

The Role of Knowledge and Innovation in Sustainable Technology Development: Analysis Bibliometric Review

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Abstract

The future of sustainable technology in education will be driven by interdisciplinary collaboration, technological innovation, and policy integration to address pressing environmental challenges. The main objective is to analyze the development of research on sustainable technology using a bibliometric approach with the VOSviewer tool. The study identifies key trends, collaboration patterns, and evolving themes in the element of technology in sustainability, energy, and development-related literature. Publication data was obtained from Google Scholar using the keyword "sustainable technology," which was then analyzed using the Publish or Perish, Mendeley desktop, and VOSviewer tools. The study identified a total of 990 papers from 2014 to 2024. The results of the analysis showed that keywords such as "sustainability," "sustainable technology," and "wastewater treatment" dominated the research network, with clusters reflecting the relationship between clean technology, innovation, and patent analysis. By fostering a knowledge-driven approach, the next generation of professionals will be empowered to design scalable, eco-friendly solutions that promote resilience in communities and industries. As societies move toward carbon neutrality and climate adaptation, education and technology will remain central to achieving long-term sustainability goals, ensuring a greener, more equitable future for all.

Keywords: - Sustainable technology, bibliometric analysis, PoP, VOSviewer, innovation, sustainable development

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1. Introduction

The rapid advancement of global technology presents increasing challenges, necessitating a conceptual framework for sustainability that highlights various interrelated subfields, including sustainable technologies, energy, green technology, and environmental sustainability (Berawi, 2017). In the context of education and knowledge, sustainable technology plays a crucial role in developing solutions to ecological challenges (Liu et al., 2023). This elaboration focuses on the key variables influencing sustainable technologies in the education system, explaining both their practical applications and the

theoretical significance behind these factors (Smith, 2024). Education serves as the foundation for advancing sustainable technology (Ab Hamid et al., 2024). The application of sustainability emphasizes key concepts such as technology adoption, energy efficiency, sustainable agriculture, circular economy, and many more, all of which are fundamental to shaping sustainable education curricula (Pantic & Cain, 2022). The inclusion of these elements underscores the importance of integrating sustainability principles into academic research, engineering, and environmental sciences (Rupnik et al., 2020).

Institutions must prioritize educating students on sustainability knowledge, decision-making processes, and the impact of technological advancements on the

environment (Bennett et al., 2018). Practical applications of this knowledge include developing a green engineering approach, implementing renewable energy systems, and designing sustainable infrastructure within educational institutions (Assey, 2020).

One of the critical elements of sustainable technology is the excitement of knowledge through innovation and research (Block & Song, 2022). The connection between clean technology, product function, and innovation development underscores the importance of scientific research and intellectual property in advancing sustainability (Ghobakhloo et al., 2023). Education in sustainable technology is essential for developing a knowledgeable workforce capable of implementing solutions to environmental challenges. Universities and research centers play a vital role in fostering an ecosystem where innovation drives technological advancements (Sharma & Gupta, 2024). This is achieved through academic publications, open-source technology platforms, interdisciplinary research collaborations, and the patenting of new sustainable technologies, ensuring that knowledge remains both accessible and applicable, widely used.

Sustainable technology education is not limited to theoretical studies but also encompasses real-world applications (Peter et al., 2024). Academic institutions must implement sustainable practices within their infrastructure to serve as innovative guides for students. Beyond practical applications, sustainability education must also address ethical considerations, implications of technology, and environmental issues (De Medeiros et al., 2014). In addition, understanding priorities such as product life cycle assessment, carbon footprint reduction, and the socio-economic impacts of sustainable technology are essential for making informed decisions. In addition, understanding priorities such as product life cycle assessment, carbon footprint reduction, and the socio-economic impacts of sustainable technology is essential for making informed decisions (Saw et al., 2023). Educational institutions should offer courses in sustainability ethics, green technology, and social responsibility to prepare students for leadership roles in a sustainable environment (Khaddour & Deng, 2023; Salazar et al., 2024).

Therefore, research is needed not only to analyze global trends but also to provide strategic guidance for companies and policymakers in enhancing the implementation of technology in sustainability (Verma et al., 2023). Because of that, bibliometric analysis is a statistical method used to analyze publications and identify trends, key research areas, and relationships among studies (Marisa et al., 2024). In this study, bibliometric analysis is applied, with bibliometric visualization serving as one of the primary methods. Through this visualization, the research provides a structural overview of the topic being studied. The rationale for using descriptive bibliometric analysis in this study is that it examines the literature from a descriptive perspective. The primary objective of applying bibliometric analysis is to identify emerging trends in academic articles and journals (Permana & Lukito, 2024).

This environmental audit study utilizes the software Publish or Perish, which offers a comprehensive understanding of development and progress over time. Additionally, this research provides new insights for future studies. By leveraging the VOSviewer tool, this study visualizes the main themes, collaboration patterns among researchers, and relationships between keywords in the existing literature (Marisa et al., 2024). The findings of this research are expected to offer a broader perspective on future research directions and contribute to more effective environmental highlighted. Furthermore, this study aims to address several research questions and achieve its broader objectives.

1. What is the progress in the study of sustainable technology?
2. What are the prominent titles in this field?
3. What are the publication sources and citation numbers linked?

1.1 Theoretical Studies

The significant growth in research on sustainable technology, as reflected in the literature, suggests that the field is rapidly evolving (Ni et al., 2023). As global challenges such as climate change, resource depletion, and pollution become more pressing, educational institutions must prioritize sustainability research. Future educational initiatives should focus on environmental education and knowledge dissemination, as these are critical factors in advancing sustainable technology (Bennett et al., 2018). By integrating theoretical understanding with practical applications, educational institutions can play a transformative role in addressing global sustainability challenges and equipping the next generation with the skills to drive technological innovation for a greener future (Ali et al., 2024).

1.2 Bibliometric Studies

Bibliometric studies are methods used to analyze scientific publications and related information. In this approach, several elements are analyzed, including the level of production, citation, and distribution of scientific literature, using informatics and statistical techniques. This method is useful for exploring the relationships and interactions between publications and scientific fields, as well as for evaluating the performance of individuals, institutions, and disciplines within the context of research (Donthu et al., 2021).

1.3 Tool VOSviewer

VOSviewer is a software tool that is highly useful for the development of bibliometric network analysis and visualization. Researchers have chosen VOSviewer because it offers various features that facilitate scientific data analysis, particularly in the field of bibliometrics (Wardhana et al., 2023). In addition, VOSviewer will help plan future research directions and provide insights into the

contributions of individuals, institutions, and scientific fields within academia. With its user-friendly interface, VOSviewer supports a wide range of data sources, such as Lens.org, OpenAlex, PubMed, Crossref, Scopus, Emerald, and Google Scholar, allowing users to efficiently analyze and visualize publication data. This bibliometric software, VOSviewer, is designed to analyze and visualize scientific publications. This tool enables users to view citation, co-citation, and keyword analysis data in the form of easy-to-understand and intuitive graphs and diagrams.

This study aims to identify publications on the sustainability of technology in today's world and describe their characteristics, using bibliometric analysis to explore publication trends and gain insights into sustainability research in the field of education. Bibliometrics is a statistical method used to analyze publications (Phoong et al., 2022; Wang et al., 2021; Zhang et al., 2019 & Zyoud et al., 2015). Bibliometrics forms the basis for determining the most popular and significant publications in a particular field (Zyoud et al., 2022). It is a research method that provides comprehensive information by combining science, mathematics, and statistics to analyze knowledge quantitatively (Zhang et al., 2019). Thus, bibliometrics is a statistical method that provides information related to publications and is used to analyze publications in a specific field.

In the visualizations generated by VOSviewer, including network maps and keyword groupings, an intuitive representation of the complex relationships between authors, articles, and keywords is provided. These visualizations improve the accessibility of results, enabling stakeholders to understand the dynamics of complex research landscapes.

2. Research Methods

The research method of bibliometric analysis is employed to answer research questions by studying the development of relevant studies and literature. To conduct a comprehensive bibliometric analysis, a systematic literature review will be performed to identify relevant articles, conference papers, and reviews related to technology.

This study uses national and international publication data obtained from the Google Scholar website. The keyword used is "sustainable technology," and the Harzing's Publish or Perish (PoP) tool was utilized to collect papers accessed on February 1, 2025. In this study, researchers adopted the PRISMA method, with the initial phase involving identification, followed by screening, eligibility, and finally, inclusion, as shown in Fig. 1 (Moher et al., 2009).

The first step involved identifying relevant publications using search strings and removing identical or duplicate publications. The topic and scope are "sustainable technology," meaning only publications with these terms were selected for the advanced search process. A total of 996 publications using the Google Scholar database from 2014 to 2024 were identified, with no duplicates found.

The second step, screening, was carried out to select publications in subject areas and languages. The subject area chosen is sustainability because it is central to this research, and the language required for the research is English, as it is the most widely used international language in scientific communication. The only type of document required in this research is articles.

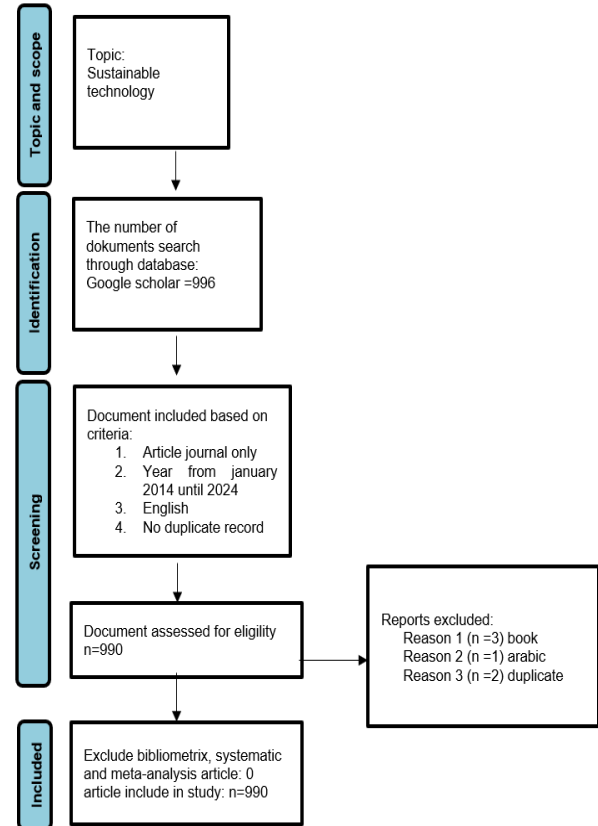


Fig. 1: Prisma method (Moher et al., 2009)

After the screening process, six publications were excluded from the data because they did not meet the criteria, leaving 990 publications remaining. The flow chart illustrates the number of publications and a linear trend line for each year over the past decade. Citation trends for these publications were examined annually, and the average number of citations per publication was calculated using Microsoft Excel. From the table, the number of citations was 36436 during the 10 years. To determine the h-index and g-index, Harzing's Publish or Perish software was used, as shown in Table 1. This categorization reflects the journals with publications ranked above a certain threshold.

The distribution of publications by country was visualized using Microsoft Excel, creating a world map that showcases the varying concentrations of publications across different countries. This method aligns with recent research emphasizing sustainable technology, as evidenced by the growing body of literature highlighting the positive impact of environmental audits, particularly on companies focused on sustainable development and ecological balance globally. Additionally, VOSviewer software was

employed to generate network visualizations that illustrate relationships between countries. To analyze the research focus, the co-occurrence of keywords related to sustainable technology was examined using Google Scholar's database, which underwent preprocessing. The shared keywords were then visualized using software to identify the prominent research themes.

Table 1. Research data metrics

Publication years	2014-2024
Citation years	11 (2014-2024)
Paper	996
Citations	36436
Cites/year	3312.36
Cites/paper	36.58
Cites/author	11330.24
Paper/author	385.38
Author/paper	3.54
h-index	98
g-index	157
hi,norm	51
hi,annual	4.64
hA-index	37
Paper with ACC	1,2,5,10,20:683,591,431,245,114

The graph in Fig.2 illustrates the trend of publication in the field of sustainable technology from 2014 to 2024, showing a consistent rise in research output over the years. The following years saw steady growth in sustainable technology-focused research, with 60 publications in 2016, 68 total publications in 2017, and a total of 83 publications in 2018. However, a slight decline occurred in 2019 (76 publications) before the number recovered in 2020 with 80 publications. The increase in the number of studies is due to many researchers collaborating between countries, some is also due to changes in artificial intelligence technology and the attempt to achieve low costs in solving environmental problems (Musleh Al-Sartawi et al., 2022 & Hadmar et al., 2024).

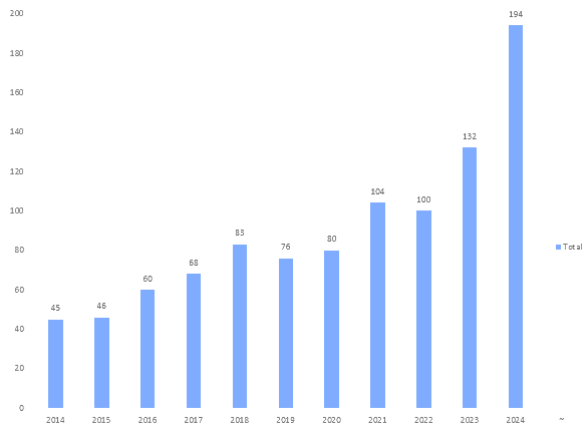


Fig. 2: Trend of publication

Other than that, the matter is due to the initial trend also

shows a gradual increase in interest in sustainable technology research, possibly influenced by the awareness of the public and academic lecturers around the world about technological change. In addition to the choice to use renewable energy in the industrial sector, and increased investment towards a move to green technology, causes a new dimension of industrial revolution 4.0 impression (Salama et al., 2019 & Shao et al., 2024).

For the next 2022 indicate a small decrease to 100 publications, the trend increased significantly again in 2023 with 132 publications, which shows renewed interest in areas such as renewable clean energy, greenhouse effect, and prioritizing environmentally friendly materials. However, the most significant growth occurred in 2024, when the number of publications rose to a total of 194, marking the highest increase in publications ever recorded. This sharp increase suggests that the world is now shifting towards research in the direction of a sustainable medium, perhaps also due to regulations framed through stronger policies, as well as technological advances and increased funding for researchers for digital-related studies.

Overall, the upward trend in sustainable technology publications highlights the field's increasing importance in academia and industry. The drastic rise in 2023 and 2024 reflects the urgency for innovative solutions to combat climate change, reduce carbon emissions, and promote circular economy principles. If this trajectory continues, sustainable technology research will likely become a dominant area in scientific discourse, driving global efforts toward a greener and more resilient future.

3. Results and Discussion

Table 2 illustrate a structured summary of various review articles from different research domains, highlighting the authors, article titles, journal names, affiliated institutions, countries, and annual citation counts. The articles span diverse fields, including environmental sustainability, additive manufacturing, catalysis, textile waste management, and sustainable finance. The citation counts indicate the academic impact of these articles, with Daneshvar et al. (2022) receiving the highest number of citations per year (119) and Musleh Al-Sartawi et al. (2022) receiving the lowest (74). The geographical diversity of the authors, from Malaysia to Bahrain, further emphasizes the global nature of contemporary research and collaboration.

The first article by Daneshvar et al. (2022), affiliated with the University of Nottingham Malaysia, discusses biologically mediated carbon capture using microalgae for CO₂ biofixation and biomass valorization. This research, published in the Chemical Engineering Journal, addresses the growing concerns surrounding climate change and carbon emissions by exploring sustainable biological solutions. With its significant citation count, this study indicates strong interest and relevance in environmental sustainability and engineering. Similarly, Jiang et al. (2018), from the University of Auckland, New Zealand, reviewed support structures for additive manufacturing in

the Journal of Manufacturing and Materials Processing. Their work contributes to advancing 3D printing

technologies by optimizing support structures, a crucial aspect of industrial and biomedical manufacturing.

Table 2: Publication with the most citations in 2014-2024

Author	Title Article	Journal	Country	Citation per year
Daneshvar et al., 2022	Biologically-mediated carbon capture and utilization by microalgae towards sustainable CO ₂ biofixation and biomass valorization—A review	Chemical Engineering Journal	University of Nottingham, Malaysia	119
Jiang et al., 2018	Support structures for additive manufacturing: a review	Journal of Manufacturing and Materials Processing	University of Auckland, Auckland, New Zealand	93
Li et al., 2021	MXenes as noble-metal-alternative co-catalysts in photocatalysis	https://www.sciencedirect.com/journal/chinese-journal-of-catalysis	South-Central University for Nationalities, China	77
Behera et al., 2021	A review on the treatment of textile industry waste effluents towards the development of efficient mitigation strategy: An integrated system design approach	https://www.sciencedirect.com/journal/journal-of-environmental-chemical-engineering	Kalinga Institute of Industrial Technology, Bhubaneswar, India	76
Musleh Al-Sartawi et al., 2022	The role of artificial intelligence in sustainable finance	Journal of Sustainable Finance & Investment	Ahlia University, Manama, Bahrain	74

Li et al. (2021), affiliated with South-Central University for Nationalities, China, analyzed the potential of MXenes as noble-metal alternative co-catalysts in photocatalysis. Their study, published in the Chinese Journal of Catalysis, focuses on enhancing catalytic performance while reducing costs by substituting expensive noble metals. Behera et al. (2021), from the Kalinga Institute of Industrial Technology, India, reviewed strategies for mitigating textile industry waste effluents. Published in the Journal of Environmental Chemical Engineering, their work highlights an integrated system design approach for waste treatment, reinforcing the importance of sustainable industrial processes in one of the most polluting global industries.

The final article, by Musleh Al-Sartawi et al. (2022), represents a shift from environmental and engineering research to the financial sector. Affiliated with Ahlia University, Bahrain, their study examines the role of artificial intelligence in sustainable finance, emphasizing AI-driven decision-making for financial stability and investment sustainability. Published in the Journal of Sustainable Finance & Investment, this research aligns with the increasing interest in integrating AI into economic models for efficiency and sustainability. Collectively, the articles in the table reflect a diverse range of contemporary academic efforts, demonstrating how institutions worldwide are addressing pressing global challenges through interdisciplinary research.

Fig 3 shows a visualization of the relationship between the co-occurrence of keywords in research related to sustainability and sustainable technology. Currently, research on sustainability in the context of reporting is growing with a focus on sustainability in improving transparency and technology. This study shows that "sustainability" and "sustainable technology" are in the limelight due to their high frequency and wide connectivity, indicating that these two keywords are the main themes in the literature analyzed. Connecting lines that can show the close relationship between key keywords and other terms, such as "sustainable development", "clean

technology", "innovation", and "wastewater treatment", which form a strong conceptual network.

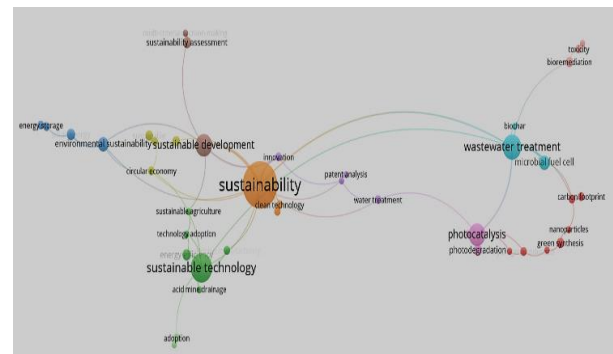


Fig. 3: Mapping visualization

The colorful clusters in this visualization reflect the grouping of relevant subtopics. The orange cluster focuses on core concepts such as "sustainability" and "sustainable technology", which are related to the main objectives of the research. Meanwhile, the blue cluster highlights aspects related to wastewater treatment, while the green cluster discusses external factors, such as the influence of technology adoption and energy. The relationships between clusters show that these themes complement each other, providing broader insights into the implementation of sustainability in a variety of contexts.

Meanwhile, study conducted by Yin. et al. (2018) concluded that the sustainable environment in that direction is more significant, but not to another thing that is still not much concerned is clean technology based on the figure above. This visualization provides a comprehensive overview of research patterns in the field of sustainability, while showing the importance of the relationship between technology, sustainability, and sustainable development. By utilizing this co-occurrence analysis, researchers can identify dominant subtopics as well as find opportunities for further exploration in the

literature that are still under-discussed.

The visualization in Fig 4 highlights the trend of increasing collaboration in sustainability, sustainable technology, and sustainable development. This research is expected to be able to examine sustainability in technology so that the policy of differences in development standards in various applications causes variations in results and use. Therefore, the development of universal standards and technology is an urgent need so that sustainability management can have a maximum impact on sustainability management around the world. The colors on the graph depict the development of research from 2014-2022, which shows increased attention to mitigation issues over time. This linkage reflects the importance of its role in assessing the industry's performance on sustainability aspects. In (David et al. 2022) study, he stated that there is a lot of focus on energy, food sources and water sources but based on the fig 4 above, energy storage is still being researched until now to be developed and explored. With increasing global pressure to address climate change and environmental conservation, sustainable technology is becoming a strategic tool to ensure industry's competitiveness while strengthening their commitment to sustainability.

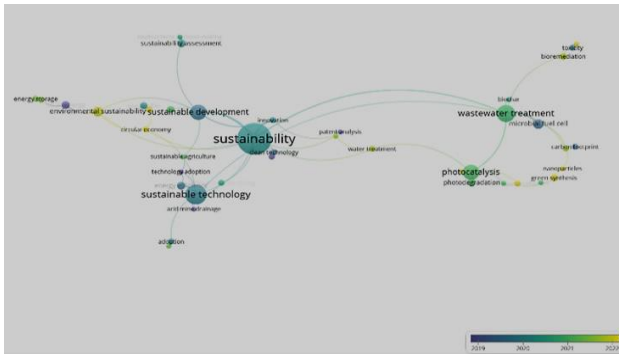


Fig. 4: Trend research

Fig 5 shows a bibliometric visualization in the form of a heatmap created using the vosviewer device. This visualization maps the relationships and relationships between keywords (word cloud) that often appear together in a dataset, especially related to "sustainability". Key keywords such as "sustainable technology", "sustainable development", and "wastewater treatment" are shown in bright yellow, indicating a high frequency of occurrence in literature.

Other keywords, such as "sustainability assessment", "circular economy", and "energy efficiency", although of lower intensity, still play an important role in this topic (Prashar & Vasudev, 2021). This visualization shows that the focus of the research is on the relationship between industry players and the role of academic, organizational, and sustainability management. Using this heatmap, researchers can identify trends and potential areas that still need further exploration in the field of sustainability (Chamboko-Mpotaringa & Tichaawa, 2021). Among the fields that have not much more explored are

circular economy, solar energy, energy efficiency, microbial fuel cell, multi-criteria decision making, additive manufacturing, technology adoption, and biochar by researchers based on Fig 5.

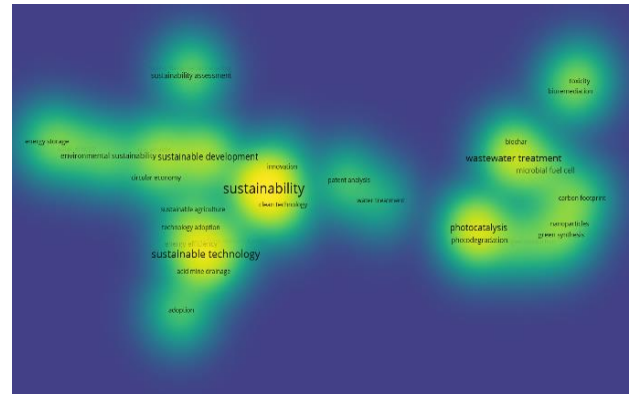


Fig. 5: Visualizes word cloud

Item density visualization illustrates the relationship between brightness level and density level. In particular, the higher the brightness level, the greater the density level, which reflects the frequency with which documents related to a particular term appear. Based on the data in the image shown, the sustainability of the population in Malaysia has a fairly high level of density.

However, the Wang et al. (2022) researcher stated that from his study, it was found that there are comprehensive, useful sustainability effects such as economic sustainability, energy sustainability, and environmental sustainability by 2025, but based on the observation of the figures above, there are still many researchers with further studies in the sustainability assessment area.

4. Conclusion

Sustainability management is a growing field, with increasing attention being paid to its role in supporting overall human life, the sustainability environment, society development, and also to company performance (Girijan, 2024). Data visualization reveals that the main themes in this study include the relationship between technology, sustainability, and management, which are intertwined in efforts to improve operational efficiency and ensure compliance with established standards (Shekhar, 2023). While challenges exist in implementing sustainability, such as regulatory variations between countries and limited organizational capacity, the potential to enhance sustainability practices through technology is immense (Ma & Najam, 2024).

The study also identified a growing focus on corporate transparency, social responsibility, and environmental performance management (Salazar et al., 2024). Therefore, it is crucial to continue developing universal standards and increasing technological capacity to maximize the impact of management efforts (Salami et al., 2024). This analysis opens opportunities for further research, particularly in

examining underexplored areas, such as the influence of outputs and the role of education in enhancing transparency within sustainability frameworks.

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

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