Article

Research of Education for Sustainable Development: Understanding New Emerging Trends and Issues after SDG 4

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ABSTRACT

Background: Current frameworks for education for sustainable development (ESD) follow the guidelines of the Sustainable Development Goals (SDGs) proposed by the United Nations in 2015, with particular attention to SDG 4, "Quality Education". As we approach the deadline set by the 2030 Agenda, a systematic review for what has been accomplished in ESD is required to facilitate quality education for all going forward.

Methods: We accumulated 571 recent publications (from 2016 to 2022) and performed a review to identify new trends and issues in ESD.

Results: The number of ESD publications has gradually increased since 2016 despite the impact of the COVID-19 pandemic on educational systems worldwide. The publications are not evenly distributed among regions and countries, implying an inconsistency in ESD progress and achievement across the globe. We identify five major educational issues in recent publications and characterize them over time and world regions. These emerging themes can serve as critical reference for fundamental-to-national ESD reform for decision makers, especially for those countries and regions with few publications. Our analysis suggests the introduction of the SDG framework in 2015 widened the scope of ESD and raised awareness of the interconnections between ESD and other socioeconomic domains (other SDGs), while ESD and water (SDGs 6 and 14) may be neglected subjects.

Conclusions: This study serves as an important step in organizing the developing trends of ESD research in the context of the SDGs and provides pivotal reference for decision makers and educators furthering SDG 4 targets and indicators.

KEYWORDS: education; quality education; sustainable development; SDG 4

ABBREVIATIONS

ESD, education for sustainable development; MDGs, millennium development goals; SDGs, sustainable development goals; UN, United Nations

INTRODUCTION

The role that education plays in sustainable development has been widely acknowledged for the past few decades. In 1972, education was formally recognized for its important influence in promoting protection of natural spaces and conservation at the Stockholm Conference [1,2]. Standing on the importance of education for natural protection, environmental education around the world has evolved with no controversy or politicization to deal with environmental degradation and its associated social and economic ramifications [3]. Higher education institutions have since responded by integrating environmental education and education for sustainable development (ESD) into their systems [4], though the two may differ in terms of approach and priorities [5]. Over the last two decades in particular, there has been a growing global consensus under the purview of the United Nations (UN) regarding the importance of ESD in empowering students and promoting sustainability to address various environmental, social, and economic challenges [6]. At the same time, ESD has been increasingly incorporated into global policy initiatives by governmental institutions. The UN's launch of "Decade of Education for Sustainable Development" in 2004 serves as an excellent example, aiming to integrate concepts and principles of sustainable development into both formal and informal education [7]. Broadly speaking, it has become widely agreed upon that ESD provides the knowledge and approaches required to tackle complex situations and move society towards sustainable development [8]. Moreover, schools and universities are expected to transform and adapt their functions and governance in response to the changing global issues of this century [9].

With ESD gaining increased attention, relevant research has been growing over the past two decades accordingly [10]. Many publications have reviewed the trends of ESD and organized achievements, educational issues, and practical challenges at regional and global scales [11–14]. However, as the current agenda of ESD is primarily focused on the Sustainable Development Goals (SDGs), which were created by the UN in 2015 as a successor to the Millennium Development Goals (MDGs) [15], the newest major achievements and issues emerging remain unclear. As SDG 4, "Quality Education", demonstrates a wider scope than its predecessor in its emphasis of inclusive education, lifelong learning, and reducing inequalities [16,17], we may observe new trends in ESD research following the formulation of the SDGs.

After the passage of SDG 4, most review studies have focused on certain aspects of ESD or SDG 4 targets and indicators. For example, through

literature review and content analysis, previous efforts have conceptualized major achievements and developing trends in the fields of entrepreneurial education [18], engineering education [19], chemistry education [20], architectural education [21], learning environments [22], and core sustainable competency [23]. These important studies also point out potential challenges that urgently need to be addressed in order to implement ESD more effectively. Nonetheless, as a whole, the evolution of ESD research bodies since the formulation of SDGs remains unclear. Some pioneering research works have performed bibliometric reviews of literature to provide a better understanding of the ESD domain [7,24], but the publication year range of ESD research included in these studies mostly falls into the period prior to the formation of the SDGs. As we have surpassed the halfway point to the 2030 Agenda deadline, a more up-to-date systematic review is required to provide a clear picture of new emerging trends and issues following the SDGs' creation. Moreover, because of the nature and framework of the SDGs, there is a growing body of literature focused on the interrelationships among the 17 global goals [25,26]. This unique trend of academic publications, with ESD being one of the primary objectives, needs to be considered given that it is not commonly seen prior to 2015. Furthermore, the knowledge gap may be more pronounced as a result of the COVID-19 pandemic, which has resulted in a pause to many education systems around the world beginning in early 2020 [27]. Understanding major achievements and issues as a whole in ESD after the formation of the SDGs is needed to provide a critical reference for decision makers seeking to formulate better policies on quality education for all.

To bridge this current knowledge gap in ESD research, we perform a meta-analysis, synthesizing 571 recent ESD papers with publication years ranging from 2016 to 2022, identifying major research trends and issues in ESD since the formulation of the SDGs. Specifically, we aim to address the following research objectives: (1) to investigate how the number of ESD publications has changed in the years following the creation of the SDGs, (2) to identify the global distribution of the ESD papers, (3) to characterize the major topics or issues that recent ESD publications have addressed (as well as resolving the emerging issues over time and world regions), and (4) to reveal which journal includes the most records on the subject and which papers accumulate the highest number of citations. Our work can serve a critical review for recent ESD publications and achievements from a global perspective, capture unique emerging trends and issues of ESD literature following the SDGs, and act as an important reference for a more inclusive and successful ESD framework, particularly as the SDGs' target year of 2030 is quickly approaching.

MATERIALS AND METHODS

To collect data on recent ESD research works, including both papers with ESD as a sole focus and papers with ESD as one of their objectives, we

searched for literature in the Web of Science and Google Scholar database in June of 2023. In the Web of Science search engine, keywords used were: [education OR quality education] and [sustainability OR sustainable development OR sustainable development goals] and [teaching OR learning OR skill OR training OR school OR college OR university] in Title [28] and with publication year ranging from 2016 to 2022 (after the formulation of the SDGs). As the SDGs were proposed in September of 2015, we excluded papers published in or before that year. We accumulated 373 papers from this search after removing unwanted document types (e.g., conference papers, data papers, and editorial materials). These papers generally had ESD as sole focus. As we aimed to review other important ESD papers, including those where ESD is one of the main topics or issues addressed, we used the Google Scholar database to expand our search. Keywords used were: [education OR quality education OR teaching OR learning OR training OR school OR University] and [sustainability OR sustainable development OR sustainable development goals]. In total we conducted 21 searches. In each combination of keyword searches, we set publication years as 2016 to 2022 and downloaded all literature through the tenth page of search results (downloads of the same record was avoided by clearing cookies) before moving on to the next search. These steps in Google Scholar accumulated 631 papers, many of which address SDGs with ESD as one of the core focuses. Our final database included 571 papers after screening all initial records (Figure 1).

We recorded general information from each paper, including title, publication year, journal, accumulated citations as of February 20th, 2024 (the period of manuscript revision) in the Google Scholar database, country and continent in which educational events took place, scale of the educational topic, interactions with other SDGs (if applicable), and whether or not the COVID-19 pandemic was mentioned. Some papers did not mention the country of origin for educational events because of a lack of applicability (e.g., a paper discussing general definition of ESD). In this case, we assigned these publications the country with which the first author was affiliated.

Moreover, through a systematic review, we identified five major issues that recent ESD studies address: (1) Education, Pedagogy, and Learning; (2) Developing Trends of Educational Institutions; (3) Industry-Academia Collaboration and Out-of-School Education; (4) Educational Policy and Governmental Institutions; and (5) SDG 4 Targets, Indicators, and Achievements. We defined and introduced these issues in detail in the Result section. We categorized each paper into one of the five key issues based on its topic and content. In the event a paper covered more than two educational issues, we selected the most dominant one. Finally, we utilized ArcGIS Pro (Esri, version 3.0) and R (Version 4.1.1) for descriptive analysis and data visualization.
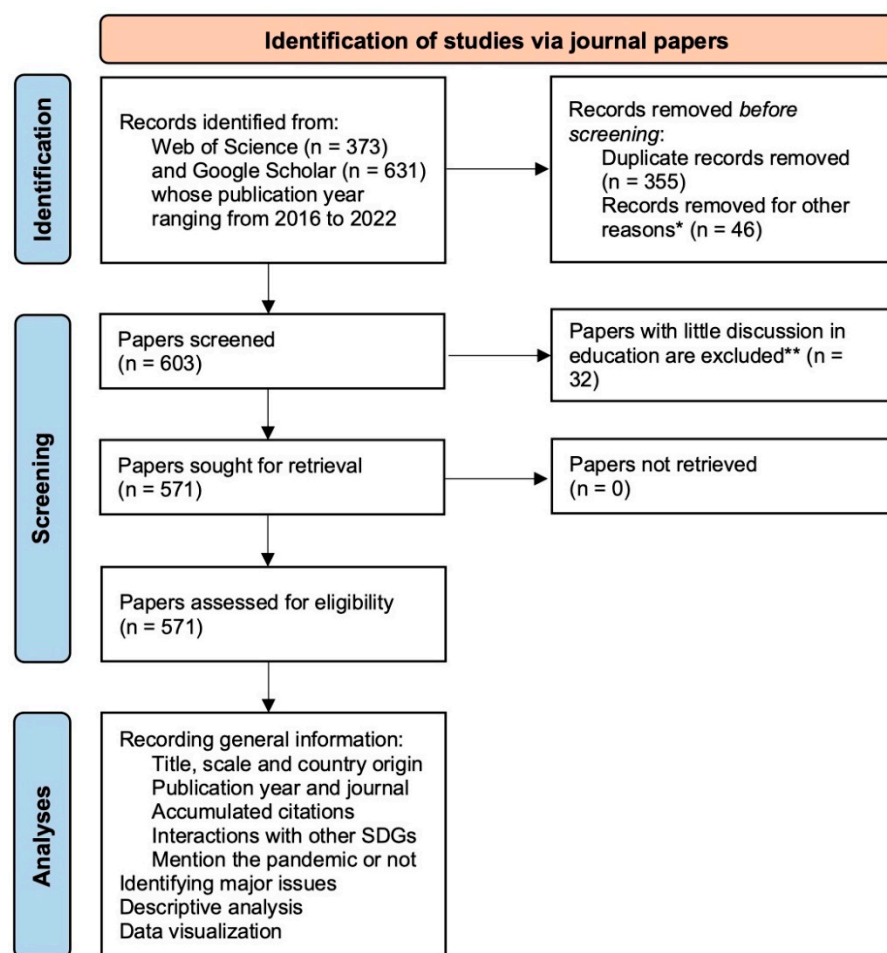
Figure 1. The flow diagram depicts the process of this study. Records were obtained from academic journals, resulting in 571 total papers after screening. Analyses included data processing and statistical analyses. This figure is based on the template of Prisma Flow Diagram [29] under the terms of the Creative Commons Attribution License. (*: other reasons included papers not having an English version and papers only mentioning sustainability or sustainable development, but not education; **: papers were excluded because education for sustainable development is not one of the main topics being addressed).

RESULTS

Descriptive Analysis of the Recent ESD Paper

The number of recent ESD publications has generally increased since 2016 (Figure 2), regardless of the relatively high production from the journal *Sustainability* (see Supplementary Figure S1). Among the 571 ESD papers that we have cited, the journal *Sustainability* has the highest number of publications, followed by the *Journal of Cleaner Production, International Journal of Sustainability in Higher Education, Environmental Education Research*, and the *Journal of Teacher Education for Sustainability* (Table 1). However, these journals are slightly different from the ones that accumulated the highest number of citations. The journal that has the highest number of total citations is still *Sustainability*, followed by the *Journal of Cleaner Production, International Journal of Sustainability in Higher Education, Sustainability Science,* and finally *Nature* (Table 1). In

Table 2, we list the top ten papers accumulating the highest number of citations, with authors, paper title, main research objective, major issue addressed (based on our classification mentioned in Materials and Methods), and publication journal. It is important to note that most of these top-citation papers address the interactions among the 17 SDGs or provide new insights and measures to achieve the SDGs. Due to this finding, we further list the top ten papers with ESD as sole focus that accumulate the highest number of citations in Table 3.

Our results indicate that Spain, the United Kingdom, the United States, Germany, and Sweden, are the top five countries most frequently chosen for educational events (Table 3 and Figure 3). We found that the ESD events and achievements documented in the recent literatures are not evenly distributed among countries and continents, with a higher number of ESD works focusing on Europe and North America (Table 4 and Figure 3). Most literature addresses educational issues at the global, national, or local scale, while regional-scale works are less common (Table 4).

We further explore whether recent ESD papers discuss the other SDGs or the COVID-19 pandemic. Among the 571 papers in our dataset, 243 (42.6%) discuss at least one more SDG. The SDGs generally appear with relatively equal frequency, as many papers study all 17 SDGs together. In particular, SDGs 3, 1, and 8 appear the most frequently, while SDGs 6 and 14 appeared the least (Figure 4), implying the sole relationship between education and water might be a relatively neglected subject. For the ESD papers whose publication year is after 2020 (n = 302), there are 97 papers (32.1%) that mention or discuss the impacts of the pandemic on educational systems.
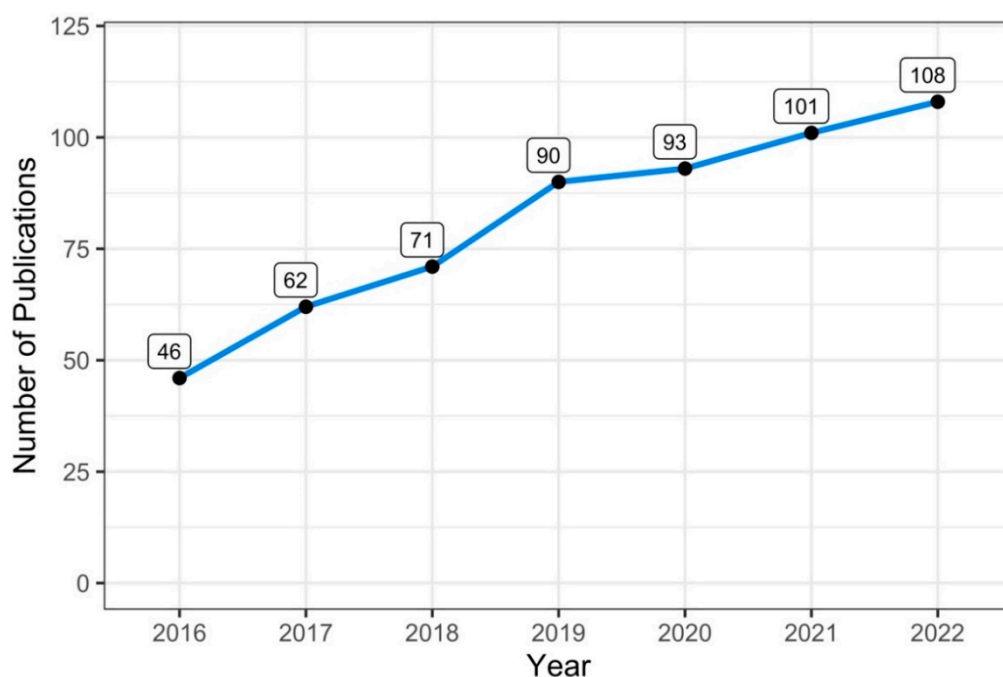

Figure 2. Number of ESD publications from 2016 to 2022. The exact values of publications in each year are labeled adjacent to the points.

Table 1. Top journals publishing the highest number of ESD papers and accumulating the highest total citations.

Means of Classification	Subgroups	Counts	Percentage of Total in Each Variable
Number of Papers published by Journal	*Sustainability*	99	17.3%
	Journal of Cleaner Production	39	6.8%
	International Journal of Sustainability in Higher Education	25	4.3%
	Environmental Education Research; *Journal of Teacher Education for Sustainability*	10 (in each)	1.8% (in each)
	International Review of Education; *Sustainability Science*	8 (in each)	1.4% (in each)
	Environment, Development and Sustainability; *Higher Education*; *Journal of Sustainable Tourism*; *Sustainable Development*; *World Development*	5 (in each)	0.9% (in each)
Total Accumulated Citations by Journals (as of February 20th, 2024)	*Sustainability*	6613	13.4%
	Journal of Cleaner Production	5406	10.9%
	International Journal of Sustainability in Higher Education	2498	5.1%
	Sustainability Science	2070	4.2%
	Nature	2064	4.2%
	Nature Sustainability	1592	3.2%
	Nature Communications	1510	3.1%
	Soil	1480	3.0%
	Earth's Future	1328	2.7%
	Environmental Education Research	1063	2.1%

Table 2. Top ten recent papers relevant to ESD accumulating highest total citations.

Author(s) and Year	Paper Title	Major Research Objectives	Major Issue Addressed*	Journal and Accumulated Citations[#]
Nilsson et al. 2016 [30]	Policy: map the interactions between Sustainable Development Goals	Authors propose a seven-point scale of SDG interactions to organize literature and evidence and provide decision-making reference for national priorities	SDG 4 targets, indicators, and achievements	*Nature*; 1895
Sachs et al. 2019 [31]	Six transformations to achieve the Sustainable Development Goals	Authors introduce six SDG Transformations as modular building-blocks to achieve the goals; each Transformation explores priority investments and regulatory challenges to inform government, business, and society	Education, Pedagogy, and Learning	*Nature Sustainability*; 1567
Vinuesa et al. 2020 [32]	The role of artificial intelligence in achieving the Sustainable Development Goals	Authors identify the role of Artificial Intelligence on the SDGs and targets by employing a consensus-based expert elicitation process	Education, Pedagogy, and Learning	*Nature Communications*; 1510

Table 2. *Cont.*

Author(s) and Year	Paper Title	Major Research Objectives	Major Issue Addressed*	Journal and Accumulated Citations#
Keesstra et al. 2016 [33]	The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals	To organize and discuss how soil scientists help reach SDGs in the most effective manner	SDG 4 targets, indicators, and achievements	*Soil*; 1480
Pradhan et al. 2017 [34]	A systematic study of Sustainable Development Goal (SDG) interactions	Authors analyze the SDG interactions, synergies and trade-offs by utilizing official SDG indicator data for 227 countries	SDG 4 targets, indicators, and achievements	*Earth's Future*; 1328
Stafford-Smith et al. 2017 [35]	Integration: the key to implementing the Sustainable Development Goals	Authors demonstrate the importance of integration among the SDGs to call for greater attention on their interlinkages	SDG 4 targets, indicators, and achievements	*Sustainability Science*; 933
Lozano et al. 2017 [10]	Connecting competences and pedagogical approaches for sustainable development in higher education: a literature review and framework proposal	Based on twelve competences and pedagogical approaches found in the literature, the paper introduces a matrix framework to provide references for curriculum design and systemic ESD	Education, Pedagogy, and Learning	*Sustainability*; 769
Lund et al. 2018 [36]	Social determinants of mental disorders and the Sustainable Development Goals: a systematic review of reviews	Authors conduct a systematic review of reviews using a conceptual framework comprising demographic, economic, neighborhood, environmental events, and social and culture domains to demonstrate how achieving the SDGs can address social determinants of mental disorders	Industry-Academia Collaboration and Out-of-school Education	*The Lancet Psychiatry*; 748
Wu et al. 2018 [37]	Information and communications technologies for Sustainable Development Goals: state-of-the-art, needs and perspectives	Authors discuss the role that Information and Communications Technologies play in the SDGs and point out potential research gap	SDG 4 targets, indicators, and achievements	*IEEE Communications Surveys & Tutorials*; 610
Annan-Diab and Molinari 2017 [38]	Interdisciplinarity: Practical approach to advancing education for sustainability and for the Sustainable Development Goals	To review the literature regarding interdisciplinarity and its application in ESD, with a successful case study	Education, Pedagogy, and Learning	*The International Journal of Management Education*; 581

* Major issue covered in each paper is categorized into one of the five categories proposed in the present study (see Materials and Methods section). # The accumulated citation as of February 20th, 2024 in the Google Scholar database.

Table 3. Top ten recent papers accumulating highest total citations with ESD as sole focus.

Author(s) and Year	Paper Title	Major Research Objectives	Major Issue Addressed*	Journal and Accumulated Citations#
Lozano et al. 2017 [10]	Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal	Based on twelve competences and pedagogical approaches found in the literature, the paper introduces a matrix framework to provide references for curriculum design and systemic ESD	Education, Pedagogy, and Learning	*Sustainability*; 769
Annan-Diab and Molinari 2017 [38]	Interdisciplinarity: Practical approach to advancing education for sustainability and for the Sustainable Development Goals	To review the literature regarding interdisciplinarity and its application in ESD, with a successful case study	Education, Pedagogy, and Learning	*The International Journal of Management Education*; 581
Leal Filho et al. 2018 [39]	The role of transformation in learning and education for sustainability	To illustrate how transformation in learning and education for sustainability is required for the commitment of faculty and the engagement of students	University and School Development	*Journal of Cleaner Production*; 502
Aleixo et al. [40]	Conceptualization of sustainable higher education institutions, roles, barriers, and challenges for sustainability: An exploratory study in Portugal	Authors investigate how the main stakeholders of Portuguese Public Higher Education Institutions tackle challenges and contribute to sustainable development	Educational Policy and Governmental Institutions	*Journal of Cleaner Production*; 475
Brundiers et al. 2021 [41]	Key competencies in sustainability in higher education-toward an agreed-upon reference framework	This study explores convergence on competencies for sustainability programs in higher education	University and School Development	*Sustainability Science*; *418*
Kopnina 2020 [42]	Education for the future? Critical evaluation of education for sustainable development goals	To call for the awareness of the paradoxes of sustainable development and encourage teaching for sustainability through various pedagogies	SDG 4 targets, indicators, and achievements	*The Journal of Environmental Education*; 385
Findler et al. 2019 [43]	The impacts of higher education institutions on sustainable development	To conceptualize impacts of higher education institutions on sustainable development based on a literature review	University and School Development	*International Journal of Sustainability in Higher Education*; 339

Table 3. *Cont.*

Author(s) and Year	Paper Title	Major Research Objectives	Major Issue Addressed*	Journal and Accumulated Citations#
Lozano et al. 2019 [44]	Teaching Sustainability in European higher education Institutions: Assessing the connections between competences and pedagogical approaches	Authors aim to investigate the degree to which sustainability is being taught, sustainability competences are developed, and pedagogical approaches are used in European higher education institutions	SDG 4 targets, indicators, and achievements	*Sustainability*; 245
Olsson et al. 2016 [45]	The effect of implementation of education for sustainable development in Swedish compulsory schools: Assessing pupils' sustainability consciousness	To investigate the effect of an explicit guiding approach in comparison with that of pupils taught in ordinary schools of Sweden	Education, Pedagogy, and Learning	*Environmental Education Research*; 242
Beynaghi et al. 2016 [9]	Future sustainability scenarios for universities: moving beyond the United Nations Decade of Education for Sustainable Development	To systematically analyze the implications of sustainable development trends and future directions that universities could consider	University and School Development	*Journal of Cleaner Production*; 237

* Major issue covered in each paper is categorized into one of the five categories proposed in the present study (see Materials and Methods section). # The accumulated citation as of February 20th, 2024 in the Google Scholar database.
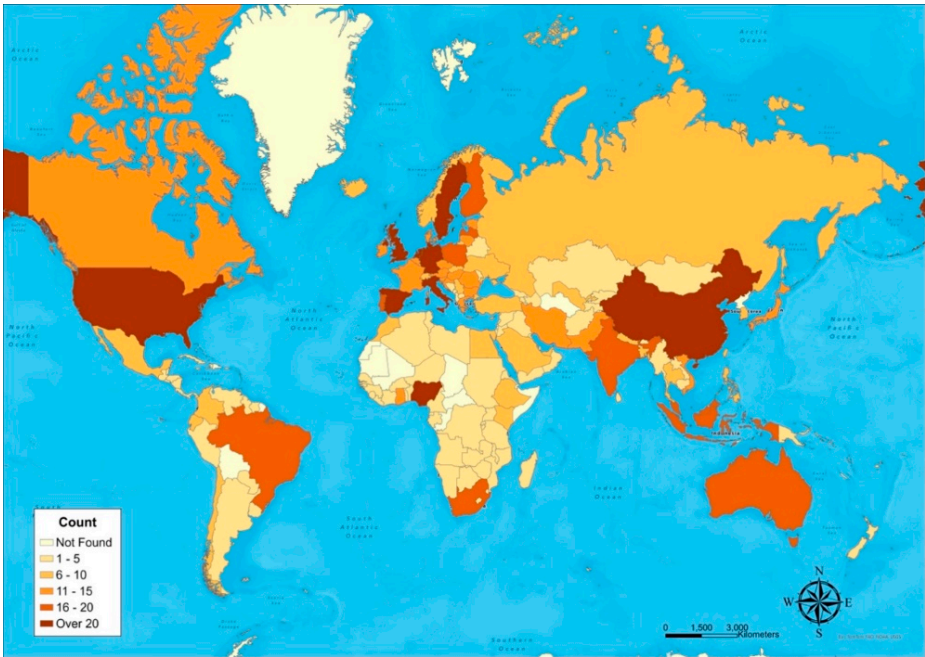

Figure 3. Global map showing the number of times ESD events took place in each country or of the location where the first author is affiliated. The frequency is shown in different colors with equal intervals. The countries where ESD events were not found are shown in white. (The base map is attributed to Esri, TomTom, FAO, NOAA, and USGS).

Table 4. Number of the recent ESD publications by different classifications.

| Means of Classification	Subgroups	Counts	Percentage of Total in Each Variable
Country (where the educational events take place or where the first author is affiliated)	Spain	57	4.7%
	United Kingdom	55	4.5%
	United States	43	3.5%
	Germany, Sweden	34 (in each)	2.8% (in each)
	China	27	2.2%
	Italy	26	2.1%
	Netherlands	23	1.9%
	Nigeria	22	1.8%
	Brazil, India	20 (in each)	1.6% (in each)
Continent (where the educational events take place)	Not Geographically Confined	213	37.3%
	Asia	133	23.2%
	Europe	118	20.7%
	Africa	56	9.8%
	Central and South America	27	4.7%
	Oceania	17	3.0%
	North America	13	2.3%
Scale (the scope of the educational events)	Global	200	35.0%
	National	165	28.9%
	Local	140	24.5%
	Regional	51	8.9%
	Not Applicable	15	2.6%
Major Issue (the most dominant issue that educational events cover)	Education, Pedagogy, and Learning	191	33.5%
	SDG 4 Targets, Indicators, and Achievements	170	30.8%
	Developing Trends of Educational Institutions	85	14.9%
	Educational Policy and Governmental Institutions	73	12.8%
	Industry-Academia Collaboration and Out-of-School Education	52	9.1%
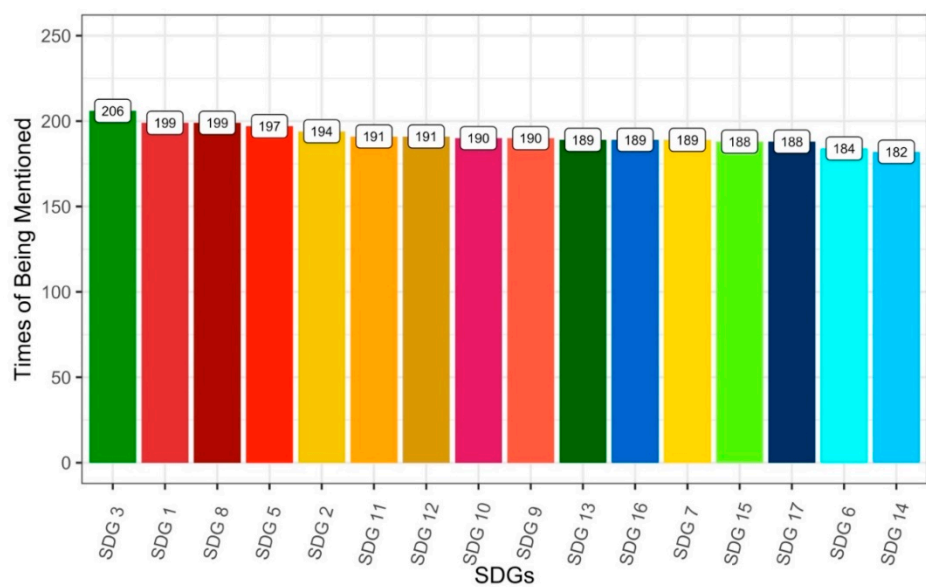
Figure 4. Frequency with which SDGs were mentioned in recent ESD studies. Times of being mentioned are from the highest (left) to the lowest (right). The exact values are shown above the bars, and the color of the bars indicates the representative color of that SDG.

Key Educational Issues Addressed in Recent ESD Paper

We performed a systematic content review for the recent ESD publications, identifying five major educational issues that have been addressed since 2016. Our analysis reveals that a majority of papers (over 60%) focus on "Education, Pedagogy, and Learning" and "SDG 4 Targets, Indicators, and Achievements", while the number of the papers covering the issue of "Industry-Academia Collaboration and Out-of-School Education" ranks the lowest (Table 4). Moreover, to investigate the potential variation of the five themes across different time periods and geographical regions, we plot the number of publications separated by the five issues over time (Figure 5) and across regions (Figure 6). In Figure 5, the number of publications for all issues demonstrates an increase since 2016, excluding the issue "Education, Pedagogy, and Learning", which decreases after 2020, likely as a result of the pandemic impacts. Furthermore, the relatively high publication numbers in "Education, Pedagogy, and Learning" and "SDG 4 Targets, Indicators, and Achievements" remain consistent across different regions, and "Industry-Academia Collaboration and Out-of-School Education" still rank the lowest (see Figure 6). The highest proportion of ESD publications fall in the category "SDG 4 Targets, Indicators, and Achievements" at a global (universal) scale. In this section, we further discuss each of the five major educational issues identified and review publication examples in more detail.
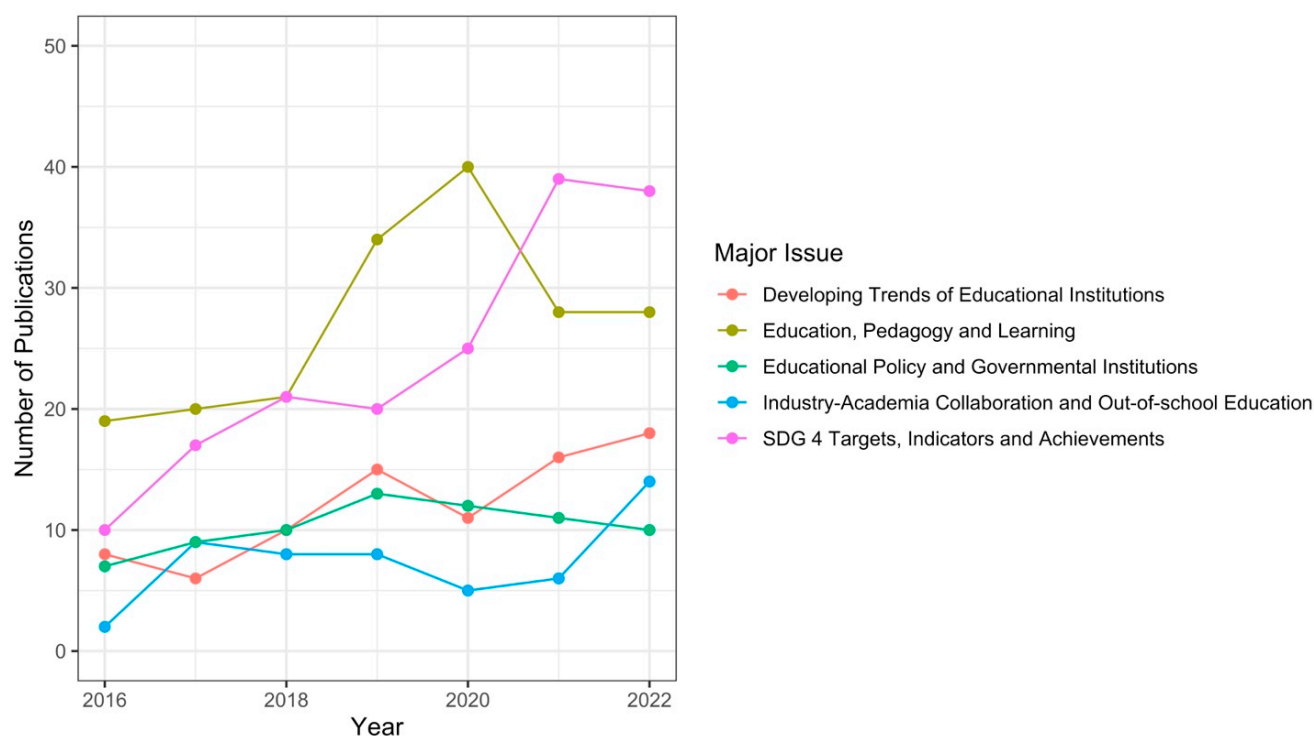

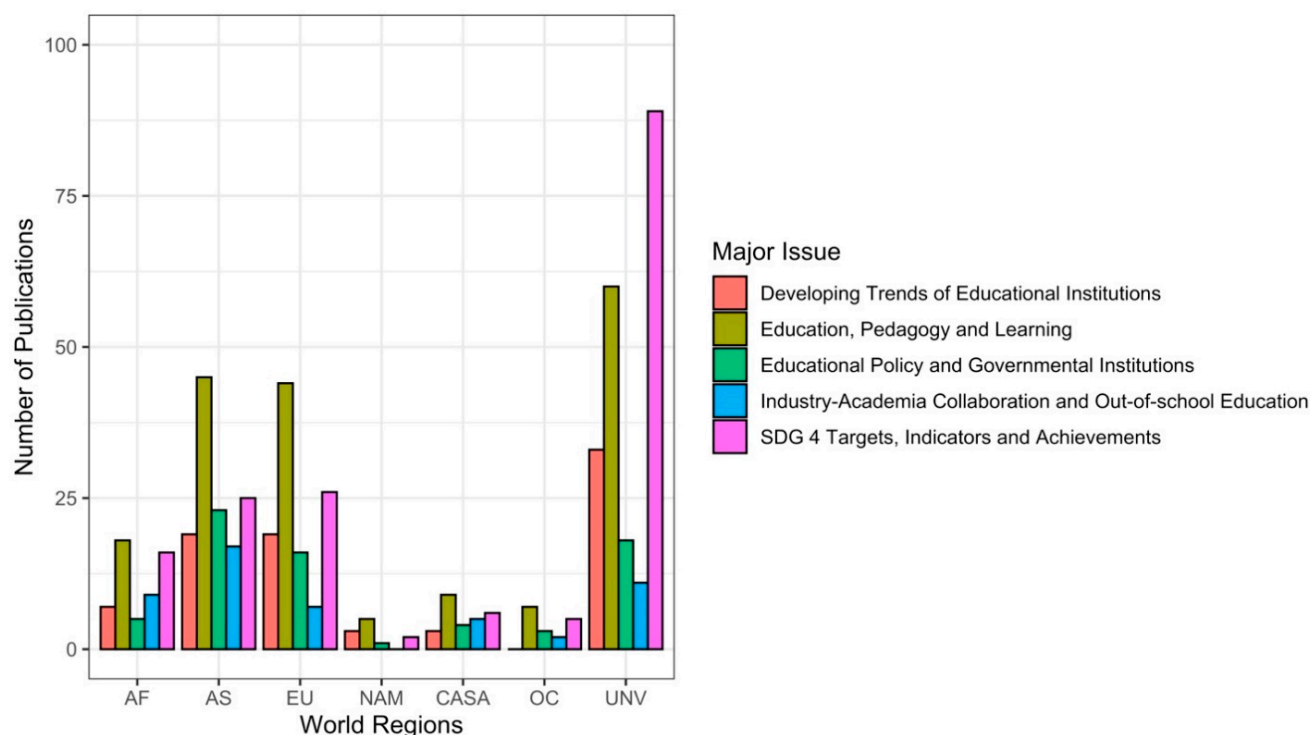**Figure 5.** Number of ESD publications visualized by the five issues from 2016 to 2022.

Figure 6. Number of ESD publications visualized by the five issues among world regions. Note that the relatively low number of publications in some regions (e.g., NAM, North America) does not necessarily indicate few publications were found from those regions; many publications address ESD at a global scale (not geographically confined), while the institutions with which author(s) are affiliated may be located within those regions with low number of publications shown in this figure. (Abbreviation: AF, Africa; AS, Asia; EU, Europe; NAM, North America; CASA, Central and South America; OC, Oceania; UNV, Universal, not geographically confined).

Education, pedagogy, and learning

ESD papers placed into the category, "Education, Pedagogy, and Learning" propose unique definitions and concepts for education or introduce innovative teaching methods to enhance students' learning outcomes relating to sustainable development. For instance, as lifelong learning is an integral part of the framework of SDG 4, several studies discuss the philosophy and scope of adult education and lifelong learning for sustainable development [46–49]. Among new pedagogies for sustainability purposes, e-learning is a popular topic discussed in many literatures, appearing across countries and regions [50–53], although the theoretical foundation and implementation procedures of e-learning in those literatures may differ. Moreover, several studies highlight the need of interdisciplinary pedagogical practices to build up critical and reflective thinking in students for different perspectives of sustainability, as the broad agenda of the SDGs requires the participation of multiple disciplines and sectors [38,54,55]. Other innovative teaching methods proposed to meet different learners' needs in ESD include, but are not limited to, capability approach [56], collaborative learning [57], and evolving learning [58].

Developing trends of educational institution

The papers addressing the issue, "Developing Trends of Educational Institutions" discuss potential directions of future development that educational institutions can pursue for sustainable development purposes. We found that some papers focus on the developing trends in primary and secondary schools, while most papers address how higher education institutions can transform to achieve sustainable development. Overall, the scope of developing trends is wide, extending to different levels of educational systems in an institution. The topics that are smaller in scale include fundamental changes in course design [59], and new tools for evaluating the sustainability status of curriculums [60,61] and whole programs [62]. Examples of large-scale development topics include new educational systems for enhancing sustainability student competencies [63], practical implementations of the SDGs in higher educational institutions [64,65], and potential challenges that educational institutions may encounter in achieving sustainability [66,67].

Industry-academia collaboration and out-of-school education

Our analysis reveals that the number of papers categorized into the issue of "Industry-Academia Collaboration and Out-of-School Education" is the lowest among the five major issues. In this group, some literature addresses how industry-academia collaborations can contribute to sustainability [37,68]. Others discuss the educational events or training programs taking place outside of educational institutions, such as in mining companies [69], oil and gas businesses [70], and hotel companies [71]. These educational events are often part of corporate social responsibility projects. On the other hand, some out-of-school educational activities target residents and local communities to promote sustainable development through community education [72], citizen science [73], and local-scale ecotourism [67,74,75].

Educational policy and governmental institutions

The papers categorized into the issue of, "Educational Policy and Governmental Institutions" concentrate on the formulation and assessment of educational policies, as well as government agency educational events relating to sustainability. For example, a recent study discusses the ways that the Punjab Government in India can improve the practical implementation of SDG 4 in primary education [76], while another work defines key stakeholders and social strategies in education policy reform [77].

Notably, the ESD papers relating to educational policy often have broad impacts, focusing on the national or regional level. This is likely due to the inherent nature of policy, often exerting a power that binds people together by advocating for normative guidelines [78]. For instance, a previous study reveals how new language policies can contribute to

sustainable development in Estonia and Latvia [79], while another demonstrates how the enactment of language policy can promote sustainable development for ethnic minorities in Laos [80]. Other education-related sustainability policies discussed in these studies involve teaching strategies in Turkey [81], assisting higher education institutions in Thailand [82], and financing higher education in sub-Saharan Africa [83].

In addition to proposing new educational policy, some works assess the effectiveness of existing ESD policies and point out relevant issues or challenges that demand attention [84–86]. For example, one comparative review indicates that policy and practice focusing on ESD and global citizenship in the four nations of the UK have remained peripheral to teacher education [87]. Another analysis in Indian National Education Policy suggests that policy proposals can be free of defects when capitalizing on a public point of reference to promote prosperity of the country [88].

SDG 4 targets, indicators, and achievements

For the articles addressing, "SDG 4 Target, Indicators, and Achievements", common research objectives include assessing the appropriateness of SDG 4 targets and indicators, and evaluating relevant educational achievements under SDG 4 guidelines. Some recent literature, for example, reveals that adult education is frequently left behind [89], and lifelong learning is similarly often neglected from quality education initiatives [90]. To more effectively assess achievements relating to SDG 4, a variety of evaluation techniques have been proposed, such as developing a global tool for monitoring early childhood development [91], using Metadata for assessing inclusive and quality education [92], and employing a disaggregated data-analysis approach to achieve literacy and numeracy for youth and adults [93]. Most of these papers point out fundamental issues and challenges of achieving SDG 4 frameworks and as such, can serve as an important reference for future educational transformation.

Papers studying the interactions between SDG 4 and other SDGs are also categorized into this group [30,94–96]. The interactions among the SDGs are classified as synergy (positive) or trade-off (negative), depending on whether two or more actions relating to different SDGs will result in an effect that is greater or less than the sum of the individual effects [97]. According to a recent publication, SDG 4 has the strongest synergistic relationship with SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities), but the greatest trade-off relationship with SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land) [23]. Understanding these interactions among the SDGs can help decision makers govern frameworks more coherently and develop effective laws and policies [98].

DISCUSSION

Number of ESD Publications after the SDGs

This study reveals that the number of ESD publications gradually has increased since 2016, regardless of the emerging issues we have conceptualized (see Figure 2 and 5). We suspect that this is because the official formulation of the SDGs elevated attention towards ESD. In the UN's 2030 Agenda for Sustainable Development, SDG 4 validates the role of education and educational systems on sustainability from a global perspective [99]. As such, the idea of reaching SDG 4's targets have become a crucial responsibility shared among all individuals, educational institutions, and governments [100]. Moreover, the positive effects of education on sustainable development are widely acknowledged in the sectors of technology, business, and entrepreneurship [101,102]. Therefore, ESD's rise in recognition likely promotes research opportunities for scholars and experts seeking to address education-related issues to achieve SDG 4 [103].

Due to the outbreak of the COVID-19 pandemic beginning in early 2020, higher education and educational institutions nearly reached a freezing point for some time [104]. The closure of schools, universities, and educational systems in turn may have hampered the progress of ESD research. This is reflected by our finding that the number of publications in "Education, Pedagogy, and Learning", which includes various pedagogies and classroom settings as one of the focuses, has decreased since 2020 (Figure 5). However, it seems that the pandemic has not severely impacted ESD research as a whole, as the decrease in publications one might expect is not present in our data (Figure 2). This continued steady stream of publications is likely a result of scholars switching to alternative educational approaches during the pandemic [105]. As such, the impact of the COVID-19 pandemic on ESD and progress toward achieving the SDGs offers a new, critical topic of investigation, see [106,107]. Therefore, we suggest that the pandemic may not have substantially hampered ESD research and publications since 2020. Future works can further explore whether the trend reverses, as many educational systems worldwide gradually resume following the pandemic.

The Distribution of ESD Publications by Countries

Our analysis indicates that the number of ESD publications are unevenly distributed among countries and regions. While acknowledging some papers may not be written in English and therefore are not included in our dataset, we believe the uneven distribution of publications to some degree implies an educational inequality across the globe. When we reference the world population and education data from 2015 to 2025 [108], we find that countries with more ESD publications have a higher percentage of adults (age 15 or higher) who have completed post-secondary education by country (see Supplementary Table S1). In our

dataset, most of the ESD works focus on higher education and higher education institutions. When we find more recent ESD publications were produced in a country, it suggests to a certain degree that there are more educational events for sustainable development ongoing. We expect that this will likely facilitate a higher portion of people acquiring educational resources in that country.

Although ESD aims to reduce inequity and promote sustainability under the framework of the SDGs, the likelihood and opportunity to implement ESD is often impeded for many countries by their inherent socioeconomic inequality [36,109]. For example, a previous study demonstrates that, from a global perspective, students with higher socioeconomic status are more likely to be presented with appropriate learning opportunities [110]. Moreover, a further global analysis reveals that low educational attainment is correlated with lower economic status and poorer public health, a phenomenon which is more prevalent among some underrepresented groups [111]. Therefore, the strong disparity we have observed in the number of publications among countries may imply that achieving ESD is especially challenging for developing or low-income countries [80,112] as a result of other hardships. However, this also speaks to the importance of considering the interdependencies between education and other SDGs. With this in mind, policymakers must adopt novel theoretical frameworks which consider these factors in order to implement ESD and other dimensions of sustainability for all [31,113].

Issues in ESD Research after the SDGs and Future Research

In this study, we identify five major educational issues from recent ESD publications. We suggest these emerging themes, coupled with their trends over time and distribution among world regions, are unique developments occurring after the formulation of SDGs. This is particularly pronounced in the issue "SDG 4 Targets, Indicators, and Achievements", as many papers falling into this category focus on the effectiveness of SDG 4 targets and indicators, as well as the interrelationships among SDGs. Notably, the emerging themes "Education, Pedagogy, and Learning" and "SDG 4 Targets, Indicators, and Achievements", demonstrate relatively higher numbers of publications, regardless of world regions (Figure 6). Typically, publications that fall into the category "Education, Pedagogy, and Learning", such as those that focus on the development and practice of new pedagogies and classroom settings to promote ESD, require relatively less time to complete. This may result in a higher number of publications from this category, with the exception of the decrease occurring after the pandemic. On the other hand, as the formulation of the SDGs elevates the awareness and importance of sustainable development [114,115], we may expect a rise in publications in the category "SDG 4 Targets, Indicators, and Achievements". These papers would primarily address interactions among SDGs and ESD as one of the major objectives, topics that we have seen increase in number since 2015. We believe these

are some of the reasons explaining the higher publications numbers in "Education, Pedagogy, and Learning" and "SDG 4 Targets, Indicators, and Achievements" compared to other emerging themes. Overall, the five issues proposed in this study suggest a new trend has emerged in ESD research following the formulation of the SDGs. Today, initiatives like the UN Decade of Education for Sustainable Development (DESD) have helped to formulate critical momentum that promotes government and decision maker focus on international cooperation and development of innovative educational policies and programs [116].

The framework of the SDGs defines sustainable development with three major dimensions and leverages clear targets and indicators. This development may promote the convergence of ESD research efforts with other aspects of sustainability. In this study, we found that around 44% of the recent publications address SDG 4 alongside at least one other SDG, and the likelihood for each SDG covered by the literature is fairly even (see Figure 4). These findings may suggest that recent ESD research not only covers a wider scope of education (see [46,49,117]) and teaching strategies [113,118,119], but also emphasizes the interrelationships with other domains of sustainability and SDGs (see [34,97]). This is further accentuated by the focus of research on interactions between ESD and health and well-being (SDG 3), no poverty (SDG 1), and decent work and economic growth (SDG 8) (Figure 4). Moreover, a majority of papers accumulating the highest number of citations addressed the interconnections among the SDGs compared to the papers having ESD as a sole focus (see Table 2 and 3).

Education has played a vital role for achieving sustainable development for all. Our work notably suggests that the context of the SDGs has widened our theoretical framing and created more openings for ESD research, as exemplified by the diversity of educational topics and issues addressed in recent publications. This analysis also supports the notion that the SDGs raise our awareness of the interactions and interdependencies between ESD and other global goals in the environmental, social, and economic sectors [120,121]. Nevertheless, given the potential discrepancy of ESD publication and progress among regions (see Figure 3 and 6), policymakers from countries falling behind can consider substantial education reform. These reforms can range from fundamental changes in pedagogy and curriculum and developmental agendas of educational institutions, to changes in national policy and the focus of SDG interrelationships, as indicated by the major issues we identify in this work. Note that more than one third of the recent publications address educational issues which are not geographically confined (see Table 4). We believe the important message delivered from those works can be widely applied. This research also points out some issues that may be often neglected in the ESD literature, like Industry-Academia Collaboration and Out-of-School Education, the sole interactions between ESD, clean water and sanitation (SDG 6), and life below water

(SDG 14) (see Table 4 and Figure 4). We expect more educators, decision makers, and future researchers can incorporate those topics, e.g., see [122,123] in order to ensure ESD covers different dimensions of sustainability. As we have surpassed the halfway mark to meeting the goals set in the 2030 Agenda and emerged from the most difficult trials brought on by the pandemic, this work critically organizes recent ESD studies. We seek to provide references for the future research, frameworks, and assessments necessary to achieve quality education for all under SDG 4.

CONCLUSIONS

In this study, we conducted a review of recent SDG 4 and ESD publications to identify major educational trends and issues emerging after the UN's proposal of the SDGs in 2015. Results indicate that the number of publications has gradually increased from 2016 to 2022. Although one might expect a decrease of publications from 2020 onwards, our findings suggest the COVID-19 pandemic did not substantially impact ESD research worldwide. Additionally, the number of publications is not evenly distributed across countries and continents. This imbalance of ESD progress implies that the challenge of educational inequality remains unresolved. We subsequently identified five major educational issues from recent ESD studies, including: (1) Education, Pedagogy, and Learning; (2) Developing Trends of Educational Institutions; (3) Industry-Academia Collaboration and Out-of-School Education; (4) Educational Policy and Governmental Institutions; and (5) SDG 4 Targets, Indicators, and Achievements. These emerging issues were intended to conceptualize the nature of ESD research bodies after the formulation of the SDGs, particularly with regards to the issue SDG 4 Targets, Indicators, and Achievements. Through this process, we sought to identify which papers evaluate the efficacy of SDG 4 and investigate the relationship between SDG 4 and other global goals. Further characterizing these issues over time and among world regions, we suggest these categorizations can act as critical references for decision makers in countries falling behind in ESD who are considering implementing fundamental-to-national reform. We also observed that the SDG framework widened the range and scope of ESD research, as many of the recent publications cover at least one additional SDG. Simultaneously, we pointed out the interrelationships between areas which might be neglected, such as ESD and water (SDG 6 and SDG 14). Overall, this research serves as a critical step for organizing progress made in ESD and provides references for policy and decision makers to practically achieve quality education for all as we approach the deadline for the 2030 Agenda.

SUPPLEMENTARY MATERIALS

The following supplementary materials are available online at https://doi.org/10.20900/jsr20240006. Supplementary Figure S1: Number of

ESD publications from 2016 to 2022 without including the records from the journal of *Sustainability*, given their disproportionately high productivity. The exact values of publications in each year are labeled adjacent to the points. Supplementary Table S1: Pearson's correlation analysis between number of ESD publications and average education level by countries.

DATA AVAILABILITY

The dataset generated from (or analyzed in) the study can be found at the website of the Knowledge Network for Biocomplexity in open access via https://knb.ecoinformatics.org/ upon publication.

AUTHOR CONTRIBUTIONS

SCC designed the study. SCC collected the data. SCC, CK analyzed the data. SCC performed data visualization. SCC, CK wrote the paper.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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