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Mapping the relationship between education for sustainable development and climate change education: A bibliometric analysis

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Abstract: This study explores the relationship between Education for Sustainable Development (ESD) and Climate Change Education (CCE), focusing on their roles in addressing global environmental challenges. Through a bibliometric analysis of 468 scientific publications indexed in Scopus from 2015 to 2025, key themes such as sustainability, climate change, and the Sustainable Development Goals (SDGs) were identified as central to research in these fields. The findings emphasize the increasing importance of interdisciplinary approaches, emotional engagement, and the integration of ESD and CCE into curricula. The study also highlights the critical role of teacher education and the need for more sustainable practices in higher education, particularly in light of international student mobility. The research underscores the need to embed ESD and CCE into educational policies and frameworks to advance the global sustainability agenda. The bibliometric mapping reveals that publication output has grown sharply since 2020, with Walter Leal Filho, Maria Ojala, and Janet Richardson emerging as the most influential authors, while co-word analysis identifies transformative learning, systems thinking, and eco-anxiety as rapidly emerging research frontiers that bridge ESD and CCE.
Keywords: Education for Sustainable Development; Climate Change Education; Sustainability; Teacher Education; Sustainable Development Goals.

INTRODUCTION

Education for Sustainable Development (ESD) and Climate Change Education (CCE) are two areas gaining increasing attention in global education, as reflected in the UNESCO ESD for 2030 Roadmap and the Greening Education Partnership, which position these fields as priorities in international education policy (UNESCO, 2020, 2024). These two concepts are closely related to the environmental challenges faced today and in the future, especially in the context of climate change. ESD and CCE play a significant role in preparing the younger generation to face and overcome these challenges. Although ESD and CCE have specific focuses, they share the same goal of building awareness and actions that support environmental sustainability. Climate

change is one of the biggest challenges facing humanity today. The effects are already being felt worldwide, in the form of more frequent and severe natural disasters, such as floods, droughts, storms, and sea-level rise (Calvin et al., 2023; World Meteorological Organization (WMO), 2024). To mitigate these impacts, it is essential to understand the causes and consequences of climate change, as well as the steps that can be taken to reduce greenhouse gas emissions. This is where the CCE comes in, aiming to educate the public about climate change and motivate the actions needed to address it (Hadiapurwa et al., 2024a; Luthfia, 2025; Sibanda & Manik, 2023).

ESD, on the other hand, has a broader scope. ESD covers environmental issues, such as climate change, as well as the social and economic aspects of sustainable development. ESD aims to provide the knowledge, skills, values, and attitudes necessary to create a more sustainable future (Hadiapurwa et al., 2024b; Santoso et al., 2025). ESD covers a wide range of topics such as social justice, the green economy, and sustainable management of natural resources (Kopnina, 2020). ESD seeks to integrate various aspects of sustainability into the educational curriculum at all levels, from primary to higher education. This integration includes teaching about climate change, biodiversity, natural resource management, social justice, and the green economy. Thus, learners not only gain theoretical knowledge but also understand the relevance and practical application of these concepts in everyday life. ESD encourages an interdisciplinary approach, where various subjects are interconnected to provide a more comprehensive understanding of sustainability.

ESD creates a framework that integrates various aspects of sustainability into education. One key component of ESD is the development of critical thinking skills. Students are invited to question existing assumptions, analyze various perspectives, and make decisions based on evidence and ethical values. Critical thinking skills are essential for confronting complex sustainability challenges, such as climate change and environmental degradation (Shutaleva, 2023). In addition, ESD also encourages creativity and innovation, which is key to finding new and better solutions to sustainability problems (Haim & Aschauer, 2024; Riess et al., 2022; Souto, 2022). Active participation and collaboration are also essential elements in ESD (Fernando & Tajan, 2024; Hung & Pan, 2025). Students are invited to engage in authentic community projects, working with stakeholders such as local governments, non-governmental organizations, and the private sector. Through this engagement, learners learn about sustainability and develop the social and leadership skills necessary to influence positive societal change (Boeske, 2023; Miao & Nduneseokwu, 2024; Oe et al., 2022). Collaboration also strengthens a sense of belonging and responsibility for sustainability issues.

The evaluation of ESD program effectiveness is essential. By evaluating changes in students' knowledge, attitudes, and behaviors after participating in ESD programs, we can identify the strengths and weaknesses of existing programs and provide helpful information for future improvements. In addition, the evaluation can also help measure the program's long-term impact on environmental sustainability at the local and global levels (Abbass et al., 2022; Dushkova & Ivlieva, 2024). ESD is an ongoing educational endeavor and requires long-term commitment from all parties. Continuously updating and improving ESD programs ensures that future generations will be better prepared to face environmental challenges (Oe et al., 2022; Yadav et al., 2022). Support from governments, international organizations, and various other stakeholders is critical to

the success of ESD. With strong cooperation and commitment, we can create a more sustainable and equitable future for all.

Climate Change Education, or CCE, is an educational approach that aims to increase public understanding of climate change, its causes, impacts, and steps to reduce it. CCE strives to equip individuals with the scientific knowledge and practical skills necessary to face the challenges posed by climate change (Hadiapurwa et al., 2024a; Luthfia, 2025; Sibanda & Manik, 2023). CCE shapes a more aware and proactive generation in protecting the environment, as empirical studies have shown that structured climate education increases both environmental awareness and pro-environmental behavior among learners (Kwauk & Casey, 2021; Monroe et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2020). Climate change is a global phenomenon driven by rising concentrations of greenhouse gases in the atmosphere from human activities, such as burning fossil fuels, deforestation, and intensive agriculture. The impacts include increased global temperatures, changes in weather patterns, rising sea levels, and increased frequency and intensity of natural disasters. Through CCE, learners are taught about the scientific processes underlying climate change and how its impacts are felt across the world. This education helps learners understand the urgency of this problem and the need for immediate action.

One of the main objectives of CCE is to develop critical awareness among learners. They were invited to understand the relationship between human action and climate change and question unsustainable practices (Álvarez-Nieto et al., 2022; Olsson, 2022). Learners gain theoretical knowledge through this approach and develop attitudes and values that support sustainability. This critical awareness is essential so that they can become agents of change in their society. CCE teaching methods often use an interactive and participatory approach (Luthfia, 2025; Santoianni, 2024). Field projects, scientific experiments, simulations, and group discussions are examples of effective teaching methods about climate change (Kumar et al., 2023; Maspul, 2024). This approach allows students to see the impacts of climate change firsthand and encourages them to think critically and find innovative solutions.

CCE is a sustainable effort that requires long-term commitment from all parties. Strong support from governments, international organizations, and various other stakeholders is required to achieve success. By continuously updating and improving CCE programs, it is hoped that future generations will be better prepared to face the challenges of climate change. We can create a more sustainable and prosperous future for all with strong cooperation and commitment.

There are several reasons why integrating ESD and CCE in the education system is so important. First, education is a powerful tool for social change. Educating the younger generation about sustainability and climate change creates a more environmentally conscious and responsible society (Luthfia, 2025; Santoianni, 2024). Second, ESD and CCE help learners develop the critical thinking and problem-solving skills to face future challenges. Third, through education, it is hoped that it can encourage innovation and creative solutions to environmental problems.

Education Integration for ESD and CCE is a strategic step toward creating a more holistic education system that addresses today's global challenges. While these two approaches have different focuses, they are complementary and can have a greater impact when applied in an integrated manner. Combining ESD and CCE can strengthen

educational efforts in building the awareness, knowledge, and skills needed to create a sustainable future.

One way to integrate ESD and CCE is through a thorough and interdisciplinary curriculum (Fernández et al., 2023; Hung & Pan, 2025). This curriculum simultaneously teaches environmental, social, and economic issues, providing learners with a comprehensive understanding of how climate change affects various aspects of life. For example, when discussing energy in science class, educators can relate it to the economic impact of renewable energy and the social implications of reliance on fossil fuels. This approach helps learners see the complex relationships between different factors.

The challenges in integrating ESD and CCE cannot be ignored. One of the main challenges is the lack of resources and training for educators. Many educators may lack the knowledge or skills to teach these topics effectively (AlAfnan & Dishari, 2024). Therefore, there is a need for training and professional development programs specifically designed to help educators integrate ESD and CCE into their teaching. This training can include interactive teaching techniques, technology, and a project-based approach.

Although ESD and CCE are often considered separate fields, there is significant overlap between them. These two areas emphasize the importance of environmental awareness, proactive action, and community involvement. They also emphasized the importance of collaboration between various sectors of society, including government, business, and civil society. Thus, integrating ESD and CCE can create a more comprehensive and practical approach to environmental education (Brock et al., 2025; Hung & Pan, 2025; Masoudi, 2024). One of the main challenges in integrating ESD and CCE into the educational curriculum is the lack of resources and support (AlAfnan & Dishari, 2024). Many schools, especially in developing countries, do not have access to adequate teaching materials or training for educators (Cayabas Jr & Sumeg-ang, 2023; Farabi et al., 2025). In addition, the curriculum is often too crowded with other subjects, making it difficult to incorporate topics on sustainability and climate change.

ESD and CCE are two essential and interrelated fields in environmental education. Integrating these two concepts into the education system can help create a more environmentally conscious and responsible society. However, more incredible support is needed from governments, international organizations, and other stakeholders to achieve this goal. With strong cooperation and commitment, we can create a more sustainable and equitable future for all. This study uses bibliometric analysis to determine the relationship between ESD and CCE. This study's results will identify relationships and gaps in the research on this topic.

METHODS

This study uses bibliometric analysis to measure publication patterns in the scientific literature. The analysis was performed using VOSviewer (version 1.6.20) for keyword co-occurrence, network, overlay, and density visualization, supplemented by the Bibliometrix R package (Biblioshiny interface) for performance analysis, thematic mapping, and trend topic detection. This analysis allows researchers to identify research trends, collaboration networks, and relationships between topics within a field of study. Bibliometric analysis can provide insights into research developments, author influence, and interactions across various subfields using publication data from scientific databases.

The data source used in this study is the Scopus database. Scopus was selected for three reasons: (1) it provides broader coverage of peer-reviewed journals in the social sciences and education, which is essential for ESD and CCE research; (2) it offers structured metadata (author affiliations, keywords, and citation counts) fully compatible with VOSviewer and Bibliometrix input formats; and (3) prior bibliometric studies on sustainability education have predominantly relied on Scopus, allowing the present findings to be compared with earlier work. Scopus was chosen because it is one of the largest and most comprehensive databases of scientific literature, covering journal articles, conference papers, and other types of publications.

The following are the steps taken in the bibliometric analysis method, adapting the four main stages in Table 1, namely: (1) define the aims and scope of the bibliometric study, (2) choose the techniques for bibliometrics analysis, (3) collect the data for bibliometrics analysis, and (4) run the bibliometrics analysis and report the findings (Donthu et al., 2021).

Table 1. Bibliometric Analysis Method

Bibliometric Analysis Stage	Information
Define the aims and scope of the bibliometric study	a. To determine the relationship between Sustainable Development (ESD) and Climate Change Education (CCE) b. To discover the opportunities for multidisciplinary integration of ESD and CCE concepts.
Choose the techniques for bibliometrics analysis	a. The bibliometric techniques used are Network Visuality to find out the relationship between keywords, Overlay Visualization to find out the correlation between keywords based on the average occurrence, and Density Visualization for the distribution of keyword density related to "Education for Sustainable Development (ESD)"
Collect the data for bibliometrics analysis	a. Design the search term based on the scope defined in Step 1 b. Select the database based on the adequacy of its coverage c. Fetch the bibliometric data based on the choice of the bibliometric analysis technique in Step 2 d. Clean the data before processing.
Run the bibliometrics analysis and report the findings	a. Science Mapping; Summarize the bibliometric structure and intellectual structure using network metrics, clustering, and visualization techniques.

Data were collected using the advanced search feature in Scopus, with final data retrieval completed on 15 November 2025 to ensure the most recent indexed publications were captured. After obtaining a list of documents that meet the inclusion criteria, the data is downloaded in CSV format for further processing. The downloaded data includes essential information such as title, abstract, keywords, author, affiliation, year of publication, and number of citations. This data is then processed and imported into bibliometric analysis software.

The PRISMA structure depicted in Figure 1 outlines the systematic process followed in this study to select relevant articles for the bibliometric analysis. The PRISMA flow diagram is a widely recognized methodology for systematic reviews, ensuring transparency and consistency in data collection. The study began by identifying a total of 961 records from the Scopus database, based on a defined search query that included keywords TITLE-ABS-KEY (("Education for Sustainable Development" OR "ESD" OR "Sustainability Education" OR "Sustainable Development Goal 4") AND ("Climate Change" OR "Global Warming" OR "Climate Crisis")) AND PUBYEAR > 2014 AND

PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English")).

Figure 1. PRISMA Structure

The next phase involved screening these records to eliminate those that did not meet the inclusion criteria. A total of 130 records were excluded based on publication date, leaving 831 for further assessment. After applying additional filters, such as document type and publication stage, and excluding articles in languages other than English, 363 records were removed. Ultimately, 468 studies were included in the bibliometric analysis, providing a robust and focused dataset that reflects the most relevant research on the intersection of ESD and CCE in addressing global sustainability challenges. This rigorous selection process ensures the reliability and relevance of the data used in the study.

RESULTS AND DISCUSSION

Results

Publication Growth

The publication growth chart (Figure 2) shows a clear, substantial increase in scientific publications on Education for ESD and CCE from 2015 to 2025. The number

of articles published annually began modestly at 7 in 2015, reflecting the early stages of research development in this field. However, there is a noticeable upward trend, with publications reaching 15 articles in 2016 and steadily increasing each year thereafter. By 2021, the number of articles had reached 58, and by 2025, it had surged to 103, marking a significant rise in interest and scholarly output.

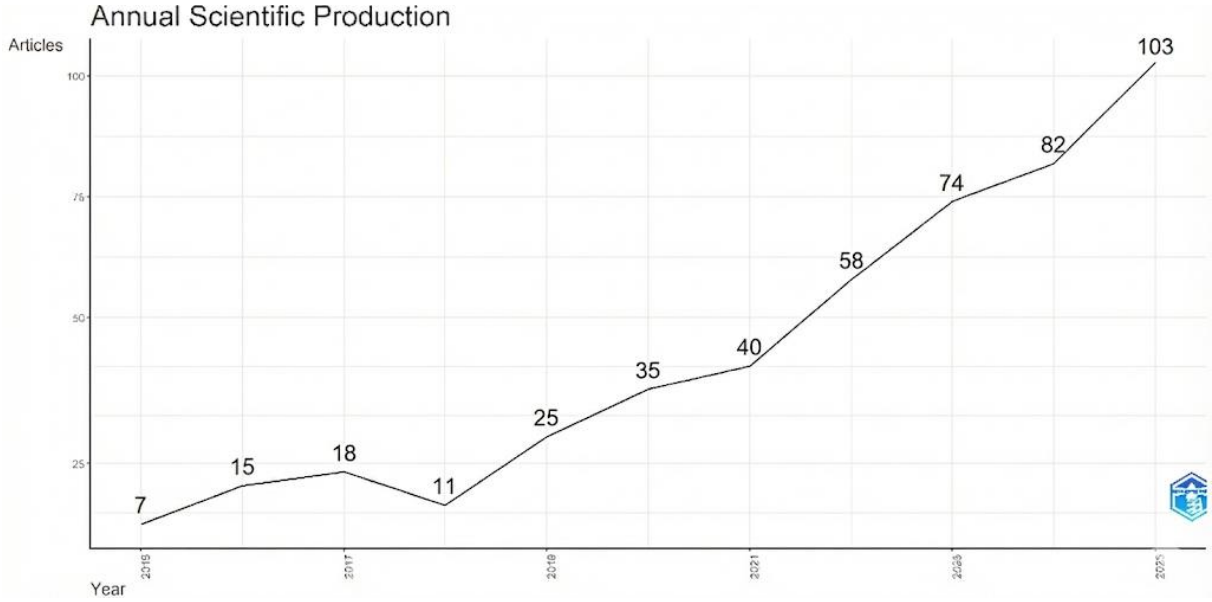

Figure 2. Publication Growth 2015-2025

This growing trend in scientific production highlights the increasing recognition of the importance of ESD and CCE in addressing global environmental challenges, particularly in the context of climate change. The sharp rise in publications from 2020 onwards coincides with global events such as the SDGs and the heightened urgency surrounding climate change action. This suggests that both academia and policymakers are increasingly focused on integrating sustainability and climate change education into educational systems worldwide. The consistent growth observed in this graph reflects a broader, long-term commitment to advancing knowledge and solutions through research in these critical areas.

Author Analysis

Table 2 provides a list of the top 10 most impactful authors in the fields of ESD and CCE, based on their article count, citations, and H-index. The author with the highest citation count is Walter Leal Filho from Universität Hamburg, who has amassed 47,386 citations across 3 articles, resulting in an H-index of 105. This suggests that his work has had a significant and lasting impact on the academic community, particularly in sustainability education. His substantial citation count reflects his leadership and influence in the field, likely due to his extensive research contributions and authoritative position in academia.

Other notable authors on the list include Maria Ojala from Örebro University, with 5,378 citations and an H-index of 27, and Janet Steven Richardson from the University of Plymouth, with 4,989 citations and an H-index of 34. Ojala's significant citation count indicates her strong influence on the emotional and psychological dimensions of climate change education, particularly her work on hope in sustainability education. Similarly, Richardson's work on higher education and sustainability is highly regarded,

as reflected by her high citation numbers. These authors, along with others like Bettolli, Bögelholz, and Grose, contribute to a diverse body of work in sustainability education, spanning theoretical frameworks, policy research, and practical teaching methods. Their collective influence indicates a broad, collaborative effort to advance ESD and CCE across regions and research methodologies, underscoring the importance of multidisciplinary approaches to tackling global sustainability challenges.

Table 2. List of the 10 most impactful authors

Author	Affiliate	Articles	Citation	H-Index
Walshe, Nicola	University College London	6	805	15
Grose, Jane	University of Plymouth	4	1164	18
Ojala, Maria	Örebro University	4	5378	27
Richardson, Janet Steven	University of Plymouth	4	4989	34
Bettolli, Maria Laura	Centro Científico Tecnológico-San Juan	3	1173	22
Bögeholz, Susanne	University of Göttingen	3	1867	20
Filho, Walter Leal	Universität Hamburg	3	47386	105
Jiménez, Jeremy David	SUNY Cortland	3	142	6
Kvamme, Ole Andreas	University of Oslo	3	99	6
Olmo, M. E.	Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos	3	516	12

Co-Word and Topic Analysis

The treemap in Figure 3 provides a detailed visual representation of the key themes and topics within the literature on ESD and CCE. The two largest categories in the visualization are “Education for Sustainable Development” (113 occurrences, 13%) and “Climate Change” (110 occurrences, 13%), reflecting their prominence as primary subjects of interest in the research landscape. These results align with the increasing global attention given to both environmental sustainability and climate change education. The prominence of these two categories suggests that scholars are increasingly focusing on how education can address the global environmental challenges posed by climate change and the broader sustainability agenda.

Within these two dominant categories, several sub-themes emerge, such as “Sustainability Education” (52 occurrences, 6%) and “Climate Change Education” (48 occurrences, 6%), underscoring the close relationship between sustainability and climate change as educational topics. Other significant themes include “Higher Education” (41 occurrences, 5%) and “Teacher Education” (19 occurrences, 2%), indicating the importance of specialized training and institutional support for educators who teach these topics. There is also a noticeable presence of topics related to educational strategies, such as “Transformative Learning” and “Systems Thinking” (both 2%), reflecting an increasing interest in innovative pedagogies that encourage critical thinking and interdisciplinary approaches to sustainability and climate change.

Smaller but noteworthy themes such as "Environmental Education," "SDGs," and "Self-Efficacy" point to specific areas of focus within the broader ESD and CCE fields, suggesting a diversity of perspectives on how education can foster not only awareness but also actionable solutions. This includes fostering attitudes and knowledge that empower individuals to become proactive agents of change. Furthermore, subtopics such as "Eco-Anxiety" and "Climate Crisis" highlight the emotional and psychological dimensions of climate change education, which are increasingly being explored as part

of comprehensive educational strategies to address both the cognitive and affective aspects of learning.

Figure 3. TreeMap of the most frequently used words

The co-occurrence network in Figure 4 highlights the interconnectedness of various terms within the fields of ESD and CCE. The larger nodes, such as "Education for Sustainable Development," "Climate Change," "Sustainability," and "Climate Change Education," serve as central hubs, linking to a variety of related concepts that reinforce the interdisciplinary and multi-faceted nature of these fields.

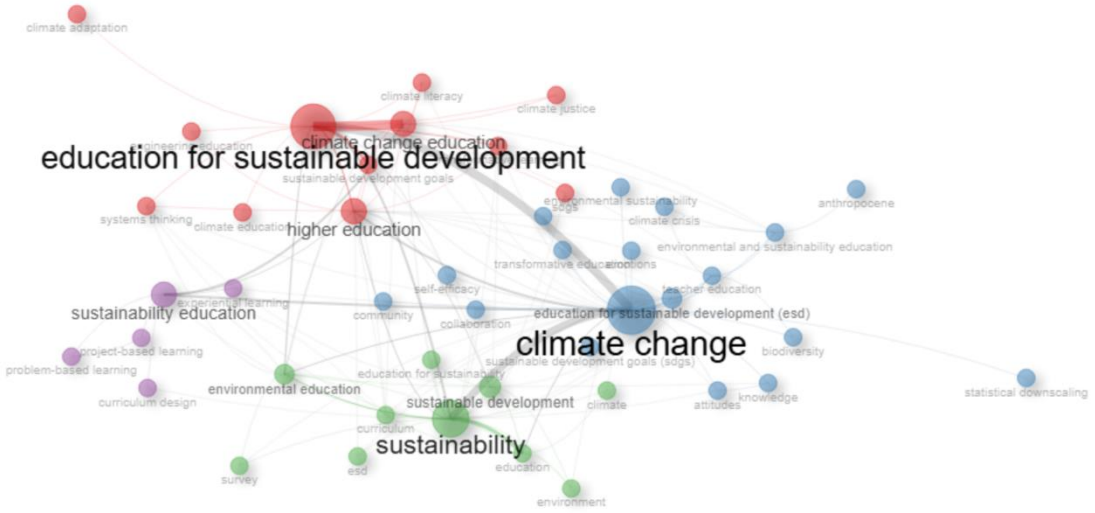

Figure 4. Co-occurrence Network

The network's centralization around terms such as “climate change education” and “sustainability” suggests that these concepts are foundational to both ESD and CCE research. Notably, several terms, such as “climate crisis”, “environmental education”,

and “transformative education”, cluster around these central hubs, indicating a strong thematic relationship and a growing body of literature on how education can address ongoing climate and environmental challenges.

Additionally, the proximity between “higher education”, “teacher education”, and “sustainable development goals (SDGs)” reveals the crucial role of formal education structures and curricula in advancing sustainability goals through educational frameworks. There is also a clear connection among “systems thinking,” “problem-based learning,” and “project-based learning,” highlighting pedagogical approaches that integrate sustainability and climate change education into practical, action-oriented learning models. These interconnections point to the growing importance of interdisciplinary approaches in environmental education, as well as the need for more robust teacher training and educational reform to implement these concepts effectively.

Figure 5 provides a clear overview of the evolving research trends in ESD and CCE. From 2015 to 2025, the frequency of key terms such as "systems thinking," "eco-anxiety," and "climate change and sustainability education" has risen significantly, reflecting a growing emphasis on both interdisciplinary approaches and the psychological impact of climate change within educational research.

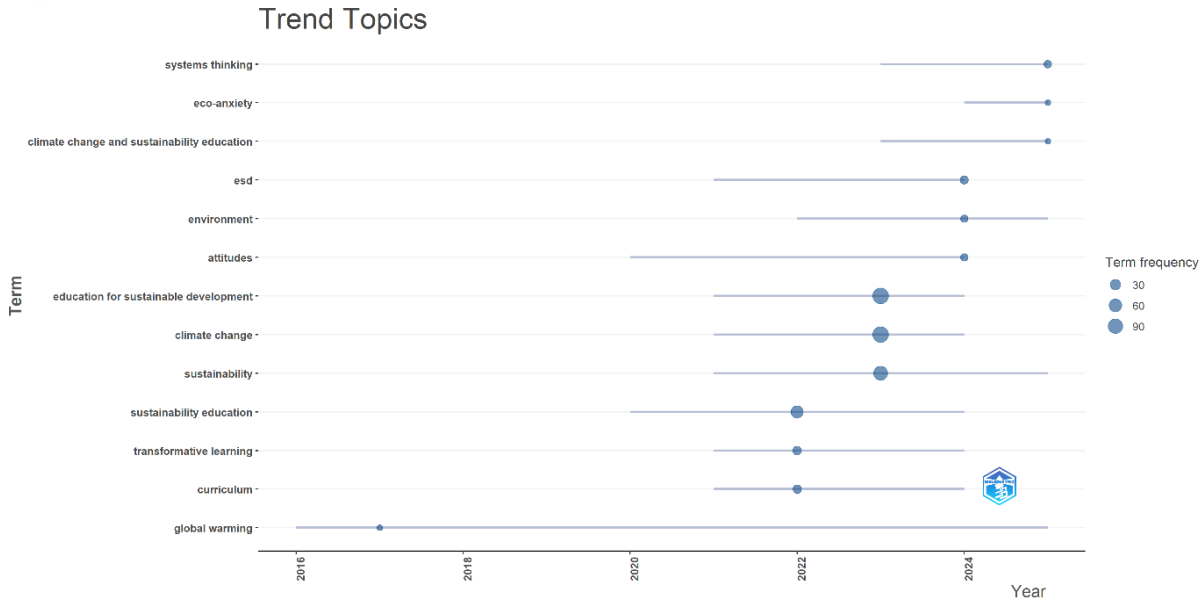

Figure 5. Research topic trends 2015-2025

Terms like “education for sustainable development” and “climate change” show steady growth, with notable spikes from 2020 onwards, indicating an increasing focus on these core topics. This increase coincides with global initiatives such as the SDGs, which have driven research to understand how education can contribute to sustainability and climate change mitigation. Furthermore, the term “transformative learning” gained popularity around 2021-2022, highlighting an educational shift towards fostering more profound, change-oriented learning experiences to address sustainability challenges.

The term "global warming," however, shows a flat trend, suggesting that its educational discussions may have plateaued or shifted toward broader, more integrative terms such as "climate change" and "sustainability education." This could reflect the transition from raising awareness about the scientific aspects of global warming to

more actionable, interdisciplinary approaches to climate change and sustainability in educational curricula.

Citation Analysis

The studies presented in Table 2 reflect diverse approaches and perspectives on ESD and CCE, shedding light on their role in addressing global environmental challenges. Kopnina's (2020) critical evaluation of Education for Sustainable Development Goals (ESDG) offers a deep examination of the limitations inherent in the current sustainability framework (Kopnina, 2020). She argues that the sustainability-through-growth paradigm on which ESDG relies is fundamentally flawed. This model assumes that economic growth can be decoupled from environmental harm, yet it has consistently failed to reduce inequality, biodiversity loss, and the impacts of climate change. Kopnina advocates a shift towards educational models that embrace degrowth, ecopedagogy, and circular economies, empowering communities to challenge the status quo and pursue more ecocentric paths to sustainability.

Table 2. List of the 10 most cited documents

Author and Year	Article Title	Citation	Citation per Year
(Kopnina, 2020)	Education for the future? Critical evaluation of education for sustainable development goals.	424	60.57
(Ojala, 2017)	Hope and anticipation in education for a sustainable future.	166	16.60
(Shields, 2019)	The sustainability of international higher education: Student mobility and global climate change.	150	18.75
(Aikens et al., 2016)	Environmental and sustainability education policy research: A systematic review of methodological and thematic trends.	150	13.64
(Shulla et al., 2020)	Sustainable development education in the context of the 2030 Agenda for sustainable development.	146	20.86
(Liu et al., 2015)	Changes of NPP and their relationship to climate factors based on the transformation of different scales in Gansu, China.	143	11.92
(Tomas et al., 2019)	Are first year students ready for a flipped classroom? A case for a flipped learning continuum.	132	16.50
(Sonetti et al., 2019)	About the triggering of UN sustainable development goals and regenerative sustainability in higher education.	128	16.00
(Dixon et al., 2016)	Evaluating the stationarity assumption in statistically downscaled climate projections: is past performance an indicator of future results?	124	11.27
(Laloë et al., 2017)	Climate change and temperature-linked hatchling mortality at a globally important sea turtle nesting site.	117	11.70

Similarly, Ojala (2017) contributes to the discourse on ESD by exploring the role of anticipatory emotions, particularly hope, in fostering a sustainable future (Ojala, 2017). Her study reveals that while ESD equips students with essential competencies for addressing sustainability issues, it often neglects the emotional dimensions of learning. Ojala emphasizes that hope, despite concerns about fostering unrealistic optimism, can play a transformative role in empowering individuals to engage proactively with climate challenges. By integrating hope into the curriculum, Ojala calls for a more emotionally aware form of education that encourages students to navigate the uncertainty

of the global future with resilience and agency, contributing to a more hopeful and action-oriented approach to sustainability education.

Shields (2019) shifts the focus to the environmental impact of international student mobility, highlighting a significant yet often overlooked aspect of higher education's sustainability footprint (Shields, 2019). His study reveals that Greenhouse Gas (GHG) emissions associated with international student travel are growing faster than overall global emissions. While higher education institutions tend to focus on operational emissions, they often overlook the broader environmental costs of student mobility. Shields urges universities to critically assess the environmental impact of international travel and adopt more sustainable practices, such as promoting virtual learning, to reduce their overall carbon footprint. This research emphasizes the need for higher education to adopt a holistic approach to sustainability, addressing both direct and indirect environmental impacts of its operations.

Aikens et al. (2018) provide a systematic review of Environmental and Sustainability Education (ESE) policy research, identifying key trends and gaps in the field (Aikens et al., 2016). By analyzing 215 research articles from 71 countries, the authors highlight the significant underrepresentation of certain regions and the dominance of non-empirical studies. They call for more empirical research into policy development, particularly regarding the complexities of implementing sustainability education policies. Aikens et al.'s work lays the foundation for future studies that examine the intersection of ESE with broader environmental and climate change policy frameworks, pushing for a more inclusive and rigorous exploration of policy effectiveness and the integration of sustainability into educational governance.

Shulla et al. (2020) further the discussion on ESD's role in advancing the Sustainable Development Goals (SDGs), specifically examining how ESD can contribute to achieving SDG 4 (Quality Education) and other interconnected goals (Shulla et al., 2020). Their research underscores the importance of multi-stakeholder networks, such as the Regional Centers of Expertise (RCEs), in fostering sustainable development through education. By mapping the relationships between ESD components and various SDGs, Shulla et al. demonstrate the multidimensional relevance of ESD in addressing complex global issues, including climate action, energy, and responsible consumption. Their study advocates a systems-based approach to education, where ESD is seen not only as a tool for teaching but also as a strategic means of achieving the SDGs through partnerships and regional collaboration.

Liu et al. (2015) and Dixon et al. (2016) provide complementary insights into the environmental and methodological aspects of climate change research, respectively (Dixon et al., 2016; Liu et al., 2015). Liu's study on Net Primary Production (NPP) in Gansu, China, offers valuable data on the impact of climate change on various biomes, which is crucial for understanding the regional consequences of global environmental shifts. By linking climate factors to changes in NPP across different land types, Liu's work highlights the vulnerability of ecosystems. It underscores the importance of incorporating local climate data into sustainability education. Dixon et al.'s work, on the other hand, challenges the stationarity assumption in statistical downscaling methods, which are commonly used to refine climate projections. Their findings suggest that current models may not accurately predict future climate conditions, a critical consideration for developing effective climate change education curricula that reflect the uncertainties and evolving nature of global warming projections. Both studies point

to the need for more robust, data-driven approaches in climate education, ensuring that students are prepared to navigate the complexities of environmental change with accurate and up-to-date information.

These studies collectively underscore the dynamic nature of ESD and CCE research, highlighting the urgent need for a multidisciplinary approach to education that incorporates emotional, environmental, and policy-driven perspectives. From Kopnina's critique of growth-oriented sustainability models to Ojala's exploration of hope in ESD, the works presented here reveal the diverse ways in which education can play a pivotal role in addressing the global environmental crisis. Moreover, research by Shields, Aikens et al., Shulla et al., Liu et al., and Dixon et al. highlights the importance of integrating climate and sustainability issues into educational frameworks, urging policymakers and educators to consider both the immediate and long-term environmental impacts of educational practices. Together, these studies offer valuable insights into how education can evolve to meet the challenges of climate change and sustainable development, fostering a generation of students who are not only knowledgeable but also empowered to act.

Concept Mapping

Figure 6 presents a thematic concept map that visualizes the relationships among themes in ESD and CCE. The map is divided into four quadrants, each representing different categories of thematic development and relevance. The quadrants show the current status of these themes in terms of their research density (development degree) and centrality (relevance degree). This mapping provides valuable insights into the most important and emergent themes within the education for sustainability and climate change education sectors.

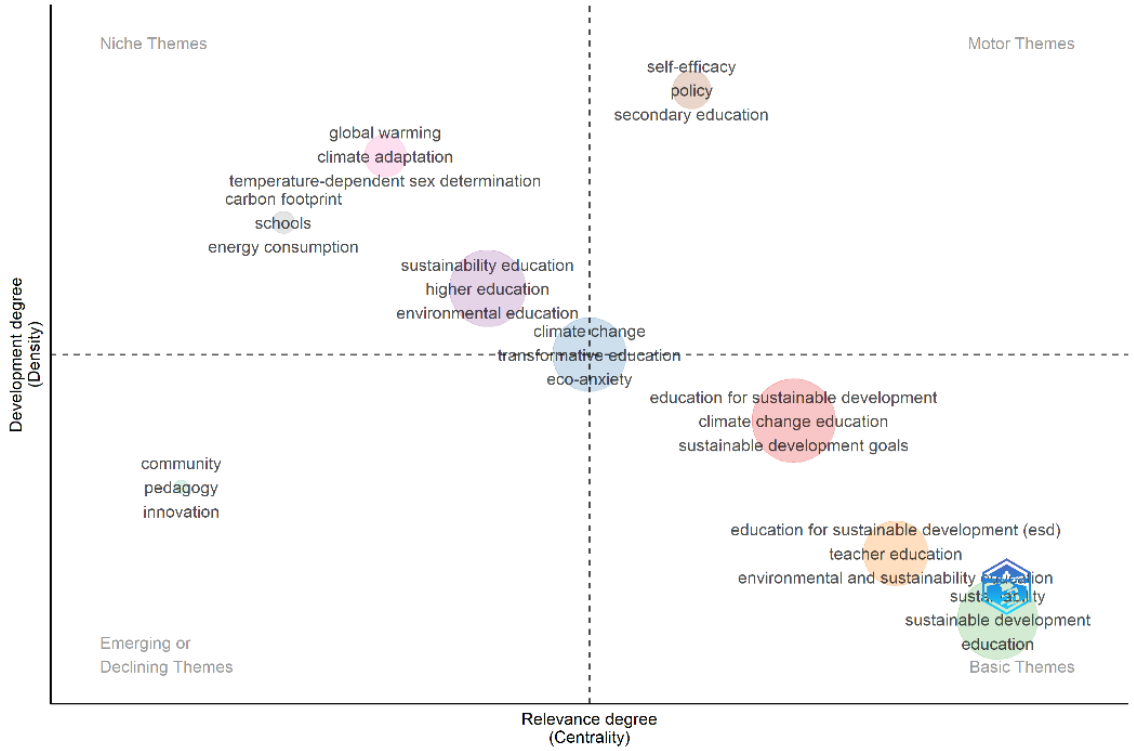

Figure 6. Thematic concept mapping

The Motor Themes quadrant (upper-right) is where the most central and developed themes are located. In this area, key terms such as "Education for Sustainable Development," "Climate Change Education," and "Sustainable Development Goals (SDGs)" dominate, reflecting their high relevance and mature research status. These themes have become central to academic discussions on sustainability and climate change education. Their widespread recognition and integration into educational frameworks align with global efforts to address environmental issues through education, with "education for sustainable development" playing a particularly central role in guiding educational policies and curricula worldwide.

Moving to the Basic Themes quadrant (lower-right), we observe terms like "Sustainability Education," "Teacher Education," and "Environmental and Sustainability Education." These terms are foundational in understanding the broader scope of ESD and CCE. They are considered fundamental to the development of more specialized and applied topics, but are not as central or as fully developed as the motor themes. These basic themes represent the educational structures and approaches that support sustainability and climate change education. The importance of teacher education is especially notable, as it emphasizes the need for well-trained educators who can effectively teach these critical subjects and foster sustainability awareness in future generations.

In the Niche Themes quadrant (upper-left), we see more specialized or emerging themes such as "Climate Adaptation," "Global Warming," and "Energy Consumption." These topics are less central but have higher development potential, indicating that they are important emerging areas of research. They are closely related to specific challenges or solutions within sustainability and climate change, but have yet to gain the same level of attention or integration as the themes in the Motor and Basic categories. Themes like "Eco-Anxiety" and "Transformative Education" also fall into this category, highlighting the growing focus on the psychological aspects of climate change and the pedagogical shifts needed to address complex, global environmental issues.

Lastly, the Emerging or Declining Themes quadrant (lower-left) includes terms like "Community," "Pedagogy," and "Innovation," which, while important, are seen as either emerging themes that are developing in relevance or declining themes that are being replaced by newer, more focused topics. These themes indicate the evolving nature of ESD and CCE research, in which certain ideas, such as general community involvement, may be losing dominance to more specialized discussions of system-based thinking or the integration of the SDGs in education. The presence of terms like "Self-efficacy" in this quadrant may suggest an emerging interest in psychological factors related to learners' agency in sustainability practices. However, this research is still in its early stages.

Discussion

The findings of this research underscore the increasingly critical role of ESD and CCE in addressing global environmental challenges. Specifically, the bibliometric outputs presented above the annual publication growth from 7 articles in 2015 to 103 in 2025 (Figure 2), the treemap dominated by “Education for Sustainable Development” and “Climate Change” at roughly 13% each (Figure 3), and the co-occurrence network in which “sustainability,” “climate change education,” and “SDGs” function as central hubs (Figure 4) point to three interconnected patterns in the field: a rapid expansion

of scholarly output, a consolidation of thematic vocabulary around sustainability and climate, and a growing emphasis on the psycho-emotional and pedagogical dimensions captured by emerging terms such as “eco-anxiety” and “transformative learning.” These patterns frame the discussion that follows. One key observation is the strong alignment of the study's findings with previous research, particularly in the thematic development and the relevance of core topics such as sustainability, climate change, and the Sustainable Development Goals (SDGs). As highlighted by previous research, the critique of the sustainability-through-growth paradigm in ESDG is crucial (Kopnina, 2020; Kopnina & Benkert, 2022; Marco & Orlando, 2026). This study reinforces Kopnina's call for educational frameworks that transcend traditional growth models and embrace degrowth, ecopedagogy, and ecocentric approaches. This argument is echoed directly in our co-word analysis (Figure 4), where “sustainability,” “sustainable development goals,” and “transformative education” form a tightly connected cluster, and in the thematic map (Figure 6), where ESD and SDGs occupy the motor-theme quadrant. At the same time, degrowth-adjacent concepts remain peripheral, suggesting that Kopnina’s critique, although highly cited, has not yet reshaped the field's dominant vocabulary. The growing prominence of these themes in the literature is evident, with ESD and CCE emerging as central pillars in shaping global sustainability education (Kopnina, 2020; Mohanty et al., 2024; Tafese & Kopp, 2025). The discussion in this research thus builds upon and supports the idea that ESD must go beyond technical knowledge and include transformative models that advocate for social and environmental justice.

Additionally, Ojala’s work on hope and anticipation in ESD is reflected in the study's findings regarding the emotional dimensions of education (Ojala, 2017). The increasing focus on emotional awareness, such as hope and eco-anxiety, evident in the co-occurrence and trend topic analyses, aligns with Ojala’s argument for integrating hope to foster engagement with sustainability challenges. This research supports the view that future-oriented competencies in ESD should include cultivating emotional awareness, particularly hope, to counterbalance the pessimism and inaction often associated with climate change. This study’s emphasis on the emotional aspects of ESD contributes a nuanced perspective, suggesting that education should equip learners not just with knowledge, but also with the emotional resilience necessary to face an uncertain and changing global future (Ojala, 2017).

Previous research by Shields focuses on the environmental impact of international student mobility in higher education, which also intersects with the findings of this study, particularly the analysis of sustainability and climate change issues in the context of higher education (Shields, 2019). This research confirms the growing attention to the environmental costs of student mobility, suggesting that higher education institutions need to broaden their sustainability initiatives to include the carbon footprint of student travel. The study advocates for a more comprehensive approach to sustainability in universities, aligning with Shields' argument that higher education’s contribution to climate change mitigation should include both operational emissions and the broader impacts of academic mobility. The findings of this study echo the need for policy shifts in higher education to ensure that educational practices effectively contribute to global sustainability goals.

The systematic review by Aikens et al. on Environmental and Sustainability Education (ESE) policy also provides an important theoretical foundation for this research

(Aikens et al., 2016). The study highlights significant under-representation of certain regions and calls for more empirical research into policy development in ESE. In this study, the theme of policy research emerges as an important area for further exploration, particularly the integration of ESD and CCE into policy frameworks. By examining gaps in research across regions and methodologies, Aikens et al. pave the way for this study's focus on the need for more empirical research that addresses the intersection of policy, ESE, and climate change education. This research reaffirms the need to expand and diversify policy research in these fields to ensure the effective integration of sustainability and climate change education into national and global educational policies.

In terms of practical implications, this study provides valuable insights for educators and policymakers seeking to integrate ESD and CCE into curricula. The thematic concept mapping and co-occurrence network highlight the importance of interdisciplinary approaches in both fields. The growing emphasis on themes such as "systems thinking," "transformative learning," and "environmental education" suggests a shift toward a more holistic understanding of sustainability that transcends traditional disciplinary boundaries. For practitioners, this means incorporating cross-disciplinary curricula that address environmental, social, and economic issues simultaneously. Furthermore, the growing prominence of "teacher education" as a key theme highlights the critical role of well-trained educators in facilitating the successful integration of ESD and CCE into the curriculum. Therefore, this research underscores the importance of investing in teacher training programs and resources to ensure educators are equipped to address the complex, multifaceted challenges of sustainability and climate change education.

Looking forward, the findings of this study call for further research into the emotional and psychological aspects of climate change education. While the growing focus on "eco-anxiety" and "hope" in the literature is promising, more empirical studies are needed to evaluate the long-term effects of emotional engagement in sustainability education. Additionally, the study identifies significant gaps in research on the environmental footprint of higher education institutions, particularly the sustainability implications of student mobility. Further studies could explore the development of more sustainable models for student exchange and mobility, potentially leveraging technology to reduce the carbon footprint of physical travel. Moreover, the impact of various pedagogical models, such as "transformative education" and "project-based learning," should be examined in greater detail to determine which approaches are most effective in fostering lasting behavioral change among learners. These areas of research will be critical for advancing the integration of ESD and CCE in ways that are not only educationally effective but also aligned with broader sustainability goals.

CONCLUSION

This study provides valuable insights into the evolving relationship between ESD and CCE, emphasizing their growing importance in addressing global environmental challenges. Through bibliometric analysis, key themes such as sustainability, climate change, and SDGs emerged as central to the research landscape. The findings highlight the increasing focus on interdisciplinary approaches, emotional engagement, and the integration of ESD and CCE into curricula, ensuring that education fosters not only knowledge but also critical thinking and emotional resilience to confront the urgent issues of climate change and sustainability.

The research contributes significantly to both theoretical and practical discussions. Theoretically, it expands on existing frameworks by integrating emotional awareness and policy dimensions into sustainability education. In practice, the study emphasizes the critical role of teacher education and the need for curricula that address the interconnected environmental, social, and economic dimensions of sustainability. It also draws attention to the overlooked environmental impact of international student mobility, urging higher education institutions to adopt more sustainable practices.

From a policy standpoint, the study emphasizes embedding ESD and CCE into educational frameworks and policies to ensure alignment with global sustainability goals. It also suggests that future research should explore the environmental footprint of higher education institutions and investigate the psychological aspects of climate change education, both of which are becoming increasingly relevant in the current context.

In conclusion, this study deepens our understanding of the connection between ESD and CCE and their vital role in shaping the future of sustainability education. Based on the bibliometric analysis of 468 Scopus-indexed publications (2015–2025), this study makes three specific contributions: (1) it documents an approximately fifteen-fold increase in annual publication output, indicating that the intersection of ESD and CCE has matured from an emerging niche into an established research field; (2) through co-word and thematic mapping, it identifies a consolidated core of motor themes (ESD, climate change education, SDGs) alongside fast-rising frontier themes (transformative learning, systems thinking, and eco-anxiety) that mark the current research frontier; and (3) it reveals two underdeveloped research gaps the carbon footprint of higher education and the psycho-emotional dimensions of climate learning that warrant dedicated empirical investigation. It highlights important implications for educators, policymakers, and researchers, calling for continued efforts to refine and integrate these educational approaches. Future research should focus on evaluating the effectiveness of educational practices and exploring new pedagogical models that incorporate emotional, policy, and environmental perspectives, fostering a more sustainable and equitable world.

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