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Research Article

Profiling SDG 4 Research in Southeast Asia: Developing a Comprehensive Research Metrics Model

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ABSTRACT

This study contributes to both academic and scholarly works, providing an evidence-based approach to policy making by offering clear pathways for enhancing SDG 4 research quality, dissemination, and international cooperation. This can ultimately support sustainable educational development throughout the region. This study employs a rigorous Scientometric approach using Scopus and Scival data (2015-2024) to evaluate the SDG 4 research landscape across six countries: Indonesia, Malaysia, the Philippines, Vietnam, Singapore, and Thailand. Leveraging quantitative and visual analytics, the research explores publication trends, citation dynamics, collaboration networks, and institutional productivity. Results show a surge in publication output, particularly from Indonesia and Malaysia, with a predominant focus on topics like e-learning, case studies, computer-aided instruction, and sustainable development. However, while publications rise, citations exhibit a declining trend, suggesting potential concerns over research quality or a lag in impact. Thematic analysis also highlights underexplored areas such as teacher training, equity in data collection, and policy harmonization across nations. The study also develops a Structural Equation Model (SEM) to unpack relationships between collaboration, open access, and research impact. Findings challenge the notion that higher collaboration inherently drives impact, showing instead that open-access visibility is a more consistent predictor of citation performance. Overall, the research provides critical insights into how Southeast Asian countries are progressing toward achieving SDG 4, while identifying gaps in inclusivity, technological integration, and policy implementation.

Keywords: ASEAN, Scientometrics, Research metrics, SDG4, Quality education.

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INTRODUCTION

SDG4 is recognized as the cornerstone of sustainable development, emphasizing inclusive and equitable learning opportunities for all. In recent years, Southeast Asian nations such as Thailand, Singapore, the Philippines, Vietnam, Indonesia, and Malaysia have increasingly contributed to research aligned with SDG 4. A Scientometric analysis of this study can illuminate how these countries are performing regarding published research, citation metrics, and collaboration among different countries. Thus, this study leverages the Scopus database utilizing SciVal to analyze the SDG 4 research performance of the six countries, providing insights into collaboration networks, publication outputs, citations, research topics, and emerging trends.

This paper also prepares a comprehensive research performance model to compare these countries and forecast future directions. Key findings include identifying research gaps, leading institutions and journals, collaboration networks, trending topics, and affiliation network analysis, all presented with data-driven evidence and visualizations for clarity and research rigor.

This Scientometric investigation aims to explore the landscape of SDG 4 research in southeast Asia through quantitative analysis. This study seeks to identify emerging research topics, track the region's distribution of SDG 4 related research, and assess the impact on scientific discovery and educational practice.

The paper specifically aims to (1) analyze the landscape of SDG 4 related research in the southeast Asian region; (2) evaluate gaps in existing research to identify the underexplored areas, particularly those critical to the academe, research institutions, and the broader scientific community, ensuring alignment with national and global priorities; (3) generate actionable insights to inform evidence-based policy development address research gaps, optimize resource allocation to research trends, and foster interdisciplinary and collaborative SDG4 research networks.

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REVIEW RELATED LITERATURE

With Education for Sustainable Development (ESD) as a major component, SDG 4 in Southeast Asia places a strong emphasis on high-quality education. This target is essential to accomplishing more general sustainable development goals since education enables people to support social justice, economic growth, and environmental sustainability. ESD is a crucial component of SDG 4, promoting awareness and skills necessary for sustainable living. Target 4.7 focuses on ESD and Global Citizenship Education, encouraging sustainable behaviors and equipping young people with the knowledge and abilities they need for a sustainable future (Valenzuela *et al*., 2024). Effective policymaking is hampered by the fact that just 51% of SDG 4 indicators are covered (Shoobridge, 2024). Despite almost universal primary education, nations like the Philippines record significant dropout rates and poor learning results (Albert *et al*., 2023). Through conferences and awards, SEAMEO encourages ESD and sustainable teaching methods (Valenzuela *et al*., 2024). To address educational issues comprehensively, nations are urged to create all-encompassing plans (Albert *et al*., 2023).

Southeast Asia has several formidable obstacles in achieving Sustainable Development Goal 4 (SDG 4), chief among them being systematic disparities, incomplete data, and problems with resource distribution. These obstacles make it more difficult for the area to offer high-quality, inclusive education to everyone. Recent global crises have made educational opportunity disparities worse, disproportionately impacting underprivileged communities. Coordination of policy across sectors is necessary since the quality of the home and community environment before school admission has a major impact on educational achievements (Porter, 2024). The disaggregated data, especially for disadvantaged populations, has substantial gaps, and only 51% of SDG 4 indicators are sufficiently provided. Data-gathering efforts frequently neglect groups including those attending non-governmental schools and those living in conflict-affected areas (Shoobridge, 2024). Disparities in quality and access continue despite growing education budgets, and many nations fall short of international standards for educational investment. Efforts to raise educational quality are further complicated by a shortage of trained teachers and poor infrastructure (Alfarizi and Sari, 2024).

For Southeast Asia to attain Sustainable Development Goal 4 (SDG 4), significant problems with curriculum design, data scarcity, and educational inclusion must be resolved. A multifaceted approach is required as countries strive to achieve SDG 4's objectives to ensure all people have access to high-quality, equitable education. Emphasizing tangible and intangible performance indicators will be essential for measuring educational outcomes. Future curriculum design in Southeast Asia is anticipated to concentrate on individual-centric learning, incorporating technological advancements to enhance educational dynamics (Mustafa *et al*., 2023). Although SDG 4 encourages inclusion and lifelong learning, major disruptions from the COVID-19 epidemic have made already existing disparities worse (Jane *et al*., 2023). To address the changing requirements of various populations, especially in disadvantaged circumstances, ongoing efforts are required to modify educational practices (Edwards *et al*., 2023).

Indonesia demonstrated the Tigo Luhah Tanah Sekudung community, which improves sustainability and environmental management by incorporating indigenous knowledge into teaching methods (Widowati *et al*., 2024). Effective teacher training and data monitoring are essential for promoting inclusive education practices and reaching SDG 4 by 2030. Although Cambodia has made progress in this area, obstacles still exist because of limited knowledge of inclusion and a lack of governmental support (Pov and Chhy, 2023). In Laos, SDG4 seeks to lessen educational disparities, however, its implementation is restricted to vocational training and basic education, which restricts upward mobility and creates unfavorable educational opportunities (Jeong and Hardy, 2023). Through educational activities, teachers play a crucial role in addressing violence and establishing peace. In Myanmar, education is viewed as an essential instrument for peacebuilding, and including peace education in curricula to promote social cohesion is important (Shah *et al*., 2019). Evaluating initiatives to achieve SDG4 and guaranteeing that no one is left behind has been made possible in large part by the All-Party Parliamentary Group Malaysia (APPGM) (Lee *et al*., 2024).

In the Philippines, SDG 4 launched the No Child Left Behind (NCLB) Policy, which aims to provide all children with fair access to high-quality education. However, because of issues like socioeconomic inequality, dwindling parental participation, and an over-focus on standardized testing, the Holistic Literacy Enhancement Program is required (Ryanne *et al*., 2024). Singapore acknowledges that education is a means of achieving better health and well-being, emphasizing the reciprocal relationship between education and health outcomes. Programs that incorporate health education into the curriculum seek to promote students' holistic development, which further supports SDG4 objectives (Sørensen, 2024). Thailand's attainment of SDG 4.2.1 shows that, compared to the worldwide average of 75%, about 92.3% of children aged 3-4 is developmentally on track in terms of health, learning, and psychological well-being. However, continued efforts are required to alleviate imbalances (Topothai *et al*., 2022). Even during the pandemic, Brunei has made great strides in ensuring equitable access to education by enacting policies that accommodate a range of learning needs. The country's Ministry of Education has implemented reforms to align with SDG 4 targets, emphasizing high-quality education as a foundation for sustainable development (Haidi and Jaidin, 2023). East Timor's new curricula have a strong emphasis on sustainability and incorporate energy resource management into

science instruction. The curriculum encourages students to make responsible decisions by highlighting the connections between science, technology, and society (Capelo, 2013). SDG 4 in Vietnam places a high priority on equitable education and training, as shown by indicator 4.5.1 on the Equity Index. However, disparities in national ownership and data disaggregation impede the ability to effectively monitor educational inequality and discrimination among vulnerable groups (Vu and Long, 2021).

Technology and innovation are crucial to attaining Sustainable Development Goal 4 (SDG 4) in Southeast Asia by enhancing educational accessibility, quality, and inclusivity. Integrating various technologies can help address the unique issues facing the area, particularly for marginalized groups like children with disabilities. Assistive technology (AT) provides children with disabilities with the means to acquire a high-quality education and participate fully in society. According to case studies, AT can considerably raise educational standards and lessen inequality in Southeast Asia (Shi *et al*., 2022). MOOCs and intelligent tutoring systems are examples of digital learning tools that can improve educational efficiency and equity. Research indicates that by giving everyone access to chances for lifelong learning, these technologies, when properly deployed, can greatly aid in reaching SDG 4 (Ahuja, 2023). For technological breakthroughs to be implemented successfully, stakeholders must be encouraged to form collaborative ecosystems. In Southeast Asia, a focus on inclusive innovation can aid in addressing regional issues and advancing sustainable development (Taventi, 2023).

METHODOLOGY

This scientometric study systematically evaluates and quantifies publications related to SDG 4 to identify research patterns, impact, and emerging trends within the field. Employing a rigorous data collection framework, the study leverages advanced scientometric techniques, including authorship analysis, country and institutional research performance assessment, and keyword mapping, to provide a comprehensive overview of scholarly activity in SDG 4 research in Southeast Asia. Scientometric mapping, widely recognized for domain analysis and trend identification (Widowati *et al*., 2024), is central to this study. By utilizing clearly defined and replicable assessment criteria, the methodology offers valuable insights into the structural landscape of SDG 4 research (Pov and Chhy, 2023). Analyzing publications spanning 2015 to 2024, this study delivers critical insights into the current state of SDG 4 research and its potential future directions.

Data Collection

A total of 31,940 SDG 4 research-related publications were retrieved from the Scopus database. Scopus was chosen for its extensive peer-reviewed, high-quality literature, rigorous indexing criteria, and integrity in excluding predatory journals.

The data set was acquired using Elsevier's SciVal tool, which identified SDG 4-related publications from 2015 to 2024. The majority were 19,050 (59.6%) are journal articles, and conference proceedings 10,492 (32.9%). Publications addressing SDG4 research were also associated with other overlapping research areas.

Data Analysis and Tools Used

Data processing, statistical analysis, and visualization were conducted using Python within the Google Colaboratory environment. Python was chosen for its flexibility and extensive libraries tailored for scientific computing and data analysis. It also facilitated network analysis, of emerging patterns and interconnections within SDG4-related research.

Furthermore, text clustering techniques, including word cloud analysis, were employed to extract contextual themes from publication titles and abstracts, offering qualitative insights into the prevailing research directions in sustainable education.

RESULTS AND DISCUSSION

Table 1 shows the bibliometric analysis of Scopus-indexed sources reveals a strong thematic convergence in research on E-learning, Engineering Education**,** and Computer-Aided Instruction, particularly within conference proceedings and multidisciplinary journals. The Journal of Physics: Conference Series and AIP Conference Proceedings dominate in publication volume, highlighting a trend where conference platforms serve as significant venues for disseminating applied and experimental educational research.

The prevalence of keywords such as Case Study**,** Testing**,** Learning Outcome**,** and Secondary Schools suggests a focus on evaluating the efficacy of digital and blended learning strategies within real-world educational contexts, often in STEM fields.

Interestingly, Self-Efficacy and Sustainable Development emerge in journals like Sustainability (Switzerland) and International Journal of Innovation, Creativity and Change, indicating a growing interest in integrating psychosocial and environmental perspectives into educational technologies.

Furthermore, the inclusion of COVID-19**,** Online Learning**,** and Electronic Learning in several high-frequency keyword sets (e.g., ACM and IJETER) reflects the pandemic's enduring impact on educational research priorities. Notably, the repetition of certain terms (e.g., "Case Study" and "E-learning") across multiple journals reinforces their centrality in current discourse.

Overall, this result underscores a global scholarly emphasis on technology-mediated education**,** particularly in the STEM and sustainability domains, while also pointing to the versatility of conference proceedings as pivotal outlets for empirical educational research.

Table 1: Top 10 Prominent Scopus Source Title in Southeast Asia.

Sl	Scopus Source Title	TP	Keywords
1	Journal of Physics: Conference Series	2697	Testing, Secondary Schools, Learning Outcome, Case Study, Mathematics, E-learning, Computer-Aided Instruction, Engineering Education.
2	AIP Conference Proceedings	1343	Testing, Case Study, Secondary Schools, E-learning, Learning Outcome, Engineering Education, Mathematics, Engineering Education, Computer-Aided Instruction.
3	ACM International Conference Proceeding Series	617	E-learning, Computer-Aided Instruction, Case Study, Engineering Education, COVID-19, Online Learning, E-learning, Electronic Learning, Testing, Learning Outcome.
4	IOP Conference Series: Earth and Environmental Science	608	Case Study, Testing, Sustainable Development, Indonesia, Learning Outcome, Secondary Schools, Environmental Impact Assessment, High School Student.
5	Sustainability (Switzerland)	342	Sustainable Development, Industrial Sector, Higher Education Institution, Case Study, E-Learning, Educational Policy, Engineering Education, Self-Efficacy, Consumer Behavior, COVID-19.
6	International Journal of Innovation, Creativity and Change	318	Case Study, Secondary Schools, Self-Efficacy, E-learning, Computer-Aided Instruction, Testing, University Students, Sustainable Development, Entrepreneurship Education.
7	International Journal of Learning, Teaching and Educational Research	297	Case Study, E-learning, Engineering Education, English as a Foreign Language, COVID-19, Case Study, Online Learning, Self-Efficacy, Computer-Aided Instruction, Adolescents.
8	Universal Journal of Educational Research	296	Case Study, E-learning, Computer-Aided Instruction, Testing, Secondary Schools, Case Study, English as a Foreign Language, Engineering Education, Learning Outcome.
9	International Journal of Evaluation and Research in Education	279	E-learning, Case Study, COVID-19, Online Learning, Computer-Aided Instruction, Self-Efficacy, Professional Occupations, Adolescents, Testing, Case Study.
10	E3S Web of Conferences	278	Case Study, E-learning, Sustainable Development, Case Study, Engineering Education, Computer-Aided Instruction, Industrial Sector, Higher Education Institution, Internet of Things.

Table 2 highlights the top 10 institutions contributing to SDG 4 research, with Indonesia dominating the list through seven universities, led by the Indonesia University of Education (742 publications), followed by Yogyakarta State University (586) and the State University of Malang (558). These institutions prominently feature themes such as case study methods, e-learning, online learning, and testing, especially within secondary schools and mathematics education. Their focus reflects a strong national commitment to educational reform through localized, evidence-based practices supported by technology-enhanced instruction.

Malaysian institutions, including Universiti Kebangsaan Malaysia, Universiti Teknologi MARA, and Universiti Teknologi Malaysia, also show significant contributions, with research spanning sustainable development, COVID-19 education impacts, language instruction, and engineering education. These universities are actively exploring broader educational policy issues and technological adoption, often employing interdisciplinary approaches that integrate digital tools, such as machine learning and virtual reality, to enhance learning outcomes and inclusivity.

Across all ten institutions, recurring keywords such as computer-aided instruction, self-efficacy, and English as a Foreign Language indicate shared regional priorities in advancing digital learning ecosystems and learner-centered education. The strong presence of case study research reflects a methodological preference for applied, context-specific investigation. Overall, the table reveals a vibrant research landscape in Southeast Asia, with Indonesia and Malaysia at the forefront of educational innovation aligned with the goals of SDG 4.

Figure 1a illustrates the trends in publications and citations in SEA from 2019 to 2024, revealing an increase in publications (R^2=0.79) and a decline in citations (R^2=0.95). The strong negative Pearson correlation (-0.91, *p*-value=0.01) indicates a significant inverse relationship. While publications are growing, citations are sharply decreasing. This suggests that newer publications may not receive as many citations, possibly due to lower impact, increased volume with diluted influence, or a lag in citation

accumulation. The divergence between rising publications and declining citations highlights a potential quality concern or shifts in citation behaviors.

Figure 1b shows a steady increase in both publications and authors in SEA from 2019 to 2024, with the number of publications growing (R^2=0.79) and the number of authors increasing (R^2=0.64). The strong positive correlation (0.93, *p*-value=0.01) suggests a significant relationship between the rise in authors and the number of publications. This trend indicates an expanding research community that contributes more publications annually. However, the relatively lower R^2 for authors suggests that, as the number of authors increases, fluctuations may be influenced by external factors such as collaborations, research funding, or institutional policies.

Figure 1c indicates a consistent increase in publications and the number of contributing countries in SEA from 2019 to 2024, with the number of publications growing (R^2=0.79) and the number of countries increasing yearly (R^2=0.84). The strong positive correlation (0.97, *p*-value=0.00) suggests a highly significant relationship between the rise in publications and the expansion of international collaborations. This trend highlights the growing global engagement of SEA researchers, potentially improving research diversity and impact. However, sustaining this growth may require continued efforts to foster international partnerships and secure research funding opportunities.

Figure 1d highlights a steady increase in publications and the number of contributing institutions in SEA from 2019 to 2024, with the number of publications growing (R^2=0.79) and the number of institutions increasing (R^2=0.64). The strong positive correlation (0.91, *p*-value=0.01) suggests a significant relationship between the rise in publications and the expansion of institutional participation. This trend indicates a growing research ecosystem

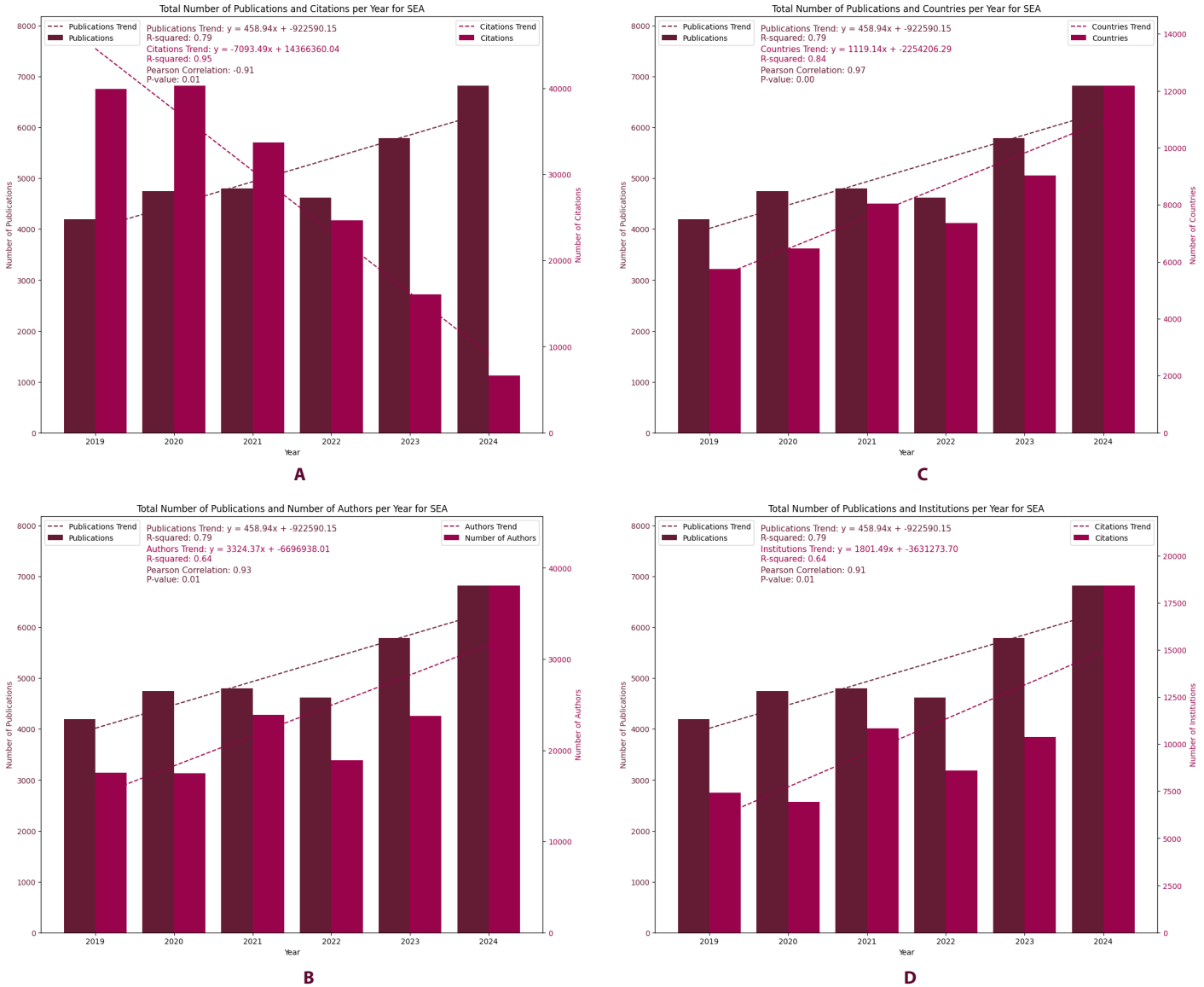


Figure 1: Trend Analysis of Publications and Related Domains per Year for SDG4: (a) Total Number of Publications and Citations; (b) Total Number of Publications and Authors; (c) Total Number of Publications and countries; (d) Total Number of Publications and Institutions. (a)

where more institutions actively contribute to scholarly outputs. However, while institutional involvement is increasing, the moderate R^2 suggests external factors such as funding, research collaborations, and policy changes may influence publication trends.

Figure 2a reveals an inverse relationship between the number of citations and the number of authors in SEA from 2019 to 2024, with citations declining annually (R^2=0.95) while the number of authors increases yearly (R^2=0.64). The strong negative correlation (-0.83, *p*-value=0.04) suggests that as the number of authors grows, the number of citations decreases significantly. This trend may indicate an oversaturation of publications leading to citation dilution, a lag in citations for newer research, or a shift in citation behaviors. The findings raise concerns about research impact, emphasizing the need for improving publication quality and visibility rather than just increasing volume.

Figure 2b illustrates a strong inverse relationship between the number of citations and the number of contributing countries in SEA from 2019 to 2024, with citations declining annually (R^2=0.95) while the number of countries increasing yearly (R^2=0.84). The strong negative correlation (-0.92, *p*-value=0.01) suggests that the average number of citations per publication decreases significantly as the number of countries contributing to publications increases. This may indicate a shift towards broader international collaboration, but at the cost of diluted research impact, delayed citation accumulation for newer works, or lower visibility of emerging research. These findings underscore the importance of enhancing global participation and improving the quality and citation potential of research outputs.

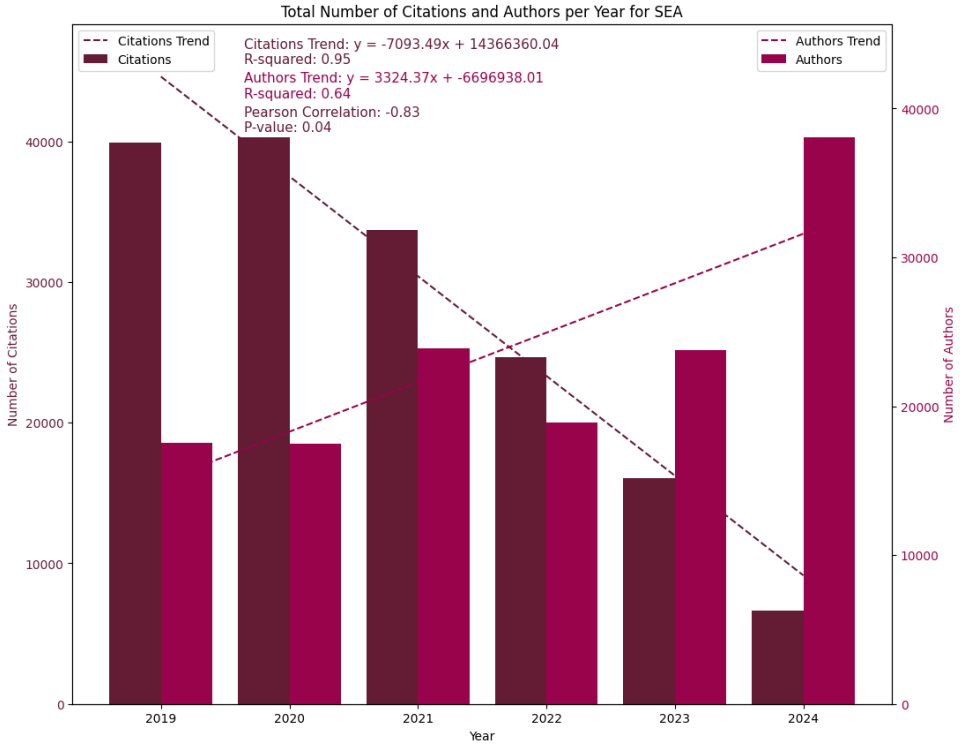
Figure 2c illustrates a strong inverse relationship between the number of citations and the growth of open-access publications in SEA from 2019 to 2024, with citations declining annually (R^2=0.95) while open-access publications increase annually (R^2=0.86). The negative Pearson correlation (-0.84, *p*-value=0.04)

Table 2: Most Prolific SEA Institutions - Total Publications with most used Keywords.

Sl. No.	Institutions	Country	TP	Keywords
1	Indonesia University of Education	ID	742	Sustainable Development, Case Study, Online Learning, Special Need, Testing, Secondary Schools, E-learning, Case Study, Testing, Mathematics.
2	Yogyakarta State University	ID	586	E-learning, Testing, Case Study, Secondary Schools, Computer-Aided Instruction, Learning Outcome, Testing, Engineering Education, Self-Efficacy, Case Study.
3	State University of Malang	ID	558	E-learning, Case Study, Computer-Aided Instruction, Engineering Education, English as a Foreign Language, Testing, Case Study, Engineering Education, Self-Efficacy.
4	Universitas Sebelas Maret	ID	442	Case Study, Testing, E-learning, Computer-Aided Instruction, Computer-Aided Instruction, Secondary Schools, Mathematics, Case Study, Engineering Education.
5	Universiti Kebangsaan Malaysia	MY	424	Case Study, E-learning, Sustainable Development, Language Instruction, COVID-19, Engineering Education, Computer-Aided Instruction, Self-Efficacy, English as a Foreign Language, Case Study.
6	State University of Jakarta	ID	404	Case Study, Testing, Computer-Aided Instruction, Secondary Schools, E-learning, Learning Outcome, Engineering Education, High School Student, Case Study, Self-Efficacy.
7	State University of Padang	ID	396	Testing, Secondary Schools, Learning Outcome, Computer-Aided Instruction, E-learning, High School Student, Engineering Education, Learning Mathematics, Mathematical Problem.
8	Universiti Teknologi MARA	MY	387	E-learning, COVID-19, Case Study, Online Learning, Computer-Aided Instruction, English as a Foreign Language, Engineering Education, Adoption, Machine Learning.
9	Bina Nusantara University	ID	369	E-learning, Case Study, COVID-19, Computer-Aided Instruction, Online Learning, Virtual Reality, Sustainable Development, Corporate Social Responsibility, Social Media, Regression Analysis.
10	Universiti Teknologi Malaysia	MY	340	E-learning, Case Study, Computer-Aided Instruction, Engineering Education, Sustainable Development, COVID-19, Information System.

suggests that the number of citations decreases significantly as open-access publishing increases. This trend may indicate that while open access improves research accessibility, it does not necessarily translate into higher citations, possibly due to lower perceived quality, increased competition, or a lag in citation accumulation. Ensuring visibility and impact for open-access research may require more substantial indexing, better dissemination strategies, and improved research quality.

Figure 3a illustrates a positive relationship between the number of authors and open-access publications in SEA from 2019 to 2024, with the number of authors increasing annually (R^2=0.64) and open-access publications growing annually (R^2=0.86). The Pearson correlation (r=0.71, *p*-value=0.12) suggests a moderate



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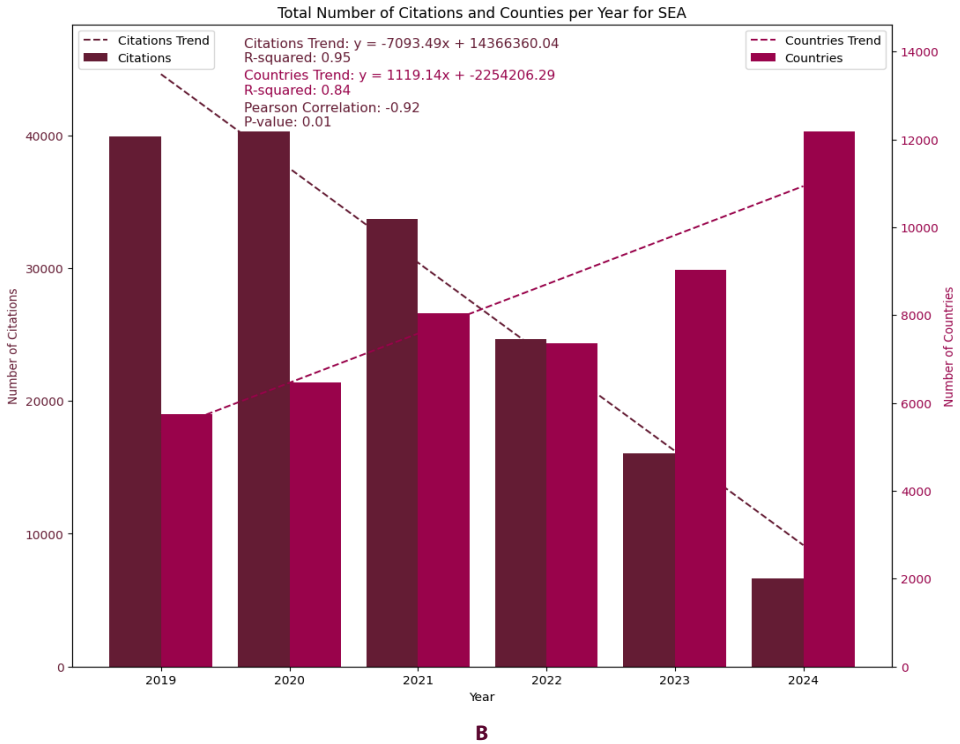

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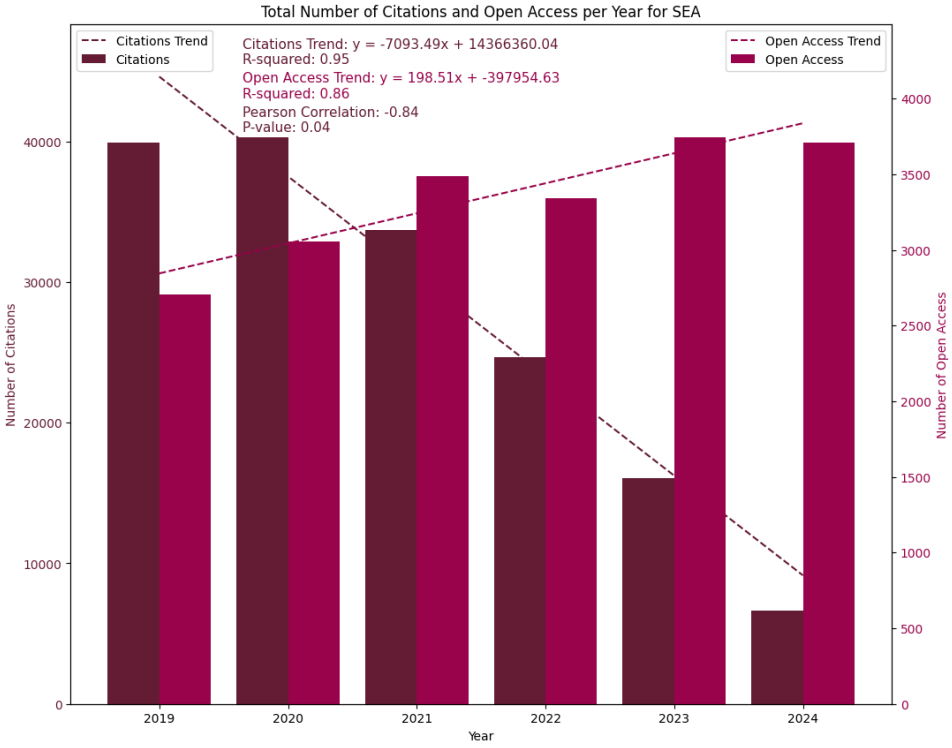

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Figure 2: Trend Analysis of Citations and to other domains per Year for SDG4: (a) Total Number of Citations and Authors; (b) Total Number of Citations and Countries; (c) Total Number of Citations and Open Access. (a)

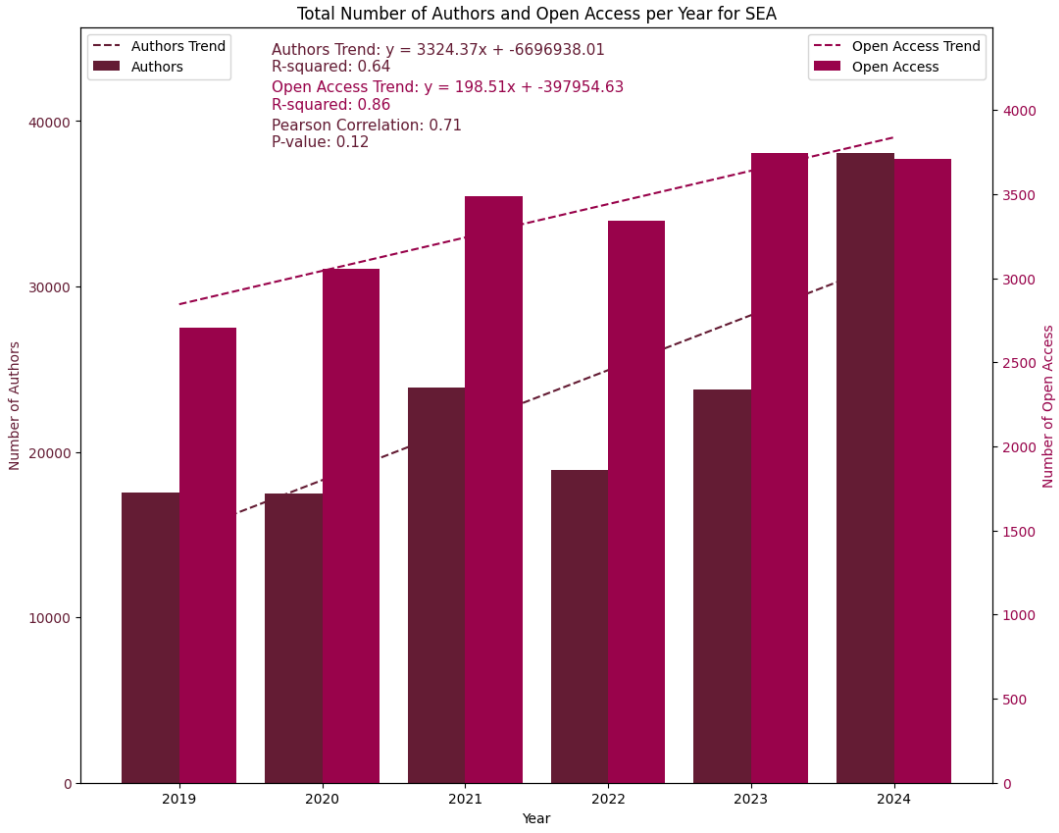
positive relationship; however, the lack of statistical significance means this association is not strongly conclusive. While the rising number of authors aligns with the increase in open-access publications, external factors such as funding, institutional policies, and publication preferences may influence this trend. Strengthening incentives for open-access publishing could further enhance accessibility and the dissemination of research.

Figure 3b highlights a strong positive relationship between the number of authors and the number of contributing countries in SEA from 2019 to 2024, with the number of authors increasing annually (R^2=0.64) and the number of countries growing annually (R^2=0.84). The high Pearson correlation (r=0.97, *p*-value=0.00) indicates a significant relationship, suggesting that the number of contributing authors also increases as international collaboration expands. This trend reflects a growing global research network in SEA, promoting diversity in academic contributions. However, sustaining this growth may require more substantial research infrastructure, funding, and policies to maximize the impact of these collaborations.

Figure 4a demonstrates a positive relationship between the growth of open-access publications and the number of contributing countries in SEA from 2019 to 2024, with open-access publications increasing per year (R^2=0.86) and the number of countries growing per year (R^2=0.84). The strong Pearson correlation (r=0.83, *p*-value=0.04) suggests a significant relationship between the expansion of international collaboration and the rise in open-access publications. This trend highlights the growing global reach and accessibility of research from Southeast Asia (SEA). However, ensuring that open-access publications maintain high visibility and impact may require further strategies, such as indexing, research quality enhancement, and stronger institutional policies that support open-access dissemination.

Figure 4b illustrates a positive relationship between open-access publications and the number of contributing institutions in SEA from 2019 to 2024, with open-access publications increasing annually (R^2=0.86) and institutions increasing annually (R^2=0.64). The Pearson correlation (r=0.70, *p*-value=0.12) suggests a moderate positive association, although not statistically significant, indicating that open-access publications tend to increase as more institutions engage in research. This trend reflects expanding institutional participation in open-access publishing, but variability in institutional policies, funding availability, and research output quality may influence the strength of this relationship. Encouraging more institutions to support open-access initiatives could enhance research visibility and accessibility.

Figure 4c presents a moderate negative relationship between the number of contributing institutions and the number of research views in SEA from 2019 to 2024, with the number of institutions increasing annually (R^2=0.64) and the number of views declining



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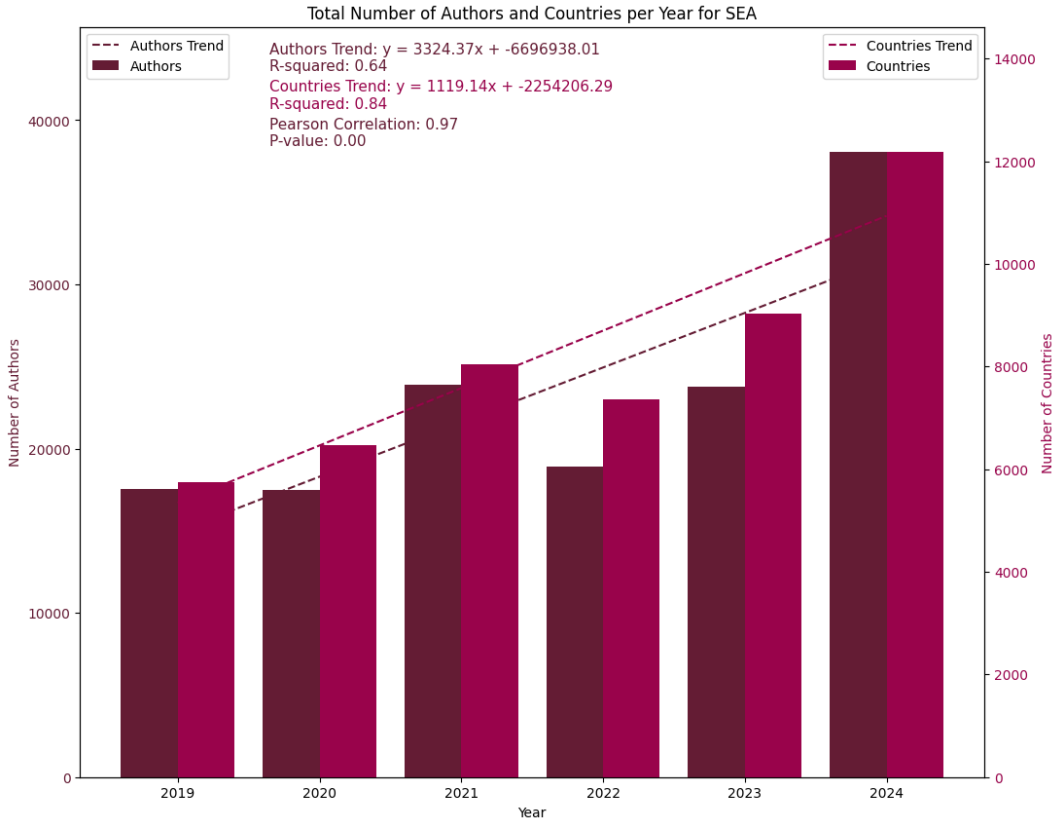

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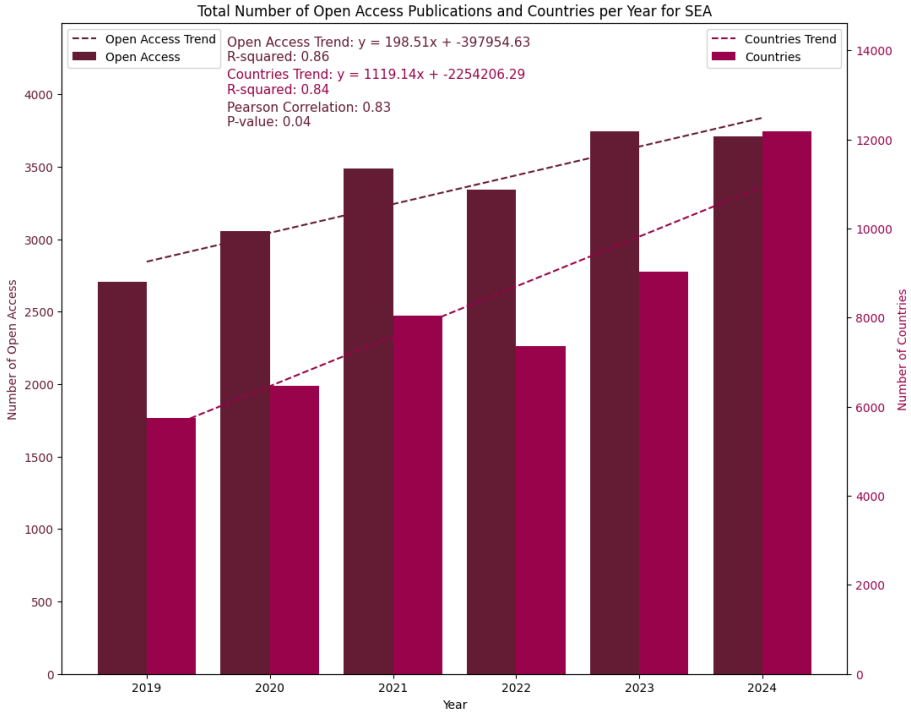
Figure 3: Trend Analysis of Authors and to other domains per Year for SDG4: (a) Total Number of Authors and Open Access; (b) Total Number of Authors and Countries. (a)

annually (R^2=0.08). The Pearson correlation coefficient (-0.51, *p*-value=0.30) suggests a weak negative association; however, the lack of statistical significance indicates that this trend may not be conclusive. While institutional participation in research is growing, the decreasing number of views suggests possible challenges in visibility, engagement, or audience reach. Strengthening dissemination strategies, indexing in high-impact databases, and promoting institutional research outputs may help improve visibility and readership.

Figure 5 illustrates the annual trend in the count of publication types across six Southeast Asian countries from 2014 to 2023.



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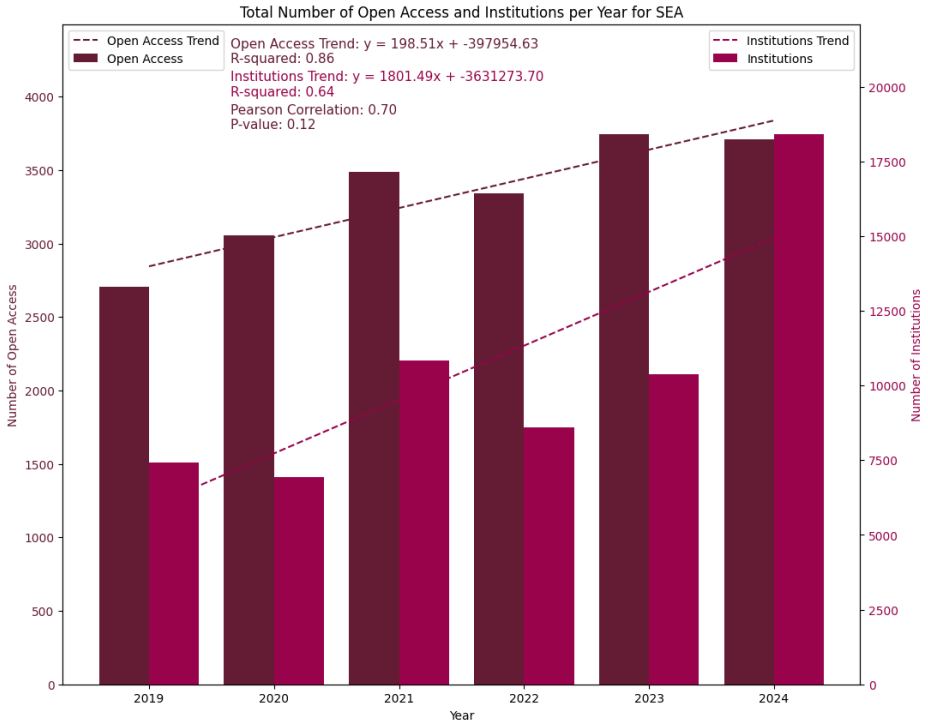

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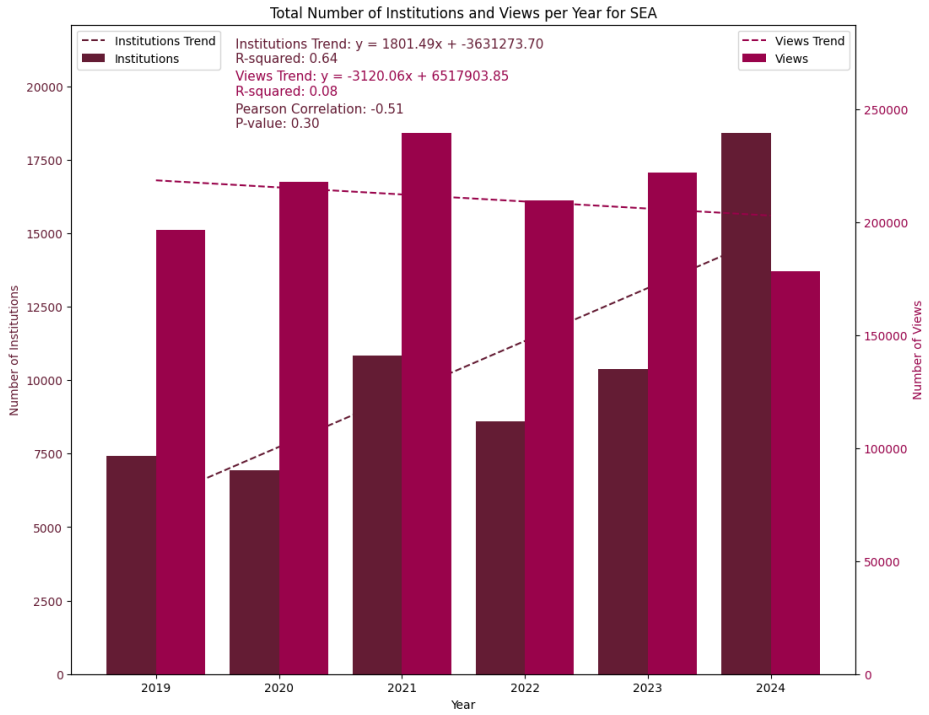


Figure 4: Trend Analysis of Open Access Publications and to other domains per Year for SDG4: (a) Total Number of Open Access Publications and Countries; (b) Total Number of Open Access Publications and Institutions; (c) Total Number of Open Access Publications and Views.

Indonesia (ID) exhibits the most significant growth, with a sharp surge from 2017 to 2020, peaking in 2020 before experiencing a slight dip and then rebounding in 2023. Malaysia (MY) maintains a steady and consistent upward trajectory, securing the second-highest publication output by the end of the period. Other countries, such as the Philippines (PH), Singapore (SG), Thailand (TH), and Vietnam (VN), demonstrate gradual increases, with Singapore and Thailand slightly outpacing the others. This trend highlights Indonesia's leading and accelerating role in regional research productivity, especially post-2017, while other countries follow more moderate yet steady growth patterns in academic publication activity.

Figure 6a presents both historical data and a forecast of the number of publications from 2014 to 2029. The historical trend shows a steady increase from 2014 to 2020, followed by a plateau and slight fluctuations through 2023. Notably, a resurgence is observed in 2023, which serves as the basis for the projected upward trend. The forecast, spanning from 2025 to 2029, anticipates continuous growth, with publication counts expected to rise from approximately 6,416 in 2024 to 9,315 by 2029. This optimistic projection suggests a strong and sustained momentum in research productivity in the coming years, likely driven by increasing regional research investments, institutional capacity-building, and digital access to scholarly platforms.

Figure 6b illustrates both historical and projected trends in the number of collaborative countries from 2014 to 2029. From 2014 to 2023, there is a clear upward trajectory, marked by occasional dips, reflecting a consistent increase in international research collaborations. Notably, a significant rise occurs between 2018 and 2021, followed by a slight fluctuation before the trend recovers in 2023. The forecast for 2025 to 2029 predicts robust growth in collaboration, with the number of collaborative country instances expected to rise from 9,878 in 2024 to 14,411 by 2029. This trend suggests that international cooperation in research is expected to deepen, likely driven by the global push to address shared challenges, such as sustainability, digital transformation, and public health, through cross-border academic networks.

Figure 6c presents both historical and projected trends in the number of institutions contributing to SDG 5 (Gender Equality) research from 2014 to 2029. The historical data reveal a rapid rise in institutional participation between 2014 and 2016, stabilizing at a high level through 2018. A notable drop occurs in 2019, followed by a gradual recovery and growth through 2023. The forecast from 2025 to 2029 anticipates a steady increase in the number of participating institutions, from 1,049 in 2024 to 1,226 in 2029. This upward trend suggests a renewed and expanding institutional commitment to gender equality research, reflecting the increasing prioritization of SDG 5 within academic and policy-related discourse.

Figure 7a displays the distribution of various Open Access (OA) types associated with SDG 4 publications from 2014 to 2023. The data reveals a substantial increase in open-access publications over the years, particularly beginning in 2018. Among the OA types, Green Open Access consistently dominates, indicating a

preference for repository-based self-archiving. Gold and Hybrid Gold access models also show notable growth, particularly between 2018 and 2023, indicating an increase in the adoption of fully open and partially open publishing. By 2023, all OA types will experience visible expansion, with emerging contributions from Bronze/Green and Hybrid Gold/Green, reflecting the diversification of OA strategies. Overall, the chart highlights a growing commitment to accessible knowledge dissemination in support of SDG 4 (Quality Education).

Figure 7b shows a stacked bar chart illustrating the annual distribution of publication types related to SDG 4 (Quality Education) from 2014 to 2023. Articles overwhelmingly dominate across all years, showing a consistent and substantial increase, particularly since 2018. Conference papers form the second most prominent category, contributing significantly from 2019 to 2023, which may reflect growing academic engagement through conference platforms. Other types, such as books, chapters, and reviews, appear more modestly but steadily, indicating diverse yet less frequent dissemination formats. The data highlights a notable expansion in overall scholarly output post-2018, suggesting increased attention and funding toward SDG 4-related research, with a clear preference for peer-reviewed journal articles as the primary mode of academic communication.

Figure 7c displays the distribution of publication types by country for SDG 4-related research. Indonesia (ID) leads significantly, with the highest count of publications, dominated by articles and a substantial share of conference papers, reflecting a strong culture of both journal and conference dissemination. Malaysia (MY) follows, also with a high volume of articles and a notable presence of conference papers. The Philippines (PH), Singapore (SG), Thailand (TH), and Vietnam (VN) show lower but steady outputs, primarily through journal articles. Across all countries, articles remain the most common publication type, indicating their central role in communicating SDG 4-related findings. This distribution reveals Indonesia and Malaysia as the regional hubs for education research output, likely due to supportive research policies, institutional participation, and regional collaboration.

Figure 7d illustrates the distribution of different Open Access (OA) types by country for SDG 4 publications. Indonesia (ID) dominates with the highest total, primarily through Green Open Access (OA), indicating a strong reliance on institutional or subject repositories for public access. Malaysia (MY) also contributes significantly, with a more diversified OA profile that includes Gold, Hybrid gold, and Hybrid gold/Green models. In contrast, the Philippines (PH), Singapore (SG), Thailand (TH), and Vietnam (VN) have lower total OA outputs but still show a preference for Green OA. The data highlights Indonesia and Malaysia's leadership in making education-related research openly accessible, supporting regional knowledge dissemination and equity in access, which aligns with the goals of SDG 4.

Figure 8 shows the word cloud visualization of the most frequently occurring terms from the "Topic name" used in the SDG 4 research in SEA revealing key thematic focuses in SDG 4-related research. Prominent terms such as "case study," "e-learning," and "engineering education" dominate, indicating a strong emphasis on applied research, digital learning environments, and technical education. Other significant phrases include "computer-aided instruction," "secondary school," and "learning outcome," reflecting a focus on educational technology and assessment at various educational levels. The presence of "sustainable development" and "foreign language" also highlights the interdisciplinary and inclusive nature of educational

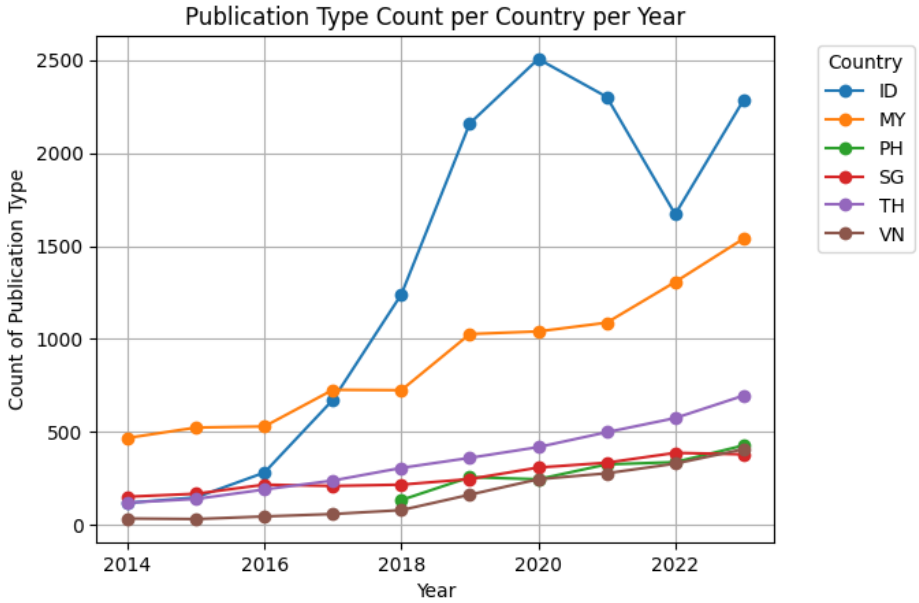
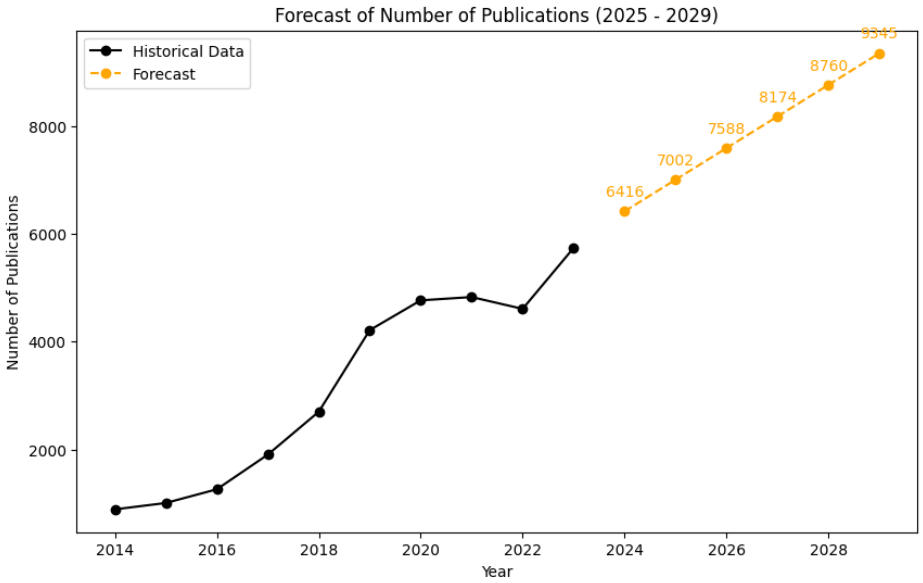


Figure 5: Publication Type Count per Country per Year.

research. Overall, the word cloud underscores the centrality of technology-enhanced and context-based learning approaches in the global pursuit of SDG 4.

Figure 9 illustrates the Sankey diagram, which shows the interconnected flow of publication types across Southeast Asian countries (ID, MY, TH, SG, PH, VN), revealing clear trends in scholarly dissemination. A significant portion of research output from Indonesia (ID) and Malaysia (MY) is directed toward conference papers and articles, indicating a strong alignment with conference proceedings and journal publications, respectively. Thailand (TH), Singapore (SG), and Vietnam (VN) exhibit a more balanced distribution across publication types, though journal articles still dominate, indicating a consistent preference for peer-reviewed platforms. The Philippines (PH) contributes fewer publications overall, but channels most of its outputs into articles and chapters, reflecting a selective yet focused engagement in academic publishing.

The middle node-publication type-acts as a central bridge connecting countries with their favored dissemination channels. Notably, articles from all countries are primarily directed toward journal sources, while conference papers are published mainly in conference proceedings, highlighting a clear structural pattern in publication behavior. Chapters, though less dominant, link countries like MY and PH to books and book series, suggesting some engagement with scholarly collections. Overall, the Sankey diagram reveals a structured and hierarchical flow from national academic systems to global publication formats, with journal



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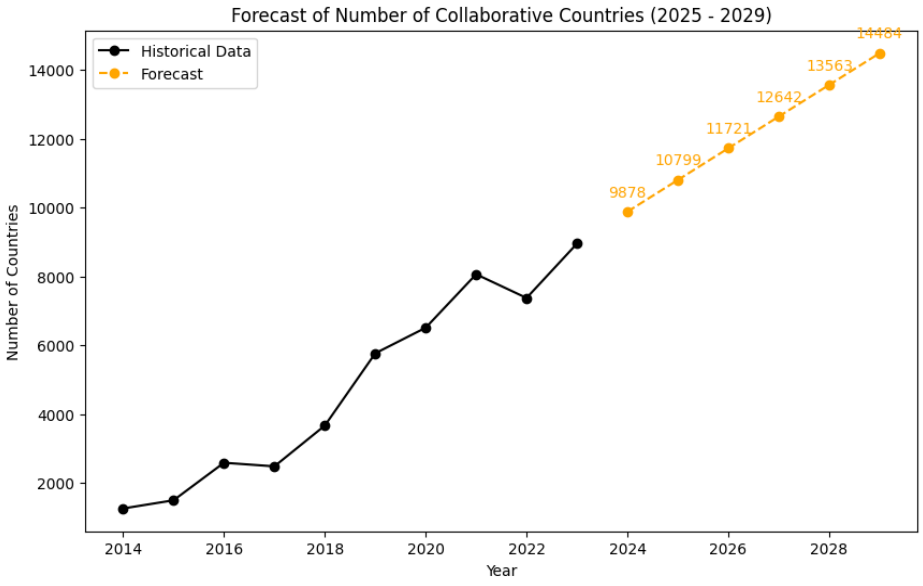

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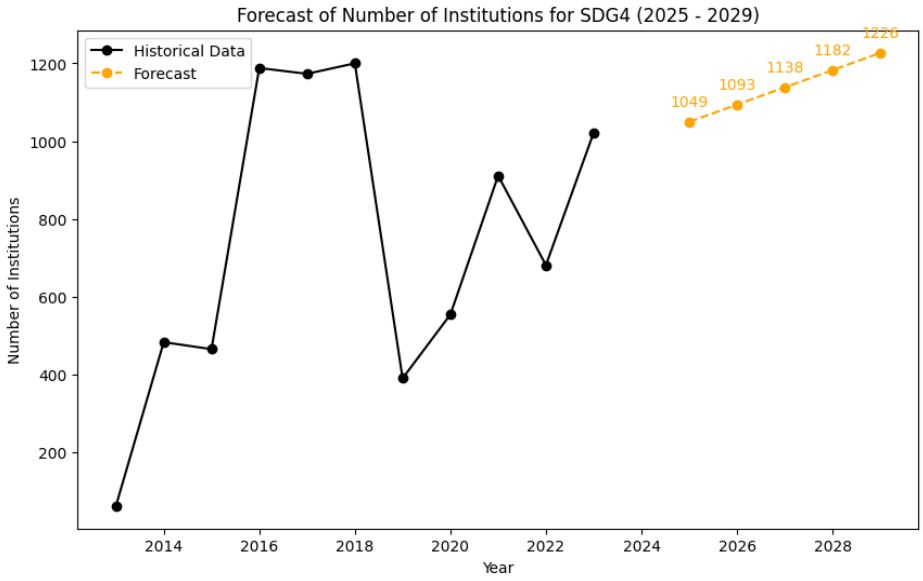

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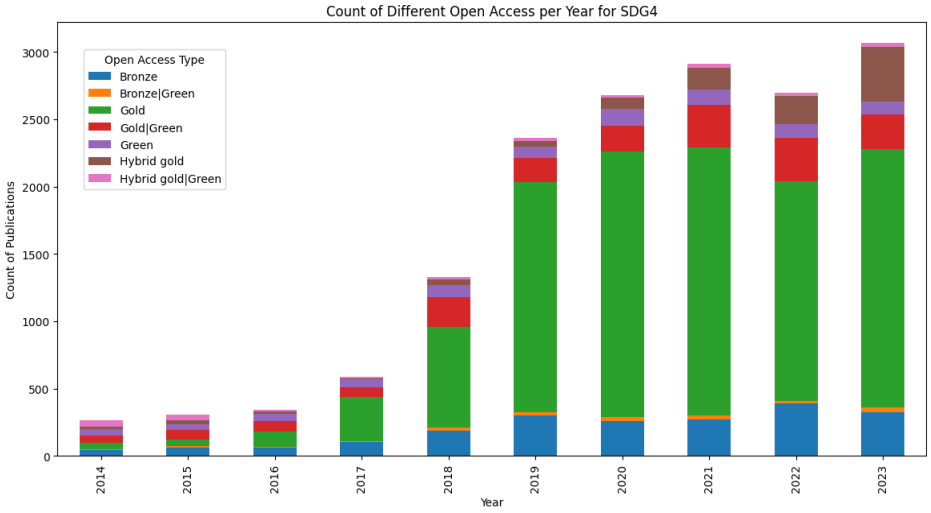
Figure 6: Forecasting SEA Research Performance: (a) Forecast on the Number of Publications; (b) Forecast on the Number of Collaborative Countries; (c) Forecast on the Number of Institutions doing SDG 4 Research. (a)



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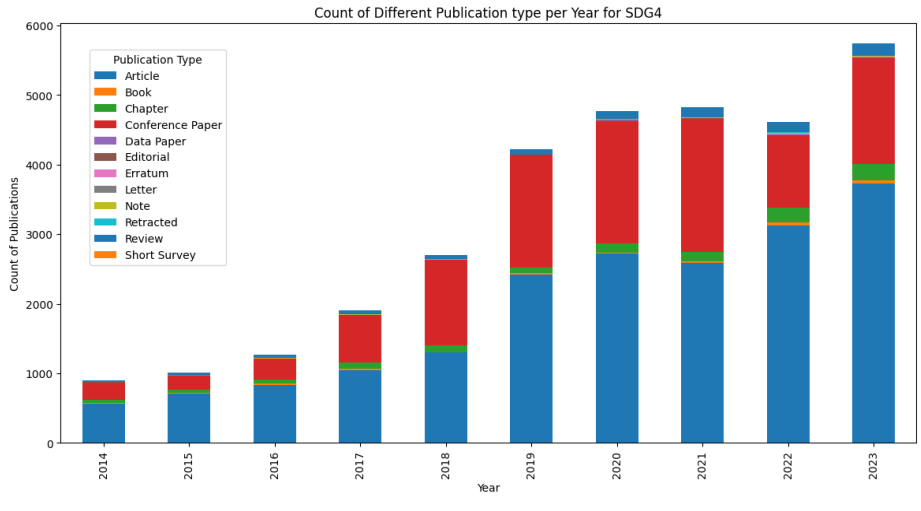

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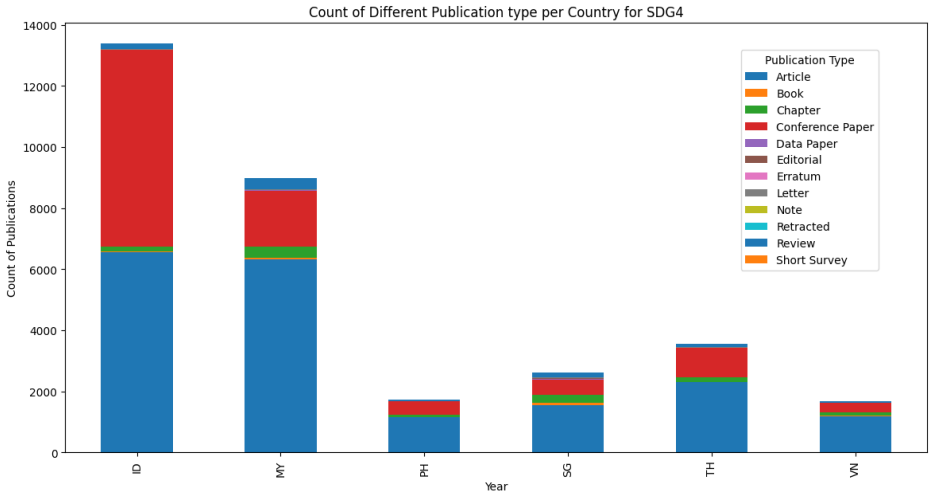

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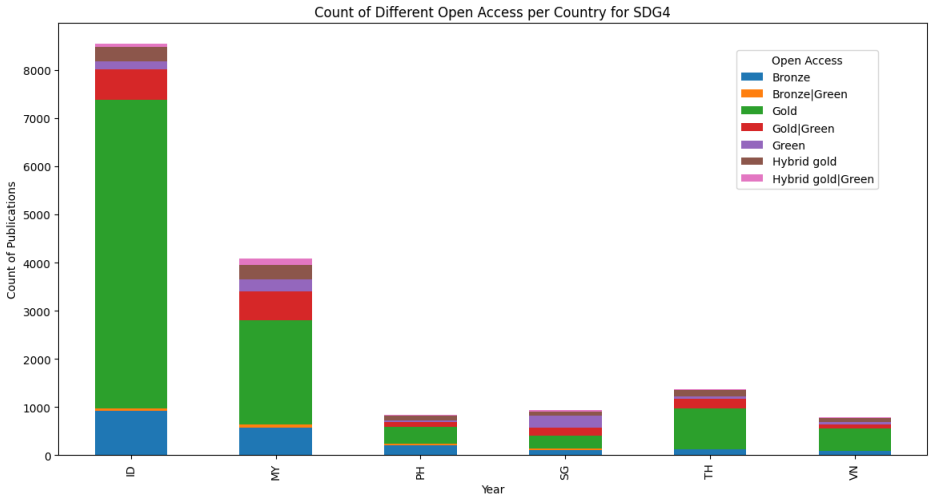

D

Figure 7: Stack Presentation of Metric Counts; (a) Different Open Access per Year; (b) Different Publication Type per Year; (c) Different Publication Type per Country; (d) Different Open Access Type per Country.

articles serving as the primary scholarly currency across the region.

Figure 10 shows the correlation matrix, which reveals several notable relationships among research-related variables in SEA. A strong negative correlation (-0.99) between authors and citations suggests that citation counts decline as the number of authors increases, possibly indicating citation dilution or lower research impact per author. Similarly, institutions exhibit a strong negative correlation with citations (-0.81), suggesting that increased institutional participation does not necessarily lead to more citations. Meanwhile, open-access publications and views exhibit a near-perfect positive correlation (0.99), indicating that open-access articles receive higher visibility but may not always translate into citations. Countries and citations exhibit a strong negative correlation (-0.92), indicating that increased international collaboration does not necessarily lead to higher research impact in terms of citations.

To address these challenges, researchers and institutions in SEA should focus on producing quality-driven research outputs rather than merely increasing publication volume. Encouraging high-impact collaborations, publishing in top-tier journals, and enhancing research dissemination strategies will improve citation impact. Additionally, institutions should support better indexing, open-access visibility, and engagement with policymakers and global research networks to ensure broader academic influence. Future policies should balance expanding research participation and maintaining high citation impact, ensuring that SEA's growing research contributions gain greater recognition and influence in the global academic community.

Figure 11 presents the Structural Equation Model (SEM) that elucidates the latent dynamics underlying scholarly

productivity and impact across the dimensions of collaboration, openness, and dissemination. Three latent constructs were identified-Collaboration, Open Access Influence (OA Influence), and Research Impact-and their linkages to observed variables were tested through a correlational framework. Collaboration, as reflected by the number of authors, countries, and institutional affiliations, exhibited strong positive loadings with Authors (r=0.95) and Countries (r=0.95), affirming its role as a key driver in scientific cooperation. However, a weak negative correlation with Institutions (r=-0.23) suggests potential disparities in institutional centrality or publication gatekeeping, a nuance consistent with findings from large-scale network studies in scientometrics.

The latent construct OA Influence, composed of Open Access, Views, and Publications, demonstrated substantial loading strengths (ranging from 0.99 to 1.00), highlighting the central role of accessibility and visibility in amplifying scholarly dissemination. Notably, the pathway from OA Influence to Research Impact (r=0.47) confirms hypotheses in prior literature that open dissemination significantly predicts citation performance and scholarly recognition. The mediating role of Publications, which loads on both OA and Impact constructs,

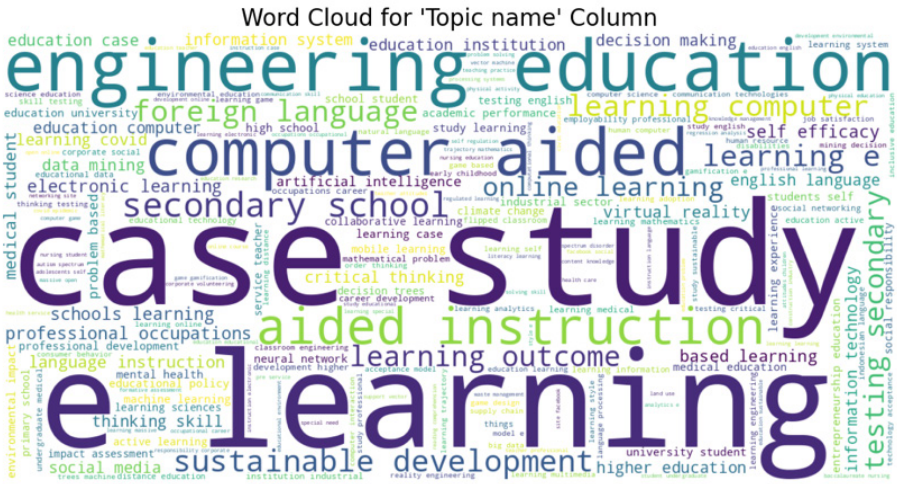

Figure 8: Word Cloud Visualization from the Prominent Topics in SDG4.

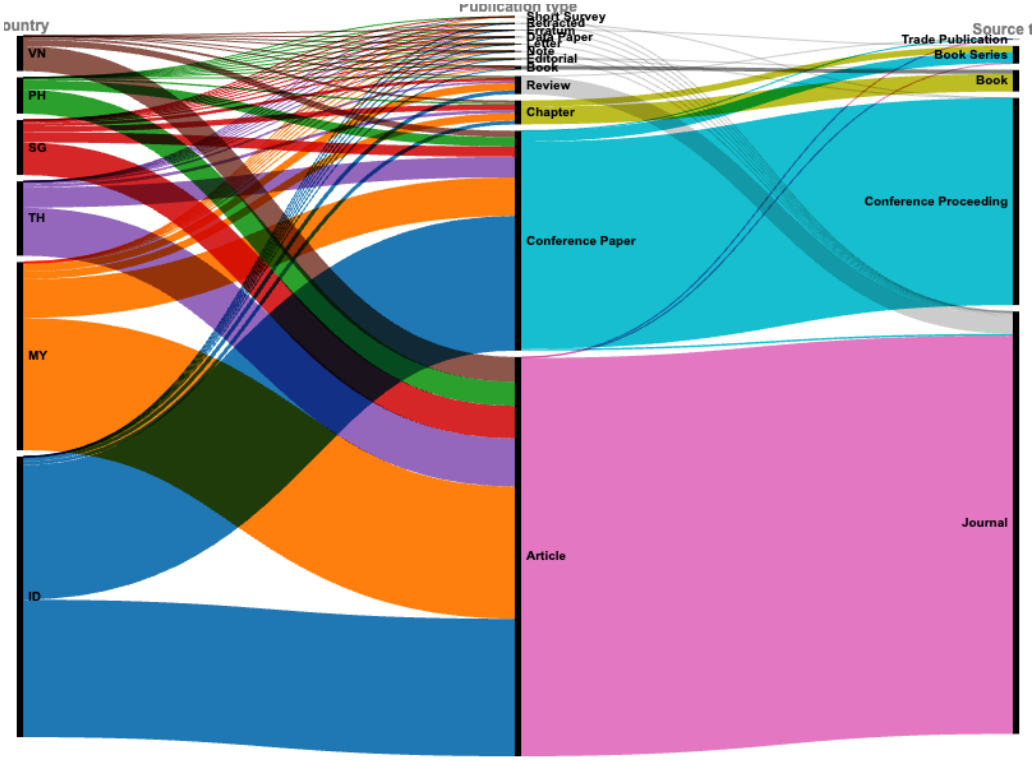

Figure 9: Threefold Sankey Diagram between Countries, Publication Type, and Scopus Source Type.

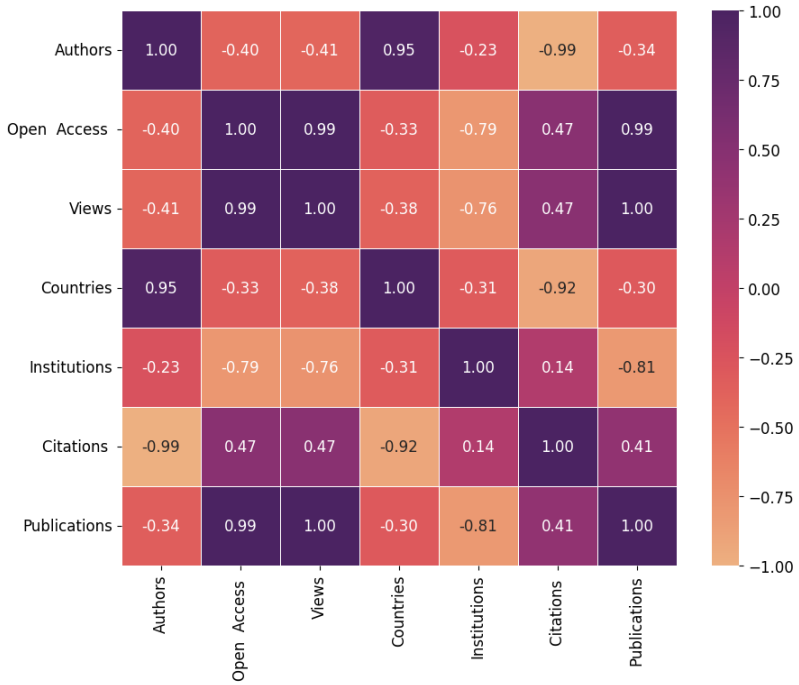

Figure 10: Correlation Heatmap of the different domains.

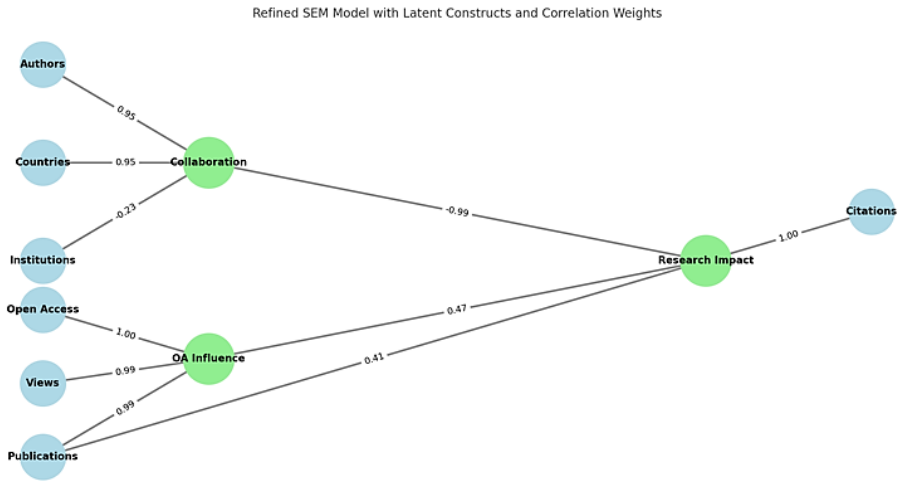

Figure 11: Structural Equation Model of the SDG4 Research Metrics in Southeast Asia.

reflects its dual function as both a product of dissemination and a precursor to measurable academic value.

Most critical is the inverse relationship between Collaboration and Research Impact (r=-0.99), which challenges conventional assumptions in Scientometric literature that international and multi-author collaborations inherently yield greater citations. This negative path coefficient may reflect saturation effects, authorship inflation, or unbalanced contribution models that dilute academic credit, especially within lower-institutional-capacity contexts. Furthermore, the direct path from Research Impact to Citations (r=1.00) confirms the model's alignment with core bibliometric theory, which posits that citations are the emergent metric of cumulative influence, shaped by both structural (collaboration) and functional (open-access dissemination) factors. The model, therefore, provides an empirically grounded yet theoretically nuanced representation of the drivers of research visibility and impact in the evolving landscape of global scholarly communication.

CONCLUSION

This Scientometric investigation into SDG 4-related research across Southeast Asia reveals significant progress and persistent challenges in achieving inclusive and high-quality education. The rise in publication volume-especially from Indonesia and Malaysia-signals a maturing research ecosystem, strengthened by digital education methods, cross-border collaborations, and

conference-based dissemination. However, a declining trend in citations across the region suggests that increasing publication quantity alone does not guarantee higher impact. The Structural Equation Model (SEM) confirms that open-access dissemination contributes more directly to research visibility than collaboration metrics, challenging established bibliometric assumptions.

Another concerning trend is the disparity in institutional involvement and thematic diversity. While engineering education, e-learning, and case study research dominate, essential areas like peace education, teacher inclusion, and indigenous knowledge systems remain underexplored. Furthermore, open-access strategies, such as Green OA, are prevalent but not always accompanied by increased citation growth, indicating a need for improved quality control and dissemination planning.

To enhance the impact and inclusivity of SDG 4 research in Southeast Asia, institutions should prioritize quality over quantity by investing in research training, strengthening peer review mechanisms, and encouraging publication in high-impact journals. Expanding the thematic scope to include equity, inclusion, early childhood development, and peacebuilding is essential, as these areas are currently underrepresented in the literature. Strengthening institutional participation through targeted research incentives is particularly crucial for underperforming countries such as Laos, Cambodia, and Myanmar. Moreover, fostering strategic collaborations should go beyond co-authorship to focus on meaningful, outcome-driven partnerships. Finally, enhancing research visibility through improved indexing, quality-assured open-access dissemination, and translation into local languages will ensure broader accessibility and relevance. Implementing these recommendations can help Southeast Asia bridge gaps in educational equity, elevate scholarly output, and strengthen policy frameworks essential for achieving SDG 4 and sustainable development goals.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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