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Leading countries and research networks advancing clean production and environmental sustainability in Southeast Asia

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Abstract

Purpose – This study aims to assess the response of the Association of Southeast Asian Nations (ASEAN) to cleaner production and environmental sustainability, with a specific focus on identifying the leading countries and research networks driving these efforts.

Design/methodology/approach – A benchmarking academic journal was chosen, and the journal's archive was comprehensively examined. To construct the data set, a conventional keyword search technique was applied in February 2023 to filter for ASEAN affiliations. The study used hybrid bibliometric analyses and multi-criteria decision analysis (MCDA) to analyze the collected data and address the research purpose.

Findings – The data analysis revealed a rising research trend, particularly after 2014. Malaysia had the most publications, followed by Thailand and Singapore, and their publications had the most cumulative citations among ASEAN countries. Research collaborations between Malaysia, Thailand and Singapore were frequent, but participation from other countries was low. The research topics on which ASEAN members focused were also identified, but it became apparent that there was little coordination. A scant few collaborations involving more than two countries were observed; thus, the MCDA analysis concluded that research leadership was absent in ASEAN countries.

Originality/value – This study contributes insights to the existing literature and offers a valuable overview of the research direction and collaboration status of cleaner production and environmental sustainability in the ASEAN region, thus benefiting policymakers. Additionally, this study introduces a novel approach combining bibliometrics analysis with MCDA to assess research collaboration, thus providing a novel methodology for future research policy evaluations.

Keywords Cleaner production, Bibliometric analysis, Environmental sustainability, Multi-criteria decision-making (MCDM), Association of Southeast Asian Nations (ASEAN)

Paper type Literature review

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1. Introduction

The Association of Southeast Asian Nations (ASEAN) has launched a number of initiatives and programs to promote cleaner production and environmental sustainability (Mehmood *et al.*, 2022). However, to the best of the authors' knowledge, full awareness is lacking regarding which countries are scientifically leading the efforts to achieve clean and sustainable production in practice. Consequently, this work aims to fill this gap in the literature by identifying key contributors to the fields of cleaner production and environmental sustainability. In particular, this study aims to assess ASEAN's response to sustainable, clean production by conducting a systematic review of the relevant literature published in the field by ASEAN members. Furthermore, the study intends to track progress over time, share valuable knowledge and best practices and raise awareness of the region's efforts in this critical area. The novel approach of systematically mapping the contribution and evolution of research on cleaner production and environmental sustainability in the ASEAN region will capture the union's significant strides in addressing this pressing issue. As a result, the findings of this study will not only shed light on ASEAN's development, growth and new advances in clean production and environmental sustainability but will also serve as a valuable resource for international policymakers to inform future paths toward achieving sustainable and environmentally conscious practices.

2. Literature review

As the global economy becomes increasingly interconnected and interdependent, the role of environmental sustainability in economic development has been widely acknowledged as a crucial factor in long-term growth and prosperity. Many existing ecosystem issues, however, have worsened in recent years to the point that they could likely result in a serious global environmental crisis (Khan *et al.*, 2022a, 2022b). This outcome was first predicted in the 1987 United Nations report on sustainable development and has since been supported by numerous studies and reports (Organization of Economic Cooperation and Development [OECD], 2011). The degradation of ecosystems, such as forests, rivers and fertile lands, because of pollution and overuse creates barriers to economic progress and exacerbates poverty, particularly in rural areas (Garg, 2020). In addition, environmental issues such as health problems and food insecurity caused by pollution can have significant impacts on communities and further worsen poverty in areas where it is already difficult to earn a living or receive an education (Abideen *et al.*, 2021; Kopittke *et al.*, 2019; Tan and Kamaruddin, 2019). Significant gaps in legislation and standards are impeding the implementation of these changes and reflect the serious problems posed by plastic trash in Asian waterways (Leal Filho *et al.*, 2022a). The adoption of the United Nation's sustainable development goals (SDGs) in 2015 evoked a sense of optimism regarding their achievable implementation by the year 2030 (Leal Filho, 2023). International partnerships to create synergies are one way of developing global sustainability to facilitate the implementation of the SDGs (Leal Filho *et al.*, 2022b).

ASEAN was established on August 8, 1967, in Bangkok, Thailand, as a political and economic organization of ten countries: Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, Vietnam, Laos PDR, Myanmar and Cambodia (ASEAN, 2022). Over the past five decades, it has experienced impressive economic growth and become a major contributor to the global economy (Khan, 2021). However, this growth has not come without its challenges, particularly in terms of environmental sustainability (Kasa, 2021). In recognition of the importance of environmentally sustainable growth, ASEAN member states have adopted various declarations and implementation plans, including the ASEAN Socio-Cultural Community Blueprint (2009) and the State of the Environment

Report (2007, 2009), based on their public reporting (ASEAN, 2016). These initiatives emphasize the economic importance of environmental protection and demonstrate ASEAN's commitment to sustainable development. Furthermore, subregional initiatives, such as the Indonesia–Malaysia–Thailand Growth Triangle, have been established to address the environmental and social challenges faced by these countries and promote sustainable growth (ASEAN, 2016). ASEAN is now promoting environmental cooperation among its members for sustainable development and regional integration. This cooperation is guided by the ASEAN Socio-Cultural Community Blueprint 2025 (ASEAN, 2016), which aims to create a dynamic and inclusive community that is sustainable, resilient and dynamic. The aim of this cooperation is to conserve and sustainably manage biodiversity and natural resources, promote environmentally sustainable cities and encourage sustainable consumption and production. Besides, each ASEAN member state has demonstrated a tremendous commitment to advancing environmentally responsible growth in the ASEAN economy (Han *et al.*, 2022).

Nonetheless, to sustain its sustainable growth as a major player in the global economy, ASEAN requires crucial ecosystem services, such as clean water, arable land and unpolluted air. ASEAN member states must continue to prioritize environmental sustainability in their economic development strategies (ASEAN, 2016; Lord and Tangtrongjita, 2016) and work together to create a more sustainable future for the region and the world. Researchers should therefore investigate how better collaboration can be fostered among stakeholders to bring about sustainability (Khan *et al.*, 2023a).

ASEAN, as a region of rich biodiversity, hosts approximately 20% of all known diverse species of living creatures (ASEAN, 2022), underscoring the urgent need for environmental protection and commitment to sustainability. ASEAN is experiencing rapid economic growth and consequently faces serious challenges in the area of environmental protection (Han *et al.*, 2022). Environmental deterioration is a critical issue for ASEAN's future development and sustainable integration (Ahmed *et al.*, 2017). ASEAN is trying to address the United Nations' SDGs, and its environmental challenges include water management, waste management, deforestation and land degradation, sea and air pollution and climate change (Agus *et al.*, 2020). However, urbanization and excessive consumption of food, water and energy have led to environmental and economic challenges (Dey *et al.*, 2020).

The ASEAN nations are now focusing on cleaner production in various industries, such as poultry, agriculture and food, and are also promoting the commercial production of biofuels from palm oil (Dey *et al.*, 2021). Indonesia and Malaysia are shifting their focus to the global natural gas market while reducing the use of non-renewable energy and promoting environmentally friendly economic changes through green funding and financing (Raihan and Tuspekova, 2022). ASEAN countries are striving to decarbonize and reduce their greenhouse gas emissions and become world leaders in green energy innovation and development (Nepal *et al.*, 2021). Budget tagging for climate change has been implemented in Indonesia to promote sustainability (Gonguet *et al.*, 2021). Yet, to achieve long-term financial and environmental goals, it is important for ASEAN to emphasize the need to combine efforts and resources (Khan *et al.*, 2022).

Despite the environmental sustainability goals and efforts outlined above, several ASEAN members, including the Philippines, Malaysia, Indonesia, Vietnam and Thailand, are among the top ten ocean polluters, and uncollected and illegally discarded plastic waste contributes thousands of tons to ocean pollution each year (ASEAN, 2022). This waste alone poses a hazard for marine life, including the presence of microplastics that can enter the food chain and may harm human health (Guzman, 2022). Last but not least, addressing

environmental challenges remains crucial for the stability and future prosperity of the ASEAN region (ASEAN, 2022).

The rise of sustainability concerns has motivated global research on cleaner production and environmental sustainability practices and their financial consequences (Khan *et al.*, 2023b; Gracia and Siregar, 2021). However, according to Leal Filho *et al.* (2022c), there are significant differences among Asian nations when it comes to sustainability practices in higher education institutions. Such institutions in far-eastern nations such as Indonesia, Malaysia and Thailand are thought to exhibit higher sustainability practices (Leal Filho *et al.*, 2022d). Leal Filho *et al.* (2023) emphasize the value of encouraging global cooperation initiatives to promote declarations and foster the sustainable development movement. However, Leal Filho *et al.* (2022e, 2022f) note the gaps in our existing knowledge of how countries can pursue sustainable development goals. For ASEAN's goal of promoting sustainability, related scientific contributions play a crucial role in evaluating the results of the efforts made and programs launched. Upadhyaya and Rajasekharan Pillai (2019) both point to the importance of research in bolstering a region's economy and improving its sustainability. The direct, indirect and flow-on effects of research increase value-added, production and technology capacity as well as consumer surplus and many others (Sukoco *et al.*, 2023). Besides, there have been dramatic shifts in scientific inquiry throughout the ASEAN countries over the past few decades, coinciding with the region's rapid development (Ho-Le and Nguyen, 2018). As a result, this research seeks to explore the extent of research efforts and collaborations among ASEAN members in addressing the cleaner production and environmental sustainability movements.

3. Method

This study's overarching goal is to learn more about the level of cooperation between ASEAN scholars working on sustainability issues. To do so, it requires a benchmark by which to evaluate the results of scientific investigations. Identifying such a standardization framework was an interim goal and was accomplished qualitatively by consulting the relevant literature and conducting a survey of representative ASEAN scholars. The 50 participants in a sustainability-related conference were approached. Respondents participated voluntarily, and the anonymity of their responses was respected to maintain confidentiality. The aim was to identify highly regarded journals within the ASEAN research community as a benchmark publication platform.

Then, using the identified benchmark platform to achieve the research objective of evaluating the relative importance and interconnections among countries in this field, the authors used a two-pronged approach consisting of:

- a systematic literature review with bibliometric analysis support; and
- systematic modeling with multi-criteria decision analysis (MCDA) support.

The combination of bibliometric analysis and MCDA in this work stands out as a methodological novelty that contributes significantly to the body of knowledge.

This study adheres to successful systematic review practices to ensure the validity and reliability of the findings (Abideen *et al.*, 2023; Sorooshian *et al.*, 2023a, 2023b). Accordingly, the following five steps were taken to ensure the data collection process was repeatable:

(1) Reviewing available databases and identifying those that were relevant
(2) Defining a search formula and data collection process
(3) Clearly defining the underlying data-analysis steps and their objectives

(4) Constructing valid inclusion/exclusion criteria
(5) Recording the outcomes of the analysis

Even though bibliometric tools indicate the number of publications, international collaboration and contributing researchers, these data do not necessarily indicate that a certain country is taking the lead in terms of mentoring and guiding researchers within ASEAN. It is possible that a country publishes a great deal of research with other countries but is not the leader in ASEAN research on the topic. Therefore, to determine whether this is so, besides bibliometrics analysis, the study used the MCDA decision-making trial and evaluation laboratory (DEMATEL) method to analyze the data. Bibliometrics software was used to create visual charts by uploading data from the database, while the DEMATEL methodology was used to create a causal network model that represents the causal relationships between different variables (Ali *et al.*, 2016; Falatoonitoosi *et al.*, 2012). DEMATEL is based on graph theory (Ali *et al.*, 2016) and can be implemented using Excel software; it is capable of analyzing the structure of complex network problems in real-world situations (Falatoonitoosi *et al.*, 2014; Sorooshian *et al.*, 2023a, 2023b). The phases involved in using the DEMATEL method are the following (Falatoonitoosi *et al.*, 2014; Ali *et al.*, 2016; Sorooshian *et al.*, 2023a, 2023b):

- Data collection: Information was extracted from the benchmark platform and included publication numbers for each ASEAN country.
- Data analysis: The data were analyzed and processed to identify relationships between countries in terms of the number of publications. The analysis can be broken down into the following steps.

Initially, the direct-relation matrix was constructed via equation (1), where X refers to the number of publications and n is a country repetitive:

$$Z = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \ldots & 0 \end{bmatrix} \tag{1}$$

The matrix was then normalized by dividing each element by the largest row sum of the Z matrix. Equation (2) gives the total direct effect of the factor with the greatest direct impact on the other variables. Equations (3) and (4) show how to compute the matrix:

$$\max_{0 \le x \le 1} \sum_{j=1}^{n} z_{ji}. \tag{2}$$

$$S = \max_{0 \le x \le 1} \sum_{j=1}^{n} z_{ji}. \tag{3}$$

$$\mathrm{D} = \frac{Z}{S} \tag{4}$$

Projecting the total relation matrix T, the causal relationship matrix is next. In this step, we calculate whether each system factor pair has a total or direct/indirect relationship. As shown in equation (5), the matrix of indirect influence converges to the null matrix based on the assumptions. Equation (6) holds when the null matrix (I) is an $n \times n$ identity matrix. However, equation (7) was used to define the matrix of the total relation T:

$$\lim_{k\to\infty} D^k = 0. \tag{5}$$

$$\lim_{k\to\infty} (I + D + D^2 + \ldots + D^K) = (I - D)^{-1}. \tag{6}$$

$$T = D(1 - D)^{-1}. \tag{7}$$

Next, the sums of the rows and columns of matrix T are needed. The vectors R and C represent the sums of the rows and columns in the matrix T. Let vector R be $n \times 1$ and vector C be $1 \times n$. When $i = j$, the prominence is defined as $(R_i + C_j)$ and illustrates the impact of the element and the total extent to which one is influenced. The degree to which an element influences and is influenced is represented by the prominence of the $(R_i + C_j)$ term.

The DEMATEL result defines a cutoff and depicts a causal chain. Setting a threshold value for filtering out the negligible effects in matrix T is essential to explain the structural relationship among the criteria while maintaining the complexity of the system at a manageable level. The cutoff value, denoted by the mean of all the cell values in matrix T, is used in cases of accusation. However, the benchmark, as noted by Chen (2012) and Hsieh *et al.* (2016), is something that the decision-maker can set. If it is too low, the resulting diagram will be too complicated to provide meaningful insight into which course of action to take. If the threshold is set too high, many elements will be given in isolation without any indication of how they relate to one another. Obtaining a useful cause-and-effect diagram and sufficient data for making decisions requires setting an acceptable threshold value:

- Causal network model creation: The DEMATEL methodology creates a causal network model that represents the causal relationships between countries.
- Identification of critical elements: The DEMATEL model was used to identify the critical country in the system.
- Evaluation of performance: The DEMATEL model was used to evaluate the performance of each country, the degree of interdependence between countries and the most critical country in the system.

As a result, using a two-pronged approach, this study provides a comprehensive analysis of the data using a bibliometrics approach hybridized with the DEMATEL MCDA to determine the relative importance and interconnections among countries in the field.

4. Results and discussion

The results of the study are broken down into three distinct parts: the selection of a benchmark platform, the bibliometric analysis and the DEMATEL outputs.

4.1 Identification of a benchmark platform

A total of 50 experts in the ASEAN region were polled to determine which academic journals they considered to be most relevant for this study. Of the 50 researchers, 11

responded that the *Journal of Cleaner Production* (ISSN: 0959–6526) is among the well-regarded journals in the field. Note that *Sustainability* (Switzerland) attained the second position in their ranking of preferences; however, as this journal might not be the first choice of all scholars because of its publication fees, the *Journal of Cleaner Production* was chosen as a benchmark publication platform. In addition, the selection of the journal represents a small sample size that may not represent the views of all researchers in the field. Overall, however, the fact that the sample of ASEAN researchers named the *Journal of Cleaner Production* as a well-regarded and influential journal in their field indicates that it is among the benchmarks of research outputs on the subject. The *Journal of Cleaner Production* thus serves as a benchmark for measuring the scientific performance and research collaborations in sustainability and waste management among ASEAN members (Geng *et al.*, 2019; Hamner, 1999; Yuan and Sun, 2023).

In the field of sustainability research, the *Journal of Cleaner Production* is a reputable publication that is widely recognized. The journal is noteworthy for its broad scope, prestigious editorial board, rigorous peer-review process and emphasis on clean production and sustainable manufacturing. As a result, the *Journal of Cleaner Production* is a feasible, reliable and valid benchmark for researchers interested in contributing to sustainable practices and technologies. ASEAN researchers are particularly linked to this journal through its focus on sustainability issues in the region, the high number of articles authored by ASEAN researchers, and the potential for its research to inform policy and practice in the ASEAN region.

The journal's high impact factor also indicates the widespread recognition and influence of its research, making it a strong benchmark for sustainability researchers around the world. Overall, the *Journal of Cleaner Production* is a respected and influential publication that provides a valuable benchmark for researchers interested in advancing sustainability research in the fields of clean production and sustainable manufacturing. The journal is well-regarded and focuses on theoretical and practical research in cleaner production, embracing environmental and sustainability challenges faced by businesses, governments, educational institutions, regions and societies.

Thus, the authors chose the *Journal of Cleaner Production* as their baseline as it has published many papers from Asia in addition to being one of the leading journals in the field of environment, sustainability and sustainable development; this is also attested by the literature (Fichter *et al.*, 2022; Francisco *et al.*, 2023; Haba *et al.*, 2022; Lima *et al.*, 2023; Yuan and Sun, 2023). The objective of this paper is to assess ASEAN's response to cleaner production by surveying the relevant literature that has been peer-reviewed and published by the chosen benchmark journal. The *Journal of Cleaner Production* is a Scopus-indexed publication; hence, the SCOPUS database was selected for collecting the data following suggestions in the literature (Sorooshian *et al.*, 2023a, 2023b).

4.2 Bibliometric analysis

A Scopus search formula of "ISSN (0959–6526) AND AFFIL (Brunei OR Cambodia OR Indonesia OR Laos OR Malaysia OR Myanmar OR Philippines OR Singapore OR Thailand OR Vietnam)" was used, resulting in a total of 1847 documents containing information on publication and citation, authors and affiliations, and title, abstract and keywords. To gain a more in-depth understanding of the collected data, this work uses a bibliometric approach. R-Studio software was used to analyze the data collected from the SCOPUS database of the *Journal of Cleaner Production* on February 4, 2023, and the period for the keyword retrieval was set at 1996–2022. Articles, conference papers, and reviews account for 99.4% of all documents. The remaining 13 documents were excluded, namely, errata (2 documents), letters

(5 documents) and editorials (6 documents). Because of the data collection timetable, the publication and indexing for the year 2023 are not yet complete. The 28 2023-indexed documents were, however, kept for analysis. Table 1 presents a summary of the collected data.

From the data, the trend in publications shows that little importance was given to research publications in the ASEAN region before 2014. However, a significant rise in research in this area is seen from 2015 to 2021. Malaysia is the leading contributor, with 63% of the documents, followed by Thailand (17%); Singapore (15%); Indonesia (4%); and Brunei, Cambodia, Laos and Myanmar with just 1% combined. The research area data (denoted by keywords) show that Malaysia has mainly focused on palm oil, carbon dioxide reduction, greenhouse emissions and life cycle assessment, with a particular focus on sustainable development. Thailand has focused on life cycle assessment and carbon reduction, while Singapore has focused on energy utilization and pollution control. Indonesia, being the largest ASEAN country, has contributed to palm oil-related research and studies of other elements that govern environmental impact.

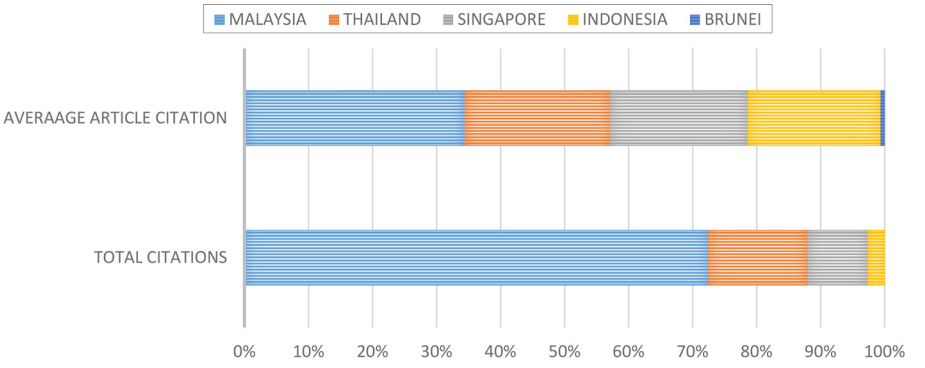
An analysis of the data on total cumulative citations and average per-article citation value country-wise is presented in Figure 1, showing the impact of the research outcomes on the global perspective.

Publications from Malaysia and Thailand account for 87% of the total cumulative citations among the ASEAN nations. The cumulative occurrences of top keywords over a timespan are portrayed in Figure 2.

Description	Results
Principal information about the data	
Timespan	1996:2022
Sources (journals, books, etc.)	1
Documents	1,847
Annual growth rate %	21.89
Document average age	4.91
Average citations per document	40.15
References	110,887
Document contents	
Keywords plus (ID)	11,869
Author's keywords (DE)	6,146
Authors	
Authors	5,615
Authors of single-authored docs	26
Author collaboration	
Single-authored documents	26
Co-authors per document	4.87
International co-authorships %	62.26
Document types	
Article	1,607
Conference paper	19
Editorial	6
Erratum	2
Letter	5
Review	208

Source: Table by the authors

Table 1. Description of the collected data



	TOTAL CITATIONS	AVERAAGE ARTICLE CITATION
MALAYSIA	34641	49.14
THAILAND	7401	32.6
SINGAPORE	4495	30.79
INDONESIA	1273	29.6
BRUNEI	1	1

Figure 1.
Total and average citations (country-wise)

Source: Figure by authors

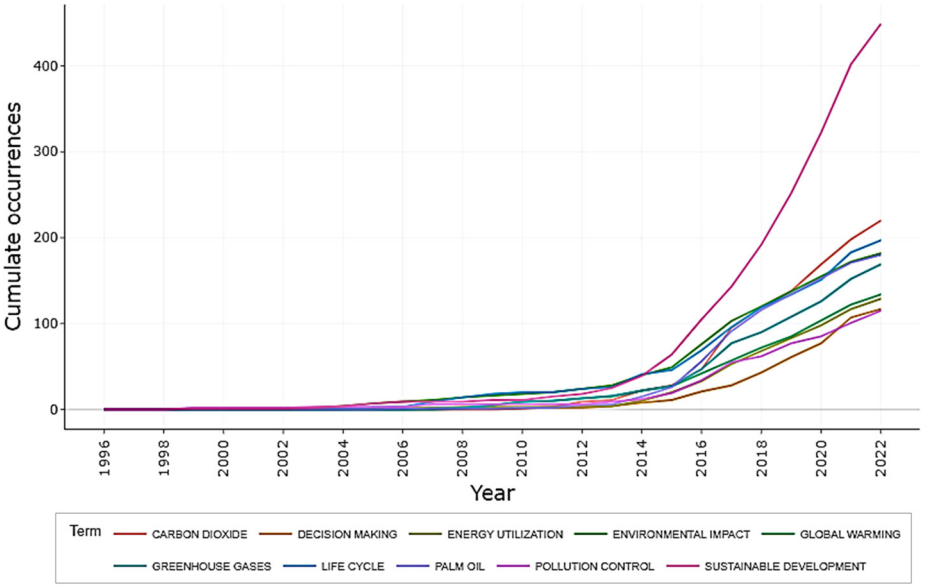


Figure 2.
Development of research topics

Source: Figure by authors

Next, the betweenness and closeness centrality of the research topics (keywords) was measured and portrayed. A centrality index and research cluster analysis were carried out to further examine the strength, activity and interaction between the research topics in accordance with the theory of social networks based on nodal links. The writers concentrated on network node centrality measurements. Centrality is a significant metric as it identifies which node occupies a crucial location within a network as a whole. Examples of centrality measurements include degree, betweenness and closeness centrality.

A network's "mediation" role is measured by a node's "betweenness centrality." If one node is the sole point of connection, transportation, or transaction for other nodes, then this node should be significant and most likely have a high betweenness centrality. The higher the betweenness centrality, the more frequently a node lies between any pair of other nodes on the network's shortest pathways of all connections.

If the length of node *N*'s shortest routes with other nodes in the network is low, then node *N* has a high "closeness centrality," which measures sum distances from one node to the other nodes. It refers to how easily and conveniently connections may be made between the targeted node and other nodes. Consequently, betweenness centrality demonstrates how a node functions as a middleman between numerous other nodes, and closeness centrality measures the similarity of study themes in terms of keywords to many others, as shown in Figure 3.

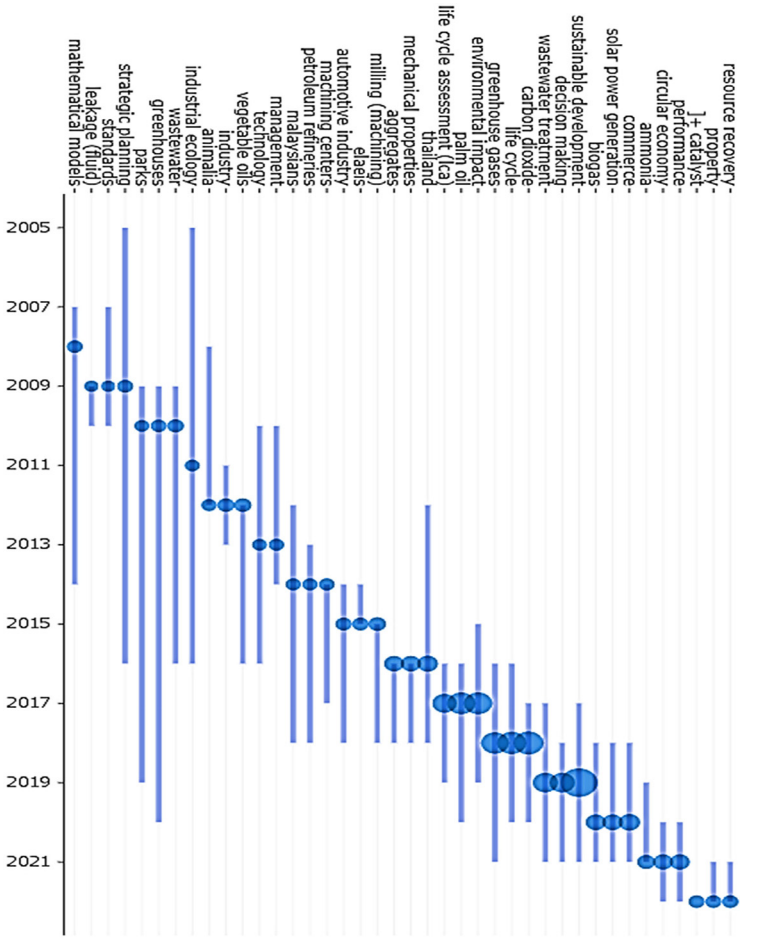
Tables 2 and 3 present quantitative descriptions in terms of clusters and keyword occurrences. Color scales are used to visualize how the measures used for each cluster or occurrence are ranked in comparison to other clusters or occurrences.

For thematic development, the period in which this research retrieved the Scopus data set was divided equally into two phases (I and II). Time-slice evolution map analysis was also used to review how research themes evolved in the first and second phases (I and II). Research areas are system-generated and segregated into basic, motor, niche and emerging themes.

The motor themes in Quadrant I are the most significant pillars shaping the field of research, while the niche themes in Quadrant II are highly developed but isolated. The emerging or declining themes in Quadrant III are weak and marginalized areas of the research field. Finally, the basic themes in Quadrant IV are less developed but still important (Zhang *et al.*, 2022). Here, biodiesels were in the niche theme, and sustainable development (environment impact) and carbon footprint (pollution control) were in the basic themes in Phase I. According to this analysis, the motor theme-based keywords are areas of research acting as supporting elements. Over the years, solar power and renewable energy have appeared as emerging themes. This theme-based cluster is based on the development density versus centrality index created with R-studio software, as shown in Figure 4.

Moreover, the data set was analyzed with VOSviewer software to determine collaboration in the area of cleaner production by country. Figure 5 illustrates the keyword relations since 2016, indicating the top keywords of research. Initially, the most researched themes were carbon footprint, CO_2 reduction, greenhouse gas emissions and water treatment. Later, research shifted to themes such as waste management, life cycle assessment, circular economy, biodiesel, palm oil and energy management.

Figure 6 represents the nodal relationships between countries, highlighting the volume of their publications. According to Van Eck and Waltman (2014), a larger node indicates a greater volume of publications, while a smaller node signifies a minimal volume of publications. The analysis reveals three major clusters in blue, green and yellow, with Malaysia having the broadest collaboration with other ASEAN members, including Thailand and Singapore.



Source: Figure by authors

Figure 3.
Centrality measures of keywords over the years

However, the visualized data do not fully show how research mentorship and leadership are performed in the union and which countries play cause-and-effect roles. Although the visualization may suggest that a particular country, such as Malaysia, has a high volume of publications globally, that does not necessarily indicate that the country is playing a significant role in research mentorship and leadership in the ASEAN Union. That is, the country may be publishing a large volume of research in collaboration with other countries but is not necessarily leading ASEAN research in the field. DEMATEL responds to this.

4.3 Result of the decision-making trial and evaluation laboratory

Table 4 presents the relationship between countries in terms of citations, highlighting the collaboration between countries through DEMATEL analysis using data collected through the Scopus search. An input matrix was constructed based on pairwise country

Node	Cluster	Betweenness (color scale)	Closeness (color scale)
179	Palm oil	39.30505	0.00214
115	Wastewater treatment	147.88142	0.00226
83	Recycling	113.42973	0.00224
79	Biodiesel	46.84975	0.00215
76	Effluents	113.49424	0.00226
71	Scanning electron microscopy	94.84252	0.00223
66	Efficiency	270.79408	0.00237
55	Catalysts	76.14047	0.00221
53	Adsorption	44.73262	0.00215
54	Fuels	152.36547	0.00230
53	Oil shale	181.98128	0.00230
49	Waste incineration	99.92967	0.00224
47	Waste disposal	164.39965	0.00230
45	Construction industry	186.12546	0.00228
41	Pollution	152.50284	0.00229
40	Chemical oxygen demand	131.45006	0.00227
39	Diesel engines	45.63466	0.00216
41	Fourier transform infrared spectroscopy	102.73276	0.00225
40	Response surface methodology	68.27012	0.00219
39	Water pollution	149.58232	0.00230

Source: Table by the authors

Table 2. Betweenness and closeness measures based on clusters

collaboration data. For example, the search formula used to retrieve data on the Malaysia–Indonesia country collaboration was "ISSN (0959–6526) AND AFFILCOUNTRY Malaysia) AND AFFILCOUNTRY (Indonesia)." On the other hand, the search formula used to retrieve data on Malaysia–Malaysia collaboration was "ISSN (0959–6526) AND AFFILCOUNTRY (Malaysia) AND AFFILCOUNTRY (Malaysia)." The search results are presented in Table 4.

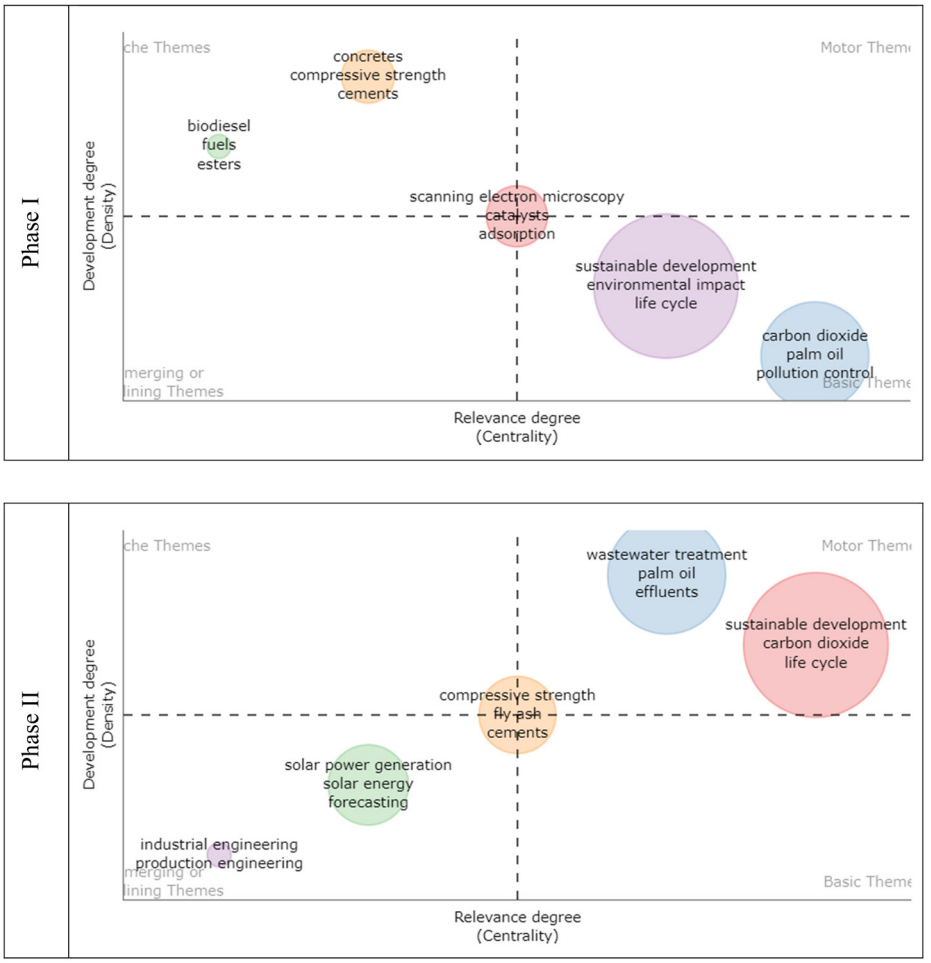
As shown in Table 4, the initial screening of the collaborations indicates that some countries, such as Laos, Vietnam, Myanmar and the Philippines, need more motivation to join with other ASEAN researchers and contribute more to the field. Although Cambodia, Brunei and Vietnam have undertaken research collaborations with other ASEAN countries, their network is limited to two other ASEAN members. This observation, however, is defined as a direct network between counties, whereas DEMATEL is a means to illustrate transitive networking. Within the research collaboration network, a transitive relationship is observed where Country A and Country C are indirectly connected through an intermediary node, Country B. The presence of an indirect connection between Country A and Country C indicates a path in the network linking these countries through shared collaborations, demonstrating a transitive relationship in the collaboration patterns among the countries. Such transitive connections are common in network analysis and can provide insights into the structure and dynamics of collaborative relationships in a given system, in this case, research collaborations between countries. For the DEMATEL analysis, the matrix T was calculated and is presented in Table 5.

The average value of all cell values in matrix T was 0.18. However, considering the high volume of publications from Malaysia, a threshold value of 0.01 was used to ensure that collaborative countries with fewer publications were not missed. Figure 7 presents the $R + D$ results, which show that among ASEAN members, Malaysia is most active in research collaboration, followed by Indonesia, Thailand and Singapore at a significant distance.

Occurrences	Betweenness centrality (color scale)	Closeness centrality (color scale)
Carbon dioxide	40.16009	0.02041
Palm oil	27.42811	0.01887
Wastewater treatment	6.82167	0.01639
Recycling	2.56991	0.01639
Biomass	1.69019	0.01639
Biodiesel	2.37425	0.01613
Effluents	1.97820	0.01493
Compressive strength	0.45777	0.01235
Scanning electron microscopy	2.79395	0.01333
Optimization	2.10897	0.01786
Cost-effectiveness	4.09345	0.01724
Concrete	1.59210	0.01370
Efficiency	1.55518	0.01563
Cement	1.11176	0.01370
Catalysts	0.27747	0.01299
Adsorption	0.09684	0.01205
Fuels	2.03815	0.01538
Oil shale	2.77175	0.01538
Sustainable development	83.37804	0.02000
Life cycle	10.48215	0.01887
Environmental impact	13.95684	0.01961
Greenhouse gases	14.34490	0.02000
Global warming	8.18532	0.01923
Energy utilization	4.32164	0.01852
Decision-making	3.32531	0.01818
Pollution control	6.09330	0.01923
Energy efficiency	4.59847	0.01786
Environmental management	2.91828	0.01786
Carbon	9.71671	0.02000
Climate change	2.14433	0.01724
Costs	10.64422	0.02000
Life cycle assessment	3.23963	0.01786
Economics	1.23318	0.01695
Gas emissions	2.58690	0.01786
Economic and social effects	2.50678	0.01786
Emission control	2.41942	0.01786
Investments	0.50641	0.01538
Fossil fuels	2.21306	0.01724
Economic analysis	1.35452	0.01695
Waste management	2.00613	0.01786
Developing countries	0.69501	0.01639
Surveys	0.25989	0.01493
Renewable energy resources	0.78108	0.01613
Manufacture	0.10003	0.01333
sensitivity analysis	0.78926	0.01639
Cost–benefit analysis	0.69199	0.01563
Planning	0.04611	0.01370
Supply chains	0.77712	0.01563
Commerce	0.21155	0.01515
Environmental sustainability	0.55263	0.01587

Source: Table by the authors

Table 3.
Betweenness and closeness centrality based on occurrences



Source: Figure by authors

Figure 4.
Time slice evolution map of research themes

The interrelationships or publication collaborations resulting from this threshold value are shown in Figure 7. The figure indicates that some countries, such as Laos, Vietnam, Myanmar and the Philippines, need more motivation to join research collaborations and contribute more to the field. Visualization of the causal relationship matrix in Figure 8 shows that there are no research networks, meaning that few collaborations involve more than two countries and there is no dominant country. Although a few countries have established some research collaborations with other ASEAN countries, the network does not yet encompass the entire ASEAN region. Four countries (40% of ASEAN members) have no direct or even transitive research collaborations. Hence, this finding highlights the need to consider ways to foster research collaborations and establish a more connected research network among countries in the region.

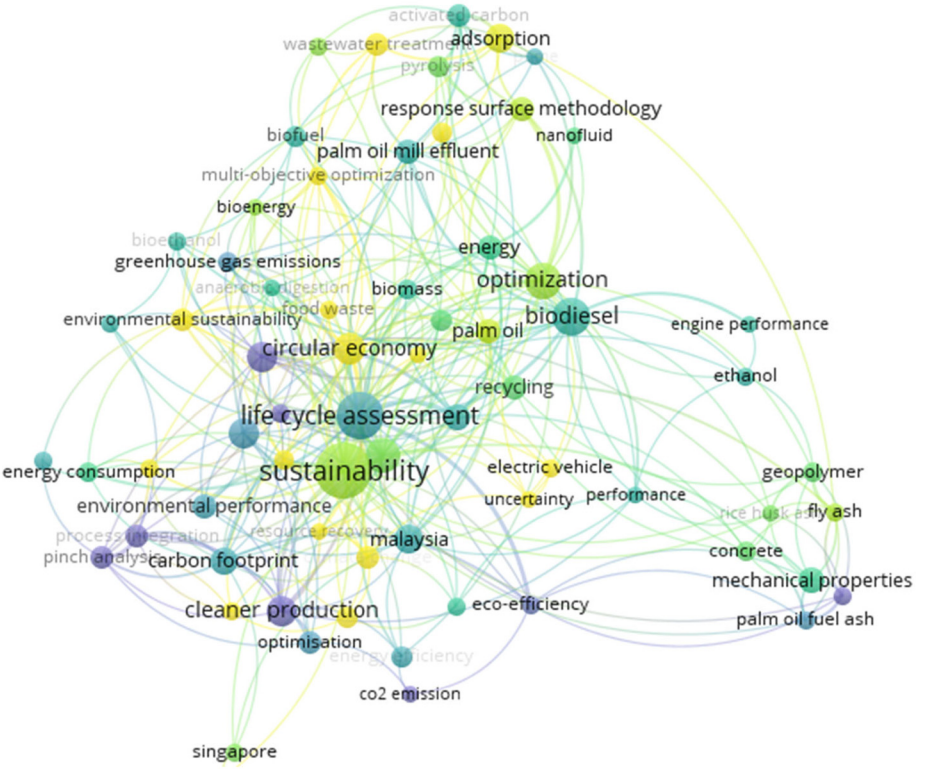


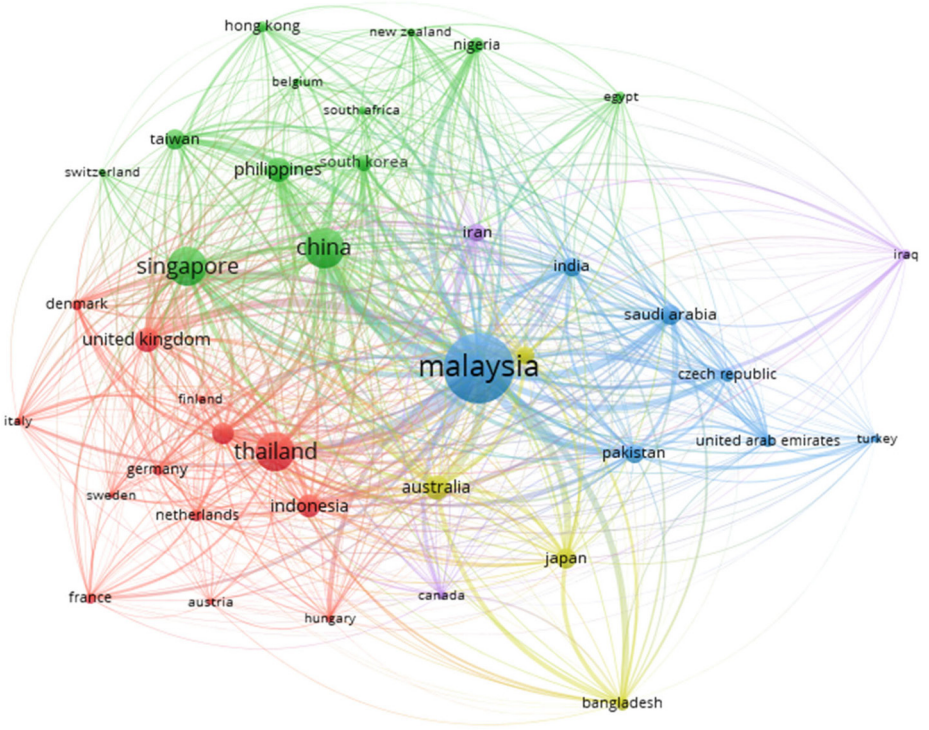
Figure 5.
Keyword relation network

Source: Figure by authors

When Country A's investigators influence Country B's research, their collaborations may enable Country B to indirectly influence Country C's research, even if there is no direct contact between researchers from A and C. This transitive network allows the flow of research leadership from Country A to pass through B and potentially impact the scientific advancements in Country C. Therefore, to bridge the existing gap, it is crucial for ASEAN policymakers to define research leadership and promote research networking.

5. Conclusion

Through a systematic literature analysis, this study provides a comprehensive overview of ASEAN's progress toward cleaner production. The level of attention and collaboration in the field is identified, along with emerging trends. While ASEAN has made strides in sustainability, challenges persist, indicating a need for greater awareness of sustainable practices. The findings align with previous studies and reveal distinct research focuses among ASEAN countries. For example, Yusup *et al.* (2015) discovered that while Malaysia has made some progress toward sustainable manufacturing practices, greater awareness among businesses about the benefits of such practices is needed. Similarly, a study from Indonesia discovered that while Indonesia has implemented a variety of policies aimed at encouraging sustainable manufacturing practices, these policies have not been effectively



Source: Figure by authors

Figure 6.
Visual representation of the nodal relationships between countries

Countries	Malaysia	Indonesia	Thailand	Vietnam	Singapore	Philippine	Cambodia	Laos	Myanmar	Brunei
Malaysia	1,067	35	16	0	13	0	2	0	0	8
Indonesia	35	128	5	0	2	0	0	0	0	2
Thailand	16	5	330	0	3	0	1	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0
Singapore	13	2	3	0	346	0	0	0	0	0
Philippine	0	0	0	0	0	0	0	0	0	0
Cambodia	2	0	1	0	0	0	3	0	0	0
Laos	0	0	0	0	0	0	0	2	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0
Brunei	8	2	0	0	0	0	0	0	0	14

Source: Table by the authors

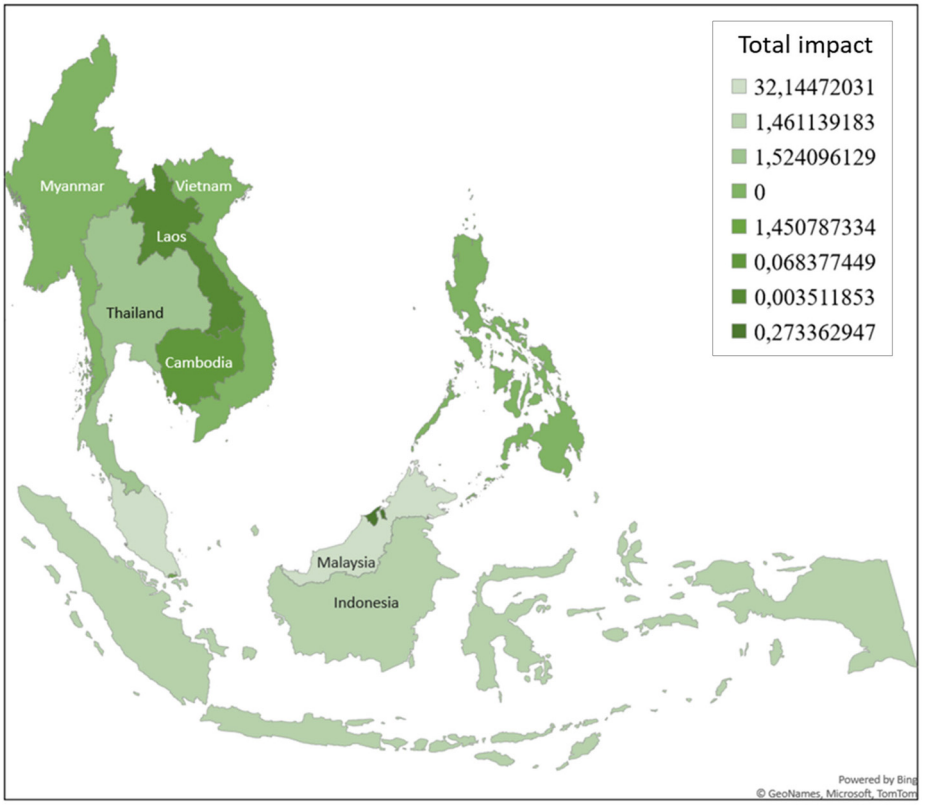
Table 4.
Country collaboration matrix

enforced (Ricardianto *et al.*, 2022). In the Thai manufacturing sector, Piyathanavong *et al.* (2019) reported existing barriers to the adoption of production sustainability. The authors discovered a significant increase in research on this topic in recent years, with a focus on subjects such as green supply chain management and the circular economy. However,

Table 5.
Causal relationship matrix

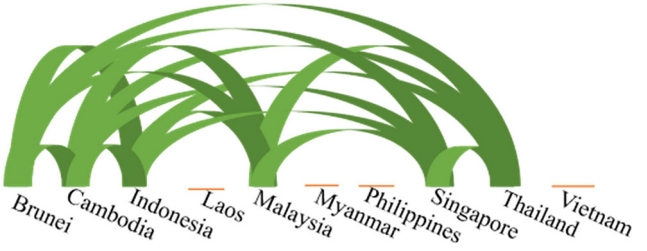
Countries	Malaysia	Indonesia	Thailand	Vietnam	Singapore	Philippine	Cambodia	Laos	Myanmar	Brunei
Malaysia	14.8055	0.5483	0.3162	0	0.2610	0	0.0280	0	0	0.1131
Indonesia	0.5483	0.1454	0.0179	0	0.0119	0	0.0009	0	0	0.0059
Thailand	0.3162	0.0179	0.4133	0	0.0105	0	0.0017	0	0	0.0022
Vietnam	0	0	0	0	0	0	0	0	0	0
Singapore	0.2610	0.0119	0.0105	0	0.4395	0	0.0004	0	0	0.0018
Philippine	0	0	0	0	0	0	0	0	0	0
Cambodia	0.0280	0.0009	0.0017	0	0.0004	0	0.0026	0	0	0.0002
Laos	0	0	0	0	0	0	0	0.001756	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0
Brunei	0.1131	0.0059	0.0022	0	0.0018	0	0.0002	0	0	0.0132

Source: Table by the authors



Source: Figure by authors

Figure 7.
Map of countries' total impact



Source: Figure by authors

Figure 8.
Research-connected countries (direct or transitive)

Piyathanavong *et al.* (2019) also stated that more research on the implementation and effectiveness of sustainable manufacturing practices in ASEAN is required.

In addition, collaboration gaps call for enhanced coordination to address regional environmental challenges effectively. Strong research leadership can guide efforts toward regional priorities, reduce redundancy and promote growth and learning. Policymakers and

industry leaders must collaborate to enforce sustainable policies. Financial support for research on sustainable manufacturing practices is essential to encourage their implementation. Integrating sustainability into research strategies and policy enforcement will drive long-term benefits.

The implications of this work extend to the scientific community, offering a roadmap for assessing ASEAN's contributions to cleaner production. The study also emphasizes the significance of regional collaboration to address sustainability challenges. By encouraging greater cooperation, the ASEAN region can promote cleaner production and sustainable development more effectively. Although the study relied on secondary data, it provides valuable insights into ASEAN's progress. Future research could incorporate primary data and investigate technology's role in research practices. Moreover, defining a research policy in the region could further enhance collaboration. Overall, this study contributes to understanding ASEAN's role in cleaner production and seeks to encourage further research and awareness in this crucial field.

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