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A bibliometric analysis of industrial symbiosis research in the ASEAN region

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Abstract

Industrial Symbiosis (IS) is considered to play an important role in realizing Sustainable Development. Furthermore, studies on IS have the potential to address the significant challenges currently facing the ASEAN region. Nevertheless, thus far no study has been conducted an overview of the research dynamics conducted out by regional researchers. This study aims to identify core literatures on IS and emerging research topics in the ASEAN. In addition, this study also analyses future IS-related research opportunities for the ASEAN region. A bibliometric analysis was conducted on articles sourced within the ASEAN region. The VOSviewer was employed to process, analyze and visualize the bibliometric data in an efficient and structured manner. Journal of Cleaner Production is the leading source of research on IS. Current research areas include Optimizing Water Use, Environmental Conservation, Energy Optimisation, and Sustainable Development Policy. Meanwhile, future research may use pinch analysis and mathematical modeling to optimise energy and material flows to maximise the potential of IS. This bibliometric analysis helps researchers identify avenues for further research on IS, particularly within the ASEAN context. It also helps them assess the likelihood of publishing their findings in a suitable journal.

Keywords

Industrial symbiosis, ASEAN region, Sustainable development, Bibliometric analysis

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Introduction

In recent years, Industrial Symbiosis (IS) has emerged as a novel approach to environmental management. IS is a concept where companies use by-products or waste from other companies to produce more without spending extra energy or resources. It aims to achieve a zero level of waste and obtain economic, environmental, and social gains [1]. Furthermore, IS can help reduce the overall carbon footprint of industries by minimizing the amount of waste sent to landfills and reducing the need for virgin resources. As more companies adopt IS, a transition to a sustainable future can be

made. Ultimately, IS is a key strategy in promoting a circular economy and moving towards a more environmentally friendly and efficient industrial system.

Meanwhile, the rapid industrial growth in the ASEAN, coupled with significant environmental challenges, has made the application of IS more relevant and urgent [2]. The early 2000s saw the rise of environmental awareness, which led to the adoption of IS by some ASEAN countries as a strategy to reduce industry's environmental impact [3]. An example of this is the waste exchange scheme between manfacturing companies, which has successfully reduced waste generation and improved resource efficiency. By continuing to encourage innovation and collaboration between companies, IS in the ASEAN region will remain an effective solution in achieving sustainable development. Furthermore, the success of the IS program in the ASEAN region has also led to increased profitability for participating companies. Sharing resources and expertise, besides being environmentally beneficial, also strengthens the overall economic competitiveness of the region. This will ultimately lead to a more sustainable and resilient industrial sector in the ASEAN region [4]. The success of these collaborative efforts will not only benefit the companies involved but also help to ensure a more prosperous and sustainable future for the ASEAN region as a whole.

However, studies on IS in the ASEAN region remains limited, with few studies addressing its specific application and potential in the context of these countries. In fact, IS has gained traction in other regions of the world, particularly in Europe [5]. This research gap is a significant challenge as it limits the understanding of how IS can contribute to sustainable development, resource efficiency and economic growth in the ASEAN. Consequently, it is essential to conduct extensive research to identify the overview of studies conducted in the ASEAN region, as well as to identify future research opportunities. Bibliometric analysis is considered to be the most effective tool for evaluating the development of research in IS [6]. It provides insights into trends, collaboration patterns, and scholarly contributions in the region. Bibliometric analysis is essential for identifying research gaps, enabling researchers to pinpoint under-researched areas and focus their efforts accordingly. Some previous studies have examined the development of IS studies to date using bibliometric analysis, but none have specifically discussed studies from ASEAN countries [6–9]. Therefore, it is imperative to identify research trends and avenues for further research on IS in the ASEAN region. Hence, this research objectives are identify core literatures on IS conducted by the ASEAN region, analyse emerging IS research topics in the ASEAN region, and analyse future IS research opportunities for the ASEAN region

Method

Scopus-indexed database is used for data collection. This procedure was to guarantee the reliability of the research data employed [10]. The keyword used was ‘Industrial Symbiosis’ and 1976 documents were obtained. Research stages of the study is shown in Figure 1.

Figure 1. Research stages

Furthermore, it was considered that the document types were article and conference, the source type were journal and conference proceeding, and the publication stage was final. There were 1462 documents obtained. Then, a filter has been applied to the data set based on the country of origin of the author. The resulting data set is limited to authors from countries within the Association of Southeast Asian Nations (ASEAN) region. These countries include Indonesia, Singapore, Malaysia, Thailand, Cambodia, Vietnam, Brunei Darussalam, Philippines, Laos, and Myanmar. Finally, there were only 119 documents obtained. Subsequently, the data is subjected to bibliometric analysis.

Bibliometric analysis is a method used to investigate and analyse the distribution of publications sourced from a number of literatures [11]. In order to achieve the research objectives, this study employed a bibliometric analysis, considering three indicators: article distribution, the cluster, and the total number of occurrences. Article distribution is conducted to identify the distribution of the articles according to the sources, countries, and the number of articles published by year. Meanwhile, cluster analysis is utilised to group the various types of IS-related research that have been conducted. In order to analyse potential future research opportunities, a co-occurrence word analysis was conducted, with a focus on publications from the most recent year. The analysis was performed by comparing the top 10 publications based on the latest year and considered on the lowest occurrences of key words. In terms of occurrence word analysis, the minimum number of keyword occurrences is set at five. Concurrently, VOSViewer was employed as a tool to conduct bibliometric analysis and providing a visual representation of the network of literature obtained.

Result and Discussion

The findings of the data analysis are presented in the form of article distribution, the analysis includes a synthesis of topics that are currently developing in relation to IS and an examination of potential future research avenues in this field.

Article Distribution

A comprehensive review yielded 119 articles on IS studies by authors from the ASEAN region from 2008 to 2024. A total of 41 sources were identified, including both journals and proceedings. The analysis revealed that 77% of the articles were published in journals, while the remaining 23% were published in proceedings. As demonstrated in Table 1, a detailed analysis of the existing on IS study is presented for 3 journals with the

highest number of articles. The Journal Cleaner of Production has been identified as a leading contributor to the production of IS articles, with authors from the ASEAN region contributing 18 articles. This journal focuses on advancing knowledge and research related to sustainable production and consumption, environmental management, including IS within it [12]. The second rank is hold by Chemical Engineering Transactions (CET), which has published 12 articles. Meanwhile, in third rank is Resources Conservation and Recycling (RCR), which contributed 7 articles. Both journals are widely esteemed in the domain of environmental sustainability. While CET is more centred on chemical engineering, RCR places greater emphasis on waste management, recycling, and circular economy practices [13].

According to articles by ASEAN country, there is only 6 countries in ASEAN that contributed IS articles, as shown in Figure 2. They are Malaysia, Phillippines, Singapore, Indonesia, Viet Nam, and Thailand. Malaysia plays a significant role as the largest contributor of IS articles, 49 authors. The implementation of sustainable development through waste management is an important priority for policymakers and other relevant stakeholders in Malaysia [14]. This is due to the fact that the nation is beginning to prepare for its transition from a developing to a developed country. Concurrently, the Philippines attained second place. Meanwhile, Singapore, a developed country in the ASEAN region, is ranked 3rd. The research conducted by Singaporean researchers on waste-to-resource platforms, and sustainability has its roots in the country's distinctive geographical, economic, and policy-driven needs. Singapore's robust commitment to sustainability, constrained natural resources, and pioneering role in eco-innovation make it an optimal setting for propelling research in these pivotal domains [15]. As demonstrated in Figure 3 which illustrates research trends by year. There is a fluctuation in the number of publications from year to year. However, the trend demonstrates an increase.

Table 1. Summary of core literatures related to the IS study

No	Journal Title	Number of publications	Link	Topic	Publisher	SJR 2023	Country	Quartile in Scopus
1.	Journal of Cleaner Production	18	Link	Cleaner Production, Environmental, and Sustainability research	Elsevier Ltd	2.058	United Kingdom	Q1
2.	Chemical Engineering Transactions	12	Link	Chemical, process, and environmental engineering	AIDIC	0.258	Italy	Q3
3.	Resources Conservation and Recycling	7	Link	Sustainable management and conservation of resources	Elsevier B.V.	2.77	Netherlands	Q1

Figure 2. Article distribution by countries

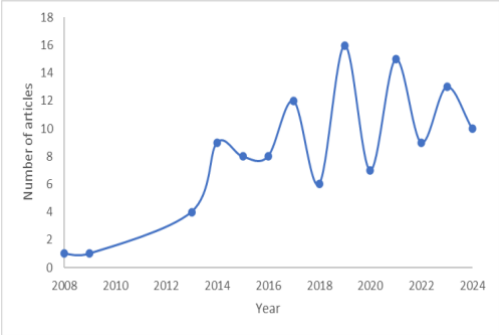

Figure 3. Article distribution by year

Emerging Research Topics of IS in the ASEAN

Co-occurrence words obtained from VOSViewer as shown in Figure 4 is used to analyse the emerging research topics of IS [16]. Frequently occurring keywords are grouped into clusters, with each cluster representing a major topic within a research area. The data processing conducted with VOSViewer revealed 4 main topics of IS from the ASEAN region:

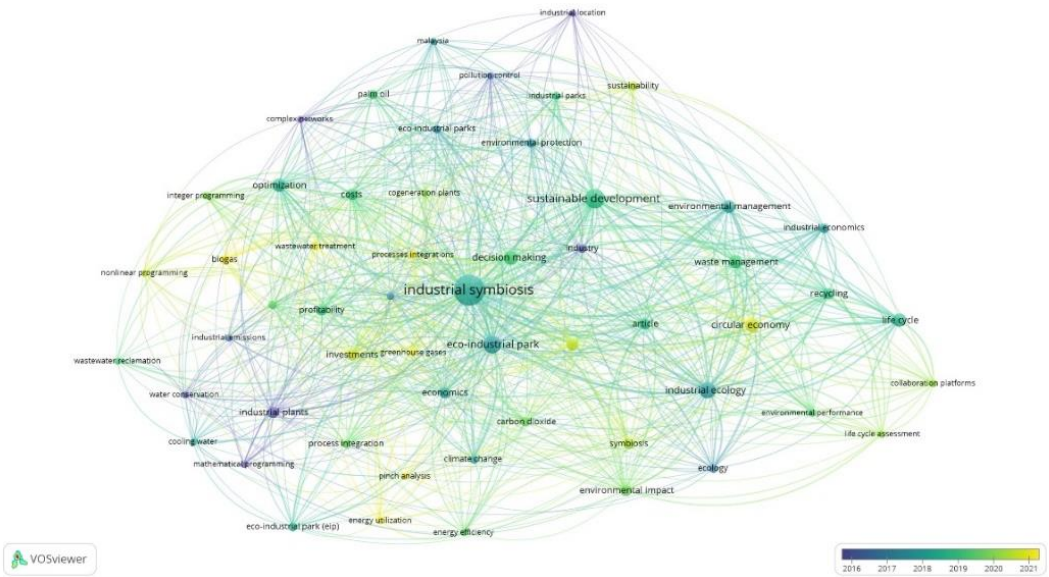

Figure 4. Co-occurrence keywords

1. Optimizing Water Use. Using water resources efficiently is not only cost-effective but also helps to mitigate environmental impacts [17]. In industry, this requires a combination of strategies, including recycling, water-efficient technologies and integrated water management. Meanwhile, IS provides a powerful framework for optimizing water use by encouraging collaboration between industries to share resources, including water.
2. Environmental Conservation. It refers to the sustainable management and protection of natural resources to ensure their availability for future generations. It encompasses several strategies designed to minimise environmental degradation, conserve ecosystems and promote sustainable development [18].

3. Energy Optimisation. It is described the process of enhancing the efficiency of energy utilisation in industrial and other sectors by minimizing energy consumption while maintaining or improving productivity and performance [19]. IS is highly relevant to energy optimization as it facilitates the sharing of energy resources, enhances efficiency, and minimises waste across industrial sectors.
4. Sustainable Development Policy. It promotes long-term ecological sustainability, economic growth, and social well-being. This provides the regulatory and strategic framework that supports and enables IS. By promoting resource efficiency, waste reduction, and collaboration among industries, IS helps achieve the goals of sustainable development [20].

Future Opportunities for IS Topics within ASEAN

A comprehensive analysis of future IS opportunities for ASEAN is crucial. Density visualization by keyword obtaining from VOSViewer as shown in Figure 5 is used as a basis to do this analysis. Density levels are represented by colour coding with higher density displaying warmer colours. Meanwhile, regions with lower density may be represented by cooler colours, such as blue or green, indicating less frequent occurrences [21]. According to Figure 5, the keywords often used such as sustainable development, circular economy, industrial ecology, environmental management, and waste management. Although, density visualization offers a valuable overview of research, but relying solely on visual interpretation. To mitigate this, a deeper investigation is conducted using the quantitative data extracted from the VOSviewer Bibliometric Analysis Table. According this table, an analysis of recent publications was conducted to identify infrequently occurring keywords, determined by their occurrences and the average publication year. The findings reveal that keywords such as pinch analysis, greenhouse gases, energy utilization, and Nonlinear Programming (NLP) are seldom mentioned in recent IS research.

Pinch analysis is a method employed to optimize energy usage in industrial processes, focusing on the efficient utilization of thermal energy through careful integration of heat and cooling systems. Subsequently, pinch analysis has been expanded to encompass a wider range of applications, including the optimisation of water and material flows [22]. Pinch analysis is an essential instrument for the implementation of industrial symbiosis. It allows the systematic optimization of energy use across interconnected industrial systems. Meanwhile, NLP refers to a branch of mathematical optimization where the objective function or the constraints, or both, are nonlinear. NLP is a valuable tool for the design, analysis and optimisation of IS networks [23]. The other rare keywords are greenhouse gases and energy utilisation. Greenhouse gases are atmospheric gases that contribute to global warming and climate change by trapping heat in the Earth's atmosphere. Energy utilisation' describes how energy is used, managed and optimised in industrial systems [24]. It has been demonstrated that IS can lead to notable improvements in energy utilisation and a reduction in greenhouse gas emissions [25].

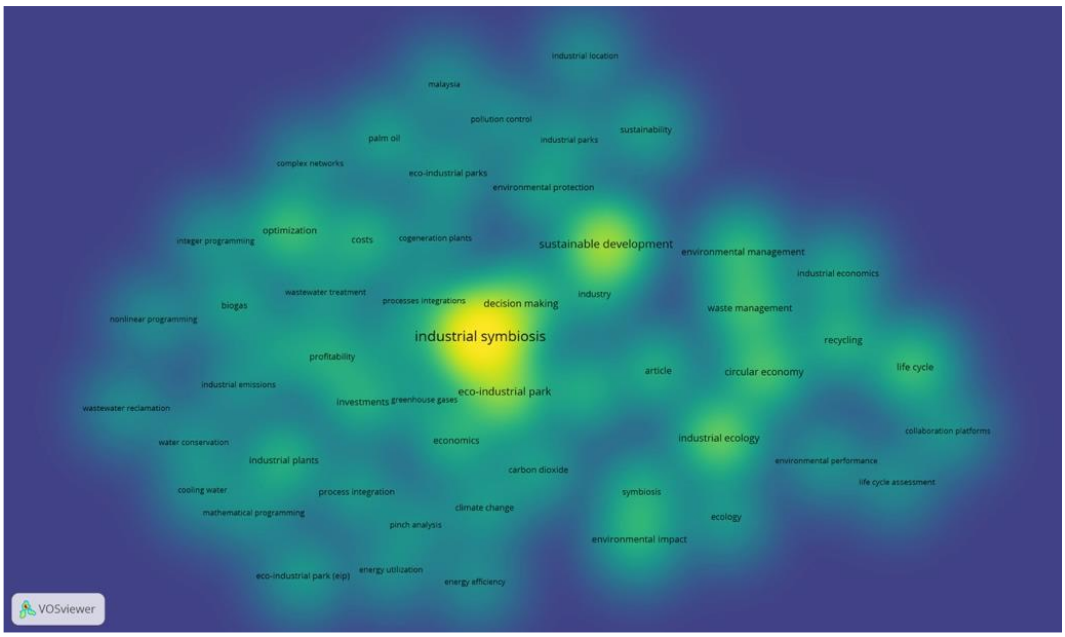

Figure 5. Density visualization by keywords

The intersection of greenhouse gas reduction, energy utilisation, NLP, and pinch analysis offers substantial opportunities for research aimed at optimising industrial sustainability according to IS concept. Pinch analysis and mathematical modelling are two such tools that can play a significant role in enhancing the performance of IS systems. Combining pinch analysis and mathematical modelling offers a more comprehensive approach to optimizing industrial symbiosis networks. The combination of these methods facilitates the development of integrated systems where both energy and material flows are optimized to reduce waste, minimize energy consumption, and reduce emissions.

The findings of this study offer valuable insights for researchers seeking to further explore avenues in the field of IS, particularly within the ASEAN context, by highlighting under-researched areas and emerging trends in the region. This study provides a foundation for developing targeted research questions and methodologies that address the unique challenges and opportunities faced by industries in ASEAN. Furthermore, the study offers guidance on the likelihood of publishing their findings in appropriate academic journals. This is achieved by mapping the alignment between emerging research topics in IS and the priorities of leading journals.

Conclusion

This study provides a comprehensive analysis of IS research within the ASEAN region, highlighting core literature, emerging research topics, and potential future opportunities. Through a bibliometric analysis of 119 documents, it was found that the Journal of Cleaner Production is a leading contributor of articles on IS. The study also reveals four main research clusters: optimising water use, environmental conservation, energy optimisation, and sustainable development policy. The analysis of recent publications suggests potential future opportunities for IS topics in ASEAN, such as the use of pinch analysis and mathematical modelling to optimise energy and material flows

to maximise the potential of IS. By mapping these trends, the study offers valuable insights into future research directions, urging ASEAN countries to explore innovative strategies to enhance sustainability and industrial collaboration. This research serves as a foundation for further academic inquiry and provides actionable guidance for advancing IS practices in the ASEAN region.

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