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Bibliometric Analysis of Earth Science Physics Learning in Higher Education: Challenges, Innovations, and Contributions to Education for Sustainable Development

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ABSTRACT

Objective: *This study aims to provide a comprehensive bibliometric analysis of earth science and physics learning in higher education within the framework of Education for Sustainable Development (ESD). The objectives are to identify research trends, major contributors, collaboration patterns, and thematic focuses that define the development of this field.* ***Method:*** *Data were collected from the Scopus database (2015–2025) using keywords related to earth science, physics learning, higher education, and sustainability. After screening, 413 relevant documents were analysed using Bibliometrix and VOSviewer to map publication trends, influential journals, key authors, institutional contributions, and keyword co-occurrence networks.* ***Results:*** *The findings reveal three phases of publication dynamics: early decline (2015–2017), rapid growth (2018–2019), and consolidation (2020–2025). The Journal of Geoscience Education dominates as the main publication source, while the United States and Indonesia emerge as the leading contributors. Thematic analysis highlights two clusters: pedagogical innovation and curriculum transformation for sustainability competencies, and the integration of technology (AI, STEM, computing) in science education. Despite increasing international collaboration, networks remain fragmented.* ***Novelty:*** *This study is the first bibliometric mapping that specifically connects earth science and physics learning with the ESD agenda. It identifies research gaps, particularly the lack of integration of sustainability dimensions in physics pedagogy, uneven global collaboration, and limited exploration of digital innovations for ecological literacy.*

INTRODUCTION

Higher education plays a central role in realising sustainable development, particularly through the integration of Education for Sustainable Development (ESD), which has been promoted globally since UNESCO's Decade of Education for Sustainable Development in 2005–2014 (Tilbury, 2011; UNESCO, 2014). This agenda is reinforced in the Sustainable Development Goals (SDGs), particularly target 4.7, which emphasises the importance of equipping young people with sustainable competencies (Wiek et al., 2011; Rieckmann, 2012; UNESCO, 2014). A number of studies show that universities act as agents of change capable of linking scientific knowledge with concrete action (Stephens et al., 2008; Fadeeva & Mochizuki, 2010; Filho et al., 2015). This emphasis has encouraged more research on ESD, both in the form of policy analysis and curriculum implementation (Scott, 2002; Scott & Gough, 2003; Reid & Scott, 2006)

A bibliometric study of ESD shows a very significant increase in publications. Yang and Xiu (2023) analysed 2,779 publications between 1992 and 2022 and identified five main themes, namely environmental education, sustainable capacity, education policy, pedagogy, and international collaboration. A similar trend was found by Tafese and Kopp (2025), who highlighted a surge in publications since 2018, peaking in 2022, with countries such as China, Spain, and Germany dominating (Hallinger & Chatpinyakoop, 2019; Bautista-Puig et al., 2020). However, they also emphasise that the social dimension of ESD remains under-researched, with research focusing more heavily on the environmental and economic dimensions (Martínez & Cruz, 2021; Tafese & Kopp, 2025). Other studies also show that although universities around the world have adopted ESD strategies, the distribution of publications and global collaboration is still uneven (Fadeeva et al., 2012; Filho et al., 2020).

On the other hand, the literature on science and physics education provides an interesting picture. Erol's (2023) study shows that research on physics education has indeed developed over the last two decades, but it is still focused on conventional pedagogical issues without explicitly linking them to the sustainability agenda. Similarly, the bibliometric analysis by Kadirhanoğulları and Köse (2023), which examines the integration of technology in science education, shows a lack of discussion regarding its relevance to ESD. In fact, earth physics learning is highly relevant to strengthening students' scientific literacy regarding real phenomena such as climate change and disaster mitigation (Murga-Menoyo, 2014; Albareda-Tiana et al., 2018). Pedagogical innovations that focus on simulations, experiments, and field experiences are believed to be capable of fostering ecological awareness while shaping transdisciplinary skills (Segalas et al., 2010; Barth & Rieckmann, 2016; Lozano et al., 2017).

Several studies confirm that the integration of ESD into higher education curricula still faces obstacles, both in terms of methodology, institutional management, and lecturer capacity (Cotton et al., 2009; Sterling, 2010; Shriberg & Harris, 2012). Research by Filho and de Brito (2018) shows that global efforts to mainstream ESD are still fragmented, while other studies highlight the lack of a consistent competency framework in higher education (Barth et al., 2007; Mochizuki & Fadeeva, 2010; Redman & Wiek, 2021). Meanwhile, universities have begun to function as living labs for sustainability (Filho et al., 2021), but the results of their implementation still vary across cultural and geographical contexts (Hargreaves, 2008; Leal Filho et al., 2019). This reinforces the argument that bibliometric research is needed to identify conceptual and geographical gaps while mapping pedagogical innovations in relation to ESD.

Thus, although research on ESD in higher education is growing rapidly (Shephard, 2008; Tilbury & Wortman, 2008), bibliometric studies that specifically link earth physics learning to ESD are still very limited.

In fact, earth-based and physics learning are the mediums closest to sustainability issues because they are directly related to natural phenomena experienced by the community (Murga-Menoyo, 2014; Filho et al., 2018). This research gap needs to be filled in order to gain a more comprehensive understanding of the direction of research, collaboration structures, and pedagogical innovations that can strengthen the role of higher education in sustainable development. Therefore, this study aims to conduct a comprehensive bibliometric analysis of the literature on earth physics learning in higher education, focusing on challenges, innovations, and contributions to ESD, so as to provide new empirical insights and a basis for the development of higher education strategies in the future.

RESEARCH METHOD

This study uses a bibliometric approach to analyse publication trends in earth and physics education in higher education in the context of Education for Sustainable Development (ESD). Bibliometric analysis was chosen because it provides a comprehensive overview of literature development, author distribution, collaboration patterns, and thematic focus in specific research fields (Moral-Muñoz et al., 2020; Donthu et al., 2021). This method is increasingly popular in educational studies because it provides a quantitative basis for understanding the direction of research and identifying scientific gaps (Aria & Cuccurullo, 2017; Cobo et al., 2018). Data were collected from the Scopus database, which was chosen for its broad coverage, high credibility, and provision of complete metadata that can be analysed with bibliometric software (Martín-Martín et al., 2021). The search was conducted for the period 2015–2025 using the keywords 'earth science education' OR 'physics learning' combined with the terms 'higher education,' 'sustainable development,' and 'education for sustainable development.' The initial search yielded 36,889 documents. To ensure the focus of the study, filters were applied by limiting the search to the fields of higher education, sustainability, and ESD, leaving 476 documents.

Next, the selection stage was carried out by reviewing the suitability of the documents. Irrelevant articles, duplicates, and non-final manuscripts were excluded. This process resulted in 476 documents, which were then further filtered to include only English-language journal articles and conference proceedings. Finally, 413 documents were selected for bibliometric analysis. Figure 1 illustrates the flow of the process of identification, screening, eligibility, and final selection of research documents. This diagram shows that from the initial 36.889 documents, through a series of rigorous selection stages, only 413 articles met the final criteria and were used as the basis for bibliometric analysis.

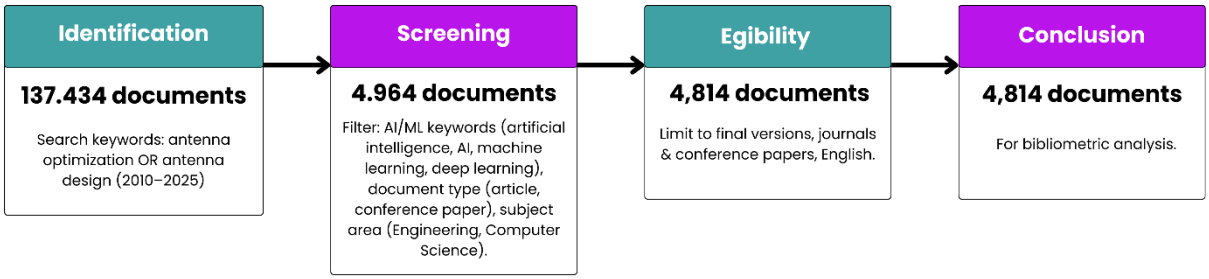

Figure 1. The selection process for research documents from 36.889 initial search results to 413 final documents for bibliometric analysis.

The analysis was conducted using VOSviewer and Bibliometrix (R package) software, which enabled the visualisation of science maps, co-citation analysis, and co-word analysis (Aria & Cuccurullo, 2017; van Eck & Waltman, 2020). The analysis stages included identifying publication trends per year, the most productive journals, major authors and institutions, dominant countries in publication, and the most frequently appearing keywords. Co-word analysis was used to identify the main research themes, while author network analysis was used to assess patterns of international collaboration (Zupic & Čater, 2015; Donthu et al., 2021).

To maintain validity, all data were exported directly from Scopus in CSV and BibTeX formats and then processed without modification. This procedure is in line with best

practices in bibliometric research that emphasise replication and transparency (Moral-Muñoz et al., 2020; Donthu et al., 2021). A limitation of this study is the use of a single database (Scopus), which, although comprehensive, may exclude important publications from other sources such as Web of Science or Google Scholar. However, the use of Scopus is still considered representative for analysis in the fields of education and sustainability due to its broad coverage in both domains (Martín-Martín et al., 2021).

RESULTS AND DISCUSSION

Results

An initial analysis of publications from 2015 to 2025 shows fluctuations in research productivity related to earth science education and physics learning in the context of ESD. Publications were relatively low in 2016–2017, then surged in 2019 with 52 articles. There was a decline in 2020 (38 articles), possibly due to the COVID-19 pandemic which limited field research (Zhu & Liu, 2020), but the trend increased again, reaching 50 articles in 2023. The year 2024 remained stable with 49 publications, while the data for 2025 (31 articles) is likely not yet final as the year is still ongoing. Overall, this trend shows three main phases: an initial decline (2015–2017), significant growth (2018–2019), and consolidation (2020–2025), as presented Table 1.

Table 1. Number of publications related to the research in the period 2015–2025

Year	Articles
2015	39
2016	21
2017	20
2018	26
2019	52
2020	38
2021	40
2022	46
2023	50
2024	49
2025	39

Citation analysis shows varying patterns throughout 2015–2025. The average citations per article (MeanTCperArt) ranged from 13 to 17 citations, with the highest value in 2018 (16.69) and relatively stable thereafter. Meanwhile, the average citations per year (MeanTCperYear) increased from 1.41 in 2015 to 2.09 in 2018, then remained in the range of 1.5–2.0 until 2025. The highest number of publications (N) occurred in 2019 with 52 articles, but the average citation value per article was not as high as in 2018. This shows a difference between the quantity of publications and the impact of citations. The visualisation in Figure 2 confirms the trend of stability in citations per article and per year after the initial growth phase of 2015–2019.

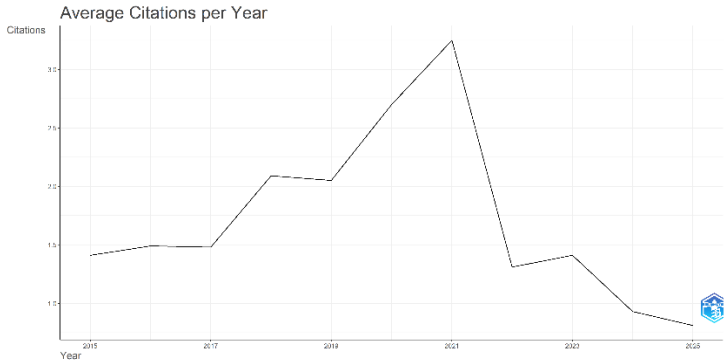

Figure 2. Average citations per article

Figure 3 shows the most relevant publication sources in the study of earth science education and physics learning in higher education in the context of ESD. The Journal of Geoscience Education is the dominant source with 44 articles, far higher than other journals or proceedings. The next positions are occupied by IOP Conference Series: Earth and Environmental Science and Proceedings of the International Astronautical Conference, each with 24 articles. Furthermore, the Journal of Physics: Conference Series (14 articles) and Sustainability (Switzerland) (12 articles) also made significant contributions. Other sources such as the International Multidisciplinary Scientific Geoconference (7), ASEE Annual Conference (6), Frontiers in Education (6), International Archives of Photogrammetry, Remote Sensing (6), and Journal of Chemical Education (6) complete the list of publications contributing to this field.

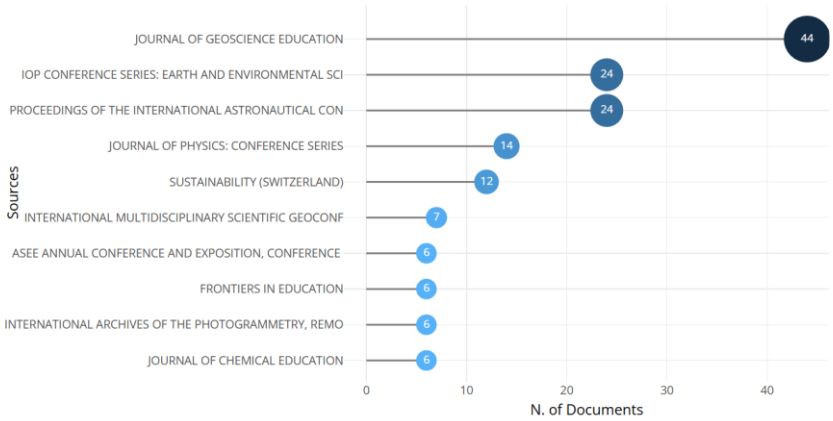

Figure 3. The most relevant publications in the field of earth science education and physics learning research

Next, Figure 4 shows the publications with the highest local impact based on their H-index values. The Journal of Geoscience Education ranks first with an H-index of 14, far surpassing other journals. Sustainability (Switzerland) ranks second with an H-index of 7, followed by the Journal of Chemical Education (H=5). Other sources such as Geoheritage and Science and Education each have an H-index of 4, while Education Sciences, IOP Conference Series: Earth and Environmental Science, and Journal of Physics: Conference Series have an H-index of 3. Acta Astronautica has an H-index of 2, making it one of the sources with relatively lower local impact.

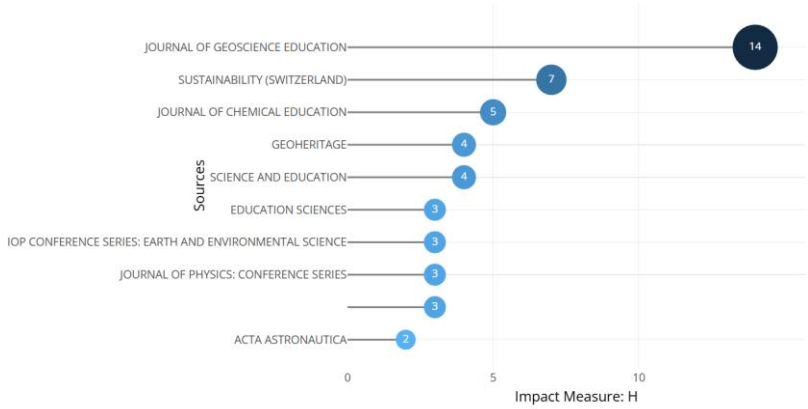

Figure 4. The Publication sources with the highest local impact based on H-index

Figure 5 shows the development of the number of publications based on the main source during 2015–2025. The Journal of Geoscience Education consistently dominates with an increasing trend from 9 articles in 2015 to more than 40 articles in 2025. Proceedings of the International Astronautical Conference also shows steady growth from 4 publications in 2015 to more than 20 in 2025. Meanwhile, IOP Conference Series: Earth and Environmental Science increased from almost zero in 2016 to more than 20 articles by 2025. Journal of Physics: Conference Series also showed an increase, albeit slower, stabilising at around 14 articles by the end of the period. Interestingly, Sustainability (Switzerland) only began contributing in 2019, but then showed consistent growth to reach around 11 articles in 2025.

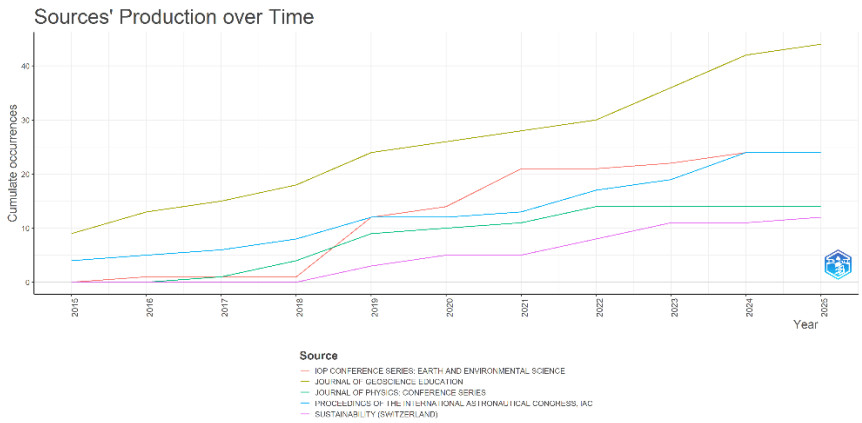

Figure 5. Development of the number of publications from primary sources (2015–2025).

Figure 6 shows the Most Relevant Authors, indicating the most productive authors in the topics of earth science education and physics learning in the period 2015–2025. The author with the highest contribution is Serevina V with 4 articles (1.08 fractionalised articles). Other dominant authors include Egger AE, Gill JC, and Janati-Idrissi R, each with 3 articles. The difference in the 'fractionalised articles' value indicates the level of contribution in collaborative publications, where not all authors have the same weight of contribution in each article.

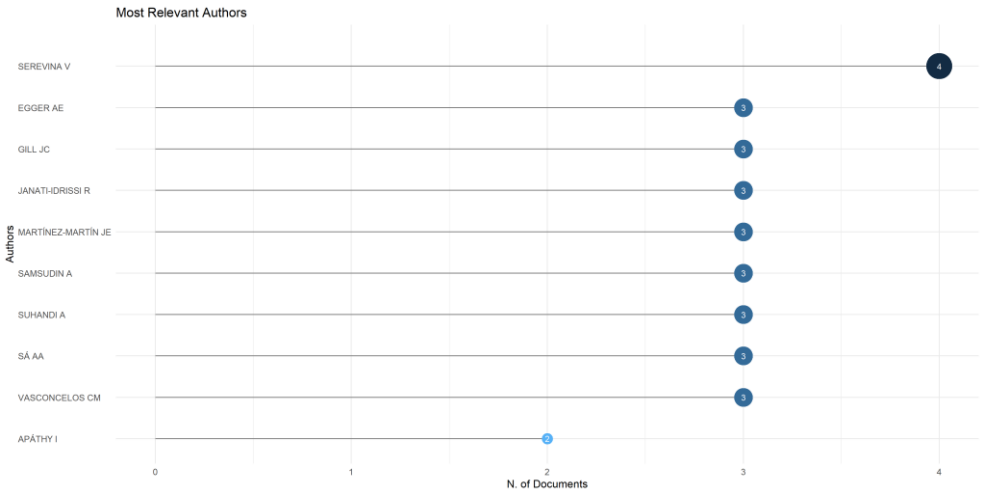

Figure 6. Most relevant authors based on the number of articles in the fields of earth science education and physics learning (2015–2025)

Figure 7 shows the productivity of authors between 2015 and 2025. Serevina V was the most prominent author with significant publication contributions in 2023, as indicated by the larger circle (denoting a greater number of articles). Egger AE and Gill JC consistently published works from 2017 to 2025, although the number remained relatively stable at 1–2 articles per year. Janati-Idrissi R and Martínez-Martín JE showed a pattern of continuous publication with contributions in recent years (2021–2025). Other authors such as Samsudin A, Suhandi A, and Sá AA were active mainly in the period 2017–2020. Meanwhile, Vasconcelos CM and Apáthy I contributed earlier (2015–2019) but did not continue afterwards.

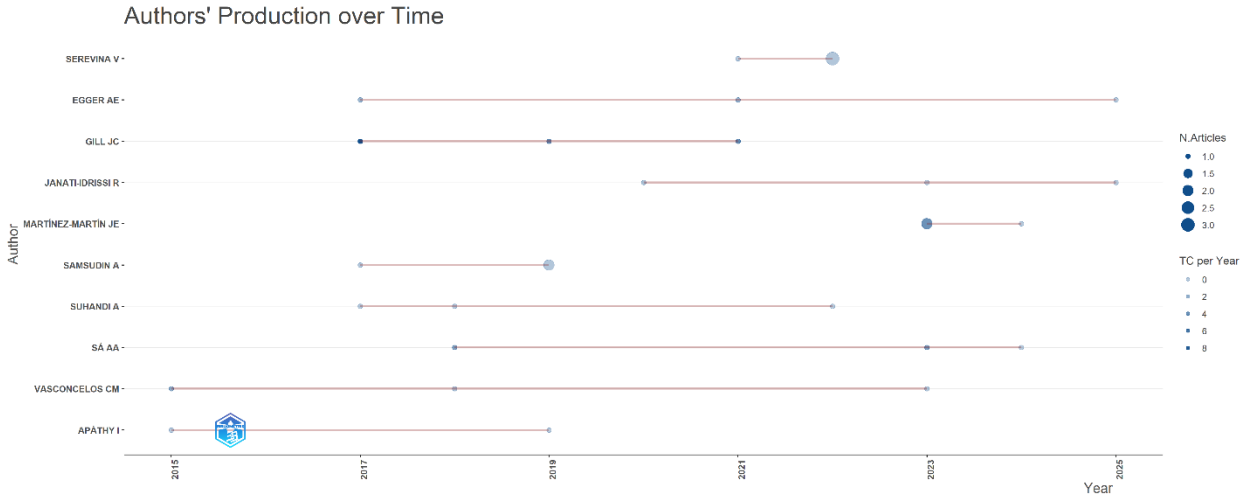

Figure 7. Productivity of leading authors from 2015 to 2025

Figure 8 shows the institutions with the largest contribution of publications in the fields of earth science education and physics learning in the context of ESD. Indonesia University of Education (UPI) ranks first with 14 articles, far surpassing other institutions. The next positions are filled by the New York City College of Technology and Pennsylvania State University, each with eight articles. The University of Northern Colorado follows with seven articles, while the Universidad Complutense de Madrid and the University of Bristol each have six articles. Several other universities, such as Florida

International University, Iowa State University, Kangwon National University, and Michigan State University, have made a balanced contribution with five articles.

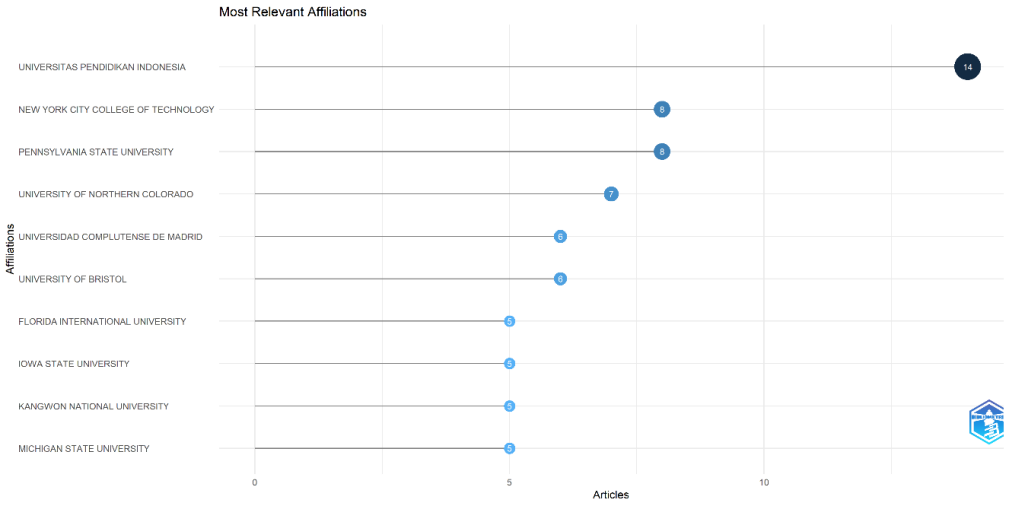

Figure 8. The institutions with the largest contribution of publications

Figure 9 shows the distribution of publications based on the country of origin of the corresponding author. The United States (USA) dominates with the highest number of publications, far above other countries. Indonesia ranks second, followed by the United Kingdom and Australia with significant contributions. Other countries such as China, Morocco, Canada, Brazil, France, Spain, and Germany are at an intermediate level, each contributing a fairly consistent number of articles. The rest, such as Italy, Belgium, Portugal, Romania, Hungary, Japan, Mexico, the Netherlands, and South Africa, have lower numbers of publications but still show involvement in this theme.

In addition, the graph also distinguishes between Single Country Publications (SCP) and Multiple Country Publications (MCP). The United States and Indonesia are dominated by SCP, while countries such as Australia, Canada, and several European countries show a higher proportion of MCP, indicating the intensity of international collaboration.

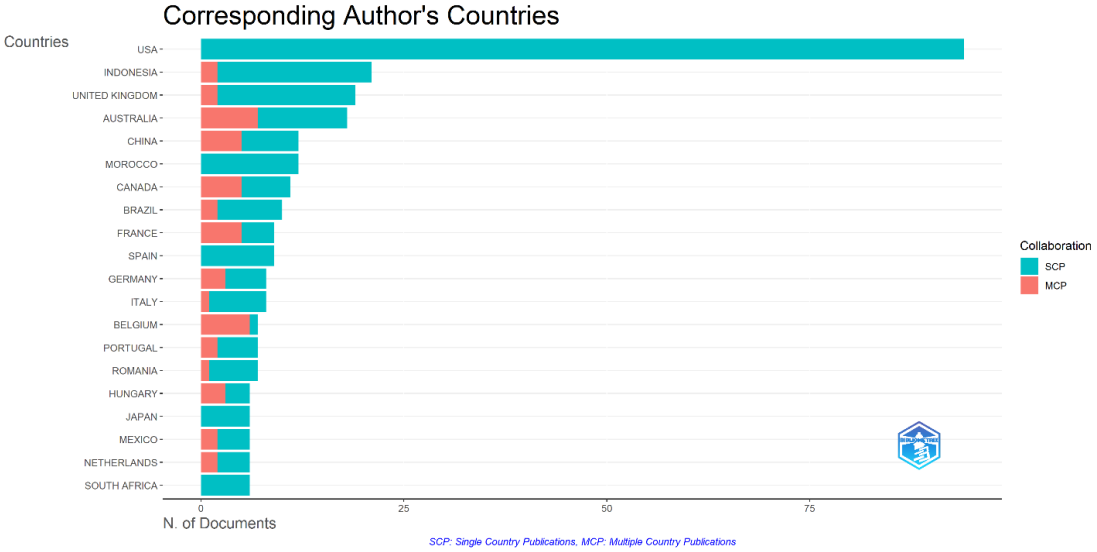

Figure 9. The distribution of publications based on the country of origin of the corresponding author

Figure 10 shows a map of the distribution of scientific production related to earth science education and physics learning in the context of Education for Sustainable Development (ESD) for the period 2015–2025. The darker blue colours indicate countries with higher productivity. The United States appears to be the largest contributor, followed by other countries such as the United Kingdom, Australia, China, Canada, Spain, Germany, France, and Indonesia. Western European and East Asian countries also show active participation, albeit with lower intensity than the United States. In addition, participation appears to be fairly evenly distributed in several regions, including South America (Brazil), North Africa (Morocco), and South Africa. This shows that research in this field has spread to various continents, albeit with disparities in contributions between countries.

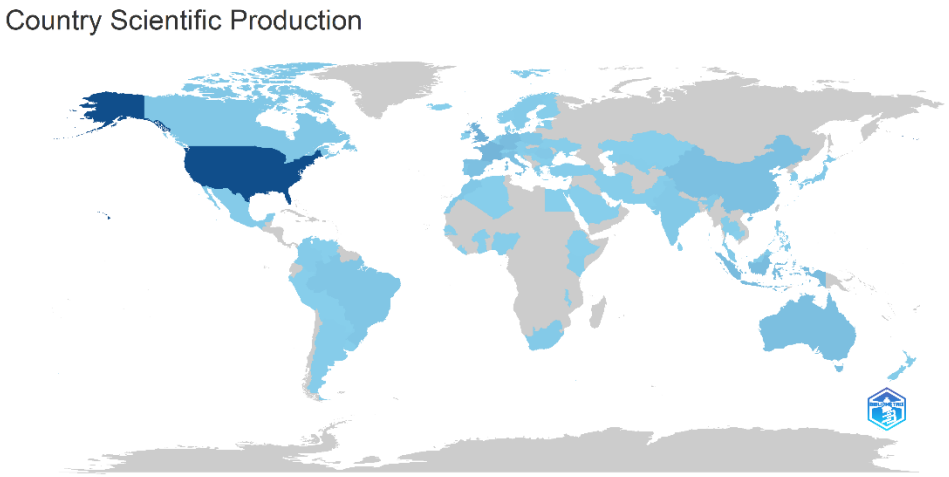

Figure 10. A map of the distribution of scientific production

Figure 11 shows the most frequently occurring words in literature related to earth science education and physics learning in the context of higher education and sustainable development. The largest words—such as 'higher education', 'education', 'teaching', 'students', 'sustainable development', and 'earth science'—indicate that the main theme of the publications centres on the role of higher education in supporting sustainability through earth science teaching. Other notable words are 'curriculum', 'sustainability', 'environmental education', and 'climate change', which indicate a focus on integrating sustainability into science learning. In addition, there are more technical words such as 'remote sensing', 'computing', and 'engineering education', which indicate that the research not only focuses on pedagogy, but also includes the integration of technology in supporting the teaching and learning process. The presence of terms such as 'decision making', 'systems thinking', and 'learning systems' shows that 21st-century competencies are also taken into account in this research.

Figure 11. Visualisation of the most frequently occurring words in publications on earth science education and physics learning (2015–2025)

Figure 12 shows the development of research topics from 2015 to 2025. The terms that appeared most consistently throughout the period were 'higher education', 'education', 'teaching', 'students', and 'sustainable development', indicating that the core of the study remained focused on the role of higher education in integrating sustainability. Topics such as 'climate change', 'curricula', and 'engineering education' began to gain traction in 2018 and were used more frequently in 2020–2023. Meanwhile, new terms such as 'artificial intelligence', 'STEM (science, technology, engineering, and mathematics)', and 'sustainable development goals (SDGs)' emerged more dominantly in the 2022–2025 period, signalling a shift in focus towards the digitalisation of learning, technology integration, and the achievement of global goals.

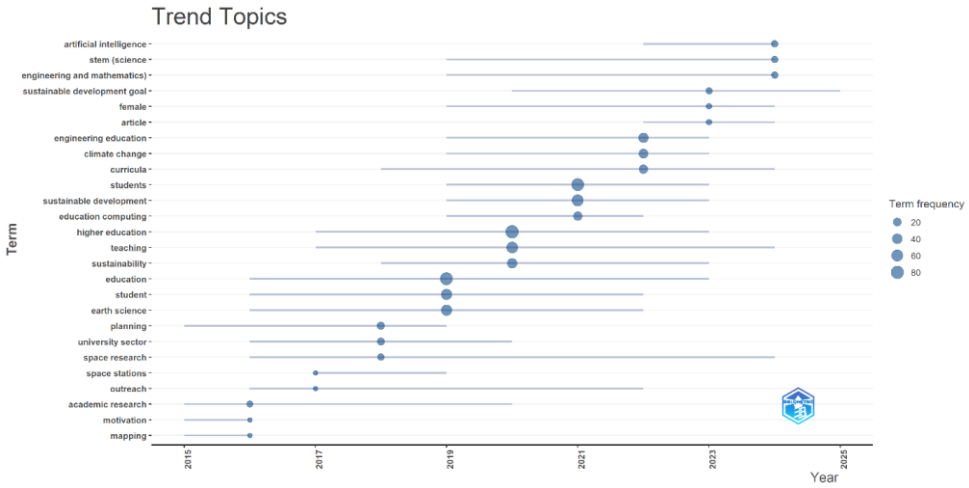

Figure 12. Research topic trends in the fields of earth science education and physics learning (2015–2025)

Figure 13 shows the co-occurrence network of keywords in publications on earth science education and physics learning during the period 2015–2025. This network forms two main interconnected clusters. The blue cluster centres on the terms higher education, earth science, curriculum, learning, and sustainability, indicating an emphasis on pedagogical aspects, curriculum development, and the integration of sustainability in higher education. Meanwhile, the red cluster centres on sustainable development,

students, teaching, engineering education, and education computing, reflecting a focus on the application of Education for Sustainable Development (ESD) in learning practices, the use of technology, and issues related to STEM and digital innovation. These two clusters are interconnected through transitional terms such as 'education', 'students', and 'sustainable development', which serve as conceptual bridges between the pedagogical dimension and the implementation of sustainability in the context of science education.

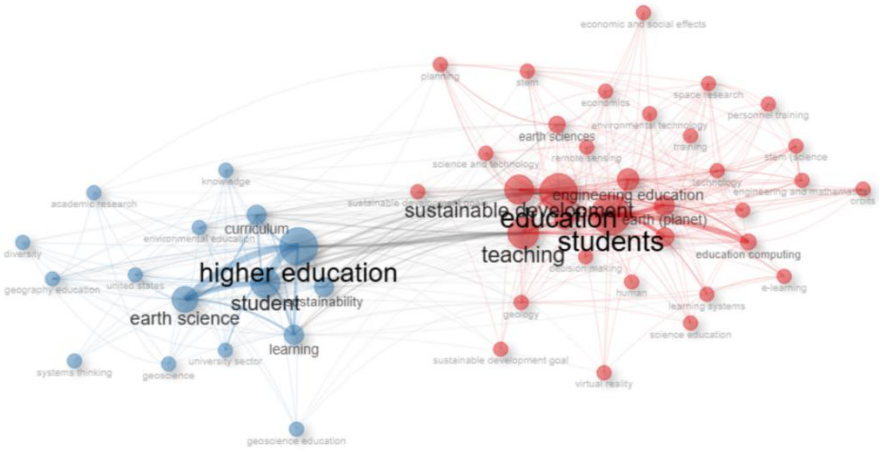

Figure 13. Keyword co-occurrence network in publications on earth science education and physics learning

Figure 14 shows the collaboration network of authors in publications related to earth science education and physics learning for the period 2015–2025. Several groups of authors can be seen to form collaboration clusters with varying strengths. The largest cluster is shown by the collaboration between Greer ML, Khan SD, Hampton DL, and Bering EA, who are closely connected with a high intensity of collaboration. Other groups with strong connections are Egidio E, Lasagna M, Gerbaudo A, and Lozar F, as well as Samsudin A, Johan H, and Liliawati W. In addition, there are also several small collaboration groups, such as Egger AE, Bateman KM, and Kastens KA, or Martínez-Martín JE, Sá AA, and Ester Mariñoso P, which show more limited cooperation. Several other small clusters involve authors such as Apathy I, Gerecs A, and Arvanitidis CD, Gourcuff C, and Dañobeitia J.

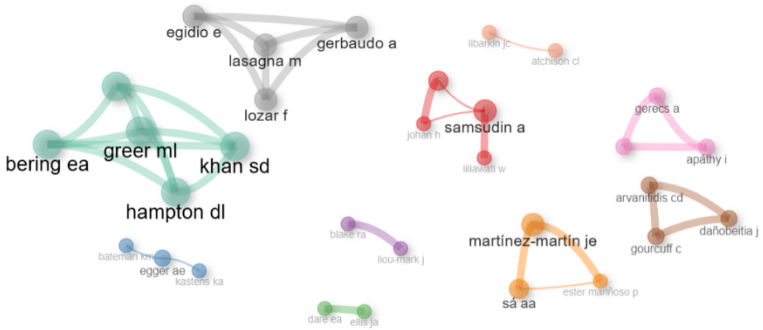

Figure 14. Collaborative network of authors in publications on earth science education and physics learning (2015–2025)

Discussion

Annual scientific production

These fluctuations reflect global dynamics in sustainable education research. The surge in publications in 2019 is in line with the strengthening of SDG implementation in higher education (Tafese & Kopp, 2025), while the decline in 2020 confirms the impact of the pandemic on academic activities (Zhu & Liu, 2020). The rapid recovery since 2021 signals adaptation through digital innovation in science education (Bond et al., 2021; Bozkurt et al., 2022). The stability of publications in 2022–2024 indicates that this field has become established as an important topic in ESD discourse (Yang & Xiu, 2023; Donthu et al., 2021), while also showing that earth physics learning is seen not only as a transfer of knowledge, but also as a strategic instrument for building ecological literacy and sustainability competencies (Martínez & Cruz, 2021).

Average citations per year

The Figure 2 indicates that increased publication productivity does not always correlate directly with citation impact. Although 2019 saw the highest number of publications, it did not produce the highest average citation rate. Conversely, 2018, with fewer articles, showed a stronger citation impact. This phenomenon is in line with the findings of Donthu et al. (2021), who emphasise that the quality and relevance of research topics often determine citation levels more than the quantity of publications.

Furthermore, the stability of citations in the 2020–2025 period indicates that research related to earth science physics learning in the context of ESD has become an established theme with consistent attention in the scientific community (Yang & Xiu, 2023; Tafese & Kopp, 2025). The COVID-19 pandemic may have also influenced citation patterns due to changes in research methods and the accelerated adoption of digital publications (Zhu & Liu, 2020; Bond et al., 2021). However, the stability of citation trends since 2021 indicates that this field is capable of adapting to global changes, including in the dissemination and citation of scientific knowledge (Bozkurt et al., 2022).

Most relevant sources

The distribution of these sources shows a concentration on journals that focus on geoscience and physics education, such as the Journal of Geoscience Education and the Journal of Physics: Conference Series. The dominance of the Journal of Geoscience Education confirms that the issue of earth science education has received significant attention in the international academic community (King, 2020). Meanwhile, the high contribution from conference proceedings (IOP Conference Series and Astronautical Conference) shows that this field is also developing rapidly through more applied and technical scientific forums, where researchers can present the latest pedagogical innovations (Donthu et al., 2021).

Interestingly, the emergence of Sustainability (Switzerland) in the top list reflects the close relationship between physics/geoscience education and the global sustainable development agenda (Yang & Xiu, 2023). This indicates that science education topics are no longer merely disciplinary in nature, but also cross-disciplinary, integrating a sustainability perspective. Furthermore, the emergence of interdisciplinary journals such as Frontiers in Education signifies a diversification of publication spaces, where science-based education is viewed as part of a broader discourse on educational innovation (Bond et al., 2021).

Sources' local impact

This H-index distribution, that presented Figure 4 ,shows the different roles of publication sources in generating citation impact. The dominance of the Journal of Geoscience Education indicates that publications in this journal are not only productive but also highly influential in directing academic discourse on geoscience education (King, 2020). The high ranking of Sustainability (Switzerland) confirms the close connection between science education issues and the sustainable development agenda, so that published articles have a wider opportunity for citations across disciplines (Yang & Xiu, 2023). Interestingly, although IOP Conference Series and Journal of Physics: Conference Series have a fairly high number of publications (Figure 3), their H-index values are only 3. This shows the difference between publication productivity and citation impact, as emphasised by Donthu et al. (2021) that the quantity of articles is not automatically proportional to the quality of their academic influence. In addition, the emergence of the Journal of Chemical Education and Science and Education in the list shows the contribution of interdisciplinary journals that enrich the discourse on science education, even though their main focus is not solely on geoscience (Martínez & Cruz, 2021).

Sources' production over time

These results confirm that the Journal of Geoscience Education serves as a major centre for publications in the field of geoscience education, not only in terms of productivity but also continuity, in line with its position as a specialist journal in earth science education (King, 2020). The growth of the IOP Conference Series and the International Astronautical Conference shows that international scientific forums are increasingly becoming strategic spaces for the development of science pedagogy discourse, particularly in relation to technology and earth sciences (Donthu et al., 2021).

The emergence of Sustainability (Switzerland) since 2019 signifies the integration of sustainability themes in science education, showing that research is no longer limited to the realm of disciplinary education but is also directed towards achieving the SDGs (Yang & Xiu, 2023; Tafese & Kopp, 2025). Thus, these data show a shift from the dominance of specific journals towards the inclusion of interdisciplinary journals, reinforcing the argument that science education research is now increasingly closely related to sustainable development.

Most relevant authors

These findings indicate that research in the field of earth science education and ESD is still dominated by a relatively small group of authors, suggesting a concentration of expertise. This is consistent with the general pattern of science education research, which often focuses on specific individuals or groups of researchers who drive research (Donthu et al., 2021). For example, the significant contribution of Serevina V highlights the important role of researchers from Asia in advancing the literature on physics and geoscience pedagogy. The involvement of Egger AE and Gill JC, who are active in international geoscience education, demonstrates cross-national collaboration that broadens the scope of research (King, 2020).

Furthermore, the presence of authors from various geographical backgrounds reinforces the argument that sustainable education issues are global in nature and require cross-disciplinary contributions (Yang & Xiu, 2023; Tafese & Kopp, 2025). The value of fractionalised articles also confirms that multidisciplinary collaboration is increasingly

important, as more and more articles are co-authored by several authors with different contributions (Martínez & Cruz, 2021).

Authors' production over time

This pattern of Figure 7 indicates that research in the fields of earth science education and physics learning in the context of ESD has not been dominated by a single author throughout the decade, but rather spread across several authors with different periods of contribution. The dominance of Serevina V in recent publications signals the emergence of a new generation of researchers reinforcing this theme, while the consistency of Egger AE and Gill JC indicates the continuity of research by established researchers in the field of geoscience education (King, 2020). The involvement of Martínez-Martín JE since 2023 is also important, as his publications are largely associated with bibliometric research on sustainable education (Martínez & Cruz, 2021). This is consistent with global trends that emphasise cross-country and cross-disciplinary collaboration in ESD research (Yang & Xiu, 2023; Tafese & Kopp, 2025). Meanwhile, the early contributions of authors such as Vasconcelos CM and Apáthy I show the initial foundations of the research, although they did not continue into the most recent period.

Most relevant affiliations

The dominance of UPI demonstrates the significant contribution of Southeast Asia, particularly Indonesia, to research in earth physics education and sustainability. This reinforces the argument that global ESD literature is not only produced in developed countries, but also in developing countries with a strong focus on science education (Martínez & Cruz, 2021). On the other hand, the presence of major universities from the United States, such as Pennsylvania State University, University of Northern Colorado, and Michigan State University, demonstrates the long tradition of science education research in North America (King, 2020). The contributions of the New York City College of Technology and the University of Bristol demonstrate the important role of institutions oriented towards the integration of technology and pedagogy in ESD (Yang & Xiu, 2023). Meanwhile, the inclusion of the Universidad Complutense de Madrid and Kangwon National University confirms the growing international collaboration on the theme of sustainability, consistent with bibliometric trends showing an increase in cross-border networks (Tafese & Kopp, 2025).

Corresponding author's countries

The dominance of the United States is not surprising, given its research capacity and strong academic tradition in science education (King, 2020). However, Indonesia's second place is quite significant as it shows the role of developing countries in strengthening global literature on earth science education and ESD (Martínez & Cruz, 2021). This is also in line with the trend of increasing Asian contributions to international education research (Yang & Xiu, 2023). The high proportion of MCP in European countries and Australia indicates strong cross-country collaboration, consistent with previous bibliometric reports that international collaboration increases visibility and citations (Donthu et al., 2021). Conversely, the high SCP in Indonesia indicates that research is still mostly conducted at the domestic level, although opportunities for international collaboration continue to grow.

Countries' scientific production

Figure 10 shows the dominance of the United States, consistent with its large research capacity, access to funding, and strong academic tradition in science education (King, 2020). However, the significant involvement of European, Australian, and Asian countries—particularly Indonesia—shows that the global literature on science education is now increasingly multipolar, no longer centred solely on developed countries (Martínez & Cruz, 2021). The contributions of developing countries such as Indonesia, Brazil, and Morocco are important because they show how ESD agendas are integrated into local contexts and higher education in the Global South. This is in line with recent bibliometric reports that emphasise the need for cross-country collaboration to expand the impact of research (Yang & Xiu, 2023; Tafese & Kopp, 2025). However, the distribution still shows gaps, with most countries in Africa, Central Asia, and the Middle East not yet contributing significantly.

The most common word

These results reinforce the notion that higher education is the primary arena for the integration of Education for Sustainable Development (ESD), where students are seen as important agents for driving change towards sustainability (Martínez & Cruz, 2021). The dominance of the terms 'sustainable development' and 'climate change' indicates that global agendas such as the SDGs and the climate crisis have become the main foundation for research in this field (Yang & Xiu, 2023). The presence of terms related to curriculum and teaching indicates that pedagogical innovation is a major concern, in line with literature emphasising the need for curriculum transformation to integrate sustainability principles (Tafese & Kopp, 2025). On the other hand, technology keywords such as 'remote sensing' and 'computing' indicate a synergy between earth sciences, physics, and digital technology to strengthen learning (Bond et al., 2021).

Trend topics

This topic trend shows an evolution in research themes. In the early phase (2015–2018), studies focused more on classic issues such as higher education, teaching, and students, reflecting an emphasis on basic pedagogical aspects. From 2018 to 2021, sustainability issues became more prominent, in line with the strengthening of the SDGs agenda and increasing awareness of climate change (Yang & Xiu, 2023). In the most recent period (2022–2025), the emergence of the terms 'artificial intelligence' and 'STEM' signifies the integration of technology in educational research, which is in line with the global trend towards digital transformation in universities (Bond et al., 2021). Furthermore, the emphasis on the SDGs indicates that research is increasingly directed towards practical contributions to the sustainable development agenda (Tafese & Kopp, 2025). Overall, these results confirm that research on earth science physics learning has evolved from basic pedagogical issues towards a more interdisciplinary, technology-based, and globally oriented approach. This demonstrates academic adaptation to social, technological, and international policy changes.

Co-occurrence network

The results of this network confirm that research in the field of earth science physics learning has two main orientations. First, research focusing on curriculum and pedagogy transformation to build students' sustainability competencies, in line with the findings of Martínez & Cruz (2021). Second, research emphasising the application of technology and

educational innovation, such as education computing, virtual reality, and STEM, which has begun to strengthen in the most recent period (Bond et al., 2021). The dominance of the keyword sustainable development at the centre of the network shows that the issue of sustainability is a common thread that connects various research approaches, both pedagogy- and technology-based. This is consistent with global bibliometric trends that show an increase in the integration of ESD in various disciplines (Yang & Xiu, 2023; Tafese & Kopp, 2025). Furthermore, the strong correlation between 'students,' 'teaching,' and 'higher education' confirms that students are seen as the main agents of change in ESD implementation (King, 2020). Thus, this co-occurrence network illustrates a complex but closely connected research ecosystem, where pedagogical innovation, sustainability, and technology reinforce each other.

Collaboration network

This network shows that research collaboration in the field of earth science physics learning still tends to be divided into relatively separate small groups, without forming a widely interconnected global network. This is in line with bibliometric literature which states that science education research is often dominated by local or regional research groups, with global connectivity still developing (Donthu et al., 2021). The large cluster involving Greer ML, Khan SD, and Hampton DL emphasises the importance of core researchers who act as drivers in building repeated collaborations. Meanwhile, the involvement of Martínez-Martín JE and Sá AA is interesting because both are also active in research related to Education for Sustainable Development, so their collaboration bridges pedagogical and sustainability studies (Martínez & Cruz, 2021; Tafese & Kopp, 2025). The presence of collaborations from different regions, such as the Indonesian author cluster (Samsudin A, Johan H, and Liliawati W), demonstrates Asia's significant contribution to the international research landscape, although this network is still regional in nature (Yang & Xiu, 2023). In general, this visualisation shows that a collaboration network has been established, but it still requires strengthening the interconnections between clusters so that research can be more global and inclusive.

CONCLUSION

Fundamental Finding : Research on earth science physics education has significantly grown over the past decade, aligning with the Education for Sustainable Development (ESD) agenda. This highlights its role in promoting sustainability, ecological literacy, and interdisciplinary approaches. **Implication :** Higher education is crucial in linking scientific literacy with sustainability. Universities are integrating sustainability into curricula, and strengthening collaborations, along with adopting emerging technologies, will further advance ESD in physics education. **Limitation :** The study's reliance on Scopus may exclude publications indexed elsewhere, and its focus on quantitative bibliometrics overlooks aspects like teaching effectiveness and learning outcomes. **Future Research :** Future studies should expand to multiple databases, explore interdisciplinary collaboration, and assess how AI, VR, and STEM integration can enhance ESD. Additionally, addressing regional disparities and developing competency frameworks will be key to advancing sustainable higher education globally.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni was responsible for methodology development, data analysis, sourcing references, and drafting the manuscript. **Binar Kurnia Prahani** contributed to

the conceptual framework, research design, and validation process. **Riski Ramadani** handled data management, project coordination, and assisted in manuscript drafting. **Titin Sunarti** provided expertise in literature review, analysis interpretation, and contributed to manuscript revisions. **Madlazim** contributed to the research methodology, data collection, and reviewed the manuscript for clarity and consistency. **Muhammad Rey Dafa Ahmadi** was involved in statistical analysis, data visualization, and contributed to the final manuscript review.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, either financial or personal, that could have influenced the content or the results of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with established standards of research and publication ethics. The authors affirm that the work presented here is original, conducted with academic integrity, and free from any form of unethical practices, including plagiarism and data manipulation.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors declare that this manuscript was prepared entirely without the use of artificial intelligence (AI) or other digital tools. The research process, data processing, analysis, writing, and editing were conducted manually by the authors, and full responsibility for the authenticity and content of the article rests solely with them.

REFERENCES

Albareda-Tiana, S., García-González, E., Jiménez-Fontana, R., & Solís-Espallargas, C. (2018). Implementing pedagogical approaches for ESD in initial teacher training. *Sustainability, 10*(7), 2193. https://doi.org/10.3390/su10072193

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Barth, M., & Rieckmann, M. (2016). State of the art in research on higher education for sustainable development. *Routledge Handbook of Higher Education for Sustainable Development, 3*(1), 100–113). https://doi.org/10.4324/9781315852249

Barth, M., Godemann, J., Rieckmann, M., & Stoltenberg, U. (2007). Developing key competencies for sustainable development in higher education. *International Journal of Sustainability in Higher Education, 8*(4), 416–430. https://doi.org/10.1108/14676370710823582

Barth, M., Michelsen, G., Rieckmann, M., & Thomas, I. (2016). Routledge handbook of higher education for sustainable development. *Routledge, 2*(3), 234-244. https://doi.org/10.4324/9781315852249

Bautista-Puig, N., Jiménez-Contreras, E., & de Moya-Anegón, F. (2020). Mapping education for sustainable development: A bibliometric analysis from 1990 to 2018. *Sustainability, 12(*19), 7913. https://doi.org/10.3390/su12197913

Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2021). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education, 18*(1), 50. https://doi.org/10.1186/s41239-021-00282-x

Bozkurt, A., Jung, I., Xiao, J., Vladimirschi, V., Schuwer, R., Egorov, G., & Paskevicius, M. (2022). Global outlook to the interruption of education due to COVID-19 pandemic: Navigating in a time of uncertainty and crisis. *Asian Journal of Distance Education, 17*(1), 1–126. https://doi.org/10.5281/zenodo.3780423

Chusniyah, A., Makruf, I., & Supriyanto, S. (2025). Two decades of sustainable development studies in higher education management: A bibliometric analysis. *International Journal of Sustainability in Higher Education, 26*(3), 614–632. https://doi.org/10.1108/IJSHE-06-2024-0410

Cobo, M. J., Martínez, M. A., Gutiérrez-Salcedo, M., Fujita, H., & Herrera-Viedma, E. (2018). 25 years at Knowledge-Based Systems: A bibliometric analysis. *Knowledge-Based Systems, 165*(3), 1–13. https://doi.org/10.1016/j.knosys.2018.11.024

Cotton, D., Bailey, I., Warren, M. F., & Bissell, S. (2009). Revolutions and second-best solutions: Education for sustainable development in higher education. *Studies in Higher Education, 34*(7), 719–733. https://doi.org/10.1080/03075070802641552

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research, 133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Erol, S. (2023). Physics education research over the last two decades: A bibliometric analysis. *International Journal of Educational Technology and Scientific Research, 8*(3), 1576–1613. https://doi.org/10.35830/ijetsar.2023.8.3.1576

Fadeeva, Z., & Mochizuki, Y. (2010). Higher education for sustainable development: An international review. *Sustainability, 2*(4), 1135–1153. https://doi.org/10.3390/su2041135

Fadeeva, Z., Mochizuki, Y., & Brundiers, K. (2012). Bridging the gap: The role of universities in sustainability science. *Sustainability Science, 7*, 1–3. https://doi.org/10.1007/s11625-012-0181-1

Fayda-Kinik, F. S. (2025). A bibliometric analysis of education for sustainable development: Critical implications for the further education and skills sector. *Education + Training*. https://doi.org/10.1108/ET-04-2022-0163

Filho, W. L., & de Brito, P. R. (2018). Advances and trends in sustainability education. *International Journal of Sustainability in Higher Education, 19*(5), 676–691. https://doi.org/10.1108/IJSHE-04-2018-0072

Filho, W. L., Brandli, L., Becker, D., et al. (2018). Sustainability science and education: The role of higher education institutions. *Springer*. https://doi.org/10.1007/978-3-319-73298-6

Filho, W. L., et al. (2015). Integrating sustainable development in higher education: Practices around the world. *Springer*. https://doi.org/10.1007/978-3-319-09549-3

Filho, W. L., Salvia, A. L., Frankenberger, F., et al. (2020). Trends in research on climate change and sustainability in higher education: A bibliometric analysis. *Journal of Cleaner Production, 256*, 120413. https://doi.org/10.1016/j.jclepro.2020.120413

Filho, W. L., Salvia, A. L., Paço, A., & Brandli, L. (2021). Universities as living labs for sustainable development: Supporting the implementation of the SDGs. *Springer*. https://doi.org/10.1007/978-3-030-63761-3

Hallinger, P., & Chatpinyakoop, C. (2019). A bibliometric review of research on higher education for sustainable development, 1998–2018. *Sustainability, 11*(8), 2401. https://doi.org/10.3390/su11082401

Hargreaves, A. (2008). The education of sustainability leaders: An international review. *Environmental Education Research, 14*(4), 391–404. https://doi.org/10.1080/13504620802156420

Kadirhanoğulları, R., & Köse, Ö. (2023). Bibliometric analysis of technology integration studies in science education. *Education and Information Technologies, 28*(2), 2031–2052. https://doi.org/10.1007/s10639-022-11341-w

King, C. (2020). Geoscience education: An overview. *Geoscience Communication, 3*(1), 1–13. https://doi.org/10.5194/gc-3-1-2020

Leal Filho, W., Skanavis, C., Kounani, A., et al. (2019). Advancing sustainability in higher education: Case studies and best practices. *Springer*. https://doi.org/10.1007/978-3-030-15604-6

Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability, 9(*10), 1889. https://doi.org/10.3390/su9101889

Martínez, F., & Cruz, C. (2021). Education for sustainable development in higher education: A systematic and bibliometric review. *Environmental Education Research, 27(*8), 1170–1188. https://doi.org/10.1080/13504622.2021.1921115

Martín-Martín, A., Thelwall, M., Orduna-Malea, E., & Delgado López-Cózar, E. (2021). Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: *A multidisciplinary comparison of coverage via citations. Scientometrics, 126*(1), 871–906. https://doi.org/10.1007/s11192-020-03690-4

Mochizuki, Y., & Fadeeva, Z. (2010). Competences for sustainable development and sustainability: Significance and challenges. *International Journal of Sustainability in Higher Education, 11*(4), 391–403. https://doi.org/10.1108/14676371011077603

Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *El Profesional de la Información, 29*(1), e290103. https://doi.org/10.3145/epi.2020.ene.03

Murga-Menoyo, M. A. (2014). Learning for sustainability in higher education: Principles and pedagogical approaches. *Sustainability, 6*(9), 6268–6282. https://doi.org/10.3390/su6096268

Ond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2021). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education, 18*(1), 50. https://doi.org/10.1186/s41239-021-00282-x

Redman, C., & Wiek, A. (2021). Sustainability competencies in higher education: Mapping curriculum transformation. *Sustainability, 13*(6), 3403. https://doi.org/10.3390/su13063403

Reid, A., & Scott, W. (2006). Researching education and the environment: Retrospect and prospect. *Routledge*. https://doi.org/10.4324/9780203967673

Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures, 44*(2), 127–135. https://doi.org/10.1016/j.futures.2011.09.005

Scott, W. (2002). Sustainability and learning: What role for the curriculum? *Journal of Curriculum Studies, 34*(2), 237–250. https://doi.org/10.1080/00220270110098491

Scott, W., & Gough, S. (2003). *Sustainable development and learning: Framing the issues*. RoutledgeFalmer. https://doi.org/10.4324/9780203165956

Segalas, J., Ferrer-Balas, D., & Mulder, K. F. (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. *Journal of Cleaner Production, 18*(3), 275–284. https://doi.org/10.1016/j.jclepro.2009.09.012

Shephard, K. (2008). Higher education for sustainability: Seeking affective learning outcomes. *International Journal of Sustainability in Higher Education, 9*(1), 87–98. https://doi.org/10.1108/14676370810842201

Shriberg, M., & Harris, K. (2012). Building sustainability change management capacity in higher education: A North American case study. *Journal of Cleaner Production, 49*, 109–116. https://doi.org/10.1016/j.jclepro.2012.07.031

Stephens, J. C., Hernandez, M. E., Román, M., Graham, A. C., & Scholz, R. W. (2008). Higher education as a change agent for sustainability in different cultures and contexts. *International Journal of Sustainability in Higher Education, 9*(3), 317–338. https://doi.org/10.1108/14676370810885916

Sterling, S. (2010). Learning for resilience, or the resilient learner? *Environmental Education Research, 16*(5-6), 511–528. https://doi.org/10.1080/13504622.2010.505427

Tafese, M. B., & Kopp, E. (2025). Education for sustainable development: Analyzing research trends in higher education for sustainable development goals through bibliometric analysis. *Discover Sustainability, 6*(51). https://doi.org/10.1007/s43621-024-00711-7

Tilbury, D. (2011). *Education for sustainable development: An expert review of processes and learning*. UNESCO. https://doi.org/10.13140/RG.2.1.1465.2006

Tilbury, D., & Wortman, D. (2008). *Engaging people in sustainability. Commission on Education and Communication*, IUCN. https://doi.org/10.2305/IUCN.CH.2008.26.en

UNESCO. (2014). *Shaping the future we want: UN Decade of Education for Sustainable Development (2005–2014) Final report*. Paris: UNESCO. https://doi.org/10.54675/unesco.2014.desd

Van Eck, N. J., & Waltman, L. (2020). *VOSviewer manual*. Leiden: Universiteit Leiden. Retrieved from https://www.vosviewer.com/documentation

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework. *Sustainability Science, 6*, 203–218. https://doi.org/10.1007/s11625-011-0132-6

Yang, C., & Xiu, Q. (2023). A bibliometric review of education for sustainable development, 1992–2022. *Sustainability, 15*(14), 10823. https://doi.org/10.3390/su151410823

Yang, C., & Xiu, Q. (2023). A bibliometric review of education for sustainable development, 1992–2022. *Sustainability, 15*(14), 10823. https://doi.org/10.3390/su151410823

Zhu, X., & Liu, J. (2020). Education in and after COVID-19: Immediate responses and long-term visions. *Postdigital Science and Education, 2*(3), 695–699. https://doi.org/10.1007/s42438-020-00126-3

Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429–472. https://doi.org/10.1177/1094428114562629

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