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An investigation of landscape of environmental education (EE): A bibliometric and systematic literature review

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ABSTRACT

The literature concerning the determinants, pedagogical approaches, and impacts of EE is growing rapidly across multiple disciplines, encouraging researchers to critically review existing research to enrich our understanding and identify research gaps. However, past review studies focused more on topical, regional and(or) intradisciplinary research, while largely ignoring interdisciplinary studies and the recent and growing literature on climate change education. This paper addresses this gap by offering a systematic and interdisciplinary review of the EE literature through a quantitative bibliometric analysis and a qualitative thematic analysis of 399 open-access journal articles published in English across multiple disciplines between 2019 and 2023. The articles were selected from the Scopus database following the PRISMA guidelines. The findings of the study enrich the current body of knowledge by a) reporting the recent evolution of the literature cutting across multiple disciplines; b) identifying four broad emerging themes in EE research: HEI as a change agent; curriculum and pedagogical integration; impact measurement and competency development; and foundations of environmental identity and behaviour; and c) suggesting several areas for future research. The findings also highlight that "educators" symbolise the principal thread that connects the broad themes identified in this research and determine the success or failure of EE in HEIs. However, the existing literature, across disciplines, offers a limited understanding of the role of environmental literacy training (or the lack thereof) for educators, which significantly affects various aspects of EE and facilitates (or impedes) educators in developing and delivering effective EE to students. This study has implications for understanding the role of educators and their capacity building within the HE sector, offering valuable insights for researchers exploring what works best in teaching environmental education.

1. Introduction

The scope of Environmental Education (EE) continues to evolve, particularly in the context of increasing focus of governments, businesses, and societies globally in bringing sustainability at the heart of human endeavours (Annan-Diab & Molinari, 2017; García-Feijoo et al., 2020; United Nations, 2015; Wals, 2014). Consequently, it is strategically important for educators and researchers to

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stay abreast, and more so for Higher Education Institutions (HEIs) that have the responsibility to educate students understand the scope and impact of human activities on the physical and natural environment and encourage the development of sustainable behaviours, irrespective of their field of study. Traditionally, the focus of EE was limited to the environmental conservation (Palmer, 2002) with a purpose of "producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (Stapp, 1969, p.34). This focus remained prominent from the 1960s through to the late 1980s, supported by milestones such as the Belgrade Charter (UNESCO, 1975), the Tbilisi Declaration (UNESCO, 1977), and the Brundtland Report (United Nations, 1987) among others (Corcoran & Wals, 2004).

During the 1990s, the scope of EE expanded to incorporate the concepts of sustainability and sustainable development, focusing largely on sustainable resource management (Tilbury, 1995). Since the beginning of the 21st century, the scope of EE has further expanded integrating the concepts such as carbon literacy and sustainable development goals (SDGs), reflecting a broader and holistic approach to education that strengthens global sustainability efforts, particularly those aimed at mitigating the impending threats of climate change (Landorf et al., 2008; Žalėnienė & Pereira, 2021). The change in the trajectory of EE and the consequent development of literature over decades, mostly contingent on the contemporary environmental challenges (Boca & Saraçlı, 2019; Kanyimba et al., 2014; Olufemi et al., 2019; Žalėnienė & Pereira, 2021), resulted not only in the fragmentation of the extant literature – as it developed in isolation under multiple disciplines – but also led to a limited consensus relating to the scope and focus of EE, as scholars attempted to define it from various perspectives often subject to the confines of their respective field of study (e.g., Engineering & Technology, Physical Sciences, Life Sciences, and Social Sciences & Humanities) (Cole, 2014; Frizon & Eugénio, 2022; Varela-Losada et al., 2022; Vargas-Merino et al., 2024; Wrase et al., 2023).

On the one hand, the growth in academic research concerning EE across disciplines indicates a growing consensus among scholars about the importance of EE in HEIs (Arshad et al., 2021; Bernaciak et al., 2021). On the other hand, it is rather odd to note that there is no significant study that reviews the existing literature and provides a comprehensive understanding of EE, summarising insights from interdisciplinary research and highlighting the recent trends. For example, recent systematic literature reviews concerning EE primarily focused on pedagogical approaches (Varela-Losada et al., 2022) and factors influencing the effectiveness of EE courses (Jiang et al., 2022). In contrast, Rohrich and Takahashi (2019) examined environmental sustainability in HEIs within Brazil, using data that predates 2019. This topical or regional focus offered valuable insights but may not have represented broader trends. Additionally, Vargas-Merino et al. (2024) conducted a bibliometric analysis of Education for Sustainable Development (ESD) in HEIs using data from 2005 to 2022. However, their restrictive keyword selection excluded pertinent EE terms and emerging topics. Another recent bibliometric and systematic review paper by Frizon and Eugénio (2022) concentrated on Management and Accounting, potentially overlooking the urgent trend of interdisciplinarity in ESD highlighted by Annan-Diab and Molinari (2017).

Furthermore, past reviews seldom accounted for the recent surge in publications on "climate change education" as part of EE that focuses on the science, impacts, and mitigation of climate change (Molthan-Hill & Blaj-Ward, 2022; Molthan-Hill et al., 2019). There thus appears to be a need for a systematic, integrative, and interdisciplinary review of EE literature to help advance our understanding in its entirety, identify broad research trends and themes, and suggest a roadmap for future research. This study aims to bridge this gap by conducting a comprehensive bibliometric and thematic analysis of interdisciplinary research related to EE. It explores underrepresented areas by mapping the intellectual structure of the field and identifying emerging themes, thereby providing a comprehensive understanding of the current state and future directions of EE. Thus, this study posits two overarching research questions (RQs).

a) How has EE research evolved across disciplines, and what are the key intellectual foundations?
b) What are the recent and future research trends in EE research?

This study conducted a bibliometric and thematic analysis of 399 articles (using Rstudio, VOSViewer, and MS Excel) which were published in the leading academic journals across multiple disciplines during 2019–2023. The articles were selected from the Scopus database using a Boolean search and several filtering criteria. Our study makes three broad contributions. Firstly, unlike past studies, it contributes to the extant research by reporting the recent evolution of the EE literature cutting across multiple disciplines (in terms of interdisciplinary trends, leading contributors, collaborative networks, funding bodies, and so on). Secondly, the review identifies four broad emerging themes in EE research: a) HEI as a change agent; b) curriculum and pedagogical integration; c) impact measurement and competency development; and d) foundations of environmental identity and behaviour. These themes capture the major shifts happening in EE, in terms of how societal priorities and international agreements — like the United Nations SDGs and international climate change agreements — are reshaping the goals, methods, and success metrics of environmental education today. In addition to highlighting the impact of these initiatives on HEIs as change agents, they respond to educators' growing call for evidence-based practices (e.g., curriculum design and impact measurement) and empower learners to take ownership of their role in protecting the planet (e.g., by fostering an environmental identity).

Lastly, several areas for future research are suggested, which are largely ignored in the extant research but are critical for a better understanding and success of EE in HEIs. For instance, based on the emergent themes, this paper argues that "educators" serve as a cornerstone that determines the success (or failure) of EE in HEIs. Yet, the extant literature provides limited understanding of the importance of environmental literacy training (or lack thereof) for educators, which significantly impacts various aspects of EE and enables (or hinders) educators in developing and imparting effective EE to students. Hence, this paper calls for more research aimed at developing understanding of the current preparedness (e.g., awareness of current environmental issues), the adequacy of training (e.g., informed approaches to teach), and the availability of support systems for capacity building in academics engaged in EE (e.g., available financial support and opportunities for continuous professional development).

The paper proceeds as follows. First, a brief overview of EE and other related concepts that have recently been included under the

broad umbrella of EE in HEIs is provided. Next, the methods and procedures which were employed in conducting the study are explained. Following this, the findings of the bibliometric and thematic analysis are reported. Subsequently, the emerging themes are discussed, and future research directions are suggested. The paper concludes with final remarks.

2. Theoretical background

2.1. Environmental education and related concepts

The term "Environmental Education" was first used at a conference held in 1965 at Keele University, UK, which broadly encompassed environmental conservation (Palmer, 2002). Meanwhile, the seminal United Nations Educational, Scientific and Cultural Organization (UNESCO) conference in Paris in 1968 was profound, as it made EE a part of the global agenda. Still, there is no consensus on a specific definition of EE in the extant literature; however, it can be broadly defined as a process of building "… a sense of values, and contribute to public well-being" (Stapp, 1969, p.36). Several landmark definitions emerged during the 1970s in the history of EE. One influential definition was formulated at the International Working Meeting on Environmental Education in the School Curriculum in 1970 at the Foresta Institute in Carson City, USA, which states that "Environmental education is the process of recognizing values and clarifying concepts in order to develop skills and attitudes necessary to understand and appreciate the interrelatedness among man, his culture, and his biophysical surroundings. Environmental education also entails practice in decision-making and self-formulation of a code of behavior about issues concerning environmental quality" (IUCN, 1970, p. 13). This definition and its conceptualisation of EE have been continuously promoted to global audiences and international institutions to raise EE's profile, leading to increased discussion and understanding of its aims, objectives, and approaches. For example, UNESCO's conference in Belgrade in 1975 further strengthened the integration of EE into national policies aiming for national development (Türkoğlu, 2019).

During the 1980s, EE was consolidated, highlighting the interdependent relationship between resource conservation and sustainable development. Furthermore, from the 1990s onward, discussions of Environmental Education have focused on what nations should do to achieve sustainable development in the 21st century. Since then, educators have defined and practiced EE in multiple ways (Boca & Saraçlı, 2019). Some scholars have argued that a comprehensive EE must involve learning in, about, and for the purpose of understanding the environment (Boca & Saraçlı, 2019). While others have explored the philosophical underpinnings of EE and contend that moral values (such as Islamic values as highlighted by Begum et al. (2021) and ecologically friendly behaviour (Liu & Guo, 2018) form the core of EE and thus help build effective environmentalism and bolster positive changes in learners (e.g., change of attitude). Hence, it is unsurprising that EE enables learners to protect nature and cultural values, raise environmental awareness, and solve environmental problems through actions (Türkoğlu, 2019).

The recent development of EE, in the milieu of changing societal needs, led to the emergence of several synonymous concepts with nuanced differences, often owing to theoretical development or as a response to impending social problems (Boca & Saraçlı, 2019). For example, ESD, which may appear synonymous with EE, focuses more on students' environmental knowledge, attitudes, and learning outcomes (Rickinson, 2001) and thus has evolved into a particular facet or emphasis within the broader field of EE (Palmer, 1998). Research concerning ESD have called for more studies shedding light on student educational experiences, preferences, and learning processes by further exploring EE theories and research practices (Huckle, 1991) focusing on children (Payne, 1998) and young people (Boca & Saraçlı, 2019) enabling EE to promote environmental sustainability (Tilbury, 1995). As previously highlighted, scholars across several disciplines (e.g., physical and life sciences), when referring to EE, simply associate it with the awareness about general issues threatening the environment, its protection, and conservation (Kanyimba et al., 2014; Olufemi et al., 2019). This understanding significantly overlaps with the broader concept of environmental sustainability in other disciplines such as business and management (Wright, 2002). It also relates to the overarching challenges of "… environmental degradation, environmental health, pollution, and so on" (Boca & Saraçlı, 2019, p. 3). However, following the Thessaloniki declaration (United Nations Educational, Scientific, & Cultural Organization UNESCO, 1997), the concept of environmental sustainability has been linked to poverty, population, food security, democracy, human rights, peace, and health, and respect for traditional cultural and ecological knowledge.

Similarly, the recent global attention on climate change issues resulted in the rise of Climate Change Education (CCE) as an emerging topic under EE. It enables university students to develop a comprehensive understanding of climate principles, combining the knowledge from various disciplines (Leal Filho, 2010). However, it is not yet fully developed considering the evolving understanding of the concept, knowledge, boundaries, as well as the requisite skills and competencies, and pedagogical approaches that need to be developed and embedded in teaching (Molthan-Hill et al., 2019). Other related concepts are environmental literacy and ecological literacy. Environmental literacy refers to the ability to perceive and interpret environmental systems and to take appropriate measures to ensure their proper functioning and improve them in a healthy way. It focuses on developing problem-solving skills in learners (Wajdi et al., 2022). Whereas the ecological literacy stresses on the systematic interactions of humans and nature, thereby enhancing learners' intellectual, physical, moral, and social development in connection with nature (Durmuş & Kınacı, 2021). In summary, this research adopts the foundational definition of EE as articulated by IUCN (1970). Building upon this, the study acknowledges that EE has progressively evolved into an interdisciplinary field, integrating related concepts to comprehensively address complex environmental challenges.

2.2. Environmental education effectiveness

The effectiveness of EE in HEIs rests on two aspects: prioritisation and implementation (which relates to effective content development and teaching). Scholars largely regard EE as the most effective solution to deal with the current environmental challenges. The

gradual inclusion of EE in the curriculum, from primary to higher education worldwide, indicates significant progress with respect to strategic prioritisation of EE (Gibson & Chase, 2002). However, when it comes to implementation, particularly in HEIs, both content development and teaching seem to be ineffective. For instance, the diversity of content makes it difficult for educators to raise students' awareness about the value of nature, as they often struggle to grasp the complexity of environmental issues. If students do not understand nature (e.g., why a forest might die?), they may not recognise the need to protect it (Maurer & Bogner, 2019). Given the evolution of EE in a variety of disciplines and considering the diversity in the content — both in depth and breadth — there is less scope for harmonisation. However, this study argues that a better understanding of the interdisciplinary research on EE together with relevant support (in terms of training and continuous professional development) would allow educators to enhance the implementation of EE in HEIs, as they will be better positioned to develop effective content, keeping students' field of study in mind, and be able to experiment with the pedagogy.

2.2.1. Pedagogy and interdisciplinary research in EE

The literature focusing on the significance of teaching content and pedagogy development concerning EE has grown over the years. The Thessaloniki Declaration, adopted in Thessaloniki, Greece (United Nations Educational, Scientific, & Cultural Organization UNESCO, 1997), affirmed that all subject disciplines must address issues related to the environment and sustainable development and that university curricula must be reoriented towards a holistic approach to education. This has led to the wide adoption of learner-centric pedagogies such as active learning (Monroe et al., 2007). The success of active-learning strategies depends on the educators' ability to combine sustainability skills with environmental emotions to foster learners' positive attitudes towards the natural environment (Leal Filho et al., 2019). In other words, the effective delivery of EE cannot be guaranteed by excellent content or effective pedagogy alone but requires "an effective combination of both the content and pedagogy" (Boca & Saraçlı, 2019).

Sauvé (2005) presented 15 pedagogical typologies, providing an overview of pedagogical approaches to enhance curricula and develop effective teaching strategies tailored to various learning contexts. Meanwhile, as environmental challenges cut across various disciplines, there is a growing recognition of the need for interdisciplinary approaches that integrate insights from diverse fields (Wright, 2002). For example, Cole's (2014) study connected architectural design to EE. Fauville, Lantz-Andersson, and Säljö (2013) discussed integrating technological tools in EE via project-based approaches. Understanding this integration is crucial for developing comprehensive educational strategies that address the complex nature of environmental issues (Tilbury, 1995; Wright, 2002). However, this paper argues that research examining how these interdisciplinary frameworks are incorporated into EE and their impact on teaching and learning remains limited.

2.2.2. Importance of educators' training in EE research

The extant literature suggests that educators play an important role in "planning teaching and learning tasks across a range of environmental knowledge, understandings, concepts, skills and attitudes" (Palmer, 2002, p. 37). Educators need to take the initiative to be more involved in identifying, developing, and implementing methods to ensure that the current and future generations of students have the necessary competence to understand and find solutions to the environmental issues (Franzen, 2017). However, this initiative on the part of educators should not be left to their volition, but there is a need for well-established training mechanism to be put in place (Durmuş & Kınacı, 2021), more so for educators for whom the complex theories and concepts of EE may be relatively new (e.g., for social studies educators). Universities, as stated in The Talloires Declaration, must "create programs to develop the capability of university faculty to teach environmental literacy to all undergraduate, graduate, and professional school students" (Association of University Leaders for a Sustainable Future, 1990, p.1).

Similarly, educators' early life experiences, which shape their ideas, attitudes, and beliefs in daily life, shouldn't be neglected in EE (Palmer, 2002). For example, Leal Filho et al. (2019) proposed an EE model for educators combining sustainability skills with environmental emotions. This provides pedagogical guidelines for shaping learners' positive attitudes towards the natural environment. Although the need for educators to be knowledgeable about various environmental issues is increasing, there is a lack of research on their current preparedness and the adequacy of training (e.g., an informed approach to teaching) (Durmuş & Kınacı, 2021) and the support systems (e.g., funding sources) to enhance their capacity in imparting EE effectively (Schlicht-Schmälzle et al., 2024).

3. Methodology

This study conducted a systematic literature review, a scientific and rigorous method for secondary research that has been widely used in business and management studies (refer Tranfield et al., 2003; Lim et al., 2021). Scholars have utilised various types of systematic literature reviews contingent on the issue being investigated. For example, meta reviews (e.g., systematic and analytical), domain-based, theory-based, and method-based reviews (Moher et al., 2010; Paul et al., 2021). As this paper explored EE as an interdisciplinary domain, it adopted a domain-based systematic literature review. Nonetheless, there are several types of domain-based systematic literature reviews, for example, structured theme-based, framework-based, bibliometric, hybrid, and conceptual reviews, among others (Donthu et al., 2020; Lim et al., 2021; Rosado-Serrano et al., 2018). This study adopted a mixed-method approach and conducted both quantitative and qualitative analyses of existing literature to achieve its objectives. A quantitative analysis (i.e., bibliometric reviews) was performed to examine the intellectual foundations of EE. Whereas a qualitative thematic analysis (i.e., structured theme-based literature review) of selected articles for the period of 2019–2023 was conducted to explore the recent research trends and identify themes.

This study only included articles published in the past five years, as it intended to build on the past systematic literature reviews (that covered articles published prior to the time period selected for this review) and utilised their findings while mapping the

intellectual foundations and identifying emerging themes. Moreover, the recent inclusion of "climate change education" under the umbrella of EE that focuses on the science, impacts, and mitigation of climate change led to a surge in publications on this topic since 2018–2019 (Molthan-Hill & Blaj-Ward, 2022; Molthan-Hill et al., 2019). Consequently, a more recent review was required to ensure that the analysis remains relevant to the current discussions and debates within the academic community, which further justified the inclusion of only recent publications in this review. Past studies, Jiang et al. (2022) for example, have also considered a similar time period for systematic literature reviews to examine the emergence of the most recent phenomena or trends in their respective fields.

The bibliometric review was suitable as it helped us analyse the citations and co-citations and visualise the collaboration networks (Donthu et al., 2020). Similarly, the structured-theme-based review was well-suited for the identification of widely used domain-specific theories, constructs, themes, and methods (Rosado-Serrano et al., 2018). However, the bibliometric and thematic analyses are separate phases designed to answer the proposed two research questions independently. The following sections explain the details of the methodical approaches and review protocol (refer to Fig. 1).

3.1. *Phase I: literature search and data collection*

In this phase, given the interdisciplinary nature of EE literature, this study focused on data collection by searching relevant literature across multiple disciplines, instead of, purely focusing on business and management literature. It utilised the Scopus database to search for articles as it is considered the most comprehensive database of scientific journals including, but not only limited to, business and management journals (Schotten et al., 2017). This study avoided performing literature search on Web of Science (WOS) database because Scopus has more user-friendly functions as compared to WOS and journals indexed in the Scopus database are not only relatively more inclusive but also meet strict quality standards for inclusion ensuring that the sources are credible and reliable (Bretas & Alon, 2021; Lim et al., 2022; Modak et al., 2020). Additionally, combining data from multiple databases would have created capacity issues and work overload during dataset integration (due to multiple formats), cleaning, and visualisation.

Although prior studies, particularly review studies in the marketing field, have commonly adopted 'Scientific Procedures and Rationales for Systematic Literature Reviews' (SPAR-4-SLR) protocol citing its compatibility to business research (Lim et al., 2022; Paul et al., 2021), this study followed the PRISMA protocol that traces its origin in the science discipline for several reasons. First, the PRISMA protocol, endorsed by the Cochrane Collaboration, is a widely recognised standard in the academic community for synthesising and reporting evidence (Moher et al., 2010). Second, it provides the standardisation, transparency, comprehensiveness, credibility, and adaptability that are required to conduct an interdisciplinary review of EE research (Tranfield et al., 2003). Third, it provides a 27-item checklist which guides authors on the essential items to include at the reporting stage. Last, it is not limited to certain subjects and disciplines, and is continuously utilised in various types of systematic reviews (Tueanrat et al., 2021). The PRISMA protocol includes four steps: identification, screening, eligibility, and included (refer to Fig. 2).

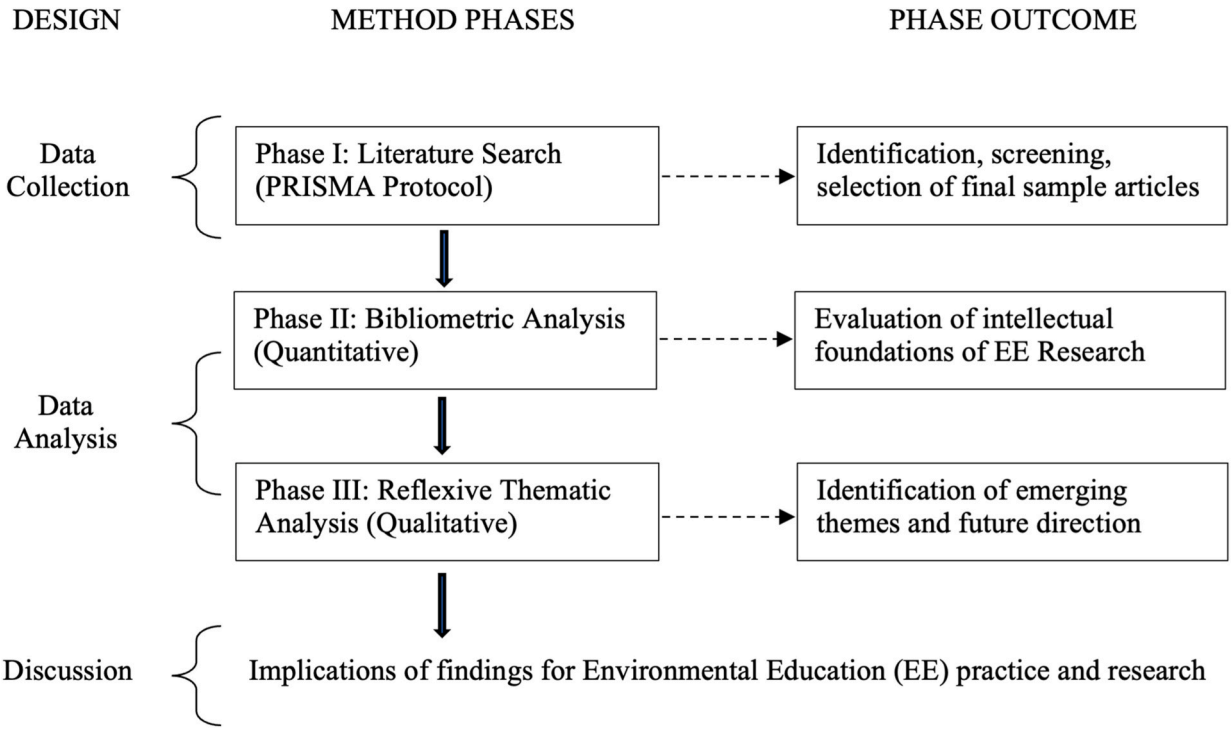


Fig. 1. Research Design and Methodological Approach.

3.1.1. Identification

At the identification stage, the authors initially searched for terms such as "Environmental Education", "Environmental Sustainability", "Sustainable Development Education", "Sustainability Education", and "Environmental Awareness" in higher education. However, these searches missed key papers on "climate change education" (Molthan-Hill & Blaj-Ward, 2022; Molthan-Hill et al., 2019), a more specific area within EE that focuses on the science, impacts, and mitigation of climate change. This oversight may be due to the lack of a universal definition and the term's interdisciplinary nature (Molthan-Hill et al., 2019). As the knowledge about the carbon emissions becomes increasingly crucial with the rise of climate change education, publications on this topic, as also shown in the preliminary search results, have surged in the Scopus database since 2018–2019. Keeping this in mind, the authors then carefully reviewed search results and performed repetitive searches by expanding key terms and applying relevant filtering criteria (refer to Table 1). As a result, 1633 articles were identified and collated for the screening stage after accounting for duplication and other filtering criteria such as publication stage ("final"), publication date ("between 2019 and 2023"), access type ("open access"), language ("English"), and resource type ("journal article"). Only open-access articles were selected to align with open-science principles — enabling anyone to access, verify, and build on our work, thus boosting transparency and reducing bias (Schraven et al., 2021).

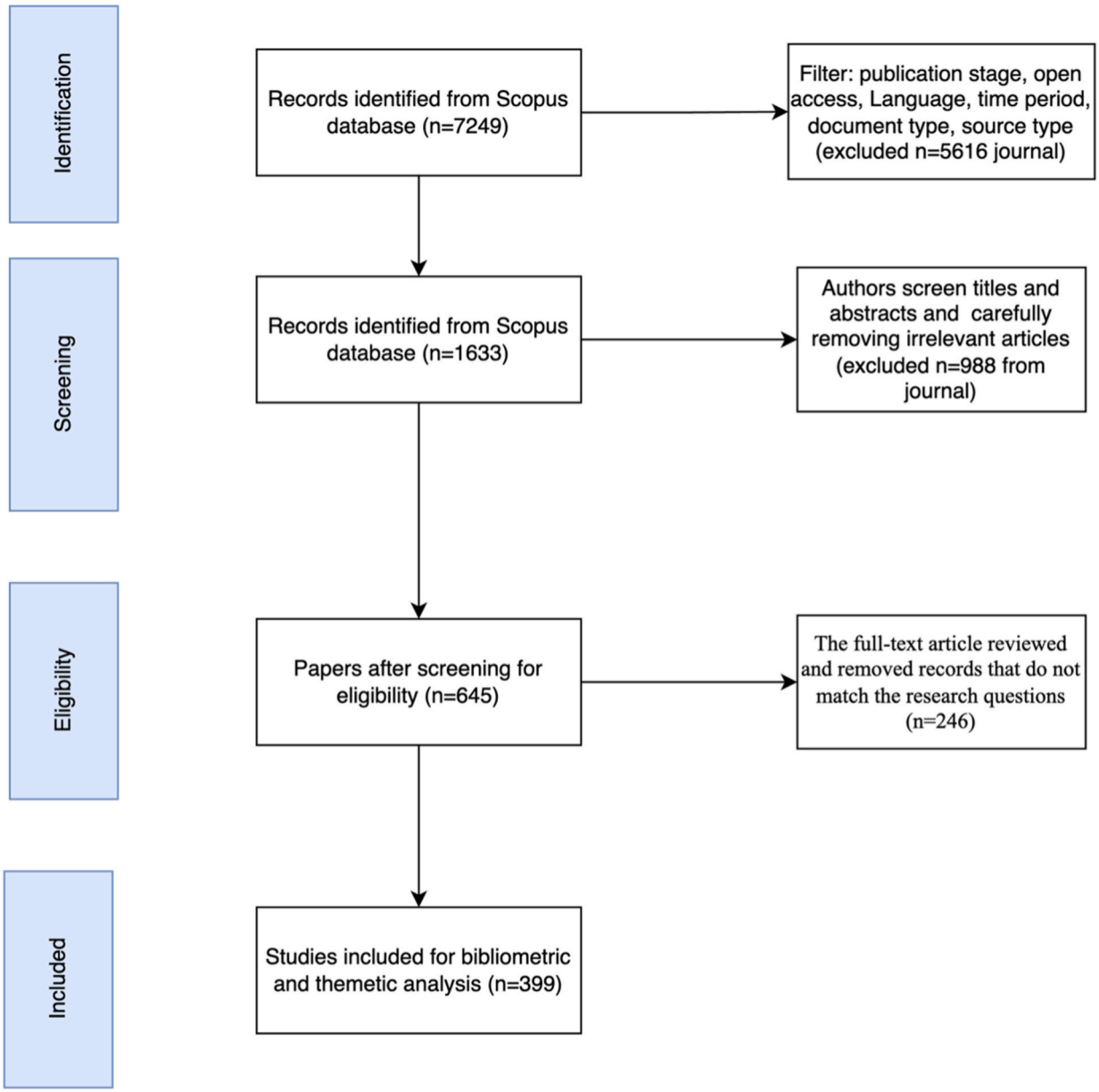


Fig. 2. The PRISMA Protocol.

Table 1
Search strings, filter criteria, and results.

Search Strings	Stage	Filter Criteria	Result (n)
"Green campus initiatives" OR "Carbon literacy" OR "Sustainability education" OR "Sustainability teaching" OR "Climate change education" OR "Environmental education" OR "Carbon footprint" OR "Low-carbon education" OR "Sustainable development education" OR "Climate action" OR "Eco-literacy" OR "Green skills" OR "Environmental sustainability" OR "Carbon reduction" OR "Environmental awareness" OR "Sustainable energy" OR "Carbon management" OR "Climate literacy" OR "Climate change mitigation" OR "Carbon-neutral" AND "Higher education" OR "College" OR "University"	Identification (n = 7249)	Publication Stage = "FINAL" Access Type = "OPEN ACCESS" Language = "ENGLISH" Time Period = "2019–2023" Document Type = "JOURNAL ARTICLES"	1633 (articles excluded- 5616)
	Screening (n = 1633)	Review of Titles and Abstract for relevance	645 (articles excluded-988)
	Eligibility (n = 645)	Full-text review	399 (article excluded- 246)
	Included		399 (final)

3.1.2. Screening

During the screening stage, the authors conducted a meticulous assessment of the titles and abstracts of the collated articles to determine their suitability for the full-text review. Despite the filtering criteria, some articles did not fit the inclusion criteria that comprised "literature is regarding environmental education in HEIs", "academic and published journal articles only", and "the publication should be in the English language". This screening phase ensured the reliability (i.e., reproducibility of screening decisions) and consistency (i.e., uniform application of criteria) of our analysis (Tueanrat et al., 2021). The authors excluded 988 papers that were found irrelevant and thoroughly documented the remaining 645 articles for the eligibility stage.

3.1.3. Eligibility

During this stage, using their subject expertise, the authors performed a full-text review of the screened studies to confirm their relevance, quality, and appropriateness for answering the proposed RQs. To minimise bias, two researchers independently reviewed each full-text article using predefined criteria, with disagreements resolved through discussion or adjudication by a third team member. Consequently, this study excluded 246 articles and finalised 399 core documents in EE literature that were found to be eligible for conducting further analysis (i.e., bibliometric and thematic analyses).

3.1.4. Included

This stage involved the downloading and saving of relevant data in.csv format for quantitative analysis (i.e., bibliometric analysis using RStudio) and downloading selected articles for qualitative analysis (i.e., full-text review to identify emerging themes and future study directions).

3.2. Phase II: bibliometric analysis

Bibliometric analysis has been widely utilised to evaluate the development of a field by exploring the structure of knowledge (e.g., producing clear and concise summaries of bibliographic details) using statistical methods, thus eliminating the researcher bias (Lim et al., 2022). To examine the intellectual foundations of the EE field, this study conducted performance analysis (i.e., both the descriptive and citation analysis) to evaluate the performance of leading authors, countries, and collaboration networks, and to identify the most influential articles and authors (based on metrics such as Total Citations (TC), H-Index, and Total Link Strength (TLS)) (Costas & Bordons, 2007; Donthu et al., 2021). Although these citation-based metrics reflect scholarly influence rather than intrinsic research quality, the citation analysis still provides valuable insights into the knowledge base of the EE domain (Donthu et al., 2021). Prior studies have advocated that the Bibliometrix R tool, which runs in the flexible statistical R software environment, surpasses other similar software because of its strong visualisation ability and accuracy of results (Bretas & Alon, 2021). Thus, Biblioshiny function of the Bibliometrix R package has been used to identify the most influential articles (using co-citation analysis and bibliographic coupling), authors, and funding sources in the EE field. Furthermore, VOSViewer has been employed to conduct co-authorship analysis to identify author collaboration networks and to visualise the results. This research preferred VOSViewer for its better presentation capability in comparison to other software packages such as CitNetExplorer and Gephi, among others (Shah et al., 2020).

3.3. Phase III: reflexive thematic analysis (RTA)

This study followed the RTA technique to identify research trends and emerging themes in EE, which is an underdefined domain characterised by complex and nuanced interdisciplinary studies. It is considered a suitable qualitative research method that is used to identify, analyse, and interpret patterns (themes) within data (Braun & Clarke, 2006). Unlike other thematic analysis techniques, RTA emphasises the role of the researcher whose interpretations and subjectivity shape the analysis and hence uncover rich insights. However, it is often criticised for its time and resource-intensive nature, subjectivity, probability of researcher bias, and skill dependency (Braun & Clarke, 2021). Nonetheless, this method is flexible, allowing for both inductive and deductive approaches to theme

development, and often involves a more iterative and reflective data engagement. This research followed Braun and Clarke's (2006) 6-steps of RTA: familiarising with the qualitative data; generating initial codes; searching for themes; reviewing themes; defining and naming themes; and producing the report. Finally, it categorised and presented themes following the analytical coding process of the "Gioia's methodology", as 1st order concepts (codes), 2nd order themes, and aggregated dimensions (Gioia et al., 2012; refer to Fig. 4). Accordingly, the study adopted an inductive approach and derived themes directly from the data instead of being pre-defined (Gioia et al., 2012). During the coding process, we generated 74 first-order codes, refined them into 12 s-order themes, and synthesised these into four overarching themes (detailed in Section 4.2).

To ensure the inter-rater reliability and minimise coder bias, the researchers met regularly throughout both the paper selection and coding stages. In the early stages, they held weekly meetings to discuss and reach consensus on which papers to include or discard. During the coding phase, they continued their collaboration via in-person meetings, where they reviewed each other's codes and related quotations, to ensure alignment on initial codes and themes. Any discrepancies were resolved through discussion, and a third researcher was involved in the resolution process in cases of disagreement. Meanwhile, researchers kept detailed reflexive journals of coding decisions, analytical memos, and theme-development notes, creating a transparent audit trail from raw data to final themes. This iterative process, combined with regular discussions, ensured reliable and consistent coding.

Furthermore, in qualitative research, researchers' perspective and worldview, known as positionality, can influence their relationships with their research subjects (Holmes, 2020; Secules et al., 2021). In line with this, we carefully reflected on the researchers' positionality in shaping our interpretations of the qualitative data (Secules et al., 2021). Our team included researchers from diverse academic backgrounds, all relevant to this study. While the lead author's research experience primarily focuses on environmental and sustainability education, the co-authors have varied experiences in circular economy, supply chain sustainability, management education, and strategic management-related research. All authors are primarily based in UK institutions, but they also have international educational backgrounds and connections with institutions in emerging economies such as China, India, and Sri Lanka. This meant that the team brought in a range of perspectives during the analytical process, alongside a comprehensive understanding of the environmental education in both developed and emerging economies. Nevertheless, there might be occasional instances when our prior experiences with interdisciplinary research and a focus on climate change education may have influenced the identification of themes, particularly in areas concerning sustainability and climate action. However, throughout the analysis, we maintained reflective attitudes and made notes on our motivations, beliefs, personal views and assumptions while engaging with the qualitative data to eliminate potential biases. During the discussions, we incorporated various perspectives to best interpret the data collectively, thereby strengthening the research quality (Secules et al., 2021).

4. Results

The results of this study are presented in two sections: bibliometric descriptive and citation analyses findings revealing the evolution and intellectual structure of the field; and RTA findings revealing the research trends, themes, and future directions of EE research.

4.1. Bibliometric analysis

The findings of the bibliometric analysis are presented in the following sections. Using the Bibliometrix R package, this study conducted bibliographic coupling and co-citation analyses. Additionally, it analysed funding sources, identified prominent authors, explored their collaboration networks across countries, and visualised these collaborations using VOSViewer.

4.1.1. Evolution of EE research: knowledge production

Our co-citation and bibliographic analysis identified leading articles in the dataset and seminal articles within the cited articles based on Total Citations (TC) and Total Link Strengths (TLS) metrics, as presented in Table 2. Total Citations (TC) — the sum of all citations received by an author's publications — serves as a direct measure of an author's scholarly impact, with higher TC indicating greater influence and quality in the field (Modak et al., 2020). While TLS measures the frequency of a paper co-cited with other papers. Thus, a higher TLS value indicates a strong emergence or influence of a paper across the entire co-citation network (Shah et al., 2020).

Table 2
Articles identified from co-citation analysis.

Author	Title	TC	TLS
Wiek et al. (2011)	Key competencies in sustainability: a reference framework for academic program development.	11	17
Lozano et al. (2017)	Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal.	8	13
Sipos et al. (2008)	Achieving transformative sustainability learning: engaging head, hands, and heart.	6	12
Sterling (2011)	Transformative learning and sustainability: Sketching the conceptual ground.	4	11
Rieckmann (2012)	Future-oriented higher education: Which key competencies should be fostered through university teaching and learning?	6	10
Lambrechts et al. (2010)	The integration of sustainability in competence based higher education: using competences as a starting point to achieve sustainable higher education.	4	10
Vare and Scott (2007)	Learning for a change: Exploring the relationship between education and sustainable development.	4	10
Shephard (2008)	Higher education for sustainability: seeking affective learning outcomes.	4	10

This study identified 28 papers for conducting co-citation analysis with a minimum threshold of 4 TC. The TLS values of the 28 articles analysed ranged between 1 and 17; thus, while compiling the list of most influential articles, this research only selected articles that had TLS values of 10 or higher. Table 2 shows the 8 most influential articles (out of 28 papers) ranked on the basis of high to low TLS values. Wiek et al. (2011) article is found to be most influential in terms of both TLS and TC metrics. Followed by the Lozano et al. (2017) article as the second most influential paper among cited references. Overall, all 8 papers identified as the most influential articles had relatively smaller TC (below 11) and TLS (below 17) values.

The bibliographic coupling analysis resulted in 52 articles. This study only considered articles that had TC and TLS values of more than 18 and 30, respectively. Findings revealed that 9 out of 52 articles had TLS values above 30, indicating their higher frequency of co-occurrence with other articles in the dataset. Table 3 lists details of these influential papers, from high to low, according to their TLS values. Among the 9 papers listed, *Tejedor (2019)* stands out as highly cited and well-connected, making it both influential and central within the research field globally. *Similarly,* Wolff and Ehrström (2020) also appeared well connected within the field with a very high TLS value, however, it hasn't been cited as frequently as other papers (low TC value of 28). On the contrary, García-Feijoo et al. (2020) appeared highly cited (high TC value of 72) but less influential (with a lower TLS value of 30), indicating that while being influential, it may not share as many references with other articles, possibly indicating the greater focus of the paper on a niche or specialised topic. While all the articles presented in Table 3 have a TLS value of 30 or higher, there are five articles in the list that have TC values in the range of 20–30, indicating that the majority of influential articles are not highly cited. This research also compiled a list of the top five articles which have very high TC values in the dataset (in the range of 77–310) but exhibited TLS values below 30 (refer to Table 4).

4.1.2. Evolution of EE research: funding opportunities

Using the threshold of 2, this research identified 28 distinct funding sponsors (Table 5). The funding sponsors span a wide range of organisations, including governmental bodies (24 sources, 90 documents), universities and HEIs (4 sources, 9 documents), non-governmental organisations (NGOs), and international programs (1 source, 2 documents), among others. These figures show that most EE funding comes from government bodies (e.g., the U.S., European nations, and China). Such concentration can skew EE research toward funders' short-term agendas, potentially narrowing the EE field's long-term goals. In particular, pan-European priorities may heavily steer research topics, methods, and collaborations — marginalising non-EU perspectives. Meanwhile, the nominal direct investment by universities reinforces dependence on external grants and leaves exploratory or community-based work under-resourced.

4.1.3. Evolution of EE research: author performance (co-authorship analysis)

To assess influential authors in EE, this study conducted co-authorship analysis using VOSviewer, employing bibliometric indicators such as h-index, publication number, TC, and TLS. The h-index reflects the impact and productivity of an author's work; a higher h-index signifies sustained influence, indicating authors who consistently produce well-cited research with significant field impact (Hirsch, 2005). Publication number measures productivity, where larger counts suggest active research engagement (Castillo-Vergara et al., 2018). Co-authorship links denote direct collaborative ties among authors, while TLS quantifies the strength of collaborative engagement (Costas & Bordons, 2007; Modak et al., 2020; Shah et al., 2020). Based on these criteria, Table 6 ranks the 15 most impactful authors by h-index (applying a threshold of $\geq$3), alongside their publication numbers, TC, links, TLS, and countries of institutions. Setting the h-index threshold at 3 ensured that relationships are recurrent and thus more significant. Additionally, this analysis generated Fig. 3, which visualises co-authorship clusters among these authors.

As shown in Table 6, authors with high h-indices typically exhibit high publication counts and TC within their networks. For instance, Mifsud, M. stands out as the leader in the field, boasting the highest h-index (6) and TC (466) numbers. Meanwhile, Jeronen, E. and Molthan-Hill, P. both have h-indices of 5, but there is a noticeable difference in their citation counts — 80 for Jeronen and 461 for Molthan-Hill. This difference could be due to several factors, such as the visibility or impact of their publications, varying citation practices across different subfields, or possibly the relative newness of Jeronen's work, which may not have had enough time to

Table 3
Articles identified from bibliographic coupling.

Authors	Title	TC	TLS
Tejedor et al. (2019)	Didactic Strategies to Promote Competencies in Sustainability	102	56
Wolff and Ehrström (2020)	Social sustainability and transformation in higher educational settings: A utopia or possibility?	28	56
Fuertes-Camacho et al. (2019)	Integrating sustainability into higher education curricula through the project method, a global learning strategy.	64	46
Expósito and Sánchez (2020)	Implementation of SDGs in university teaching: A course for professional development of teachers in education for sustainability for a transformative action.	29	39
Salovaara et al. (2020)	Sustainability science in education: analysis of master's programmes' curricula.	20	39
Türkoğlu (2019)	Opinions of preschool teachers and pre-service teachers on environmental education and environmental awareness for sustainable development in the preschool period.	24	35
Merritt et al. (2019)	Changes in pre-service teachers' values, sense of agency, motivation, and consumption practices: A case study of an education for sustainability course.	40	32
Holst et al. (2020)	Monitoring progress of change: Implementation of Education for Sustainable Development (ESD) within documents of the German education system.	21	31
García-Feijoo et al. (2020)	Systematic review of sustainable-development-goal deployment in business schools.	72	30

Table 4
Articles identified from bibliographic coupling -High TC but relatively low TLS.

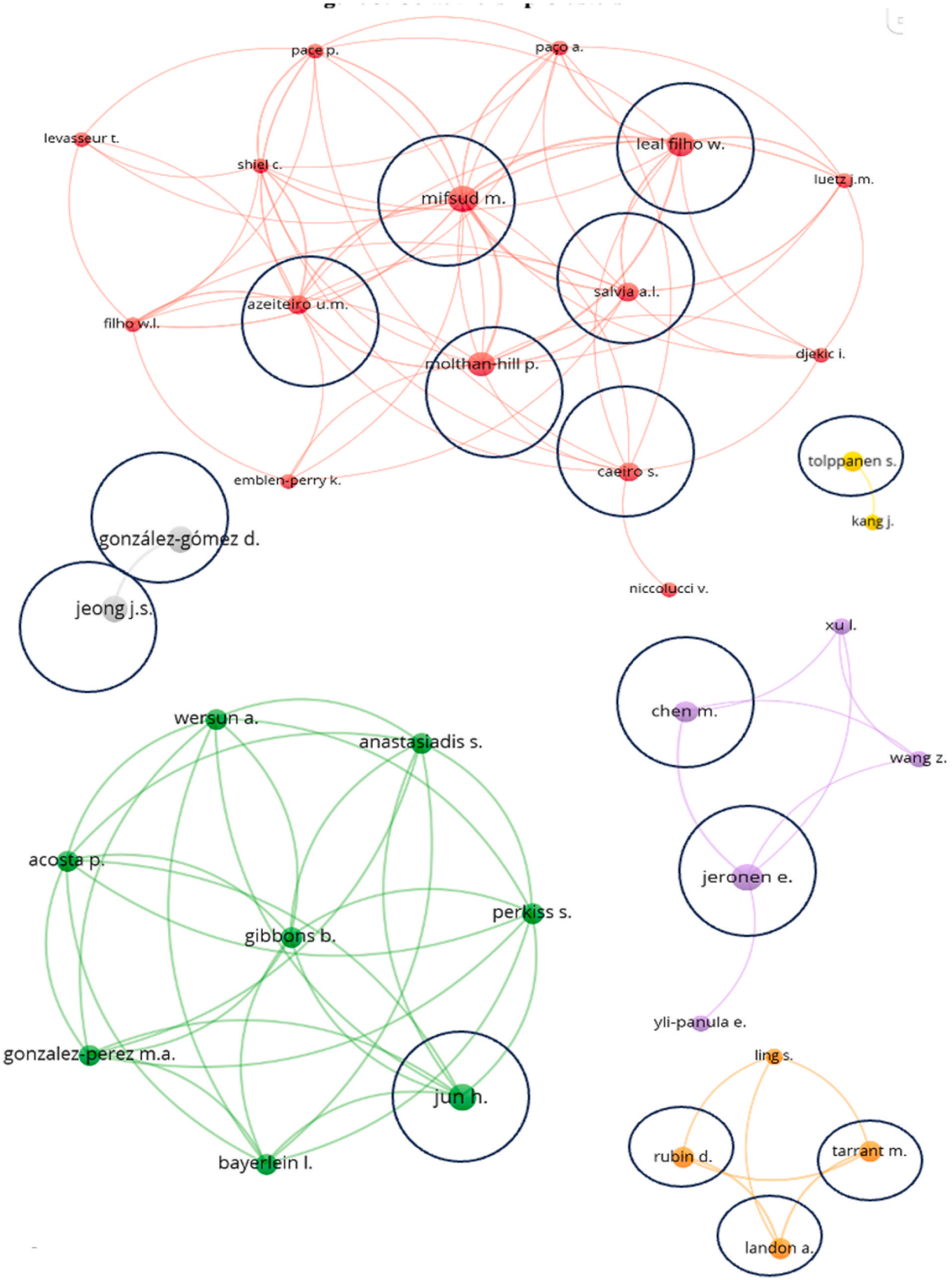
Author	Title	TC	TLS
Leal Filho et al. (2019)	Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack?	310	12
Žalėnienė and Pereira (2021).	Higher education for sustainability: A global perspective.	108	22
Boca and Saraçlı (2019)	Environmental education and student's perception, for sustainability.	91	16
Cordero et al. (2020).	The role of climate change education on individual lifetime carbon emissions.	81	22
Molthan-Hill et al. (2019)	Climate change education for universities: A conceptual framework from an international study.	77	5

Table 5
A list of funding sponsors.

Funding sponsor	Types of sponsors	Papers
European Commission	EU government	17
European Regional Development Fund	EU government	6
Ministerio de Ciencia, Innovación y Universidades	Spain government	6
Federación Española de Enfermedades Raras	Spain NGO	5
National Science Foundation	USA government	5
Fundação para a Ciência e a Tecnologia	Portugal government	4
National Office for Philosophy and Social Sciences	China government	4
Horizon 2020 Framework Programme	EU government	4
Ministero dell'Istruzione, dell'Università e della Ricerca	Italy government	3
Bundesministerium für Bildung und Forschung	Germany government	3
Ministry of Education of the People's Republic of China	China government	3
Harvard School of Engineering and Applied Sciences	USA, university	3
Erasmus+	EU government	3
Ministerio de Economía y Competitividad	Spain government	3
National Natural Science Foundation of China	China government	3
Ministerio de Ciencia e Innovación	Spain government	3
Plymouth University	UK university	2
Helsingin Yliopisto	Finland university	2
European Social Fund	EU government	2
Agencia Estatal de Investigación	Spain government	2
National Taiwan University	China university	2
Consejo Nacional de Ciencia y Tecnología	Mexico government	2
Council for Higher Education Accreditation	USA NGO	2
Gobierno de Aragón	Spain government	2
Horizon 2020	EU government	2
Japan Society for the Promotion of Science	Japanese government	2
Universidad de Granada	Spain university	2
European Cooperation in Science and Technology	EU government	2
Prince Mohammad Bin Fahd University	Saudi Arabia university	2

Table 6
15 most influential authors in the EE field.

Authors	H-Index	Publication No.	TC	Links	TLS	Countries of institutions
Mifsud M.	6	6	466	13	28	Malta
Molthan-Hill P.	5	5	461	12	19	UK
Jeronen E.	5	5	80	4	9	Finland
Leal Filho W.	4	5	435	10	18	UK & Germany
Azeiteiro U.M.	3	4	334	11	17	Portugal
Caeiro S.	3	3	311	9	9	Portugal
Salvia A.L.	3	3	82	9	14	Germany
González-Gómez D.	3	3	39	1	3	Spain
Jeong J.S.	3	3	39	1	3	Spain
Tolppanen S.	3	3	30	1	2	Finland
Chen M.	3	3	29	3	7	China
Jun H.	3	3	23	7	14	South Korea
Rubin D.	3	3	15	3	8	USA
Tarrant M.	3	3	15	3	8	USA
Landon A.	3	3	15	3	8	USA



(caption on next page)

Fig. 3. The Co-authorship Clusters.

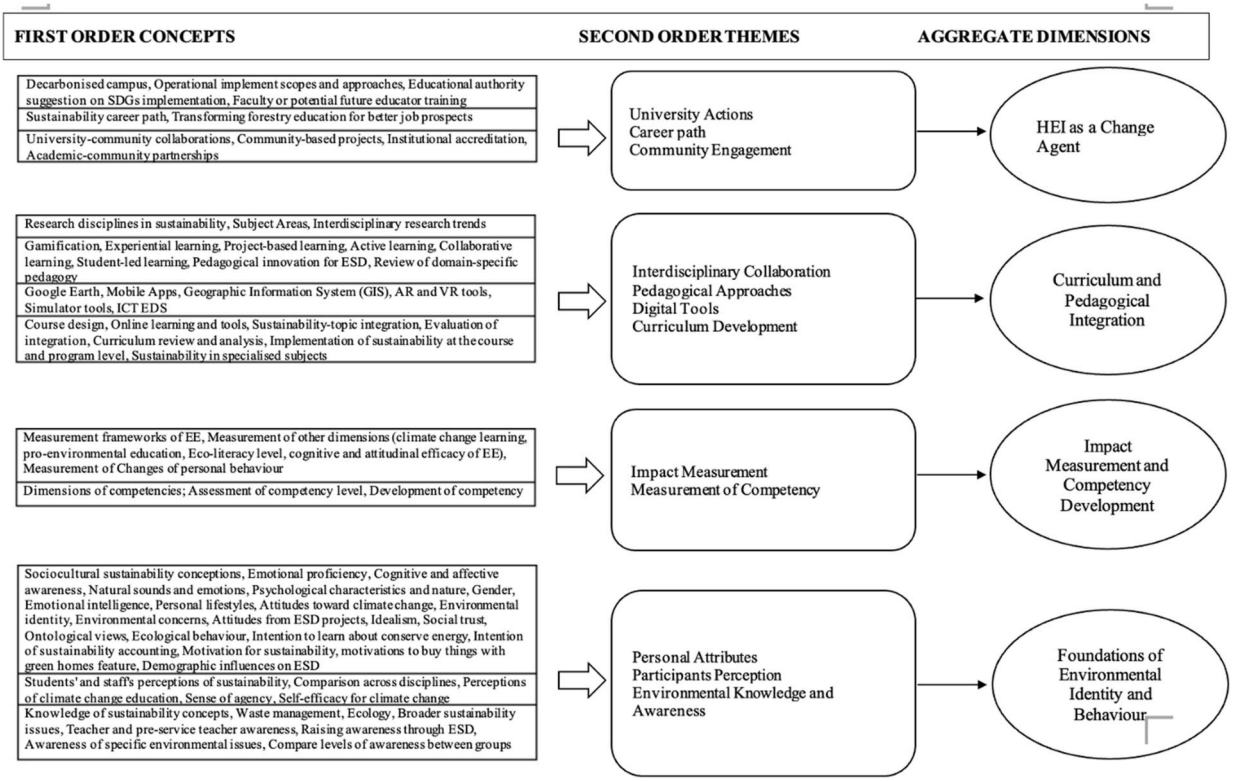


Fig. 4. Thematic Coding and Analysis Map.

accumulate as many citations as Molthan-Hill's publications.

Authors with high h-indices often exhibit strong TLS values (e.g., Mifsud M., TLS = 28; Molthan-Hill P., TLS = 19; Leal Filho W., TLS 18; Azeiteiro U.M., TLS = 17; and Salvia A.L., TLS = 14), indicating their centrality in co-authorship networks. This is reflected in Fig. 3, where the above-mentioned authors are central to the red cluster (15 authors). This suggests that, in this cluster, impactful authors (mostly from European countries) are often combining productivity with robust partnerships. Fig. 3 also presents other clusters in green (8 authors), purple (5 authors), orange (4 authors), grey (2 authors) and yellow (2 authors). Notably, high h-index authors such as González-Gómez D., Jeong J.S., and Tolppanen S. show minimal collaboration (they all have 1 link each, as shown in Table 6 and Fig. 3), which tends to limit their visibility within the broader scholarly community despite having multiple publications.

Geographically, the leading contributors are spread across Europe, Asia, and North America. Malta, represented by Mifsud M., leads in individual scholarly impact. The UK and Germany appear frequently, with authors like Molthan-Hill P., Leal Filho W., and Salvia A. L. contributing significantly, indicating strong institutional support for EE research in these regions. Portugal also emerges as a notable hub, with Azeiteiro U.M. and Caeiro S. consistently contributing to EE research. The presence of authors from Asia (e.g., China, South Korea) and the USA indicates growing global engagement, though often with lower citation impact or network strength.

4.2. *Thematic analysis: emerging themes*

To investigate RQ2 – "*What are the recent and future research trends in EE research?*", this research conducted the RTA, as explained in Section 3.3. The details of the coding structure are shown in Fig. 4. Initially, through the active engagement with the papers and several rounds of discussion, the research team identified initial codes, shown as first-order concepts in Fig. 4. Then, the team actively searched for patterns among the codes and collectively analysed their similarities and differences. This process resulted in the generation of second-order concepts, as illustrated in Fig. 4. For instance, the codes 'course design' and 'online learning and tools' are both related to the delivery approaches of EE, and thus were categorised into the code 'curriculum development'. The final stages of the RTA resulted in the formation of four aggregate dimensions, referred to as four themes in Fig. 4: 1) HEI as a change agent; 2) curriculum and pedagogical integration; 3) impact measurement and competency development; and 4) foundations of environmental identity and behaviour. The themes considered the theoretical meanings and connections among the second-order concepts. For instance, 'personal attributes', 'participants' perception', and 'environmental knowledge and awareness' represent deep personal factors and hidden elements which contribute to EE effectiveness. Accordingly, the theme 'foundations of environmental identity and behaviour' was

formed.

The following sub-sections present the analysis of the individual themes. For each theme, a definition of its meaning in the context of EE, along with an explanation of both historical perspective and emerging topics, has been provided. While all themes are important in the current study, theme 2 appears to be the most dominant. It is noted that the themes can be intertwined with each other, as they together present a comprehensive landscape of EE. Thus, this study also highlights the connections and nuances among the themes.

4.2.1. Theme 1: HEI as a change agent

Theme 1 is labelled as 'HEI as a change agent'. This means that HEIs play a crucial role in driving innovation, improving processes, and adapting to the evolving educational landscape. Among the papers reviewed, 35 contributed to this theme. From a historical perspective, findings reveal a series of "**University Actions**" that contribute to the achievement of the UN SDGs. These actions encompass sustainable management of university libraries, campus decarbonization, and the underlying values and motivations driving these efforts. Research under this theme also highlights how universities implement SDGs in their operations and their role in transforming the educational system. For example, the university community can participate in transformative institutional change through both top-down and bottom-up strategies, aimed at advancing the SDGs (Vázquez-Verdera et al., 2021), which is consistent with the historical view that HEI action can drive the EE processes. However, there is currently no systematic approach to these university actions, and therefore fostering open reflection and taking actions beyond curriculum delivery are crucial (Orhan et al., 2021).

This theme also highlights the potential of environmental sustainability as a viable "**Career Path**", which represents an emerging perspective in EE research. It includes research on transforming forestry education to enhance job prospects (Arunachalam & Pandey, 2019), with a focus on integrating environmental concerns into employability strategies. By attending sustainability-related courses, students can learn to design, prioritise, and evaluate actions that contribute to achieving their professional goals. The research also gathers alumni perspectives on pursuing careers in sustainability (Salovaara, 2022).

Furthermore, the most recent literature also indicates that universities play a critical role in "**Community Engagement**". Driven by institutional accreditation, they tend to initiate community-based projects as part of ESD (LeVasseur & Ciarcia, 2019). These collaborations typically involve a broad range of stakeholders, including academics, students, practitioners, NGOs, government bodies, entrepreneurs, and policymakers (Okada & Gray, 2023). Through such partnerships, students gain environmental-related work placements, universities receive accreditations and an opportunity to test their service-learning pedagogical approaches, academics get the opportunity to test models for academic development (e.g., the Quintuple Helix Model), and the community organisations, such as NGOs, achieve co-learning through university-community partnerships (Reeves, 2019). This extends the historical scope of HEIs from advancing EE inside a university to the broader community, which is beyond its usual purview.

4.2.2. Theme 2: curriculum and pedagogical integration

Theme 2 concerns 'curriculum and pedagogical integration', meaning EE combines different disciplines and teaching approaches together. It turned out to be a predominant theme with a significantly large number of papers (150 papers) contributing to this theme. Within this, the sub-theme "**Interdisciplinary Collaboration**" signifies an emerging trend in ESD, in contrast to the traditional EE approach that largely focused on one area, for example waste management. This further indicates that EE development draws upon the knowledge and skills from multiple academic and professional disciplines. As shown in Table A1.1 in the Appendix, out of 399 papers analysed, 205 papers were from various disciplines spanning across five main subject areas and a numbers of topics: Engineering and Technology (31 topics); Physical Sciences (6); Life Sciences (15); Social Sciences and Humanities (40); and Interdisciplinary (113). The result revealed a diverse landscape of research topics, with a notable emphasis on interdisciplinary collaboration and a broad representation of subjects. This suggests a growing interest in research that addresses complex, multifaceted challenges by drawing on insights from various fields, reflecting the interconnected nature of contemporary research endeavours.

To effectively integrate EE in the above-mentioned disciplines, many papers (Boca & Saraçlı, 2019; Leal Filho et al., 2019) have explored "**Pedagogical Approaches**". The commonly referenced methods include gamification and experiential learning, along with methods such as project-based learning also receiving significant attention. Other pedagogical methodologies or learning models such as WEARS (Wicked problem, Experiences, Available Resources, Solution), the RADEC (Read, Answer, Discuss, Explain and Create), and the Lived Experience of Climate Change, which incorporates a human dimension (from an environmental humanities perspective) into climate change education, are gaining prominence in EE. These methods have been tested in pilot studies or experiments under ESD in both conventional and online settings.

Apart from the mainstream research on pedagogical approaches, this study also finds that "**Digital Tools**" such as discussion forums, quizzes, worksheets, films, 'WikiRate', e-learning systems, Google Earth, mobile apps, Geographic Information Systems (GIS), Augmented Reality (AR), Virtual Reality (VR), and simulation are frequently used in sustainability education to enhance students' environmental awareness and overall learning experience (Tanveer et al., 2020). This represents the most recent focus of EE research, as it aligns with the rapid technological developments.

The literature under this theme also emphasises the significance of "**Curriculum Development**" in EE, which has been consistently studied historically and in recent articles. First, this paper finds that there are course design related conceptual frameworks and empirical applications that are proposed to guide the integration, e.g., 'EDUlab'. Secondly, the present study finds clear indications of the gradual inclusion of sustainability-related topics such as natural ecosystem, natural disasters and sustainable lifestyles, forest management, and green energy transitions in the curricula, mostly in disciplines such as (energy) engineering, English, agriculture, history education, food security, waste management and recycling, ocean literacy, leadership, urban planning, and humanities. Similarly, some studies investigated the different techniques, associated challenges, and potential solutions concerning the integration

of sustainability-related topics into curricula. The most recent studies also explored the sustainability-related pedagogical research, learning strategies, and student attitudes towards and commitment to sustainability.

4.2.3. Theme 3: impact measurement and competency development

Theme 3 is identified as the 'impact measurement and competency development', concerning the assessment of EE effectiveness. From a historical standpoint, the findings show that the studies concerning the **"Impact Measurement**" theme (24 papers) evaluated EE's broader impact, and cognitive and attitudinal efficacy in fostering socio-ecological resilience. It is an emerging trend that specifically examines the influence of EE on the humanistically-oriented personality of a specialist, and its impact on individual behavioural change, particularly with respect to sustainable consumption (e.g., food consumption). Specific measurement criteria include stress levels and climate anxiety in response to climate change learning, environmental literacy (e.g., knowledge, behaviours, and attitudes), sustainable development behaviours towards tourism destinations, students' ecological literacy levels, and pre-service teachers' preparedness for environmental education. For instance, Emblen-Perry (2022) proposed the Five Indicators framework to audit the effectiveness of ESG modules.

Most recently, in addition to the impact measurement, sustainability-related "**Competency Development**" has also garnered significant attention from researchers (27 papers explored this topic). They argued that to cultivate students as future sustainability change agents, they should be supported and encouraged to develop competencies such as normative and interpersonal skills; systems thinking; and anticipation, strategic planning, and implementation skills (Sá et al., 2022). Additionally, a number of studies frequently mentioned self-reliance, self-efficacy, responsible leadership, digital skills, green skills, and entrepreneurship skills as key learning outcomes of EE. Many of these sustainability-oriented skills and competencies are highly sought after by regional employers. Hence, it is crucial to educate professionals and individuals to develop these specialised skills through both formal and informal sustainable development education.

4.2.4. Theme 4: foundations of environmental identity and behaviour

Theme 4 explores deep reasons and factors connecting persons and their behaviour in the context of EE, labelled as 'foundations of environmental identity and behaviour'. As many as 74 papers contributed to this theme. Among the sub-themes, "**Personality Attributes**" is explored significantly in the mainstream research, including personality, emotions, values, and beliefs at the personal level, which are considered as the key determinants of pro-environmental behaviours. These attributes are influenced by demographic factors such as gender, academic affiliation, ethnicity, religion, emotional intelligence, lifestyle, and family education, and can significantly shape the attitudes of students and educators alike towards EE. The findings suggest that individuals' psychological, ideological, and ontological views can alter attitudes and perceptions of sustainability and climate change, thereby influencing their ecological behaviours and, as a result, shaping their environmental identity. For example, Komatsu et al. (2022) found that students' ontological views (whether independent or interdependent) influence their ecological behaviour and sustainability practices.

Similarly, "**Participant Perceptions**" of EE is another emerging sub-theme in the literature. Many scholars have explored the differences in perceptions of sustainability between multidisciplinary staff and students, emphasizing the importance of promoting a sense of agency among both staff and students. This approach aims to enhance students' and teachers' (e.g., pre-service teachers) sense of self-efficacy in relation to climate change action (Önal, 2020). Another sub-theme that emerged in our analysis is "**Environmental Knowledge and Awareness**", which shows a new aspect in the EE literature. Through engagement with EE, both environmental awareness and knowledge (e.g., waste management and ecology) can be acquired and enhanced. This research finds that there is a growing awareness of the dangers of pollution and its consequences for health, well-being, and productivity. For example, Wang et al. (2023) highlighted the importance of raising awareness through EE and international collaboration, using frameworks such as the Value-Belief-Norm Theory; while others compared awareness levels across different stakeholder groups such as students in medical, natural, and social sciences (e.g., Bernaciak et al., 2021).

4.2.5. Connections among the themes

The above findings show the dominant themes and sub-themes in EE research. Historically, studies have focused on specific areas of EE knowledge — such as ecology, waste management, and broader sustainability issues — or positioned universities as the primary drivers of EE initiatives. However, recent developments indicate a shift in focus. For example, interdisciplinary collaboration is gaining traction, reflecting a growing effort to integrate EE in teaching across academic disciplines. Additionally, university-level actions aimed at broader stakeholders, e.g., via community engagement initiatives, are receiving increasing attention in recent empirical research. Meanwhile, the advancement of technology has made digital tools an integral part of teaching, prompting new investigations into their impact.

It is noted that some elements of the themes can overlap. For example, theme 1 (i.e., HEI as a Change Agent) and theme 2 (i.e., Curriculum and Pedagogical Integration) both discuss university initiatives and curriculum design. However, for theme 1 related research, the unit of analysis is 'university' as institutions are believed to facilitate change and advance EE not only in the university but also in the broader community as well. The majority of the issues explored under theme 1 relate to university-level operations and strategies towards EE development. While in theme 2 studies, the focus is on the 'curriculum', a more micro-level exploration of the curriculum content design and effective delivery approaches. Thus, themes 1 and 2, although appearing to be overlapping in some elements, show the EE research from different levels and perspectives.

Furthermore, these themes/sub-themes can interact with each other. For instance, "University Actions" (sub-theme of theme 1), such as waste reduction projects, can raise "Environmental Knowledge and Awareness" (sub-theme of theme 4) at a personal level. Similarly, students' values and lifestyles ("Personal Attributes", sub-theme of theme 4) not only indicate their pro-environmental

behaviour, but also bring changes to the "Curriculum Development" (sub-theme of theme 2), especially under the scenarios of student-led learning and engagement. Through pedagogical approaches (sub-theme of theme 2), EE participants can learn new knowledge and skills, and in the long term, this can influence "Competency Development (sub-theme of theme 1). In theme 4, environmental identity is an important factor, including personal behaviour. It is possible that such identity can influence personal development and 'career paths' (sub-theme of theme 1). These examples demonstrate potential links among the themes, together presenting a holistic and dynamic landscape of EE research. Nevertheless, the current literature has not sufficiently explored the in-depth causes and effects or the interacting mechanisms among the themes. This can provide avenues for future research, details of which will be discussed in Section 5.

5. Discussion

This study highlighted the need for an in-depth, systematic, and interdisciplinary review of EE research by arguing that past literature reviews were incomprehensive as they either focused on specific topics and (or) regions or did not account for the emergence of recent trends (e.g., CCE, ESD) that developed in the last five years. Consequently, it set out to contribute to this research gap by positing two overarching research questions: a) How has EE research evolved across disciplines, and what are the key intellectual foundations? and b) What are the recent and future research trends in EE research? This section discusses the implications of the findings vis-à-vis the EE discipline (i.e., body of knowledge), practice, and future research.

5.1. Implications for intellectual foundation and knowledge production

As far as the intellectual foundation and knowledge production are concerned, the EE research has grown tremendously across the diversity of disciplines and has developed significant collaboration networks globally. This research work also sees some encouraging growth of government-industry-academia collaborations, supported by various funding opportunities, driving EE research. However, these collaboration networks remain heavily concentrated around leading authors and institutions, primarily based in the USA and Europe (UK, Spain, Germany, Portugal, Finland, and Malta; see Table 6). Representation from Asia is limited, with only one author each from South Korea and China included among the influential authors (as shown in Table 6). Fig. 3 illustrates six co-authorship networks, where influential authors are highlighted in circles. This indicates that not every author in large co-author groups (e.g., the green cluster) has a high impact, whereas smaller groups (i.e., grey, yellow, and orange clusters) include more influential authors. Influential authors tend to prefer close collaborations, possibly due to niche research focus, geographical proximity, or personal collaboration preferences.

Our analysis highlighted significant body of literature concerning EE, albeit in the garb of similar concepts such as sustainability, environmental science, environment conservation, ecological sustainability, ESD, and CCE and so on, have grown independently, mostly in sciences, that are largely unknown to researchers and educators in social sciences and humanities, and vice versa. Moreover, this literature is seldom acknowledged (or cited) and utilised, particularly by researchers and educators in social sciences and humanities, even though most of the underlying concepts of EE find their origins in the sciences. However, in contrast, our findings also showed that research concerning pivotal topics such as educator training, theoretical frameworks and concepts, or broad methodological tools applicable beyond the primary focus of the dataset are relatively more interdisciplinary as they are cited broadly across various research domains, indicating they may not be deeply tied to a specific discipline. This study also finds that the funding opportunities have improved but the researchers are largely underfunded (e.g., only 101 out of 399 papers received funding), highlighting the need for broader and more diverse support for EE research to enrich and enhance the interdisciplinary nature of research outcomes.

In summary, the majority of the knowledge production concerning EE, across disciplines, is largely concentrated in the US and Europe due to the collocation of leading authors, research networks, and the availability of greater funding opportunities. This uneven spread of intellectual capital, research networks, and resources globally is undermining HEIs' potential to play their part in accomplishing the SDGs goals, which is impossible without the meaningful contribution from HEIs from other parts of the world, particularly from the Asian and African continents. Moreover, much of the knowledge produced across disciplines remains within the field due to limited interdisciplinary research collaboration and dissemination, except for the knowledge related to educator training, methodological and pedagogical tools, and theoretical concepts and frameworks that are more widely shared across disciplines. This indicates an urgent need for developing more research linkages and funding avenues, both geographically and across disciplines, to promote a more global and interdisciplinary knowledge production and dissemination.

5.2. Implications for EE practice

Attention is now turned to the implications of the emerging themes identified in this study for EE practice. This study showed that the significance of EE is well established, and the extant research have broadly focused on strengthening our understanding of the criticality of the stakeholders (i.e., HEIs, students, teachers, governments, communities & society, etc.), systems and processes (i.e., curriculum development, pedagogical approaches, learning tools, competency development & measurement, and interdisciplinary collaborations, etc.), and the underlying issues affecting inefficiency of EE in HEIs (Sule & Greig, 2017; Durmuş & Kınacı, 2021; Leal Filho et al., 2021, 2022, 2023). However, the existing research points to a considerable research gap concerning the strategic prioritisation and effective implementation of EE, especially from an educator's perspective.

This paper argues that educators are the cornerstone of the strategic prioritisation (i.e., responsible for policy development and

monitoring at a higher level) and effective implementation of EE in the higher education context (i.e., implementation at both the university and school/department levels). Yet, the focus of the bulk of research concerning EE in HEIs is either "learner-centric" or "institution-centric". Thus, more "educator-centric" research is needed to understand the current preparedness (e.g., awareness of current environmental issues), the adequacy of training (e.g., informed approaches to teach), and the availability of support systems for capacity building in academics engaged in EE (e.g., available financial support and opportunities for continuous professional development). The growing relevance of EE for students, increased focus of HEIs (especially business schools) to include it as part of their curriculum and given its novelty in the context of mainstream business studies, it is natural for educators to face several challenges at every stage, from designing a course to delivering it and measuring the participants' learning experience; however, research on these issues is largely absent in the existing literature.

The literature emphasises that educators, through pedagogical innovations, must focus on developing personal attributes/competences in students, leading to the formation of environmental identity and behaviour. Even though research indicates that educators often lack environmental competencies and possess minimal knowledge about the impacts of various climate change mitigation actions (Merritt et al., 2019; Tolppanen et al., 2021; Türkoğlu, 2019), issues concerning educators' environmental literacy have not yet fully explored in the literature, hindering educators' ability to foster similar competencies in students (Leal Filho et al., 2021). Thus, the present study argues that HEIs should take leadership in developing clear guidance and support systems for EE educators such as funding sources, institutional frameworks, and training and professional development opportunities to not only enhance the effectiveness of EE but also promote the cultivation of critical competencies like sustainability literacy and active environmental stewardship among students. Considering the evolving nature of EE as a field of study, a comprehensive understanding of how EE educators can stay updated on emerging concepts and develop the skills needed to make informed pedagogical decisions, particularly in interdisciplinary contexts, and in what ways HEIs can provide requisite training, support, and professional development opportunities for educators becomes ever so critical.

5.3. Implications for EE research and future direction

As analysed in Section 4.2.5. themes interact with each other. However, the detailed interacting mechanisms remain unclear in the current literature. Thus, future research examining the relationships between the themes/sub-themes can provide a dynamic and systematic understanding of EE. Our study also identifies the potential research avenues and RQs for each sub-theme, a summary of which is provided in Table A1.2 in the Appendix. In addition, each recommended research area has been categorised, on the basis of time horizon and potential impact, as short-term or long-term and low-impact or high-impact. Specifically, short-term refers to research areas that are associated with emerging issues in EE or suggested by other researchers as urgent. Long-term refers to research areas that are time-consuming and require extensive data collection and analysis. Low-impact areas are mainly applied research, whereas high-impact research areas require theory building, which can significantly fill in research gaps that are critical to advancing the EE field.

Under the theme "HEI as a Change Agent", prior studies highlighted our limited understanding of the potential avenues to institutionalise faculty development and exposure to EE (Muldrow et al., 2019). It is highlighted that there is an urgent need (short-term) to understand educator training, as well as the collaborative role of HEIs in terms of how they diffuse EE knowledge to local communities through community-based projects (Muldrow et al., 2019). Particularly, more research is needed to enhance our understanding of how HEIs can devise policies that promote an integrated approach, across departments, to community engagement, leading to the development of efficient community engagement models (LeVasseur & Ciarcia, 2019; Reeves, 2019). This can be further extended to more research on university-government-community collaboration to advance EE (long-term). Another research area, examining the impact of EE on students' career paths and development of ways to measure that impact, can further extend the scope of EE research vis-a-vis its effectiveness (low-impact).

Similarly, prior studies identified under the theme "Curriculum and Pedagogical Integration" highlighted the critical role of pedagogical innovations (e.g., experiential methods such as embodied learning, service learning, co-inquiry, etc.) in competence development in students. However, this area is relatively underexplored, and our limited understanding of the development and adoption of innovative pedagogies is undermining the effectiveness of EE in HEIs. Recent advancements in artificial intelligence (AI) and other technological tools, such as virtual augmented reality (VAR), provide significant avenues that can be explored to develop innovative pedagogies for effective delivery of EE (Tanveer et al., 2020). Thus, future studies can endeavour to fill this gap significantly (high-impact). With regards to EE curriculum, this study finds that carbon literacy, renewable energy, and waste management are in the spotlight, whereas researchers have paid less attention to the integration and teaching of emerging topics such as the circular economy, which needs to be explored in the short term (Wrase et al., 2023). In addition, the authors argue that the lack of understanding of ever-changing curricula and pedagogical needs with respect to different study levels (e.g., for undergraduate, and postgraduate programmes), from both the educators' and learners' perspectives, is even more pronounced that offers a potential avenue for future research (high-impact).

A process-oriented framework on how to incorporate new subjects in EE can be developed in the long term. As previously highlighted, EE is developing into an interdisciplinary field spanning across disciplines such as urban planning, agriculture, engineering, and business management, among others. Prior studies indicate a lack of experiential, interdisciplinary, collaborative, and critical educational plans and projects with respect to EE (e.g., Lorente-Echeverría et al., 2022; Reeves, 2019). Accordingly, future studies can usefully explore co-learning classes in a range of disciplines, with a stronger focus on aspects such as classroom dynamics, learning outcomes, and actions that result in effective learning. The impact of such studies can be significantly high for EE practice. Furthermore, although scores of digital tools have been adopted in the EE context, the impact of emerging new technologies such as AI

on EE needs a comprehensive investigation in the short term.

Studies under the "Impact Measurement and Competency Development" theme largely explored the learner-centric impact measurement and competency development issues, except a few studies that highlighted the need for professional development programmes for educators on a continuous basis (Mavuso et al., 2022). However, there is a gap in the literature examining the determinants of EE success from the educators' perspective (Anastasiadis et al., 2021). Future studies can significantly contribute to filling this gap by developing systematic studies aimed at enhancing our understanding of educators' challenges and developing measurements to evaluate their effectiveness (high-impact). Whereas, with regards to competency development, research linking EE to leadership practices for tackling contemporary environmental problems (e.g., climate change) is still limited (Molthan-Hill & Blaj-Ward, 2022). There also seems to be a significant inclination of scholars towards certain methods, survey questionnaires, for example, while exploring EE-related issues (Expósito & Sánchez, 2020; Wrase et al., 2023). Future studies can fill this gap by developing more qualitative and longitudinal studies combining different sources of data, including programmes data, in-depth interpretation of individual opinions, reflections on practice, and evidence from students' learning, etc. to explore the leadership, digital competency, social empowerment, and impact measurement issues related to EE. This may involve more data collection to capture the evolving needs of educators vis-à-vis competency development for EE (long-term).

Finally, students' contextual characteristics significantly influence their participation in EE courses, suggesting that their personal attributes are closely linked to the theme 'Foundations of Environmental Identity and Behaviour'. The interaction between attitudes and pro-environmental behaviours is addressed (Molthan-Hill et al., 2019), whereas there is still a gap in how knowledge can lead to climate action and large-scale changes. In the short term, studies can involve educators' views on such climate action-related topics. Other macro-level factors (e.g., regulations, culture, norms & values, etc.) are not explored in the current literature, barring a few comparative studies (e.g., Boca & Saraçlı, 2019) evaluating EE performance in different countries and cultural contexts. In the long term, studies can fill this gap as regulations on decarbonization, culture and norms, both at the national and organisational level, and technological advancements can influence EE practices. Other studies, although relatively low-impact, in relation to educators' motivation and individual perspective on effective EE approach, can contribute to the understanding of environmental knowledge and awareness.

6. Conclusion

With an emphasis on the UN SDGs, there is a growing trend of HEIs implementing the concept of sustainability in their curriculum. Accordingly, the topic of EE has drawn increasingly more attention in terms of the determinant factors, pedagogy approaches and impact. Nevertheless, the bodies of literature are fragmented across various disciplines, and despite the growing attention of scholars towards the interdisciplinary nature of the EE field, there is no systematic understanding of the themes and trends of the EE research. This study attempted to fill this research gap by conducting an interdisciplinary literature review; however, there is a greater need for interdisciplinary collaborative knowledge production and dissemination, and researchers, funding bodies, HEIs, governments, and other relevant institutions should collectively promote such endeavours.

Based on our findings, first, this article provided an up-to-date landscape of the EE research, including the most cited articles, the most influential authors and their collaboration networks, and the countries and regions which are most active in EE research production. Through this, a map of academic collaboration networks has been generated to advance the understanding of the dynamic structure of this field. It has been observed that the intellectual centres, research networks, knowledge production, and funding resources are largely concentrated in the US and Europe, arguably due to their strong policy frameworks, funding, academic infrastructure, and cultural emphasis on sustainability. Other factors such as niche research focus, geographical proximity, and personal collaboration preferences of the authors, equally limit the spread of EE research globally. This is also reflected in the location and the close collaboration networks of the most influential authors in the field. On the contrary, there is limited participation of the HEIs from the other parts of the world in the broader EE field, possibly due to resource limitations and other competing priorities. However, for EE to thrive, there is a need for concerted effort to expand and strengthen the research networks and funding avenues to lesser-represented parts of the world, which can be achieved through facilitating research exchange opportunities among the HEIs globally.

Second, thematic analysis identified four predominant themes - namely, HEI as a change agent, curriculum and pedagogical integration, impact measurement and competency development, and foundations of environmental identity and behaviour and suggested future research avenues. The EE research has progressed considerably around all identified themes, however, the bulk of research concerning EE in HEIs is either "learner-centric" or "institution-centric". So, this study advocates for more "educator-centric" research going forward, including training adequacy and capacity-building mechanisms, as a limited understanding of these issues will hamper the effectiveness of HEIs in EE delivery. Educator-centric research is required to understand current preparedness, training, and support systems and to enhance our understanding of the macro-level factors influencing EE practices (e.g., cultural norms and regulations, etc.).

Third, findings highlight the integration of diverse disciplines (e.g., social sciences, engineering, physical sciences), albeit limited, into evolving EE literature, indicating interdisciplinary research on EE has more potential to find practical solutions to complex problems. Among the identified disciplines, social sciences and humanities, and engineering showed more integration than physical and life sciences. This unbalanced integration of disciplines into EE research may be because the former have flexible curricula and learner-centric approaches that make them ideal for embedding EE, unlike disciplines requiring specialised technical infrastructure. Nevertheless, more interdisciplinary integration should be promoted, as most of the content included in the EE curriculum originates from several science-based disciplines.

Finally, the current study has some limitations. For instance, it included only open-access articles; as a result, some influential

studies published in subscription-based journals may have been excluded, potentially limiting the comprehensiveness and representativeness of the findings. Future research should, however, in our view, utilise a variety of data sources and methodologies, and include more longitudinal work that has been, hitherto, a glaring limitation in the extant literature.

CRediT authorship contribution statement

Songdi Li: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zheng Liu:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Varun Chaturbhuj Tripathi:** Writing – review & editing, Writing – original draft. **Mohamed Ashmel Mohamed Hashim:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1.1
Interdisciplinary studies in EE

Discipline	Topics
Engineering & Technology	Engineering construction; Sustainable manufacturing and construction fields; Environmental engineering; Aerospace engineering and avionics; Biomedical engineering and bioinformatics; Chemical engineering and materials science; Civil engineering and infrastructure; Computer science and information technology; Electrical engineering and electronics; Mechanical engineering and mechatronics; Mining engineering and mineral processing; Nuclear engineering and radiological sciences; Optical engineering and photonics; Robotics and artificial intelligence; Software engineering and systems design; Telecommunications and network engineering; Textile engineering and fashion technology; Transportation engineering and logistics; Urban engineering and smart cities; Structural engineering and architecture; 3D printing and additive manufacturing; Augmented reality and virtual reality; Blockchain technology and cryptocurrencies; Cybersecurity and information assurance; Internet of Things (IoT) and smart devices; Machine learning and data mining; Software development and programming
Physical Sciences	Physics; Atmospheric Sciences; Earth and planetary sciences; Meteorology and atmospheric sciences; Materials science and nanotechnology; Mathematics and statistical sciences; Sports science and physical education
Life Sciences	Biology; Biomimicry and architecture; Health profession education/medical program; Dental education; Geo-cultural heritage; Botanical education; Nutrition and dietetic education; Environmental humanities; Earth science education; Marine zoology education; Conservation biology and biodiversity; Genetics and genomics; Molecular biology and biotechnology; Plant sciences and botany; Virology and infectious diseases; Wildlife ecology and conservation; Veterinary medicine and animal health
Social Sciences & Humanities	Humanities and sciences; Education; Tourism; Business, engineering & management; Real estate and facility management; Eco-linguistics/English; New environmental media; Outdoor adventure education; Earth system sciences and arts; Arts and design; Landscape architecture; National parks and protected areas studies; Innovation, entrepreneurship, and strategy; Political ecology; Liberal arts; Design education; Geography; Nursing; Early childhood education and care; Language teacher education; Media education; Female learning, scientific and humanities; Urban planning; Ecology education; Humanistic orientation of personality; Earth and environmental sciences; Geography education; Linguistics and multilingual education; Media studies and communication; Performing arts and cultural studies; Philosophy and ethics of science; Psychology and cognitive sciences; Sociology and urban studies; Tourism and hospitality management
Interdisciplinary	Sustainability, natural, and social science; Renewable energy and sustainability; Science, technology, engineering, and mathematics (STEM); Integrating the arts with science, technology, engineering, and maths; Science, technology, and business; Digital arts and technology; Urban ecology and green infrastructure; Sustainable urban planning; Public health and environmental health sciences; Finance and sustainable investment; Ecology and environmental sciences; Toxicology and environmental health; Water science and hydrology; Wildlife ecology and conservation; Astronomy and space sciences

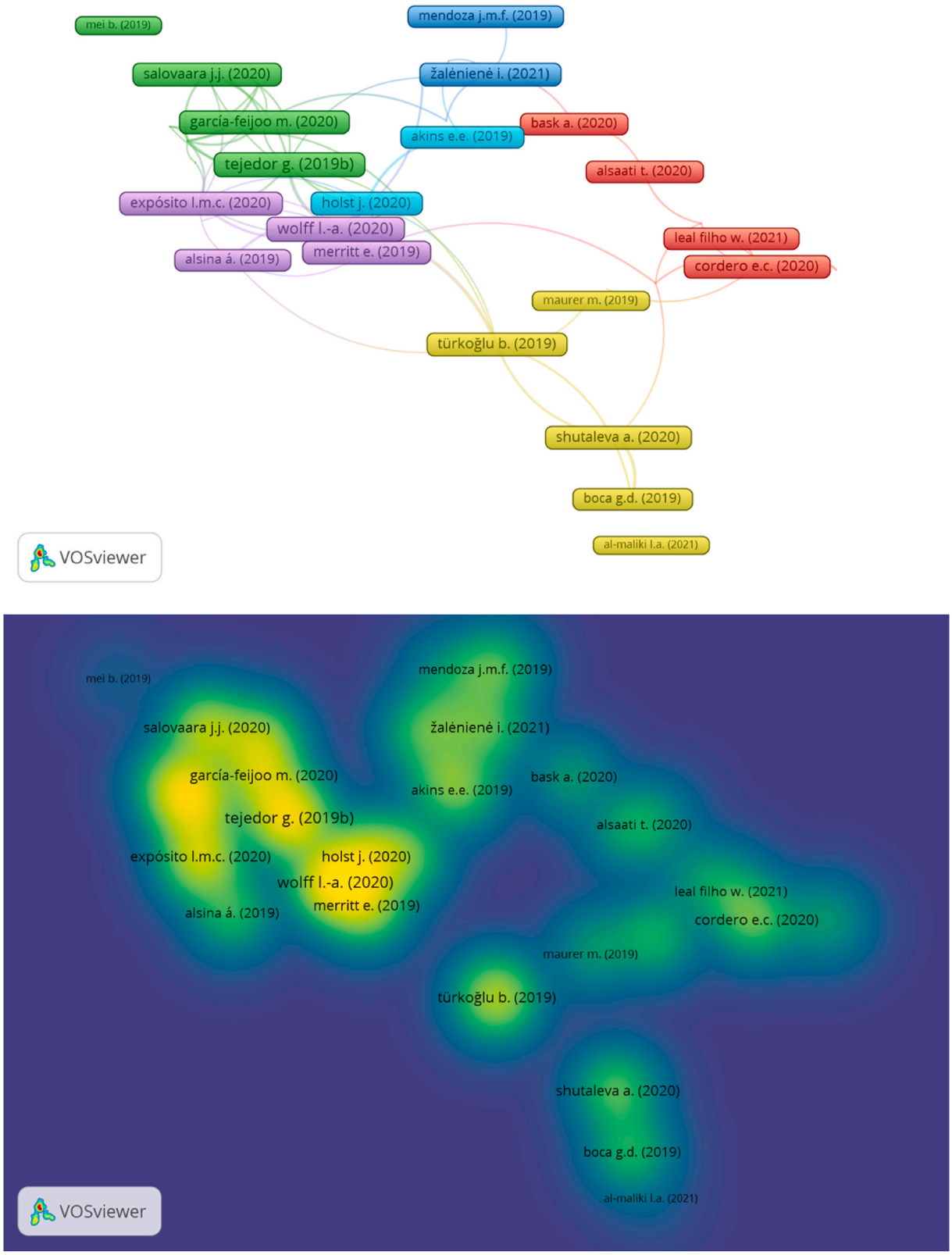


Fig. A1.1. Bibliographic coupling network and its density heat map

Notes: The size of nodes depicts the relative number of citations received by an EE article, and the link between nodes depicts the similarity of

highly cited EE articles, whereas the closeness of the nodes and various colours depict the collaboration networks of highly cited and influential authors.

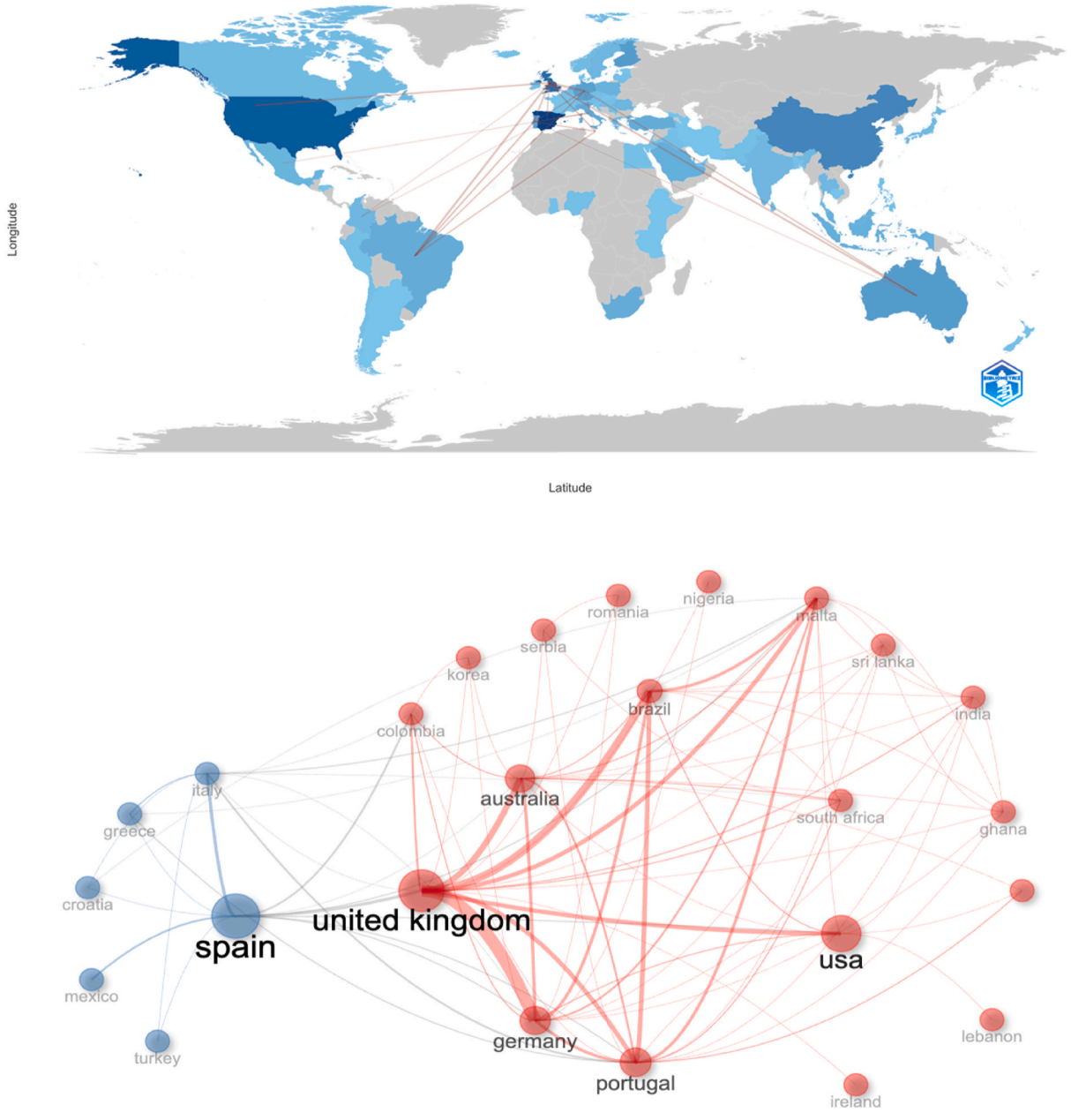


Fig. A1.2. Collaboration network across nations

The above figure depicts the country collaboration network in EE research. It presents two primary clusters of international collaboration (red and blue clusters). The United Kingdom (UK) stands out as a central participant, connecting with extensive research partnerships. It collaborates closely with Germany, Brazil, Australia, and Portugal, demonstrating strong ties of collaboration within Europe (as evidenced by the thick lines between nodes) and extending into other regions such as Asia, the Middle East, and Africa. This widespread collaboration highlights the UK's pivotal role in the field of EE research. The blue cluster further demonstrates the intra-European dynamics, revealing a mix of strong and weaker connections, where countries like Italy, Greece, and Croatia form a distinct subgroup centred around Spain. Spain, in particular, acts as a bridge in the network, linking countries like Italy, the UK, Colombia, and Mexico, thus facilitating a broader exchange of knowledge and research. Cross-Atlantic ties are also evident, particularly between the UK and the USA. Moreover, the collaboration between Portugal and Brazil highlights the impact of shared linguistic and cultural backgrounds in fostering international research partnerships.

Table A1.2
Themes, sub-themes, future research directions, and suggested research questions

Themes	Sub-themes	Future research directions	Suggested RQs
1. HEI as a Change Agent	- University Actions	- Institutionalization of educator' training (short-term)	- How to institutionalise faculty development and exposure to sustainability education?
	- Community Engagement	- University-community collaboration (short-term) - University-industry-government collaboration (long-term)	- What are the ways through which University-community collaboration can be promoted or enhanced? - How can university work with industry in EE? - What is the role of government in EE? - How can university, industry and government collaborate to promote EE?
	- Career paths	- Detailed measurement (low-impact)	- What is the quantifiable impact of EE on students' career paths?
2. Curriculum and pedagogical integration	- Pedagogical Approaches	- Pedagogical innovation (high-impact)	- What are the new approaches in EE to empower students with sustainability knowledge and action?
	- Curriculum Development	- Emerging themes e.g., circular economy (short-term) - Process-oriented framework (long-term)	- How can emerging topics be integrated in EE? - How can EE curriculum incorporate rapid changes of renewable energy? - What are the priorities across different levels of EE (e.g., undergraduate/postgraduate) - How can EE curriculum be designed, developed, and delivered?
	-Interdisciplinary Collaboration	- Interdisciplinary study, collaborative learning and co-learning (high-impact)	- How can EE be delivered differently in different disciplines? - How can EE be delivered through the collaboration among different disciplines? - Can co-learning results in better EE knowledge development?
	- Role of Digital Tools	- Impact of new digital tools on EE (short-term)	- How can digital technologies such as AI affect EE?
3. Impact measurement and competency development	- Impact Measurement	- Develop systematic measurement indicators (high-impact) - Develop long-term measurement (high-impact)	- How to measure the effectiveness of EE at individual/organizational levels in the short/long terms?
	- Competency Development	- Long-term leadership/competency (long-term)	- How can individuals develop leadership during and after the EE programmes? - What is the relationship between digital competency and EE performance? - What is the impact of EE knowledge on individual behavioural changes?
4. Foundations of environmental identity and behaviour	- Personal Attributes	- Macro-level factors (long-term) - Cross-country comparison (long-term) - Educators' view (short-term)	- How does technological advancement affect EE? - How do regulations and policies affect EE? - How does national culture affect EE? - How do educators' attitudes/experiences affect EE?
	- Environmental knowledge and awareness	- Motivation of educator EE training (low-impact) - Individual learning process, and transformation through EE training (low-impact)	- What drives current teachers to participate in EE? - How is knowledge created and shared during EE? - From an individual perspective, what is the most effective approach to engage with EE?

Data availability

Data will be made available on request.

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