research gaps that warrant attention. These findings provide researchers with valuable insights, delivering a comprehensive grasp of past, current, and potential implications in the field while pinpointing subjects requiring additional examination. The study demonstrates a remarkable contribution of AI to environmental effect by addressing massive energy consumption and carbon emissions.*

Keywords: AI**,** Artificial intelligence, Environmental impact, Sustainable AI, Sustainability

How to cite this work (APA):

Kasubi, J. W. (2025). Mapping the Knowledge Base on Sustainable AI: A Systematic Review. Journal of *Research Innovation and Implications in Education, 9*(2), 113 – 131. **https://doi.org/10.59765/vyw74p.**

1. Introduction

Artificial Intelligence (AI) has become a driving force of innovation across numerous sectors, including finance, healthcare, and education. Nevertheless, the fast growth of AI technologies has raised important apprehensions about their environmental impact, ethical issues, and long-term sustainability (Schwartz et al., 2020)(Lannelongue et al., 2021). The vast computational resources needed to train and deploy large AI models contribute to considerable carbon emissions, sparking debates on how to create more energy-efficient and environmentally conscious AI systems. In response to these encounters, the notion of Sustainable AI has arisen, promoting the development of AI technologies that balance high performance with environmental and social responsibility (Henderson et al., 2020).

As interest in sustainable AI continues to grow, researchers are exploring various strategies to reduce the negative environmental impacts of AI while preserving its effectiveness. Key areas of focus include the development of energy-efficient machine learning algorithms, optimizing hardware to decrease power consumption, and enhancing transparency in reporting AI’s environmental impact (Lannelongue et al., 2021). Furthermore, discussions on AI fairness, inclusivity, and ethical deployment are becoming vital to guarantee that AI technologies benefit society in a just and equitable manner (Schwartz et al., 2020). Given the interdisciplinary nature of sustainable AI, it is imperative to conduct a systematic review of existing literature to identify emerging trends, challenges, and future research openings.

This bibliometric review seeks to offer an in-depth analysis of the academic landscape related to sustainable AI. Utilizing bibliometric techniques, the study will trace the progression of research on the topic, detecting dominant works, main themes, and evolving research directions (Henderson et al., 2020). The review intends to offer valuable understandings into the current state of sustainable AI while also suggesting future research pathways that promote a more accountable and sustainable approach to AI development.

The volume of academic research on AI technology has grown rapidly. While the topic falls within the broader domain of sustainability, it exists at the intersection of "technological advancement" and its practical applications. Consequently, this field is inherently transdisciplinary, integrating concepts from multiple disciplines. However, scholarly work in this area remains incomplete and fragmented, as research from various fields has largely been conducted in isolation, with limited integration of analytical connections (Loebbecke & Picot, 2015; Vrontis et al., 2021). Several reviews have examined recent advancements in sustainable AI driven by various technological innovations (Garcia-Arroyo & Osca, 2021; Vrontis et al., 2021). Nevertheless, these researches have primarily focused on definite aspects of technology and related disciplines, offering only partial analyses. As a result, a bibliometric analysis is essential to bridge gaps across the literature, establish connections between different research streams, and develop a more comprehensive understanding of the field.

By combining bibliometric analysis with social network evaluation tools, scholarly networks can be quantitatively mapped. This approach enables the examination of key terms, relationships, co-citations, references, and connections across various research domains. The extracted data can then be structured into networks, providing deeper insights into the subject matter (Nyabakora & Mohabir, 2024; Priyan et al., 2023). A thorough analysis of existing research is essential for gaining a deeper understanding of the issue. Examining various aspects of global sustainable AI will provide a stronger basis for understanding the topic and expanding knowledge within the field. As sustainability efforts increasingly incorporate virtual environments, the future direction of research in this area remains uncertain.

To structure existing academic contributions and clarify the role of intelligent automation in environmental initiatives, this study conducts a bibliometric analysis of the literature on sustainable AI. This review identifies potential research areas and offers scholars a comprehensive understanding of both past and emerging trends in the Sustainable AI literature (Nyabakora & Mohabir, 2024; Priyan et al., 2023). This study also highlights the leading contributors to the field, including key authors, influential publications, prominent journals, and contributing countries. A bibliometric analysis was conducted using a science mapping approach, focusing on four core research questions that guide the evaluation:

1. How has research on sustainable AI evolved over time?
2. What key themes related to sustainable AI have been explored and examined by scholars?
3. Which areas require further investigation in future studies?
4. Who are the major contributors to sustainable AI research?

The rest of this manuscript is organized as follows: First, the concept of sustainable AI is introduced, providing an overview of its significance. Next, a literature review is presented to familiarize readers with previous research in this field. It is followed by a thorough description of methods used to identify and select relevant studies. The subsequent section presents the findings, outlining key themes in sustainable AI research and potential future developments. Finally, we discuss research gaps and provide recommendations based on the analysis, offering directions for future studies.

2. Literature Review

The rising significance of AI technologies has brought attention to serious concerns about their environmental impact. As AI systems, especially large models like GPT-3 and BERT, require substantial computational resources, their carbon emissions have become an increasing problem (Schwartz et al., 2020). Many studies have emphasized the eco-friendly costs of working out and deploying these models, underscoring the prerequisite for more sustainable AI development strategies. For example, researchers (Lannelongue et al., 2021)showed that training large language models can produce as much CO_2 as the total emissions of five cars over their entire lifespan. This realization has driven research into finding ways to balance high performance with environmental accountability, leading to the emergence of Sustainable AI as a key research focus.

A key focus within Sustainable AI is enhancing the energy efficiency of machine learning algorithms. Researchers have suggested various methods to decrease the computational costs of AI models, including algorithmic enhancements and innovative techniques for model compression (Henderson et al., 2020). Techniques such as pruning, quantization, and knowledge distillation are designed to reduce the size of models and lower their computational demands without sacrificing performance (Rogers et al., 2020). These strategies not only boost the energy efficiency of AI systems but also reduce hardware requirements, supporting the broader sustainability of AI research and deployment. Consequently, efficiency is increasingly recognized as an essential evaluation metric, alongside traditional performance indicators like accuracy.

In addition to algorithmic optimization, significant attention has been given to the role of hardware and infrastructure in reducing AI's environmental impact. The energy consumption of AI models is largely determined by the hardware used for both training and inference (Henderson et al., 2020). Researchers have investigated the potential of more energy-efficient hardware, such as specialized processors and low-power chips, to reduce the environmental footprint of AI (Lannelongue et al., 2021). Moreover, using renewable energy sources to power data centers has become an essential strategy to lower the carbon footprint of AI (Lannelongue et al., 2021). These advancements in hardware and infrastructure are vital for promoting AI sustainability, as they tackle the primary sources of high energy consumption at both the computational and environmental levels.

Beyond energy efficiency, sustainable AI research also stresses the need for transparency and accountability in AI development. Numerous studies have called for the systematic reporting of AI models' environmental impact, including their energy consumption and carbon emissions (Henderson et al., 2020). Tools like the experiment-impact-tracker have been introduced to support scholars in measuring and documenting the carbon footprint of their computational processes more effectively (Schwartz et al., 2020). Additionally, researchers have emphasized the importance of standardized metrics, such as floating-point operations (FPO), to quantify the computational workload involved in training AI models. These metrics play a vital role in aiding transparency within the field, enabling researchers and practitioners to make further informed conclusions on the sustainability of AI systems.

The essential component of sustainable AI is the incorporation of ethical principles into the design and implementation of AI systems. As AI technologies become increasingly widespread, concerns surrounding fairness, inclusivity, and bias have drawn significant attention (Schwartz et al., 2020). Sustainable AI not only focuses on minimizing the environmental footprint of AI systems but also seeks to ensure that these technologies serve the broader interests of society. This includes tackling algorithmic bias, enhancing accessibility for diverse user groups, and promoting ethical standards in AI development. The convergence of sustainability and ethics in AI is an expanding research area, with scholars advocating for responsible AI practices that consider both environmental and social impacts (Rogers et al., 2020).

The future of sustainable AI research lies in developing comprehensive strategies that combine environmental sustainability, algorithmic efficiency, and ethical responsibility. This was pinpointed by Cooper (2023) that "*AI's capability to automate tasks, process large quantities of data, and provide predictive insights will increasingly revolutionize various aspects of the daily lives.*"Experts emphasize the need for interdisciplinary frameworks that integrate insights from computer science, environmental science, and social sciences to create AI systems that are both powerful and socially responsible (Lannelongue et al., 2021). Moving forward, research will likely focus on promoting sustainable AI all over the entire lifespan of AI systems, from initial design and development to deployment and eventual decommissioning. This shift toward a more holistic approach has the potential to foster AI technologies that are not only effective and efficient but also associated with comprehensive societal goals of sustainability and fairness.

3. Methodology

Following the guidelines of Tranfield et al.(2003) and Crossan and Apaydin (2010), we conducted a bibliometric analysis to identify research trends and explore potential future directions regarding "sustainable AI." Given its transparent and reproducible nature, the bibliometric approach was chosen to improve the overall effectiveness of the review (Crossan & Apaydin, 2010). By employing a bibliometric review method, we were able to map, critically evaluate, and synthesize existing research, identifying the key themes within the field.

This study examines the developments in research on "sustainable AI" over the past years, specifically from 2016 to 2025. Given the current significance and relevance of artificial intelligence, particularly in relation to entries in the Scopus database (Nyabakora, 2023; Nyabakora & Mohabir, 2024), it was chosen as the central focus of this research. An in-depth review of 853 manuscripts was conducted on this subject. Using VOSviewer (Benziane et al., 2022; Nyabakora, 2023), an open-source tool for creating and visualizing bibliometric networks. The results of the analyzed parameters (such as co-citation, phrase co-occurrence, citations, etc.) were presented in graphical form.

VOSviewer is capable of processing data on scholars, publications, themes, sources, and nations to create clusters based on citations, co-citations, and co-occurrences (Benziane et al., 2022). The data is then presented visually to enhance understanding (Priyan et al., 2023). This tool generates a map-like display using data from the Scopus database. This study examines "sustainable AI" from 2016 to 2025, allowing for a long-term analysis of how perceptions of the field have evolved over time.

The PRISMA ("Preferred Reporting Items for Systematic Reviews and Meta-Analyses")procedure was used to establish the inclusion criteria before data collection began(Moher et al., 2009; Nyabakora, 2023; Nyabakora & Mohabir, 2024). PRISMA is a set of evidence-based tools designed to assist researchers in documenting various types of reviews, often used to assess the benefits and drawbacks of healthcare interventions. As noted (Moher et al., 2009; Nyabakora, 2023; Nyabakora & Mohabir, 2024), PRISMA emphasizes methods that ensure research is reported transparently and accurately.

3.1 Selection of articles

Hallinger and Kovačević(2019) challenged the idea that higher-quality sources are linked to the Web of Science's limited scope, arguing that discipline-specific validation is required. Their argument was a response to Mongeon and Paul-Hus(2016), who, based on their empirical study, found that the Scopus index served as a more comprehensive resource for searching and gathering papers in the social sciences. In addition, Scopus provides more advanced exporting capabilities compared to Google Scholar(Benziane et al., 2022). Scopus also offers a standardized approach for indexing works (Hallinger & Nguyen, 2020). An interdisciplinary study by Archambault et al.(2009) demonstrated a strong correlation between articles published in both “the Web of Science” and “Scopus.”

3.2 Data searching criteria

The primary exploration was conducted on March 9, 2025, using the previously established search string in the Scopus database. The "TITLE-ABS-KEY" tool was employed alongside the PRISMA methodology (Crossan & Apaydin, 2010; Pisani et al., 2017) to explore “the Scopus database” and gather only “peer-reviewed, ”double-blind” literature. The exploration was delimited to English-language papers published by March 9, 2025. By applying inclusion and exclusion criteria, we narrowed down the results to 3,993 publications. We then followed a four-step procedure to select the publications most appropriate to this study (Figure 1). When the exploration was restricted to papers within the areas of computer science, environmental engineering, business, accounting, management, economics, social sciences, finance, and econometrics, we retrieved 3,738 results. We then narrowed the selection to those specifically focused on “sustainable AI” using relevant keywords and final peer-reviewed articles from journals, reducing the count to 869. After reviewing the articles and excluding 16 that were not in English, 853 articles were retained for inclusion in our bibliometric review.

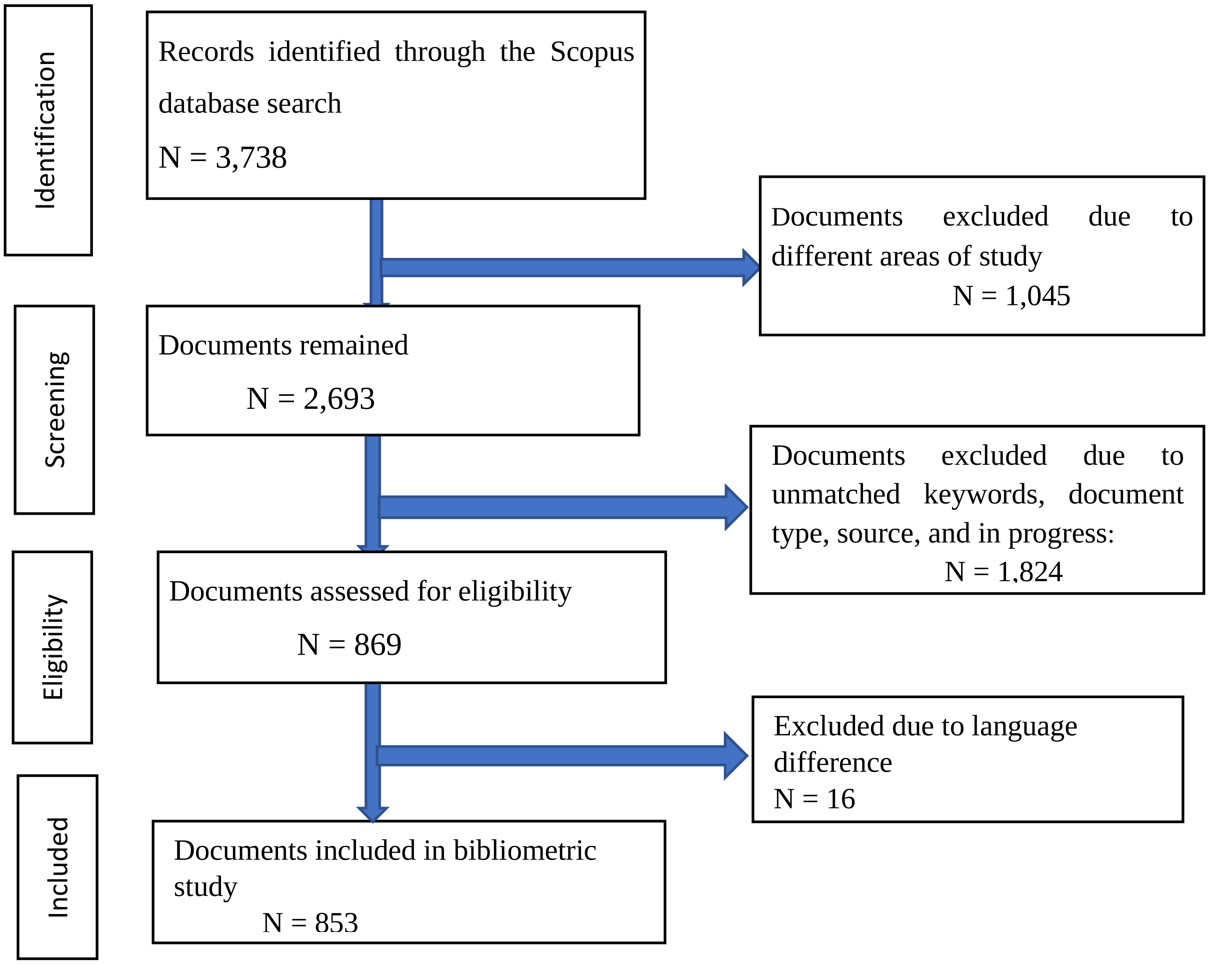

Figure 1: The PRISMA Flowchart Showing Systematic Sampling Stages (Priyan, et al., 2023)

The PRISMA method(Hallinger & Nguyen, 2020; Nyabakora, 2023; Priyan et al., 2023) was used to define the search criteria, with brackets ensuring accuracy. The search terms were refined or expanded using symbols such as the asterisk ("*") and the question mark ("?") as needed. The use of standard Boolean operators facilitated a unified search approach (Pisani et al., 2017). The search algorithm used the following phrases: (("sustainable AI" OR "green AI" OR "eco-friendly AI" OR "energy-efficient AI" OR "low-carbon AI" OR "environmentally conscious AI" OR "sustainable artificial intelligence" OR "climate-conscious AI") AND ("sustainability applications" OR "green technology applications" OR "environmental solutions" OR "climate applications" OR "ecological applications")) to narrow down the search in the Scopus database and identify relevant records. Initially, 3,993 documents were retrieved, but this number was reduced to 853 after filtering out manuscripts that did not meet the standards or were considered irrelevant (Figure 1).

4. Results and Discussion

The bibliographic data of the 853 manuscripts was preserved for use in subsequent steps. A bibliometric approach was applied to conduct a more thorough analysis of the results, which included visualizing the relationships between author co-citation and phrase co-occurrence, along with evaluating citation and co-citation patterns(Benziane et al., 2022; Nyabakora & Mohabir, 2024). This bibliometric analysis was conducted using tools such as VOSviewer, bibliometric software, Excel, Tableau, and Scopus analytics (Benziane et al., 2022; Nyabakora & Mohabir, 2024). The findings from the investigation into the sustainable artificial intelligence knowledge bases are provided in this part. The four study questions were assessed in the following order:

4.1 Direction of Research Progress in the Sustainable AI

The growing application of sustainable AI has reflected the progress in our understanding of this area. A search of the Scopus database reveals that 853 articles on "sustainable AI and its application" have been published since 2016. Table 1 presents details of the authors, titles, journals, and countries of affiliation for these documents. A review of these 853 publications shows a consistent upward trend in the number of papers (Figure 2), particularly between 2020 and 2024. Notably, 845 of these publications, or 99%, were released in the past six years (2020–2025. This upward trend suggests a promising future for the field, highlighting the growing interest among researchers in exploring sustainable AI and its application.

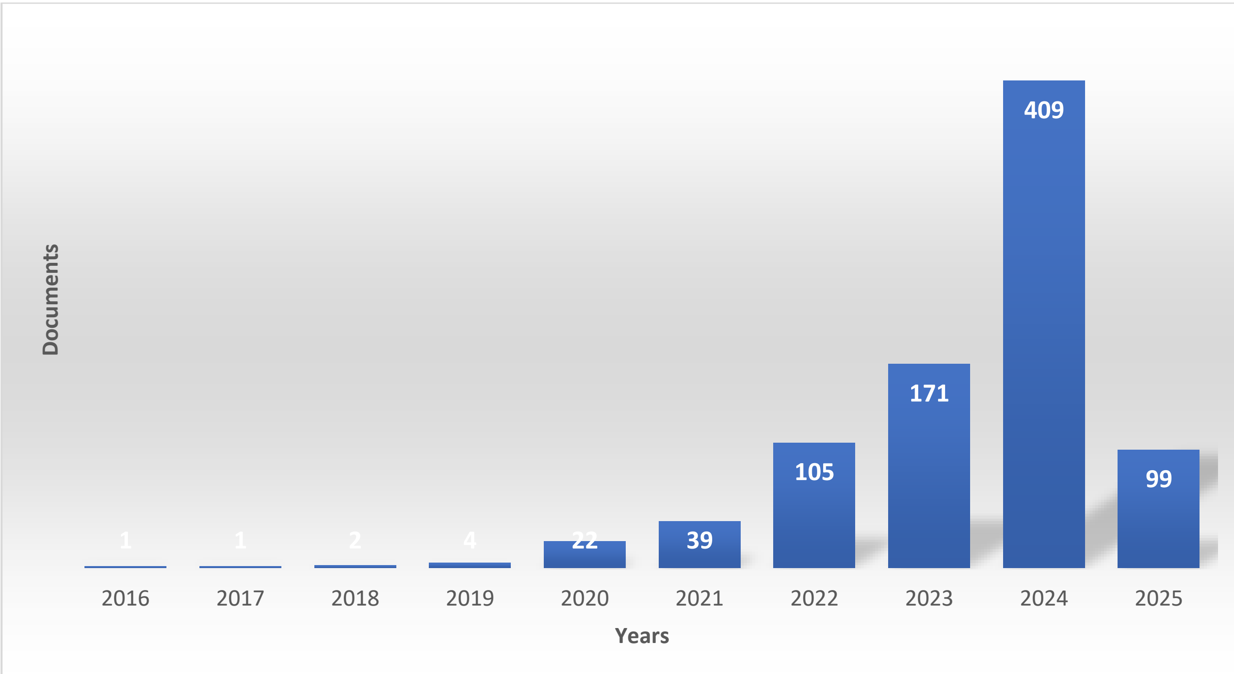

Figure 2: Research growth in Sustainable AI

4.1.1 Keywords Growth

To understand the evolution of perspectives on "sustainable AI," the incidence and correlation of co-words in papers issued between 2016 and 2025 were analyzed using VOSviewer. The number of co-words was reduced from 1,509 to 137 by applying a filter that required a keyword to appear in at least five articles (Fig. 3). Detecting the most frequently discussed topics associated with sustainable AI is essential to attaining the purposes of this manuscript.

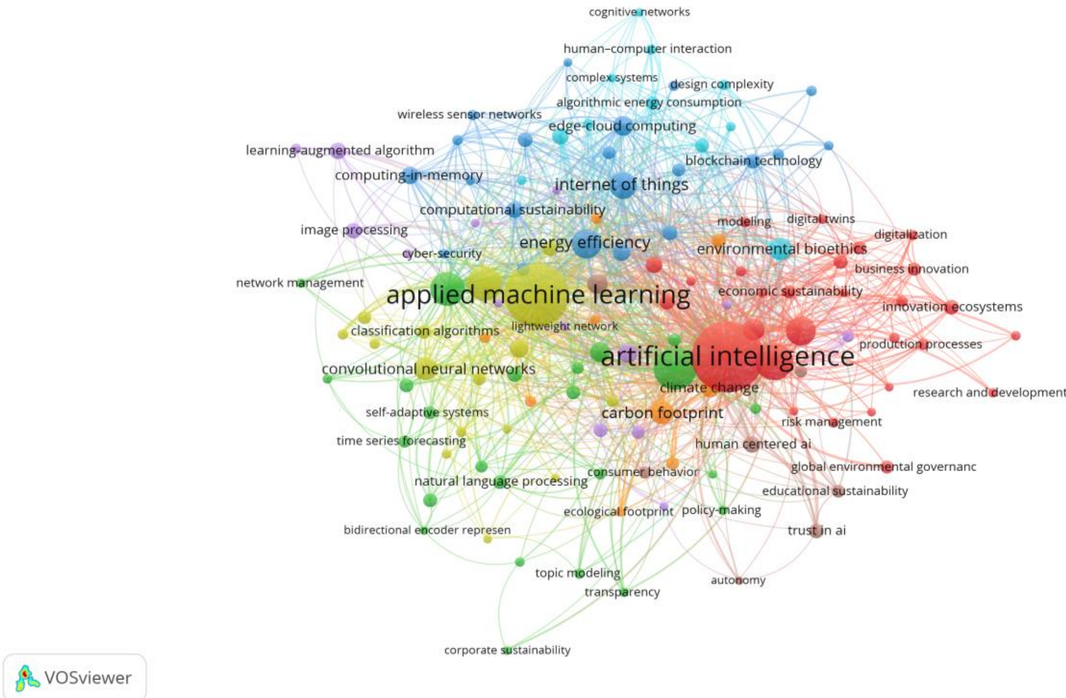

Figure 3: Keywords network map on sustainable AI

To explore the topics addressed in the literature on "sustainable AI," we conducted a keyword analysis. Initially, VOSviewer was used to detect the most frequently used words. According to the concentration map (Figure 3), the most mentioned terms were "artificial intelligence" (302), "applied machine learning" (240), "sustainable AI" (107), "sustainability" (85), "green AI" (72), "artificial neural networks" (70), "energy efficiency" (53), "sustainable development goals" (52), "internet of things" (44), and "carbon footprint" (34). The keyword analysis revealed that "sustainable AI," our focus, is still a relatively new topic, first appearing in the top fifteen trends between 2016 and 2021, reflecting its emerging presence in the environmental application. A "chronological keyword map" (Figure 3) was generated using VOSviewer, with “a minimum of five co-occurrences,” to achieve this investigation(Benziane et al., 2022; Eck & Waltman, 2017; Nyabakora & Mohabir, 2024). There were significant discrepancies in the nodes, allowing for the identification of key keywords that could link others. The manuscripts were divided into two groups for investigation, and the map inspected the distribution of co-words across these groups based on their published dates (Table 1).

Table 1: Thematic Growth in Sustainable AI Literature

ID	Label	2016-2025		Label	2016-2022		Label	2023-2025	
		OCC			OCC			OCC	
1	Artificial intelligence	302	13.45	Artificial intelligence	67	20.30	Artificial intelligence	230	17.97
2	Applied machine learning	240	10.69	Applied machine learning	34	10.30	Applied machine learning	205	16.02
3	Sustainable ai	107	4.77	Sustainability	29	8.79	Sustainable ai	116	9.06
4	Sustainability	85	3.79	Sustainable ai	27	8.18	Sustainability	56	4.38
5	Green ai	72	3.21	Green ai	24	7.27	Green ai	55	4.30
6	Artificial neural networks	70	3.12	Artificial neural networks	22	6.67	Artificial neural networks	50	3.91
7	Energy efficiency	53	2.36	Energy efficiency	13	3.94	Energy efficiency	43	3.36
8	Sustainable development goals	52	2.32	Convolutional neural networks	12	3.64	Sustainable development goals	42	3.28
9	Internet of things	44	1.96	Sustainable development goals	11	3.33	Internet of things	39	3.05
10	Carbon footprint	34	1.51	Climate change	10	3.03	Environmental sustainability	32	2.50
11	Convolutional neural networks	33	1.47	Environmental sustainability	10	3.03	Carbon footprint	30	2.34
12	Environmental bioethics	30	1.34	Big data analytics	7	2.12	Ethical behavior	23	1.80
13	Environmental sustainability	28	1.25	Explainable ai	7	2.12	Generative ai	23	1.80
14	Edge-cloud computing	24	1.07	Human-centered ai	7	2.12	Large language models	23	1.80
15	Explainable ai	24	1.07	4g technologies	6	1.82	Convolutional neural networks	21	1.64
16	Generative ai	24	1.07	Edge computing	6	1.82	Cloud environment	19	1.48
17	Large language models	23	1.02	Ethical principles	6	1.82	Energy-efficient software	19	1.48
18	Climate change	22	0.98	Open innovation	6	1.82	Edge-cloud computing	18	1.41
19	Cloud environment	20	0.89	Smart cities	6	1.82	Computing-in-memory	16	1.25
20	Energy-efficient software	19	0.85	Feature extraction	5	1.52	Blockchain technology	14	1.09

Legend: OCC = Occurrences

The study found a significant application of “artificial intelligence” (Cooper, 2023). During the first sub-period, from 2016 to 2022, around 20% of the keywords that satisfied the criterion of appearing at least five times were connected to this topic. "Applied machine learning" represented 10.3% of the keyword occurrences, while "sustainability" made up 8.8%. The keyword that represents the main theme, “sustainable artificial intelligence," was followed with 8.2% growth. Additional keywords and their descriptions are provided in Table 1."

Although the publication period from 2023 to 2025 was shorter than those of the previous sub-period, the increase in the number of published papers makes this data crucial for inclusion in the analysis. The result found that 6.48% of the terms meeting the criteria of at least five co-occurrences, related to "applied machine learning," were connected to "sustainable AI" in articles published between 2023 and 2025 (the current sub-period). Table 1 presents the top twenty keywords linked to "sustainable AI" along with their respective percentages. These are the most frequently used keywords. Compared to the previous period, this list has been updated to include new terms such as “energy efficiency,” “internet of things,” “carbon footprint,” “ethical behavior,” “generative AI,” “large language models,” “cloud environment,” “energy-efficient software,” “edge-cloud computing,” “computing-in-memory,” and “blockchain technology.”

The research from the second sub-period exposed a growth in the frequency of co-words connected to "sustainable AI" across the two sub-periods: "artificial intelligence" (67, 230), "applied machine learning" (34, 205), "sustainable AI" (27, 116), and "sustainability" (29, 56), among others. This suggests that the field continues to experience substantial growth in terms of key topics (Table 1). This was predicted by Cooper (2023) that “*AI’s capability to automate tasks, process large quantities of data, and provide predictive insights will increasingly revolutionize various aspects of the daily lives.”*

4.1.2 The Growing Trend of the Top Five Current Themes in the Domain Literature

Studying the growth history enhances understanding of the key topics central to "sustainable AI" research and helps readers grasp the subject more clearly. "Artificial intelligence" appeared in both subperiods. In the first period, it accounted for 20 percent of all occurrences, while in the second period, although the keyword continues leading the group, its growth percentage decreased to 18 percent. This might be caused by the growth of the “sustainable AI” keyword that made sharing of “artificial intelligence” keywords. "Applied machine learning" was the second most frequently used keyword in the current sub-period, accounting for approximately 16 percent of all co-occurrences. Overall, it grew by nearly 11 percent and became the second most prevalent keyword across the sub-periods (Table 1). This increase reflects the rise in research on the “sustainable AI” domain. Consequently, more research is required to gain a deeper insight on sustainable AI, as it is still growing.

“Sustainable AL” appeared in both the sub-periods. In the first period, its growth rate was 8%, while in the second period, its percentage growth increased to 9% of the total occurrences. Overall, it secured about a 5% growth rate and became the third most occurred keyword. “Sustainability” followed in the fourth position with an overall 4.8% occurrence. In the first period, it had 8.8 in the third position, while in the second period, it dropped to the fourth position with the decreasing growth rate of 4.4%. In the overall occurrences, “green AI” was the fifth most occurred. In the first period, it had 3.2% before an increase in growth rate to 4.3%, maintaining the fifth position.

Given the expected continued rapid growth of research in “sustainable AI” in the coming years, further research is necessary to thoroughly explore this emerging theme.

4.2 Logical Structure of the Domain Literature

Scholars can advance a deeper insight on the contemporary state of "sustainable AI" study by examining its "intellectual structure" (Nerur et al., 2008). This can be achieved by the use of systematic mapping and analysis techniques. By analyzing co-citations among authors, a system map formed with VOSviewer can visually represent the conceptual framework of the domain's knowledge base (Hallinger & Nguyen, 2020). This approach helps in identifying both the least and most explored themes within the topic.

Scholars have observed that writers who share similar academic ideas are often cited together in the same papers (Hallinger & Kovačević, 2019). To demonstrate this, VOSviewer can produce a system map highlighting the joint concepts among the writers referenced in the database (Priyan et al., 2023).

The co-citation map created by VOSviewer, shown in Figure4, displays 258 scholars who have been cited in at least 50 other papers. The magnitude of the nodes resembles the influence of the scholars, with greater nodes indicating more common citations by other researchers. Additionally, the colored clusters of bubbles (Figure 4) set scholars into five different research paths based on their co-citation links. A closer investigation of Figure3 discloses that the association between authors reflects the incidence of their joint citations.

The map illustrates four distinct philosophical perspectives. It also highlights the interrelation of the literature through the five clusters and the links between them. The most prominent scholars in the network map are Wang, Y. in the red cluster; Chen, Z. in the green cluster; Schwartz, R. in the blue cluster; Wang, X. in the yellow cluster; and Zhang, X. in the purple cluster. Those positioned at the centre of the clusters show their ability to integrate ideas from all four perspectives (Figure4).

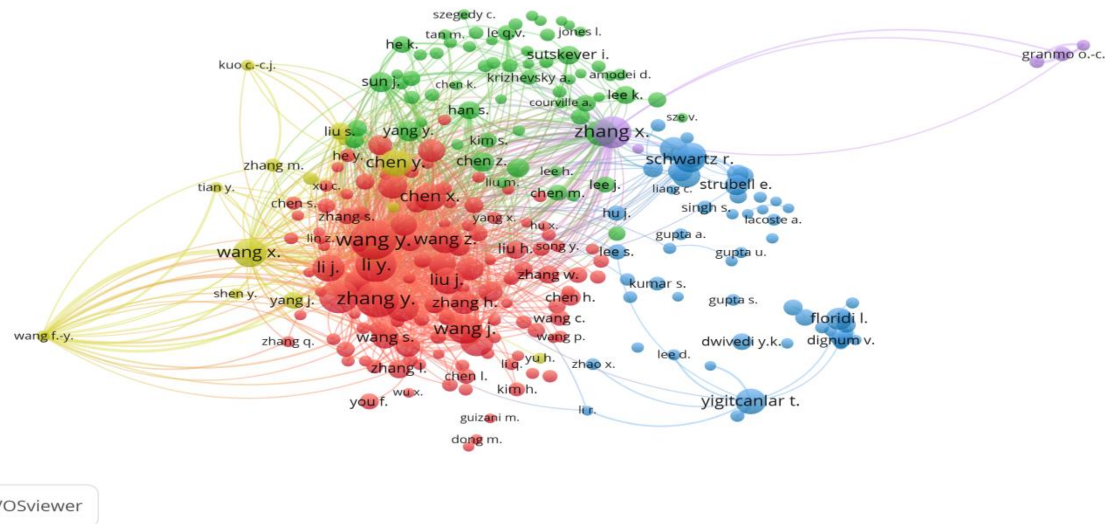

Figure 4: Co-citation analysis showing intellectual structure of sustainable AI literature

4.3 Topical Concentrations of the Domain Knowledge Base

A wide range of stakeholders can benefit from understanding the key topics and themes explored in the literature on "sustainable AI." This knowledge can offer a context for interpreting existing studies, suggest possible imminent research directions, help experts identify relevant study topics, and guide researchers in recognizing important themes and underexplored areas (Nyabakora, 2023).

A historical co-word map with at least 5 co-occurrences was generated using VOSviewer (Figure 3). This analysis examines the frequency of specific keywords in manuscripts based on their published dates. To investigate the subjects within the "sustainable AI" topic, a keyword analysis was conducted. According to the concentration map (Figure 3), the most mentioned terms were "artificial intelligence" (302), "applied machine learning" (240), "sustainable AI" (107), "sustainability" (85), "green AI" (72), "artificial neural networks" (70), "energy efficiency" (53), "sustainable development goals" (52), "internet of things" (44), and "carbon footprint" (34).

The fact that the referenced author co-occurred shows that all the clusters were connected to the central topic, even though the topic ("sustainable AI") was expressed in different ways. This was clarified by the frequently appearing keywords, which are likely to influence or be influenced by “sustainable AI." To analyze the distribution of these keywords in more depth, we created a "chronological keyword map" (Figure 3) using VOSviewer, with at least5 co-occurrences (Priyan et al., 2023). This examination of the chronological co-words (Figure 3) provides insight into how the keywords are distributed.

4.4 The Most Contributory Players in the Domain

Understanding the key authors and publications on the topic of “sustainable AI” provides valuable understanding into the existing state of knowledge and helps identify potential avenues for future research and innovation. Additionally, it enables scholars to determine which nations, sources, writers, and papers are most substantial and should be examined for a deeper understanding.

4.4.1 Fruitful Nations in the Domain Literature

By examining the most fruitful nations in the field of "sustainable AI," researchers can identify which nations are actively investigating this area, stay updated on the latest advancements, and understand the standards for "sustainable artificial intelligence" practices. Additionally, analyzing the locations of the authors of these papers can provide insight into where the majority of academic focus is being directed regarding "sustainable AI."

The global appeal of the topic "sustainable AI" is evident from the work shown in Fig. 5, which was produced across ninety-three different countries. The majority of research in this field came from the United States (144), China (122), the United Kingdom (91), India (83), Spain (78), Germany (75), Italy (68), Australia (52), Canada (47), and South Korea (45), among the other fifteen more productive countries in Table 2. These countries were the primary contributors to the body of knowledge on this subject. As shown in Table 3, researchers from the top fifteen countries with the highest citation counts—the United States (4,701), Australia (2,435), the United Kingdom (2,308), Spain (2,267), Germany (1,545), Israel (1,277), China (1,154), Norway (1,102), France (1,052), and Canada (1,039), among other top fifteen in Table 3—contributed to over seventy percent of the total citations in this field. In conclusion, the majority of research on "sustainable AI" is concentrated in developed nations, with minimal attention given to studies from underdeveloped countries. This trend significantly influences the academic landscape, with the research from these countries having a major impact in the field.

Table 2: More productive Countries in sustainable AI research

Id	Label	Documents	Citations
1	United States	144	4701
2	China	122	1154
3	United Kingdom	91	2308
4	India	83	728
5	Spain	78	2267
6	Germany	75	1545
7	Italy	68	652
8	Australia	52	2435
9	Canada	47	1039
10	South Korea	45	544
11	France	42	1052
12	Saudi Arabia	34	748
13	Japan	30	997
14	Norway	28	1102
15	Sweden	23	396

Table 3: Most cited countries in sustainable AI literature

Id	Label	Documents	Citations
1	United States	144	4701
2	Australia	52	2435
3	United Kingdom	91	2308
4	Spain	78	2267
5	Germany	75	1545
6	Israel	8	1277
7	China	122	1154
8	Norway	28	1102
9	France	42	1052
10	Canada	47	1039
11	Denmark	10	1009
12	Japan	30	997
13	Hong Kong	19	789
14	Saudi Arabia	34	748
15	India	83	728

4.4.2 Evaluation of the Most Active Journals

This part offers an in-depth outline of the leading sources in sustainable AI," assisting both academics and practitioners in staying up-to-date with the modern research and developments." It also highlights the journals that are almost certainly to accept submissions. Out of the 853 papers reviewed, 431 sources were included. Although only 30 percent of the sources had multiple publications, more than twenty-seven percent of the total corpus consisted of just the top fifteen sources (Table 4). The most prolific source was *Sustainability* (Switzerland), which published 72 articles. However, the total citation count from all 431 sources was 32,801. Of these sources, 111 had no citations (the list is not provided), and over 52 percent of all citations came from the top 15 sources (Table 4). *Sustainability* (Switzerland) was the most cited source, with 1,316 citations from 72 articles. Table 4 provides details of other notable sources.

Table 4: Most productive sources

Id	Label	Documents	Citations
1	Sustainability (Switzerland)	72	1316
2	IEEE access	51	261
3	Technology in society	12	625
4	Sensors	11	262
5	Applied sciences (Switzerland)	11	39
6	Ai and society	10	272
7	Neurocomputing	9	35
8	CM computing surveys	8	537
9	Applied intelligence	8	140
10	Journal of open innovation: technology, market, and complexity	7	555
11	IEEE internet of things journal	7	130
12	Electronics (Switzerland)	7	89
13	Artificial intelligence review	7	26
14	Journal of machine learning research	6	383

15	Applied energy	6	114

Table 5: Highly cited sources

ID	Label	Documents	Citations
1	Sustainability (Switzerland)	72	1316
2	Transactions of the association for computational linguistics	4	952
3	Communications of the ACM	3	739
4	Technology in society	12	625
5	Journal of open innovation: technology, market, and complexity	7	555
6	Journal of science education and technology	1	548
7	ACM computing surveys	8	537
8	International journal of information management	3	464
9	Journal of machine learning research	6	383
10	AI and society	10	272
11	Sensors	11	262
12	IEEE access	51	261
13	Advanced science	2	246
14	Business and information systems engineering	1	241

4.4.3 The Most Influential Authors on Sustainable AI

According to Table 6, the highest total citation count (1,202) was achieved by twelve publications from Yigitcanlar, Tan. Following closely was Kovaleva, Olga; Rogers, Anna; and Rumshisky, Anna, with 877 citations. Since the h-index takes into account all academic works, not just those related to this specific topic, it was not used as a metric in this analysis (Priyan et al., 2023). Therefore, the citation counts in Table 6 accurately reflect the writers' contributions to the topic.

Table 6: Most cited authors

Id	Label	Documents	Citations
1	Yigitcanlar, Tan	12	1202
2	Kovaleva, Olga	1	877
3	Rogers, Anna	1	877
4	Rumshisky, Anna	1	877
5	Dodge, Jesse	2	772
6	Schwartz, Roy	2	772
7	Etzioni, Oren	1	729
8	Smith, Noah A.	1	729
9	Li, Rita Yi Man	5	586
10	Corchado, Juan M.	5	566
11	Mehmood, Rashid	5	566
12	Mikalef, Patrick	2	554
13	Cooper, Grant	1	548
14	Agirre, Eneko	1	486
15	Heintz, Ilana	1	486

4.4.4 The Most Influential Documents on *Sustainable AI*

Table 7 lists the most-cited papers in sustainable AI research, based on Scopus citations. This analysis aims to assess the impact of researchers' contributions to the field. A total of fifteen papers have received over 5,203 citations. Given the relatively recent development of sustainable AI, these citation numbers are reasonable. Notably, Rogers' (2020) paper, with 877 citations, stands out as the most frequently cited in this area and is included among the top-cited works in Table 7. Consequently, Table 7 highlights the most significant and influential articles in the sustainable AI domain, along with their citation counts.

Schwartz et al.'s(2020) paper, *Green AI*, has had a major influence by promoting environmentally sustainable and inclusive artificial intelligence research. It critiques the growing computational costs and carbon emissions of "Red AI," which prioritizes accuracy over efficiency, and advocates for "Green AI" as a more balanced alternative. The authors emphasize the importance of efficiency as a key evaluation metric alongside accuracy and propose tracking floating-point operations (FPO) to measure computational work. This approach aims to reduce AI's environmental impact while making research more accessible to those with limited resources. By sparking discussions on sustainability and inclusivity in AI, the paper has become widely cited and influential in the field.

Table 7: Prolific documents in sustainable AI domain

id	Label	Description	Sources	Country	Citations
1	Rogers (2020)	A primer in bertology: what we know about how BERT works	Transactions of the association for computational linguistics	US	877
2	Schwartz (2020)	Green AI	Communications of the ACM	US	729
3	Cooper (2023)	Examining science education in chatgpt: an exploratory study of generative artificial intelligence	Journal of science education and technology	Australia	548
4	Min (2024)	Recent advances in natural language processing via large pre-trained language models: a survey	ACM computing surveys	US	486
5	Collins (2021)	Artificial intelligence in information systems research: a systematic literature review and research agenda	International journal of information management	Ireland	392
6	Henderson (2020)	Towards the systematic reporting of the energy and carbon footprints of machine learning	Journal of machine learning research	US	252
7	Lannelongue (2021)	Green algorithms: quantifying the carbon footprint of computation	Advanced science	UK	245
8	Feuerriegel (2024)	Generative AI	Business and information systems engineering	Germany	241
9	Ericsson (2022)	Self-supervised representation learning: introduction, advances, and challenges	IEEE signal processing magazine	UK	228
10	Fraga-Lamas (2021)	Green IoT and edge ai as key technological enablers for a sustainable digital transition towards a smart circular economy: an industry 5.0 use case	Sensors	Spain	227
11	Galaz (2021)	Artificial intelligence, systemic risks, and sustainability	Technology in society	Sweden	214
12	Yang (2021b)	Human-centered artificial intelligence in education: seeing the invisible through the visible	Computers and education: artificial intelligence	Taiwan	213
13	Yigitcanlar (2020c)	The sustainability of artificial intelligence: an urbanistic viewpoint from the lens of smart and sustainable cities	Sustainability (Switzerland)	Australia	187
14	Regona (2022a)	Opportunities and adoption challenges of ai in the construction industry: a PRISMA review	Journal of open innovation: technology, market, and complexity	Australia	186

15	Ozmen Garibay (2023)	Six human-centered artificial intelligence grand challenges	International journal of human-computer interaction	US	178

Cooper's(2023) paper, "*Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence*," has made a notable impact on science education by analyzing the role of "generative AI," particularly ChatGPT, in learning environments. The study examines how ChatGPT responds to science education queries, its potential in teaching, and its effectiveness as a research tool. Cooper discusses the alignment of ChatGPT's outputs with key educational themes while addressing ethical concerns such as environmental impact, content moderation, and copyright issues. The paper underscores the need for critical assessment and responsible use of AI-generated content by educators, advocating for its thoughtful integration into teaching. As an early exploration of generative AI's influence in education, the study has stimulated wider discussions and become a frequently cited resource in the field.

Collins et al.'s(2021) paper, "*Artificial Intelligence in Information Systems Research: A Systematic Literature Review and Research Agenda*," has gained widespread recognition for its substantial impact on information systems (IS) research. It systematically examines AI-related studies in IS from 2005 to 2020, highlighting key themes and uncovering gaps in the field. The paper provides an in-depth evaluation of AI's business value, practical applications, and future research directions. By addressing concerns about the fragmented nature of AI research, it establishes a valuable framework for advancing both academic studies and real-world implementations, making it an essential reference for researchers and professionals.

Lannelongue et al.'s(2021) paper, "*Green Algorithms: Quantifying the Carbon Footprint of Computation*," has had a major impact by highlighting the often-overlooked environmental costs of computational tasks. It presents a standardized framework and an accessible online tool, Green Algorithms, to estimate and contextualize the carbon footprint of various computing processes. By incorporating metrics such as greenhouse gas emissions and their real-world equivalents (e.g., travel distances or tree sequestration), the study offers practical strategies for reducing unnecessary CO_2 emissions. With applications spanning fields like particle physics, weather forecasting, and natural language processing, the paper raises awareness and promotes more sustainable computing practices. Its innovative approach has made it a widely recognized and frequently cited resource at the intersection of sustainability and computational science.

Feuerriegel et al.'s(2024) paper, "*Generative AI*," has made a significant impact on the field of Business & Information Systems Engineering (BISE) by offering a comprehensive framework for understanding generative AI within socio-technical systems. The authors examine the transformative potential of technologies like GPT-4 and DALL-E 2 in reshaping content creation, decision-making, and communication. They discuss both the opportunities and challenges these advancements present, particularly for the BISE community, and outline a research agenda to address issues such as bias, fairness, and misinformation. By emphasizing the implications of generative AI for information systems, the paper provides valuable insights and practical guidance, establishing itself as a key reference for researchers and professionals in this evolving field.

5. Conclusion and Recommendations

This review offers a basis for evaluating the current state of knowledge regarding "sustainable AI." A variety of bibliometric methods, including algorithmic processes and software tools, were used to examine the movement of information on this topic. Potential research areas were highlighted, a wide-ranging overview of prevailing knowledge on the theme was compiled, and a plan for imminent study that considers the evolving nature of the field was established.

This examination of research highlights the extensive body of work on "sustainable AI" that has accumulated since its first appearance in "the Scopus database (2016)." The majority of the literature on this subject has emerged in the past decade, possibly wing to the frequent exploration of themes such as "artificial intelligence" (302), "applied machine learning" (240), "sustainable AI" (107), "sustainability" (85), "green AI" (72), "artificial neural networks" (70), "energy efficiency" (53), "sustainable development goals" (52), "internet of things" (44), and "carbon footprint" (34).

Recent studies in this field have focused on topics such as "image compression," "convolutional neural networks," "classification algorithms," "computing in memory," "data augmentation," "resources management," "cloud environment," "transformer architecture," "transfer learning," "natural language processing," "health and environmental justice," "business innovation," "large language model," "generative AI," and "5g technologies."

Consequently, these areas require the most attention from researchers, as the data shows that they remain relatively underexplored, not only in developing countries but also in many developed nations.

This study enhances understanding of the field by reviewing past research, identifying recurring themes, and pinpointing areas that have been underexplored and require further investigation. It offers a wide-ranging outline of the subject or a detailed analysis of the reference system for researchers. For educators, this can be useful in recognizing the most studied areas, staying updated on the newest progress, and understanding the future direction of the subject to build upon existing knowledge about the sustainable AI.

This research highlights the most productive and frequently cited nations and journals, providing valuable insights to help academics and other stakeholders make well-versed decisions regarding research and publication in this subject.

6. Study Gap, Implications, and Limitations

6.1 Research Gaps

Recent research on "sustainable AI" has primarily concentrated on topics such as “Image compression,” “convolutional neural networks,” “classification algorithms,” “computing in memory,” “data augmentation,” “resources management,” “cloud environment,” “transformer architecture,” “transfer learning,” “natural language processing,” “health and environmental justice,” “business innovation,” “large language model,” “generative AI,” and “5g technologies,” the newest (Figure 4). These areas have been the subject of significant attention in the field. Consequently, they require more focus from researchers, as the data indicates that they remain relatively new and underexplored, not only in developing countries but also in most industrialized nations (Tables 1 and Figure 4).

Secondly, the research from the last sub-period exposed a rise in the frequency of co-words associated with the field across both sub-periods: "artificial intelligence" (67, 230), "applied machine learning" (34, 205), "sustainable AI" (27,116), "sustainability" (29, 56), "green AI" (24, 55), "artificial neural networks" (22, 50), "energy efficiency" (13, 43), "sustainable development goals" (11, 42), "internet of things" (0, 39), and "carbon footprint" (0, 30). This means they are all still growing, and so they need the researchers’ attention.

6.2 Implications

This study provides a comprehensive outline of the progress and existing state of "sustainable AI." It highlights key sources, publications, and potential future directions for the field, serving as a valuable resource for researchers in computer science, environmental engineering, accounting, finance, economics, and business management. Additionally, anyone interested in exploring the literature of this domain can benefit from this research.

6.3 Limitations

While using the Scopus database offers advantages in this study, there are also limitations. One common issue in bibliometric research is the potential exclusion of records from other databases such as ABI, Web of Science, and Inform/ProQuest (Jacsó, 2008; Nyabakora & Mohabir, 2024). Adding to the results from this exploration, other relevant materials like editorials, conference papers, and national journals should also be considered when discussing "sustainable AI" (Casado-Belmonte et al., 2021). Following the approach of Hallinger and Nguyen(2020) and Tiberius et al.(2020), this study used co-citation, keyword searches, and co-occurrence analysis. Including bibliographic coupling in the analysis might also be valuable. Nevertheless, the mentioned limitations suggest areas where future bibliometric research could be enhanced.

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