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Bibliometric review of the landscape and thematic structure of research on sustainable mining in ASEAN, 1942–2022

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Keywords

ASEAN; bibliometric review; Sustainable mining; co-word analysis

REVIEW

Bibliometric review of the landscape and thematic structure of research on sustainable mining in ASEAN, 1942−2022

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Abstract

This bibliometric review addressed the lack of consolidated information on the current state of sustainable mining research and practice in the ASEAN region. The review analyzed bibliographic data associated with 575 Scopus-indexed documents on sustainable mining in ASEAN nations published through the end of 2022. Descriptive statistics identified a great disparity in the scope of research on sustainable mining practices across the ASEAN countries. Surprisingly, a significant portion of the extant research on sustainable mining in the region has been authored by scholars from outside ASEAN. Keyword analyses highlighted several emerging research topics, including life cycle assessment, conservation of natural resources, climate change, and artisanal and small-scale mining. Findings from the review emphasize the need to develop and implement more comprehensive and standardized frameworks for sustainable mining within ASEAN. The findings also suggest a potential for greater coordination and more focused attention to regional regulations and policies. Several directions for future research are also proposed.

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1. Introduction

The mining industry is a crucial driver of national and regional growth, with the potential to support economic and social development [1−4]. The positive economic contributions of the mining industry are evident in job creation, corporate profitability, knock-on effects on downstream industries, and the resulting impact on export earnings [5]. However, in recent decades, scholars have also identified undesirable effects of the mining industry on the environment and society [6−8].

More specifically, it has been observed that mining can create potentially harmful environmental effects throughout a mine's life cycle [9,10]. These are evident during initial exploration, as well as in the extraction, production, transportation, and mine closure phases of mining operations [5,11]. The negative effects of mining are also visible in the over-exploitation of natural resources, deforestation, and the pollution of air, soil, and water [6,12]. Moreover, despite their profitability, mining operations often require high energy consumption and generate significant greenhouse gas emissions [13,14].

Mining activities also impact the quality of life in the communities in which they are located [8,15]. For example, mining produces toxic by-products and hazardous waste, which can impact public health and safety [7,16−18]. Thus, highly profitable mining operations often produce hidden costs for the communities in which they are located [8,19].

In recent decades, the progressive integration of the global economy has increased the demand for natural resources and highlighted the environmental and social threats associated with mining. Throughout the world, the mining sector has come under increased pressure from governments, investors, and local stakeholders to change modal practices and mitigate the negative effects that result

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from mining operations [20–22]. This has led to the exploration of alternative methods that fall under the rubric of "sustainable mining" [4,9,20,23].

Notably, interest in sustainable mining is not a new phenomenon. In 1998, the Global Mining Initiative (GMI) introduced a "sustainable mining" action plan with a vision of reshaping mining practices throughout the world [24]. In 2005, Rajaram et al. [25] proposed that mining should be "conducted in a manner that balances economic, environmental, and social considerations, often referred to as the triple bottom line … [and that] sustainable mining practices are those that promote this balance" (p. 3). Thus, research and practice in "sustainable mining" traces back over two decades.

Wu et al. [26] recently conducted a bibliometric review that synthesized critical related to the "green mining" topic. Green mining refers to the environmental dimension of the triple bottom line of sustainable mining [27,28]. Their review found rapid growth in the global literature on green mining, increased empirical research on the application of sustainability principles to mining practices, and the adoption of longer-term policy solutions designed to mitigate the adverse environmental effects of mining [26]. Their analysis found that scholars have examined green mining throughout the mining lifecycle. This includes a critical mass of research on soil, waste management, recycling, and site reclamation and restoration.

Nonetheless, the Wu et al. [26] review also identified considerable variation in the density of green mining research and practices across different countries and regions. Thus, for example, they found a relatively low concentration of green mining research in the Association of Southeast Asian Nations (ASEAN). This contrasts with the prevalence of mining in the ASEAN region [29,30]. The ASEAN nations are rich in natural resources with an extensive industrial base that offers significant intra-region investment and mineral resource trading opportunities [31–34]. Mining is a primary export revenue earner in several ASEAN countries, contributing to rural employment and throughout the mining supply chain [33,35–37].

However, despite the importance of mining to the economic and social development of ASEAN nations, scholars have yet to document the density and scope of sustainable mining research and practice in the region. This is an essential step for both policymakers and researchers who are increasingly interested in finding regional solutions to sustainability issues across a wide array of sectors and industries [29,38,39]. This represents a barrier to identifying regional strengths and weaknesses, a prerequisite to establishing viable cooperation. This gap in knowledge concerning sustainable mining management practices in ASEAN nations represents the focus of this systematic review of research.

This article reviews research on sustainable mining in ASEAN nations using a science mapping methodology [40–42]. This bibliometric review addressed the following research questions (RQs):

1. What is the landscape of research on sustainable mining in the ASEAN region, and what does this imply for future research and policy?
2. What topics on sustainable mining in ASEAN nations have attracted the most attention from scholars?
3. What is the conceptual structure of the literature on sustainable mining in the ASEAN region?

The review used the bibliometric review method to examine a dataset that included 575 Scopus-indexed documents related to sustainable mining in the ASEAN region. Descriptive statistics were used to document knowledge accumulation and analyze trends in the literature on sustainable mining in the ASEAN region between 1942 and the end of 2022. VOSviewer software was used to conduct descriptive and science mapping analyses [43]. This review contributes to the first compilation and synthesis of existing research on 'sustainable mining' in the ASEAN region. The review highlights the need to prioritize and expand sustainable mining practices within ASEAN and identifies key foci for future regional research.

2. Method

This research review used the bibliometric method to analyze the knowledge base on sustainable mining in ASEAN. The bibliometric review's strength lies in its ability to quantify and synthesize patterns in knowledge production across many documents [40,42,44]. Thus, the current review examined a significant portion of the existing literature on sustainable mining in the ASEAN region. This section describes the procedures used in identifying and analyzing documents for the review.

2.1. Identification of sources

The author selected Scopus as the document repository rather than Web of Science due to its comprehensive coverage of social science and management literature [45–47]. The criteria for selecting bibliographic data from Scopus documents involve several key aspects. This review was limited

to peer-reviewed journal articles because they tend to undergo more consistent editorial review than books, book chapters, and conference papers [48]. The review was bounded by the earliest available literature, published in 1942 to the end of 2022, aiming for a comprehensive exploration of sustainable mining in the ASEA region without limitation based on publication dates. The conceptual scope was defined as "sustainable mining in the ASEAN region" without regard to other industry-related delimitations, allowing for broader topic exploration. Thus, unlike the Wu et al. [26] review, which was limited to "green mining," this review was designed to encompass the broader perspective on "sustainable mining" discussed above. ASEAN was delimited to the countries formally participating in the Association of Southeast Asian Nations.

For the search strategy, the authors employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as guidelines for conducting a systematic collection of documents for the review [49]. Additionally, the initial search in the Scopus search engine used the specific keywords "mining" AND "sustain*" OR "eco*" OR "environ*" OR "economic*" OR "social*" within the article title and author-defined keywords. Names of the ten countries in ASEAN were included in the keyword search along with the AND operator to ensure the inclusion of articles relevant to ASEAN nations. Finally, the keywords "text" and "data mining" were included in the search string and the AND NOT operator to reduce irrelevant items produced by the search. These criteria collectively aimed to ensure a comprehensive and systematic approach to gathering relevant bibliographic data from Scopus documents, aligning with the defined objectives and scope of the review on sustainable mining in the ASEAN region.

The initial search yielded 973 published documents (see Fig. 1). Scopus filters were applied to limit the documents to journal articles and reviews published in English. This resulted in the exclusion of 372 documents. After scanning all document titles and abstracts for duplicities and topical relevance, 26 additional documents were excluded. At the end of the selection process, the review database consisted of 575 journal articles and reviews (henceforth referred to as articles) published between 1942 and the end of 2022.

2.2. Data analysis

Bibliographic data associated with the 575 Scopus-index documents were exported from Scopus to Excel. These data included authors' names, titles, publication dates, author countries and affiliations, abstracts, and various citation information. Scopus analytical tools, Excel, and Tableau software programs were used to conduct descriptive analyses that addressed the first research question. VOSviewer version 1.6.18 [50] was used to conduct the

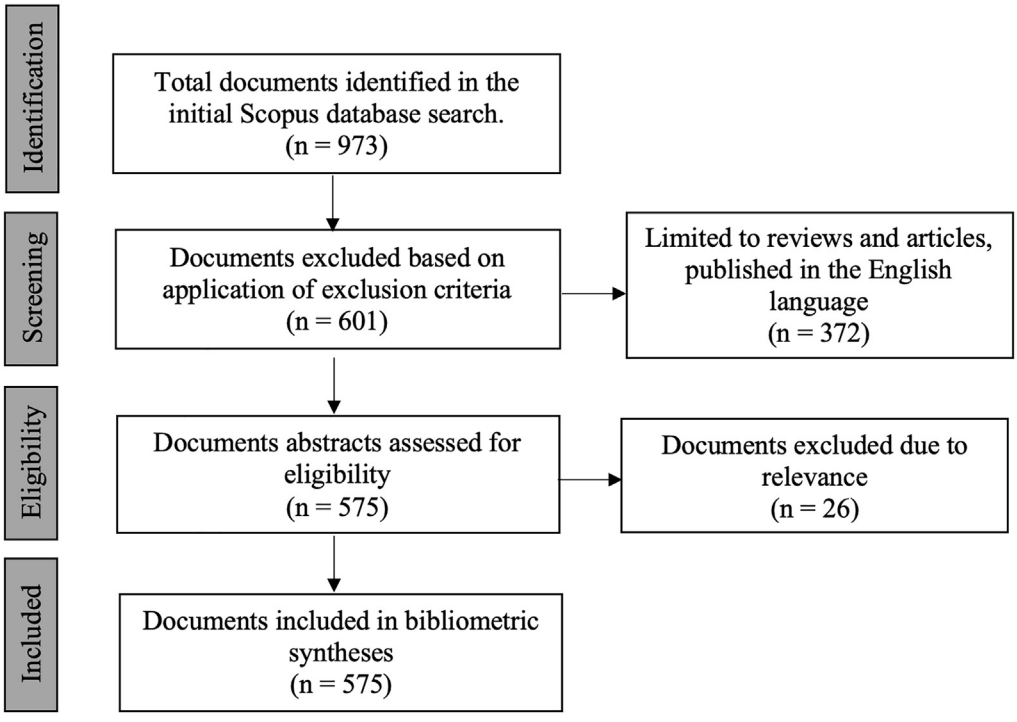

Fig. 1. PRISMA diagram detailing steps in the identification and screening of sources.

science mapping analysis of the literature on sustainable mining in ASEAN [40,41]. The use of VOSviewer added a dynamic dimension to the analysis, allowing for a more nuanced exploration of the relationships and patterns within the literature.

Before conducting data analyses, the authors had to clean the document database using a process known as "data disambiguation" [43]. This essential step aimed to standardize terminologies and unify synonymous concepts across the bibliographic dataset. Because the data in a bibliometric review consists of bibliographic meta-data, there is the possibility that more than one term could be used for the same concept. For example, in the current review, keyword analysis found similar terms for the same concept: life cycle assessment, life-cycle assessment, and LCA. The authors created a thesaurus file with instructions for the bibliometric software to replace all instances of one keyword (e.g., life-cycle assessment or LCA) with a standard form (e.g., life cycle assessment). This ensured that the results would provide an accurate analysis of the literature. The thesaurus file was uploaded into the VOSviewer software before the data analyses were executed [43].

The first research question inquiring into the landscape of sustainable mining research in ASEAN was analyzed using descriptive statistics. The growth trajectory and subject area distribution of this knowledge base were documented using Scopus analytical tools. The geographical distribution of the 575 documents was displayed using Tableau Software. This was based on the affiliation of the first author of each article. The authors used heatmaps to highlight concentration areas, enabling a more nuanced understanding of the regional hotspots in sustainable mining research within ASEAN. Moreover, the authors considered potential correlations between geographical distribution and citation impact, providing insights into the influence of specific regions on the scholarly impact of the literature.

Several keyword analyses were used to examine topical trends in the literature on sustainable mining in the ASEAN region [42,51]. In the first step, VOSviewer software was used to track the frequency with which each author-defined keyword occurred in the review documents. This simple frequency count was used to determine the prevalence of different topical foci in the literature.

Next, keyword co-occurrence analysis (co-word analysis) was used to visualize the conceptual structure of the literature [41,51,52]. Co-word analysis has been used extensively to map the conceptual structure of different disciplines and research topics [41,45,51]. As described by Zupic and Čater [42], co-word analysis is:

> A content analysis technique that uses the words in documents to establish relationships and build a conceptual structure of the domain. The idea underlying the method is that when words frequently co-occur in documents, it means that the concepts behind those words are closely related. It is the only method that uses the actual content of the documents to construct a similarity measure, while the others connect documents indirectly through citations or co-authorships. (p. 435)

In this step, VOSviewer created a matrix that tracked the frequency with which pairs of keywords "co-occurred" in the same review documents. The keyword analysis quantified the instances where two keywords occurred together in the review database's title, keywords, and abstracts of documents. Consequently, this analysis unveiled the prevalent themes and topics frequently explored in the reviewed publications [43]. For example, assume that "small-scale gold mining" and "mercury" co-occur 18 times in the database document. This would suggest that topics are related to one another [43].

In the third step, VOSviewer used the co-occurrence matrix to generate a network map that visualized the relationships among keywords in the literature based on co-occurrence patterns [43]. The co-word map grouped related keywords in proximity to one another, providing an intuitive representation of the interconnected thematic clusters within the sustainable mining literature in the ASEAN region. Co-word maps can be interpreted not only to understand topical frequency and relationships but also to visualize the conceptual space or thematic structure of literature [42].

3. Results & discussion

This section presents the results and discussion of the ASEAN sustainable-mining bibliometric analysis. The three research questions were addressed sequentially.

3.1. The landscape of research on sustainable mining in the ASEAN region

The first Scopus-indexed journal article on sustainable mining in ASEAN was published in 1942 [53]. However, scholarly interest in this topic emerged slowly in succeeding decades (see Fig. 2). Indeed, annual publication volume only began to rise after the Council of Mining and Metals (ICMM) committed to supporting sustainable development

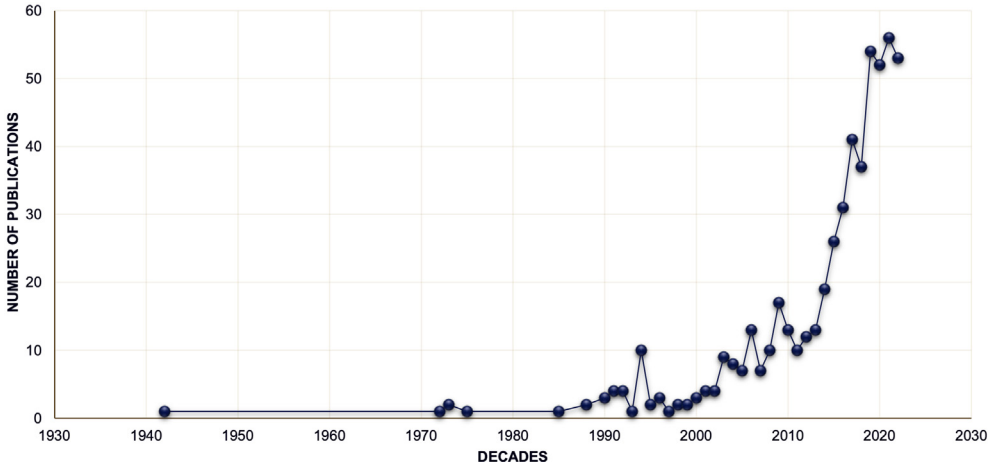

Fig. 2. Growth trajectory of the literature on sustainable mining in the ASEAN region, 1942–2022 (n = 575 journal articles).

in 2004 [18]. However, it was not until 2015 that research publications on sustainable mining in ASEAN publications increased significantly (see Fig. 2). This interest likely resulted from the publication of the 2030 Agenda for Sustainable Development by the United Nations. This included the adoption of global sustainable development goals (SDGs), which profoundly impacted all industries worldwide, including mining [54].

Subject area analysis of the 575 articles revealed the emergence of an interdisciplinary knowledge base (see Fig. 3). The environmental, social, earth and planetary sciences contributed a plurality (i.e., 53%) of the literature on sustainable mining in ASEAN nations. Scholars associated with engineering, earth and planetary sciences, and environmental science domains have focused on the environmental impact of mining, extraction efficiency, and waste management processes [55–59]. Medical and social science researchers have examined the sustainable mining health and safety dimensions, including the effects on workers and communities [12,60,61]. Scholars in the social sciences, economics, and business management fields have explored management methods that can be used to enhance mining sustainability in the region through supply chain management, project management, and human resource management [33,62].

The geographical heat map in Figure 4 visualizes the geographical distribution of research on sustainable mining in ASEAN based on the country of the first author. Notably, despite ASEAN including only ten nations, this literature includes contributions from 56 countries. The ASEAN member nations with the most contributions to this literature were Indonesia (130), Malaysia (67), Thailand (47), Vietnam (44), and the Philippines (41). The higher levels of interest among scholars from Indonesia [33,63–65] and Malaysia [66–68] is understandable since they are rich in natural resources, and the mining industry has played a significant role in their economies.

Outside of ASEAN, the most frequent contributors to this knowledge base were from Japan (64), the United States (62), Australia (56), and the United Kingdom (34). While Wu et al. (2021) found that Chinese scholars have made among the most significant contributions to the global literature on green mining, their contribution to the ASEAN literature was only in the moderate range (21). These contributions by scholars located outside of ASEAN highlight both the global interest in the region and the prevalence of collaborative research [31,34,35,37,39].

3.2. Conceptual structure of research and scholarly focus on sustainable mining in ASEAN

Co-word analysis was conducted to visualize the conceptual structure of this literature (see Fig. 5). The authors selected a threshold of at least ten occurrences of keywords to produce the co-word map. This threshold balanced the frequency of occurrence with the comprehensiveness of coverage of keywords appearing in the literature.

The sizes of nodes on the co-word map in Figure 5 indicate the relative frequency with which keywords were identified in the literature. Larger nodes reveal keywords that appeared more frequently in the corpus (e.g., Indonesia, environmental impact). Given the threshold used for this map, the smallest nodes represent keywords that occurred ten times (blood, chromium, deforestation, radiation). The lines that link keyword pairs indicate their "co-occurrence" in the review documents; dense lines

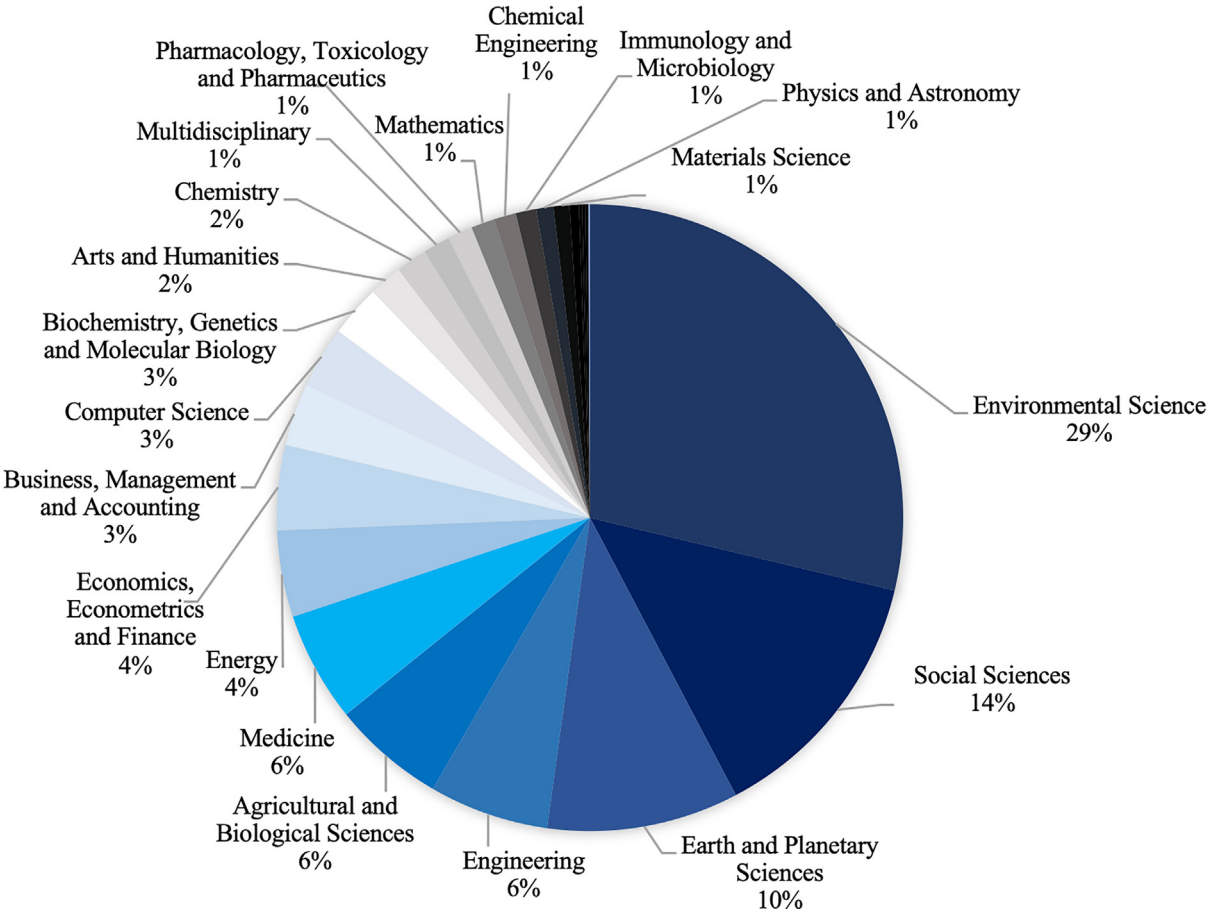

Fig. 3. Subject area distribution of the literature on sustainable mining in ASEAN, 1942–2022 (n = 575 journal articles).

suggest more frequent co-occurrence. Node proximity reveals the degree of relationship between keywords; nodes that are close together tend to be more closely related. Additionally, the co-word map draws on the patterns of keyword co-occurrence to produce colored clusters of related keywords. These clusters can be interpreted to represent the conceptual or thematic structure of the literature [41,42,51].

The co-word map in Figure 5 reveals three conceptual clusters within this literature. The red cluster associated with sustainable mining management is the largest. Mining, Indonesia, environmental impact, environmental policy, and sustainable development are cluster's most frequently occurring keywords. These terms emphasize efforts undertaken in the region to manage the mining industry for sustainability [10,36,69,70]. Based on their size and location, it would appear that researchers have paid particular attention to these issues with respect to Indonesia [64,65,71], Vietnam [10,12,72], and the Philippines [62,70].

This cluster contains a diverse set of keywords, including various aspects of sustainable mining, which are environmental concerns (e.g., climate change, greenhouse gases, deforestation), socio-economic development (e.g., corporate social responsibilities, communities, economics effects, governance), and responsible resource management (e.g., life-cycle assessment, conservation of natural resources, minerals, land use). These frequently appearing keywords demonstrate a significant focus on the importance of balancing economic development, environmental protection, and social responsibility in the mining sector to ensure a sustainable future [62,73,74]. Notably, there were numerous articles related to the role of corporate social responsibility in the enhancement of sustainable mining practices in Indonesia [74–77]. A recent publication has increasingly emphasized social licenses to operate as a significant part of mining companies' corporate social responsibility strategy [36,78].

While sustainable development was closely linked to environmental impact [38,55,57,79] and environmental policy [80–84], there were fewer connections to health-related issues [16,66,85]. This observation

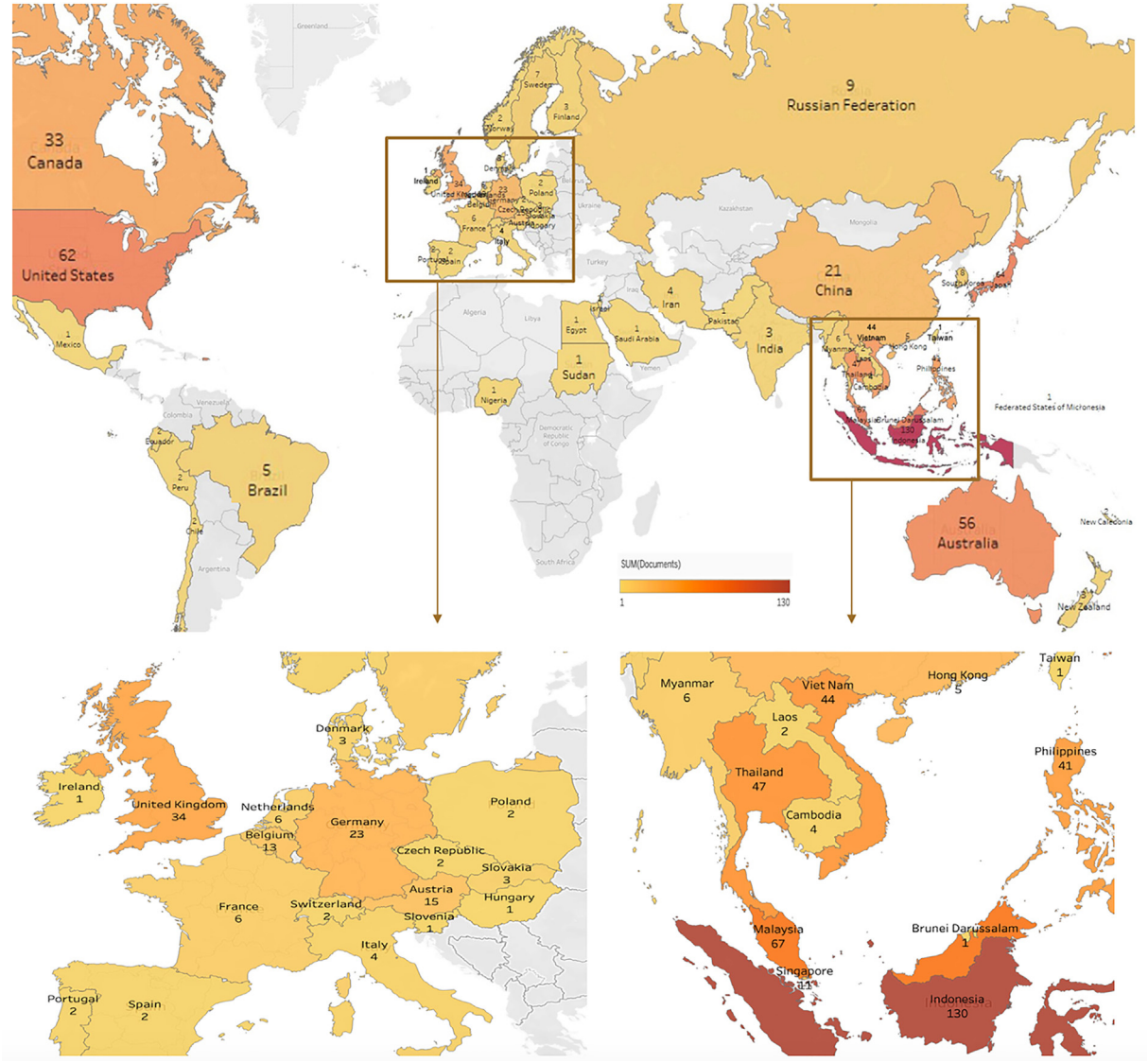

Fig. 4. Geographical distribution of the literature on sustainable mining in ASEAN, 1942–2022 (n = 575 journal articles).

suggests that the research conducted on "sustainable mining" in the ASEAN literature has strongly emphasized the environmental aspects of sustainable policy and practices rather than social and health-related issues.

Sustainable development in mining has emerged to become a key global megatrend in the mining industry [23,86]. However, the use of sustainability assessment has yet to become widespread internationally in the mining sector [8,9]. This observation also applies in the ASEAN region [87–89]. Indeed, regional studies have highlighted a need for a more comprehensive and standardized framework to guide operators toward the use of more sustainable practices [58,88,90,91].

An emerging topic is the transition from emphasizing the environmental footprint of mining operations to the broader topic of responsible management of non-fuel mineral resources throughout their life [10,19,73,92]. Life cycle assessment (LCA) methods such as ReCipe, ILCD, and IPCC have been topics of recent interest among scholars studying sustainable mining in the ASEAN region [10,72,93]. These approaches seek to quantitatively analyze the environmental effects caused by mineral and mining processes. The effects studied by researchers in ASEAN include greenhouse gas emissions, toxicity impact from substances released on land, water, and the environment, natural resource depletion, land use, and effects on biodiversity [9,10,72,92,93].

The green cluster of keywords is associated with Natural Resource Management in Mining. The keywords in this cluster focus on environmental

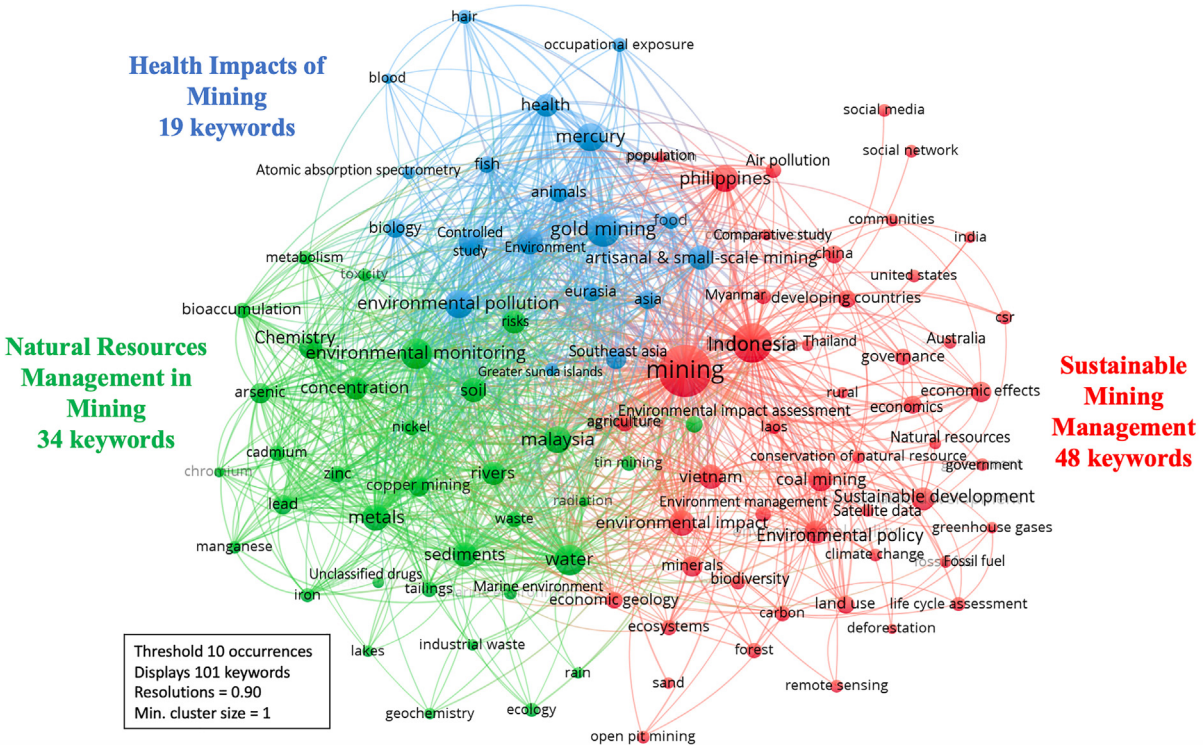

Fig. 5. Co-word map of the research literature on sustainable mining in ASEAN, 1942–2022 (n = 575 articles; threshold 10 occurrences; display 101 keywords).

monitoring and pollution (e.g., environmental monitoring, toxicity, metabolism, bioaccumulation), water and river ecology (e.g., water, river, sediments, marine environment, rain, ecology), heavy metals and contamination (e.g., cadmium, chromium, iron, zinc, lead), and waste management (e.g., waste, industrial waste, tailings). These frequently co-occurring keywords reflect an emphasis on understanding and mitigating the environmental effects of mining activities in ASEAN [10,76,90,93]. These studies also focus on the economic impact of unsustainable practices and natural resource depletion more broadly [32,33,62,71].

The interconnectedness of keywords emphasizes the need for a comprehensive approach to addressing environmental monitoring, waste management, water ecology, and heavy metal contamination issues in the ASEAN region [29,34,39,76,84]. This is consistent with persisting efforts to work towards complementarity in policies that promote the achievement of sustainable development goals in the region [29,31,69,90].

Economic geology and geochemistry are emerging as significant topics in sustainable mining in ASEAN. These topics are emphasized in all stages of the mining process, including the exploration of new deposits, resource assessment, mineral processing planning, and the management of mine waste materials [94–97]. Recent investigations have focused on leveraging economic geology and geochemistry to optimize the mining process, reduce waste, and prevent the uncontrolled release of contaminants into the environment [96,98–100]. Economic geology and geochemistry information are also utilized for statistical analysis and predictive modeling, contributing to improved mining operation efficiency and the advancement of sustainable mining practices [95,99,101,102].

The blue cluster highlights the theme of the Health Impact of Mining. This cluster of keywords highlights the social impact of the mining industry [88,103,104]. Note the proximity and frequent links between gold mining, artisanal, and small-scale mining, and keywords such as mercury, health, food, and animals. This suggests that regional scholars have devoted significant attention to studying the potential health effects associated with gold mining and artisanal and small-scale mining activities [64,70,85,105].

Artisanal small-scale mining refers to informal entrepreneurial mining activities that are often conducted without requisite licenses or permits [106,107]. Artisanal small-scale mining is often, but not exclusively, used when mining for gold. Both artisanal small-scale mining, in general, and artisanal and small-scale gold mining, in particular, use

mining practices associated with health, safety, and environmental problems [16,85]. For example, pollution due to the use of mercury in small-scale mining has become problematic throughout the region [64,71,98,108]. Thus, the uncontrolled use of mercury in artisanal and small-scale gold mining remains a hot issue among regional scholars.

The sustained interest in this issue suggests that it represents a persisting issue that remains to be solved [16,64,65,85,98]. Nonetheless, researchers have examined a variety of solutions that should be shared more widely within ASEAN [70,71,109–112]. Given the seeming prevalence of artisanal and small-scale mining in the region, this should be prioritized.

3.3. The discussion

This research review documented knowledge production on sustainable mining in the ASEAN region over the past 80 years. The review, which relied on bibliometric methods, focused on examining broad trends in the literature on sustainable mining in the ASEAN region. However, consistent with the review method [42], the review did not evaluate and synthesize the substantive findings of the studies. In addition, decisions made at the stage of document identification meant that the review, while wide-ranging in scope, did not include all possible documents. Books, book chapters, conference papers, and journal articles written in languages other than English were excluded.

This review identified a rapidly growing knowledge base consisting of 575 Scopus-indexed documents on sustainable mining in the ASEAN region. The results showed a sharp increase in publications in the last eight years, accounting for 65% of all documents included in this review. The recently growing interest in this research field might be due to the SDGs released by the United Nations, which significantly affected industries worldwide. The rapidly accelerating publication trajectory affirms that research on sustainable mining in the ASEAN is consistent with broader international trends.

Moreover, it was interesting to note that researchers' interest in sustainable mining in ASEAN included scholars not only from ASEAN countries but also from other regions (e.g., Japan, the United States, Australia, and China). The rather unusual degree of international researchers' engagement in a regional issue possibly reflects the global investment in the mining industry and related supply chains [63].

The diversity of subject areas included in this growing interdisciplinary body of knowledge reflects the triple-bottom-line approach to many sustainability issues. Thus, we noted contributions from the earth, planetary, and environmental sciences, as well as from the social sciences. This suggests further potential for interdisciplinary cooperation in tracking the inputs and outputs of mining from multiple perspectives (e.g., environmental, labor, health, economic).

The most dominant theme identified through keyword analysis concerns the negative environmental impacts of small-scale mining investigations. Indeed, documenting and analyzing the potentially adverse environmental effects of small-scale mining should continue to be a policy-related priority for research in the region [70,109,110]. The top-cited documents identified in the literature largely concern mercury contamination arising from artisanal and small-scale gold mining and the downstream effects on health and the environment [16,105,108,113]. Given the widespread poverty in many parts of the region, small-scale mining is likely to continue as a form of entrepreneurial activity in years to come. However, operators of small-scale mines in general, and artisanal and small-scale gold mining in particular, appear to lack awareness of the environmental and social risks [85,111,113]. More specifically, there is an urgent need to raise awareness and more effectively control the use of mercury in artisanal and small-scale gold mining [64,65,71,114]. Thus, this review highlights the need for education, training, and policies that promote cleaner production and reduce adverse health and environmental effects on surrounding communities [70,84,106,115,116].

Socioeconomic sustainability is another theme that arose from this review. The mining industry has increasingly emphasized social responsibility as part of its commitment to sustainability [74,77]. This has led scholars to focus on unpacking the relationship between mining and the surrounding communities [36,73,75]. This has included studies of conflict management, as well as the socioeconomic impact associated with mining activities [62,117–120].

The global emphasis on corporate social responsibility has created an expectation that mining companies will seek a more balanced and positive impact on society. This has highlighted the relevance of stakeholder engagement strategies and good governance practices within the industry [13,19,74]. For example, the mining sector has come under increased pressure to disclosure relevant social and environmental information to interested stakeholders [76,121–123].

Social license to operate has been emphasized as a critical element influencing the mining industry's

stability and sustainability [15,36]. It denotes community acceptance of mining activities, emphasizing the need for robust corporate social responsibility initiatives that address environmental concerns, stakeholder engagement, and community well-being [78]. Securing this license enhances operational credibility and legitimacy, highlighting the imperative of aligning corporate social responsibility efforts with community expectations [15]. Therefore, it highlights the necessity of integrating social license to operate considerations into corporate social responsibility strategies [36,78]. This integration underscores responsible mining practices, reinforcing the industry's dedication to ethical operations regionally in ASEAN and globally [36].

However, findings from investigations within ASEAN have cast doubt on the accuracy of data reported by some mining companies. This extends to inconsistencies in efforts to measure performance and sustainability progress across the industry in the region [121,123]. This suggests a need for greater uniformity in regional mining standards related to social and environmental disclosure practices as well as sustainability-related [62,124,125].

The results of the keyword co-occurrence analysis support the conclusion that scholarship on sustainable mining in ASEAN literature anticipated sustainable mining approaches [23,86]. The large nodes "Indonesia", "Gold mining", "Environment monitoring", and "Environmental pollution" in the co-ward map illustrate that the research on sustainable mining in the ASEAN knowledge base is focused on social and environmental issues in Indonesia. Additionally, the co-word map reveals a notable pattern in keyword connections. "Sustainable development" exhibits close associations with "environmental impacts" and "environmental policy", but no links to "health" are evident. This observation indicates that the research conducted on sustainable mining in the ASEAN literature places a stronger emphasis on the environmental aspects of sustainable policy and practices rather than addressing health-related issues in the context of mining activities. This finding is consistent with earlier research emphasizing the importance of considering broader health determinants resulting from mining activities and sustainable mining practices, aiming to safeguard the well-being of individuals in the future [66].

The temporal co-word map reflects the research priority on sustainable development, life cycle assessment, natural resources conservation, and environmental impacts. The finding confirmed the emergent need for a standardized framework for sustainable mining, including life cycle assessment (LCA) methods and mining regulations [12,58,90,126]. This aligns with the conclusion of Worrall et al. (2009), highlighting the urgent need for sustainable criteria and indicator frameworks in ASEAN's mining sector to gauge mining companies' progress toward sustainability.

Another contemporary theme focuses on artisanal small-scale mining and artisanal and small-scale gold mining, highlighting the effects of informality and mercury on health and the environment [65,85,108]. A substantial body of empirical studies provides compelling evidence for the prevalence of artisanal small-scale mining and artisanal and small-scale gold mining in the region [98,104,114,127]. This reaffirms the ongoing trends concerning the multifaceted implications of artisanal small-scale mining from political, social, economic, and environmental perspectives [70,128,129].

Several strategies have been developed to address the negative impacts of artisanal small-scale mining and artisanal and small-scale gold mining. These encompass initiatives such as the formalization of illegal artisanal small-scale mining operations [70], the enforcement of regulations governing artisanal small-scale mining activities [130], and the promotion of social order in the communities around the mining area [131]. However, studies finding solutions to the importance associated with health and the environment are scarce and need to be strengthened, leaving ample room for further research on this vital topic [132].

The sustainable mining trend is closely linked to sustainable construction, as both industries have interdependent and shared objectives [133,134]. Sustainable mining practices focus on responsibly extracting raw materials needed for sustainable construction projects [11,135]. The two industries intersect in supply chain management, carbon emissions reduction, energy conservation, waste management, stakeholder engagement, and addressing social impact [136]. By aligning their practices, sustainable mining and construction can collectively contribute to advancing a more sustainable built environment.

4. Conclusions

This comprehensive review illuminates critical trends and challenges of sustainable mining literature in the ASEAN region over 80 years. The surge in research, primarily observed in the last eight years, echoes global sustainability initiatives catalyzed by the United Nations' Sustainable Development Goals. The result of thematic analyses underscored the pressing need to address the adverse environmental impacts of small-scale

mining, particularly mercury contamination, necessitating heightened awareness, policy frameworks, and cleaner production strategies. The interdisciplinary nature of this research highlights the triple-bottom-line approach, merging environmental, social, and economic perspectives. However, discrepancies in reported data and the absence of standardized regional mining practices pose significant hurdles to sustainable mining practices.

Scholars and policymakers should concentrate on long-term mechanisms and comprehensive regional regulation on sustainable mining within ASEAN. Future research in sustainable mining in the ASEAN region should focus on exploring and addressing potential health impacts related to mining operations. By incorporating health considerations into sustainable mining practices, a comprehensive approach can be adopted that ensures both environmental preservation and the well-being of local communities and ecosystems. Further investigation and analysis are essential to address any potential health risks and social responsibility associated with mining, contributing to a more holistic and sustainable approach to mining policy and practices in the ASEAN countries. Besides, recycling and waste management studies and geoengineering for sustainable mining should also be investigated more deeply. Additionally, research on the circular economy and the Fourth Industrial Revolution (4th IR) application in sustainable mining should be conducted to advance sustainable mining to the next level. This includes implementing circular economy principles, such as resource recovery and waste management, and identifying technologies and digital solutions for smart mining that can be integrated into mining operations to enhance sustainability. Lastly, future research should focus on developing standardized frameworks and indicators for measuring and reporting sustainability performance in the mining industry [62].

These recommendations, rooted in the study's findings, underscore the need for collaborative efforts among stakeholders, propelling responsible and sustainable mining practices within ASEAN. By addressing environmental, health, and socioeconomic challenges, this collective approach will contribute significantly to regional development and attaining global sustainability objectives.

Ethical statement

As this was a review article, no ethical issues were encountered in the study's conduct.

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Conflicts of interest

The authors declare no conflict of interest.

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