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MORALITY BEFORE KNOWLEDGE

Elucidating Indonesia's palm oil supply chain trends: A bibliometric approach

William Ben Gunawan[1],[2]*
[1] *PPM School of Management, 10340, Jakarta, Indonesia.*
[2] *INTI International University, 71800, Nilai, Malaysia.*
*Correspondence: wbwilliambenwb@gmail.com

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ABSTRACT

Background: Indonesia's palm oil supply chain (POSC) plays a critical role in the global economy, contributing over 60% of the world's crude palm oil (CPO) supply. Despite extensive research on palm oil production and sustainability, there remains a lack of comprehensive bibliometric analysis that maps the evolution of POSC research, identifies key knowledge gaps, and highlights emerging trends. **Methods**: This study addresses this gap by employing a bibliometric approach to analyze academic research on POSC from 2007 to 2024. Using Scopus data and VOSviewer for visualization, the study identifies key trends, influential authors, research hotspots, and international collaborations. **Findings:** Results show a significant increase in publications since 2016, driven by global concerns over sustainability, climate change, and the social impacts of palm oil production. Indonesia leads research output, with international collaborations predominantly involving Malaysia and the United States. The findings reveal a shift toward sustainability research, emphasizing environmental challenges, smallholder inclusion, and technological innovations. **Conclusion**: This study contributes to the literature by providing a systematic mapping of POSC research, highlighting underexplored areas such as supply chain transparency and the role of palm oil in biofuels. Future research should focus on balancing economic development with environmental stewardship and leveraging interdisciplinary approaches to address sustainability challenges. **Novelty:** highlights the growing intersection of POSC research with sustainability, technological innovation, and policy development, offering valuable insights for industry stakeholders, policymakers, and researchers.

KEYWORDS: Bibliometric, Indonesia, Palm Oil, Supply Chain, Sustainability.

1. Introduction

Indonesia is one of the world's largest producers of crude palm oil (CPO), making palm oil a cornerstone of the nation's agricultural economy. Alongside Malaysia, they accounted for over 83 percent of global palm oil production. In contrast to Malaysia, which primarily exports most of its palm oil output, Indonesia stands out as one of the largest consumers of palm oil, utilizing it for both cooking oil and biofuels (Siaahan, 2024). The sector has been instrumental in driving economic growth, creating employment, and contributing significantly to the country's export revenues (Nurfatriani et al., 2022). In 2023, Indonesia's palm oil production accounted for over 60% of global supply, positioning the industry as a key player in both domestic and international markets, even though Indonesia has several competitive challenges in the CPO downstream industries (Husin et al., 2023).

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The expansion of the palm oil industry has, however, led to increasing scrutiny regarding its environmental and social impacts. The palm oil supply chain (POSC) encompasses a wide array of processes, from plantation management, extraction, and processing to distribution and final consumption (Munasinghe et al., 2019). Efficient supply chain management is essential for maintaining Indonesia's competitive advantage while addressing challenges such as deforestation, greenhouse gas emissions, land-use change, and labor rights issues (Eggen et al., 2024; Pacheco et al., 2020). As sustainability concerns mount, global markets and regulatory bodies are imposing stricter environmental and social governance (ESG) requirements on palm oil exports, making sustainable supply chain practices more critical than ever.

In recent years, research efforts have focused on optimizing Indonesia's POSC to enhance productivity, ensure traceability, and meet sustainability standards (Abideen et al., 2023; Adwiyah et al., 2023). Despite the growing body of literature on POSC, existing studies often focus on isolated aspects such as sustainability certification, smallholder participation, or technological advancements. However, there is a lack of comprehensive studies that systematically analyze the research landscape as a whole. A bibliometric analysis provides a robust methodological approach to mapping scholarly contributions, identifying influential research clusters, and uncovering emerging trends in the field (Donthu et al., 2021). Such an approach is necessary to understand the evolution of POSC research and to pinpoint critical areas that require further investigation.

This study aims to address this gap by conducting a bibliometric analysis of POSC research from 2007 to 2024. By analyzing publication trends, leading authors, international collaborations, and thematic research clusters, this study seeks to provide a structured overview of the academic landscape. Additionally, it highlights the growing intersection of POSC research with sustainability, technological innovation, and policy development, offering valuable insights for industry stakeholders, policymakers, and researchers.

The findings of this study contribute to the existing literature by systematically mapping research progress and identifying underexplored areas that warrant further attention. Understanding the trajectory of POSC research can inform future strategies for improving efficiency, sustainability, and resilience in Indonesia's palm oil industry. As the sector faces increasing global scrutiny and shifting market dynamics, a data-driven perspective on research trends can play a crucial role in shaping sustainable policies and industry practices moving forward.

1.1 Theoretical overview

The Indonesian palm oil industry plays a crucial role in the global vegetable oil market, serving as the largest producer and exporter of CPO. According to data from the Indonesian Palm Oil Association (GAPKI), the country has contributed over 50% of global palm oil production in recent years, positioning itself as a vital player in the global food and biofuel markets. The growth of palm oil production in Indonesia has been driven by a combination of increasing global demand for affordable edible oils, government policies aimed at fostering rural development, and the expansion of land allocated to oil palm plantations (Mukherjee & Sovacool, 2014; Varkkey et al., 2018). However, the rapid expansion of the industry has led to significant environmental concerns, including deforestation, habitat loss, and greenhouse gas emissions. As a result, the sustainability of Indonesia's palm oil production has become a focal point of international and domestic policy discussions, influencing the supply chain dynamics in the country (Kadarusman & Pramudya, 2019; Purnomo et al., 2020).

Indonesia's POSC is vast and complex, encompassing numerous stakeholders, from smallholder farmers to multinational corporations. Smallholders, who manage approximately 40% of the country's oil palm plantations, play a crucial role in the supply chain but often face challenges related to land tenure, productivity, and market access (Abideen et al., 2023; Ruml et al., 2022). The remainder of the supply chain is dominated by large-scale plantations owned by corporations, which tend to have more resources for

optimizing production and adhering to sustainability standards. The integration of smallholders into sustainable supply chains has been a key focus of national policy and international initiatives, such as the Roundtable on Sustainable Palm Oil (RSPO) certification (Abideen et al., 2023). However, the inclusion of smallholders in these initiatives has been uneven, and the lack of infrastructure and investment in rural areas has hindered their ability to fully participate in certified sustainable supply chains.

Recent trends in the POSC have been shaped by the growing importance of sustainability certifications, technological advancements, and shifting consumer preferences. Certification schemes, such as the RSPO and Indonesia's national Indonesian Sustainable Palm Oil (ISPO) standard, aim to promote responsible palm oil production by setting environmental and social criteria (Abdul Majid et al., 2021; Hidayat et al., 2018). While these certifications have gained traction, their adoption remains a challenge, particularly for smallholders who face barriers in meeting the strict requirements. Nonetheless, the demand for sustainably produced palm oil has been increasing, driven by international pressure from environmentally conscious consumers and regulatory frameworks in importing countries, such as the European Union's Renewable Energy Directive (RED) (Mayr et al., 2021). These developments have pushed Indonesian producers to align their practices with global sustainability standards, which has reshaped supply chain dynamics.

Technological innovation is also playing a key role in the transformation of Indonesia's POSC. Digital platforms, satellite monitoring, and blockchain technology are being explored to improve traceability and transparency across the supply chain (Abubakar & Ishak, 2024; El Hathat et al., 2023). These technologies enable more efficient tracking of palm oil from plantation to consumer, helping to address concerns related to deforestation, land use change, and supply chain transparency. In particular, blockchain has the potential to revolutionize the industry by providing tamper-proof records of supply chain transactions, ensuring that certified sustainable palm oil can be verified by downstream buyers (Sunny et al., 2020). The adoption of such technologies has been gradual, but they are seen as crucial tools for meeting both domestic and international sustainability requirements.

Another important trend is the diversification of markets for Indonesia's palm oil. Traditionally, the bulk of Indonesia's palm oil exports were destined for food and biofuel markets in Europe, China, and India. However, geopolitical developments and trade tensions have prompted Indonesian producers to explore new markets, including those in Africa and the Middle East (Rahman et al., 2021). Additionally, the growth of the domestic biodiesel market, supported by the government's B40 mandate (which requires biodiesel to contain 40% palm oil), has created new opportunities for palm oil producers, further affecting supply chain patterns (Halimatussadiah et al., 2021). This shift towards domestic use, combined with the diversification of export markets, has made Indonesia's POSC more resilient to external shocks, though it has also raised concerns about the environmental and social costs of expanding biodiesel production.

The increasing emphasis on biomass and bioenergy has further influenced research on the POSCC, particularly in optimizing its byproducts for renewable energy production. Palm oil biomass, including empty fruit bunches (EFB), palm kernel shells (PKS), and palm oil mill effluent (POME), has been recognized as a valuable resource for bioenergy generation (Liew et al., 2021; Mohammad et al., 2021; Obada et al., 2023). Advances in biomass utilization have led to the development of biogas production, biochar applications, and second-generation biofuels, all of which contribute to a more circular and sustainable supply chain. However, despite the potential, challenges remain in scaling up bioenergy solutions, including logistical barriers, inconsistent feedstock availability, and high initial investment costs (Hamed et al., 2023; Makepa et al., 2023). Furthermore, policy inconsistencies and limited technological adoption have hindered the widespread implementation of biomass-to-energy conversion in Indonesia's POSC (Rahmanta & Cahyo, 2024), creating a gap in research on how to improve the feasibility of such innovations.

While several studies have explored sustainability issues in POSC, there is a lack of holistic analyses integrating biomass valorization, circular economy models, and emerging

bioenergy technologies into supply chain frameworks. Most research focuses on isolated aspects, such as carbon emissions from palm oil plantations or life cycle assessments of biodiesel (Chew et al., 2023; Phuang et al., 2021), without addressing the interconnected nature of supply chain management and biomass utilization.

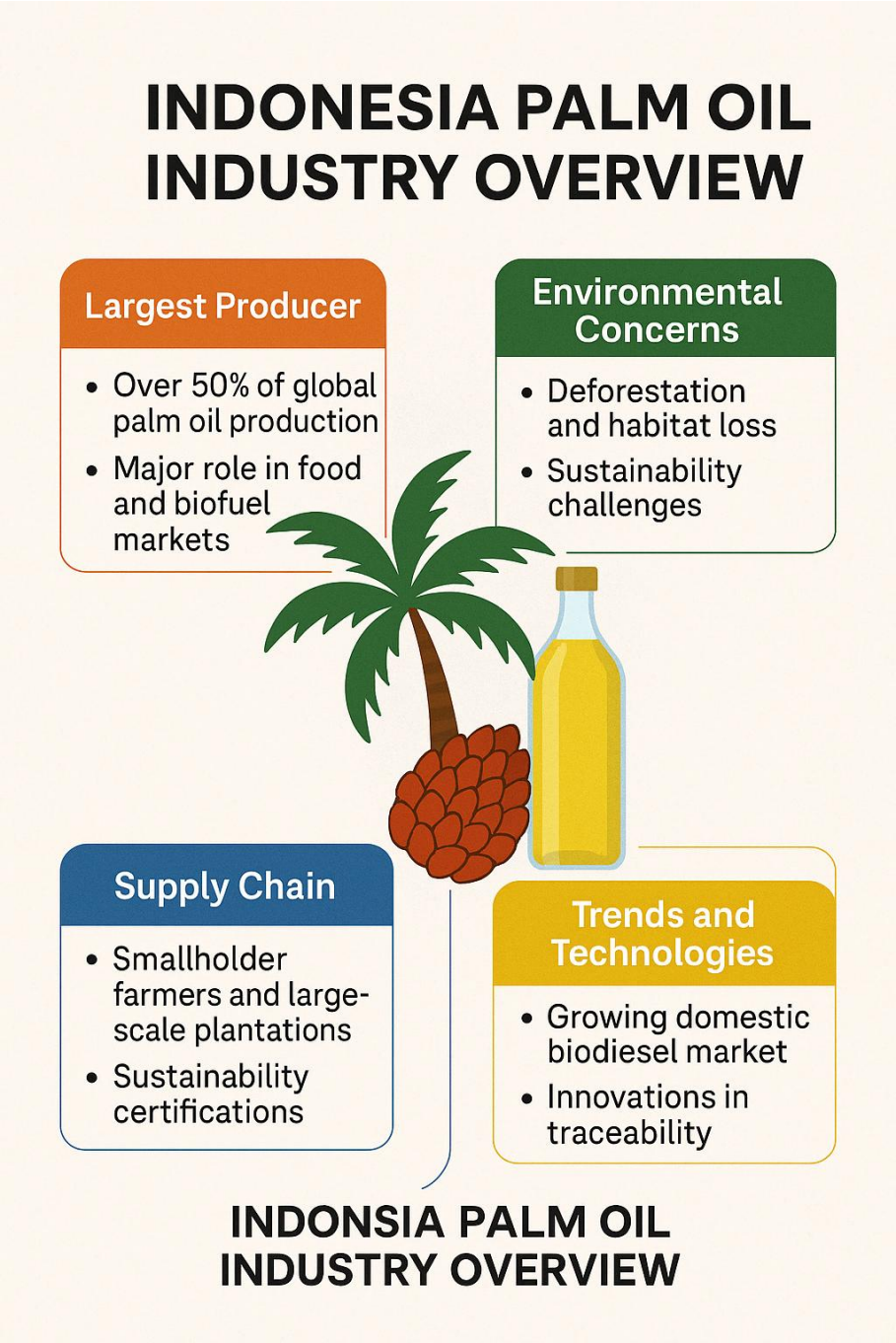

Fig. 1. Indonesia palm oil industry overview.

2. Methods

A bibliometric study is a research method that uses quantitative analysis of academic literature to assess patterns, trends, and the impact of publications within a specific field (Donthu et al., 2021). This study employs the bibliometric approach to align with its objective of mapping the scientific research on POSC. The bibliometric method was chosen for its ability to provide a comprehensive overview of a field and to objectively assess trends over time, making it highly suitable for examining the evolving trend of POSC. By evaluating

key metrics such as citation counts, keywords co-occurrences, and co-authorship networks, bibliometric analysis enables researchers to uncover the intellectual structure of a research domain and identify key developments.

To ensure rigor and relevance in the selection of studies, clear criteria were established for identifying articles pertinent to this research. A search was conducted in the Scopus database in October 2024, using the key term of ("palm oil" OR "crude palm oil") AND "supply chain" AND "Indonesia". The search strategy was designed to capture both foundational research and the latest developments in these areas, allowing for a well-rounded analysis. Scopus was selected as the primary database for this bibliometric analysis due to its extensive coverage of peer-reviewed publications across various disciplines (Singh et al., 2021). Compared to other databases like Web of Science, Scopus offers a broader scope of indexed journals and provides more detailed citation data, making it particularly advantageous for tracking research trends and assessing the influence of publications. Additionally, Scopus offers robust tools for exporting data, which facilitates further analysis in software like VOSviewer, a program designed for bibliometric visualization. VOSviewer was chosen for its ability to generate maps based on citation networks, co-authorship, and keyword co-occurrence, allowing for a clear visualization of relationships between authors, institutions, and research themes.

The article selection process was guided by several key criteria to ensure the relevance and quality of the literature included in the analysis. First, the search was not limited to any specific years to ensure complete capture of the trend. Second, only articles in English were chosen. Third, the term was searched within the Article Title, Abstracts, and Keywords. This search resulted in 112 documents as per October 2024. Once the relevant articles were finalized, the data was exported from Scopus into VOSviewer. VOSviewer was used to visualize co-authorship networks, citation relationships, and keyword co-occurrence, allowing for a detailed mapping of research trends and collaborative networks within the field. To ensure academic relevance and impact, several considerations were applied: (i) a minimum number of documents of an author was set to 1; and (iii) the keywords were selected at a minimum of 3 keyword occurrences. This visualization process helps to identify clusters of research that are focusing on similar themes, as well as gaps in the literature where further exploration is needed.

3. Results and Discussion

3.1 Time journey of publications

Figure 2 shows an evident increase in the number of recorded entries from 2007 to 2024, with fluctuations observed in the overall trend. Initially, there was minimal activity between 2007 and 2012, with the number of records ranging from 1 to 3. However, a significant growth began after 2016, as the number of records quadrupled from 2 in 2015 to 7 in 2017. This upward trajectory continued, peaking in 2020 with 19 records, the highest number in the entire period, which represents a significant leap in interest.

Following 2020, the records slightly dropped to 12 in 2021, maintaining a similar level in 2022 before increasing again to 15 in 2023. In 2024, a small decline is observed, with 13 records recorded. The percentage of total records follows a similar pattern, suggesting a growing and sustained interest over time, culminating in 2020 when both the number of records and percentage reached their highest point. This trend reflects a broadening focus and engagement with the subject during these years, possibly driven by external factors such as economic, environmental, or societal shifts.

The increase in records observed in 2023, rising to 15, can be attributed to several key factors. Post-pandemic recovery efforts intensified focus on resilience across health, economy, and environment, driving research into sustainable development and crisis preparedness. Additionally, heightened urgency around climate change, with renewed commitments to carbon neutrality and global initiatives like COP28, spurred significant interest in environmental and sustainability research. Technological advancements,

particularly in renewable energy and digitalization, further accelerated scholarly output. Moreover, geopolitical shifts, such as the Ukraine conflict, reshaped energy security strategies, prompting exploration of alternative energy sources. The growing pressure on corporations to enhance their Environmental, Social, and Governance (ESG) practices also contributed to the surge in research during 2023.

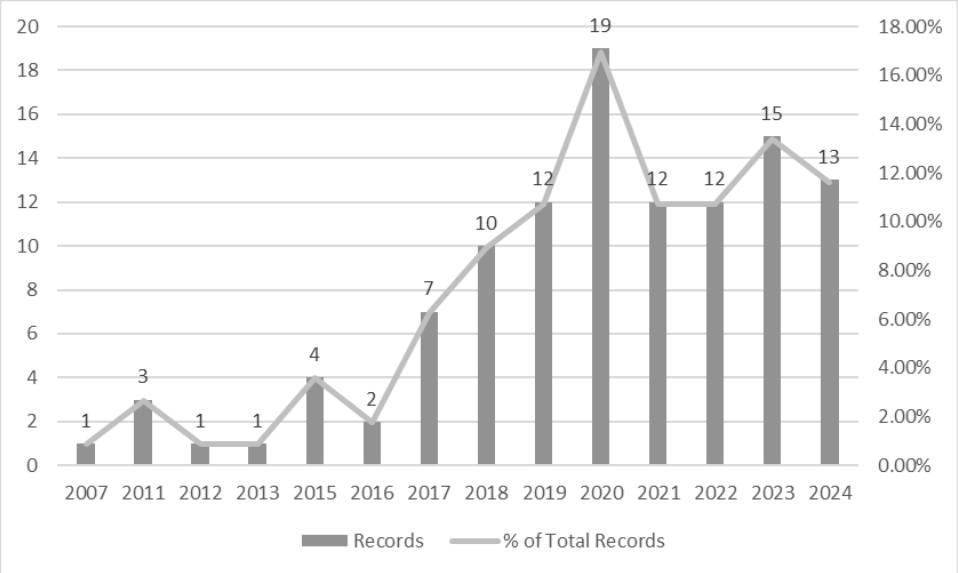

Fig. 2. Publications over the year based on the keywords searched.

3.2 Contributing sources

The analysis of the data in Table 1 indicates that the primary sources contributing to research on the POSC are a mix of both journals and proceedings. IOP Conference Series: Earth and Environmental Science contributes the most with 13 articles, accounting for 11.61% of the total 112 articles, followed by IOP Conference Series: Materials Science and Engineering with 6 articles (5.36%). Both of these are proceedings, which suggest that a significant portion of research on this topic is at an initial or exploratory stage.

Table 1. List of main sources which contribute in researching palm oil supply chain.

Name of the Journal	Articles	% of Total Documents	Status
IOP Conference Series Earth and Environmental Science	13	11.61%	Proceeding
IOP Conference Series Materials Science and Engineering	6	5.36%	Proceeding
Environmental Research Letters	4	3.57%	Journal
World Development	4	3.57%	Journal
AIP Conference Proceedings	3	2.68%	Proceeding
International Journal of Sustainable Development and Planning	3	2.68%	Journal
Land Use Policy	3	2.68%	Journal
Applied Energy	2	1.79%	Journal
E3S Web of Conferences	2	1.79%	Proceeding
International Journal Of Supply Chain Management	2	1.79%	Journal
International Journal on Advanced Science Engineering and Information Technology	2	1.79%	Journal
Journal of Cleaner Production	2	1.79%	Journal
Journal of Oil Palm Research	2	1.79%	Journal
Matec Web of Conferences	2	1.79%	Proceeding
Renewable and Sustainable Energy Reviews	2	1.79%	Journal
Sustainability Switzerland	2	1.79%	Journal

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In terms of journal contributions, Environmental Research Letters and World Development each contribute 4 articles, making up 3.57% of the total, indicating a smaller but important body of more developed, peer-reviewed research. Other journals with notable contributions include International Journal of Sustainable Development and Planning, Land Use Policy, Applied Energy, and Journal of Cleaner Production, each contributing 2 or 3 articles, suggesting that proper research, although less frequent than proceedings, is still well-represented.

Overall, proceedings make up a larger portion of the sources, indicating that much of the current work on the POSC may still be in its formative stages, with many studies being presented at conferences rather than being fully developed into comprehensive, peer-reviewed journal articles. Nonetheless, the presence of well-established journals in the dataset highlights the ongoing maturation of research in this area.

3.3 Research by countries

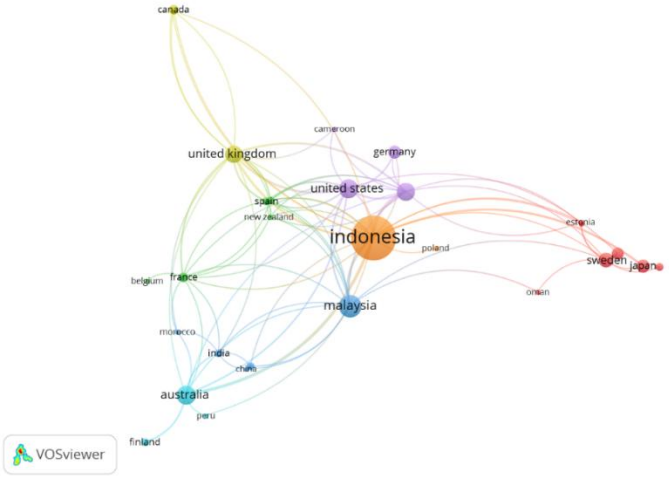
The bibliometric data reveal diverse contributions across countries in terms of published articles, citations, and link strength, reflecting varying levels of research output and impact (Table 2). Indonesia leads in article count with 66 publications, followed by Malaysia, Australia, and the United States. However, countries like Austria, with fewer articles (5), demonstrate higher citation impact (518 citations), while the United Arab Emirates, with just two articles, garnered 39 citations, indicating disproportionate influence. Indonesia (43) and the Netherlands (24) show notable link strength, signifying strong research interconnectivity. Additionally, the United States and the United Kingdom, with moderate article counts, exhibit significant link strength and citation influence. Certain countries with limited publications, such as Cameroon, which published a single article but received 139 citations, further emphasize that citation count and link strength are more indicative of research impact and interconnectedness than article volume alone. This highlights the nuanced nature of research influence, where both quantitative and qualitative metrics play crucial roles in understanding global research dynamics.

Table 2. List of countries classified by the link strength, number of publications, and citations.

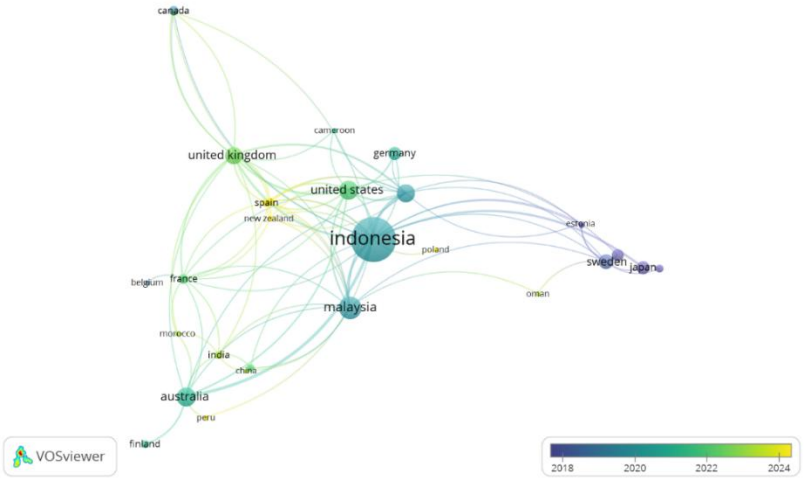
Country	Articles	Citations	Link Strength	Country	Articles	Citations	Link Strength
Indonesia	66	782	43	Switzerland	2	1	11
Malaysia	17	484	19	United Arab Emirates	2	39	4
Australia	12	302	18	Belgium	1	21	1
United States	12	461	23	Cameroon	1	139	3
Netherlands	11	324	24	China	1	32	3
United Kingdom	10	201	26	Denmark	1	0	4
Sweden	7	407	12	Estonia	1	45	4
Germany	6	144	4	Morocco	1	4	4
Japan	6	99	6	New Zealand	1	1	8
Austria	5	518	5	Oman	1	3	2
Canada	3	111	4	Peru	1	1	2
France	3	26	13	Poland	1	0	1
Brazil	2	57	2	Singapore	1	0	4

Finland	2	25	2	Taiwan	1	12	0
India	2	36	7	Thailand	1	45	4
Spain	2	1	11	Undefined	5	1	-

Figure 3 presents the network visualization of international collaborations in research on Indonesia's POSC, highlighting the contributions of various countries from 2018 to 2024. The analysis, constructed using VOSviewer, shows the presence of 29 countries, grouped into six distinct clusters based on co-authorship and citation links. These clusters signify the strength of academic collaboration, the frequency of co-authored articles, and the connection between published documents.



(a)



(b)

Fig. 3. Co-authorship analysis results country-wise: (a) network map, (b) overlay map.

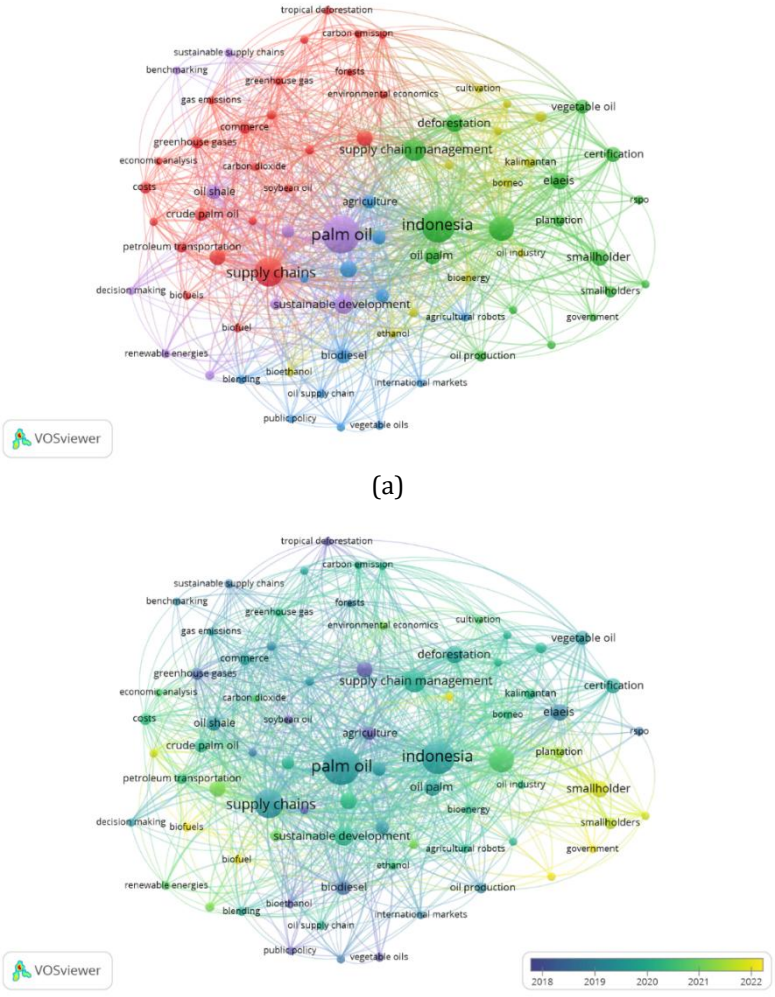
The largest cluster, shown in orange, includes Indonesia at the center, reflecting its dominant role in the field with the highest number of published articles (66) and the strongest citation link strength (43). Indonesia has extensive collaboration with Malaysia and the United States, as indicated by the prominent connections. Malaysia forms the second-largest node with 17 articles and a citation strength of 19. The United States, in the purple cluster, contributes with 12 articles and 461 citations, highlighting its significant academic influence in the research.

Other notable clusters include the blue cluster centered around Australia, with 12 articles and a citation strength of 18, and the green cluster, where the United Kingdom and Spain show active collaboration with Indonesia. The red cluster, including Sweden and Japan, represents emerging partnerships, with Sweden contributing 7 articles and 407

citations. Although some countries, such as Canada, France, and Germany, have fewer contributions in terms of articles and citations, they maintain important links with Indonesia. For instance, Canada has 3 articles and 111 citations, contributing to a growing interest in the topic. The overlay visualization further indicates the evolution of research trends over time. Collaborations with countries like Sweden, Japan, and the United States have intensified in recent years (2020-2024), while earlier contributions (2018-2020) show stronger ties with Malaysia and Australia. This analysis underscores Indonesia's pivotal role in shaping global research on POSCs, with its academic reach extending across multiple regions. The strength of international collaborations, particularly with Malaysia and the United States, reflects the transnational nature of the research in this field.

3.4 Keyword trends

The keyword co-occurrence analysis, as visualized in the diagrams, highlights the central topics and emerging trends related to palm oil research, using VOSviewer to map these keywords based on their frequency and connections in the literature (Figure 4). The first image clusters the keywords into thematic groups, with a focus on major topics such as "palm oil," "Indonesia," "supply chains," and "deforestation." These keywords are linked to others like "smallholder," "sustainable development," and "biofuels," reflecting the multidisciplinary nature of palm oil research, spanning environmental, economic, and agricultural dimensions.



(a)

(b)

Fig. 4. Co-occurrence analysis results keyword-wise: (a) network map, (b) overlay map.

The second image integrates a time component, revealing shifts in research focus over the years. Early studies, represented by blue and purple nodes, focused on traditional

supply chain topics, such as "crude palm oil" and "oil supply chains," as well as environmental concerns like "carbon emissions" and "deforestation." These were prevalent in earlier research phases. More recent studies, highlighted in green and yellow, emphasize sustainability-related terms, such as "smallholders," "certification," and "vegetable oil." The yellow nodes represent keywords from the latest research (2019-2022), indicating a shift toward sustainable practices and governance in the palm oil industry, including certification schemes like RSPO (Roundtable on Sustainable Palm Oil) and the increasing involvement of smallholders in palm oil production. This evolution reflects global trends toward balancing palm oil production with sustainable development goals.

3.5 Authors & citations

The data presented highlights the top contributing authors in terms of articles published and citations received, with distinctions drawn based on their affiliation and publishing journals (Table 3). It should be noted that Harahap, Fumi was given “et al.” since there are many authors with the same publication record as Harahap, Fumi. Therefore, they were compiled together with Harahap, Fumi.

Table 3. Top 10 authors with the largest contribution to palm oil supply chain research.

Author	Country of Origin	Affiliation	Articles	Citations	Journals in Which Author Published (Number of Articles)
Parveez, Ghulam Kadir Ahmad	Malaysia	Malaysian Palm Oil Board	2	200	Journal of Oil Palm Research (2)
Dauvergne, Peter	Canada	The University of British Columbia	2	111	Global Environmental Politics (1); Journal of Environmental and Development (1)
Harahap, Fumi et al.	Sweden	KTH Royal Institute of Technology	3	77	Applied Energy (1); Energies (1); Proceedings of the 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (1)
Jelsma, Idsert	Netherlands	Van Hall-Larenstein University of Applied Sciences	2	72	Land (1); Journal of Rural Studies (1)
Slingerland, Maja	Netherlands	Wageningen University	3	64	Agricultural Systems (1); Land Use Policy (1); Journal of Rural Studies (1)
Nesadurai, Helen	Malaysia	Monash University Malaysia	2	51	Journal of Development Studies (1); Journal of Contemporary Asia (1); TRaNS: Trans-Regional and -National Studies of Southeast Asia (1)
Heilmayr, Robert	United States	University of California, Santa Barbara	4	50	Elementa (1); Journal of the Association of Environmental and Resource Economist (1); Environmental Research Letters (2)
Carlson, Kimberly	United States	New York University	2	49	Elementa (1); Environmental Research Letters (2)

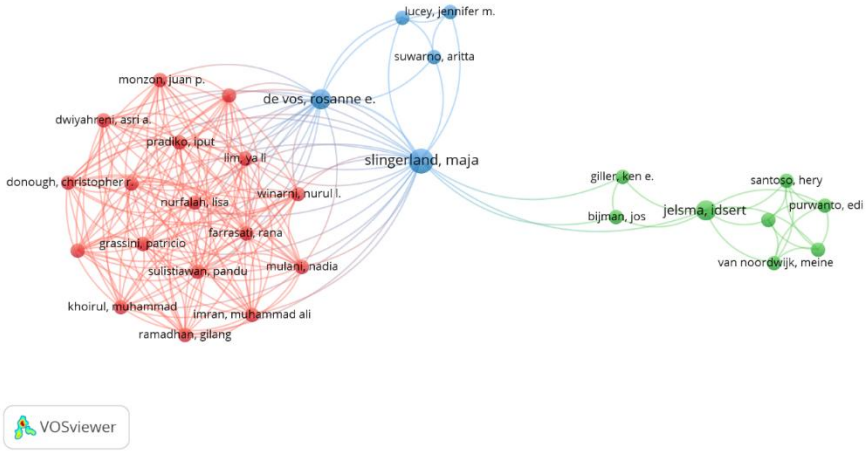
Amalia, Rizka	Indonesia	Brawijaya University	2	40	Sustainability (1); International Journal of Sustainable Development and Planning (1)
Irawan, Silvia	Indonesia	Kaleka	2	35	Frontiers in Environmental Science (1); World Development (1)

Among the leading authors, Parveez, Ghulam Kadir Ahmad from the Malaysian Palm Oil Board stands out with 2 articles and 200 citations, both published in the *Journal of Oil Palm Research*. Similarly, Dauvergne, Peter from The University of British Columbia contributed 2 articles with 111 citations, published across *Global Environmental Politics* and the *Journal of Environmental and Development*. Harahap, Fumi et al. from KTH Royal Institute of Technology in Sweden published 3 articles, receiving 77 citations, while Slingerland, Maja from Wageningen University in the Netherlands contributed 3 articles with 64 citations. It is worth noting that the publication spread includes high-impact journals such as *Applied Energy*, *Environmental Research Letters*, and *Sustainability*, indicating diverse areas of research focus. While authors like Heilmayr, Robert from the United States and Amalia, Rizka from Indonesia published 4 and 2 articles respectively, their citation counts were lower (50 and 40 citations), demonstrating that citation impact varies independently of publication count. Overall, the data reflects a global and multidisciplinary approach to research, with notable contributions from institutions in Malaysia, Canada, Sweden, and the Netherlands, across a range of environmentally and development-focused journals.

The bibliometric analysis using VOSviewer reveals a well-defined co-authorship network, with researchers grouped into distinct clusters based on their collaborative patterns. The analysis centers around the contributions of Maja Slingerland, a key figure connecting various research teams. These connections are visualized in two different ways: one focusing on thematic clusters and the other showing the temporal evolution of collaboration (Figure 5).

In the first visualization, clusters are color-coded based on their internal co-authorship density. The central figure, Maja Slingerland, acts as a pivotal connector across multiple groups. On the left side, the blue cluster revolves around Rosanne E. de Vos, with collaborators such as Jennifer M. Lucey and Aritta Suwarno. This group is closely interconnected, indicating frequent collaborations and likely shared research interests or ongoing projects. Another notable group is the red cluster, comprising researchers like Juan P. Monzon, Patricio Grassini, and Christopher Donough. This cluster demonstrates a dense network of co-authorships, reflecting strong intra-group connections and a probable focus on a common research area. On the right side, the green cluster, led by Idsert Jelsma and collaborators such as Jos Bijlman and Meine van Noordwijk, forms a cohesive subnetwork that still maintains links to the central figure, suggesting specialized but related research efforts.

The second visualization highlights the temporal aspect of the collaborations, with colors ranging from purple (indicating older collaborations) to yellow (representing more recent ones). Recent collaborations (yellow) are primarily concentrated around Maja Slingerland, involving active contributors like Rosanne E. de Vos and Jennifer M. Lucey. This suggests that recent publications and research initiatives are being driven by this group. In contrast, older collaborations (purple) are visible in the green cluster associated with Idsert Jelsma, Jos Bijlman, and Meine van Noordwijk, indicating that this group has a longer history of collaboration, though they remain active to a lesser extent in recent years. The red cluster shows a mix of older and newer collaborations, indicating steady co-authorship activities over time. Overall, the temporal evolution of the network highlights the dynamic nature of research collaborations, with Slingerland serving as a central figure who bridges both older and more recent co-authorship networks. This suggests that her work facilitates interdisciplinary collaboration and sustains the momentum of ongoing research efforts across multiple groups.



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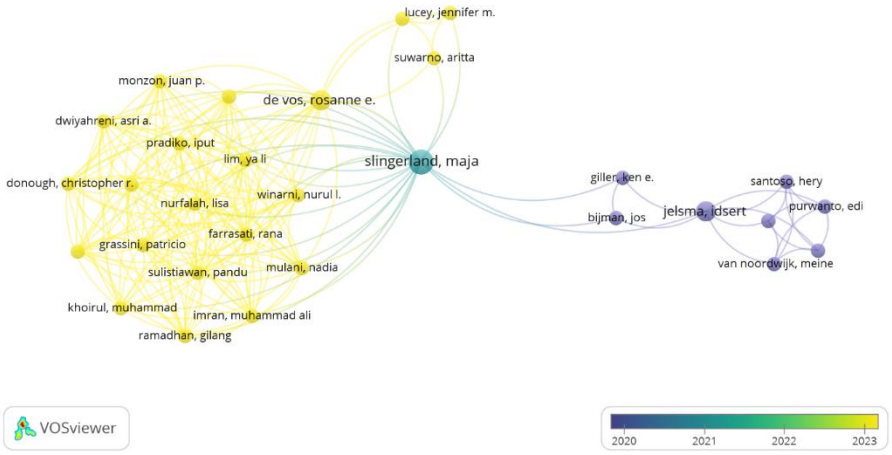

(b)

Fig. 5. Co-authorship analysis results author wise: (a) network map, (b) overlay map.

3.6 Overall discussion

The results of this bibliometric analysis demonstrate a substantial increase in scholarly interest in POSC research over the period of 2007 to 2024. The upward trajectory in published records, particularly from 2016 onwards, mirrors growing global concerns over sustainability, climate change, and economic resilience. The sharp rise in publications from 2020 likely reflects a convergence of multiple external factors such as the global pandemic, climate action commitments, and the shifting geopolitical landscape, all of which have intensified research in areas related to sustainable development and environmental governance (Mayor et al., 2021; Miller et al., 2022). This growth in research highlights the increasingly recognized importance of the palm oil industry within broader discussions on global environmental and economic issues.

The post-2020 fluctuations in the number of records, with a decline from the peak in 2020, suggest that while interest remains high, external factors such as post-pandemic recovery efforts, economic pressures, and policy developments may influence research output. The dip observed in 2024 could also indicate shifts in research funding or the emergence of competing priorities within the field of environmental sustainability, where palm oil remains a key but not the sole focus. The recent resurgence in publications in 2023,

however, underscores the enduring relevance of POSC, as both academia and industry continue to grapple with sustainability challenges and the pressures of transitioning to a more sustainable model of production and consumption (Hansen et al., 2015; Kasim et al., 2021).

In terms of geographic contributions, Indonesia unsurprisingly leads the research output, given its status as the world's largest producer of palm oil. The country's strong research interconnectivity, as indicated by link strength, also reflects the collaborative nature of POSC research, with significant contributions from Malaysia, Australia, and the United States. Interestingly, countries with fewer publications, such as Austria and Cameroon, demonstrate high citation impact, highlighting that the influence of research does not always correlate with the volume of articles. This suggests that smaller but more focused contributions can have significant impacts on the academic and policy discourse around palm oil sustainability.

The network analysis of international collaborations further highlights Indonesia's pivotal role in shaping POSC research. The presence of distinct clusters around key palm oil-producing nations, such as Malaysia, and non-producing nations, such as the United States and the United Kingdom, underscores the global nature of this issue. International collaborations, particularly between Indonesia and the United States, reflect shared concerns over deforestation, biodiversity loss, and the global implications of palm oil production. These collaborations also indicate that research into the palm oil industry is not just driven by production concerns but also by broader environmental, economic, and social justice issues (Meijaard & Sheil, 2019; Padfield et al., 2019).

The analysis of leading authors in POSC research highlights the multidisciplinary nature of the field, with scholars from environmental science, economics, and development studies all contributing to the discourse. The presence of high-impact journals such as Applied Energy and Journal of Cleaner Production in the dataset signals that research on palm oil extends beyond agricultural studies to include energy policy, supply chain management, and sustainable development (Abdul-Hamid et al., 2022; Kaniapan et al., 2021; Murphy et al., 2021). This diversity in research focus indicates that palm oil is increasingly viewed as a critical issue at the intersection of several global challenges, from energy security to environmental sustainability.

The findings of this bibliometric analysis offer valuable insights for managers, policymakers, and industry stakeholders involved in POSC management. One key implication is the necessity for stronger collaboration between academia and industry to address sustainability challenges. The growing body of research emphasizes themes such as traceability, certification, and sustainable sourcing, which indicate that companies must adopt more transparent supply chain practices to meet consumer and regulatory demands (Kasim et al., 2021; Pacheco et al., 2020). For managers in the palm oil industry, this highlights the importance of integrating research findings into business strategies, particularly in areas such as carbon footprint reduction, waste management, and sustainable land-use planning. Moreover, as research suggests increasing concerns over ESG factors, businesses that proactively align their operations with sustainable development goals (SDGs) are more likely to maintain competitiveness in global markets.

While bibliometric analysis offers valuable insights into research trends, it is important to acknowledge inherent limitations and potential biases in the underlying data. A significant concern is the dominance of English-language publications in major academic databases such as Scopus, which may underrepresent relevant research published in Bahasa Indonesia or other local languages. This linguistic bias can skew the visibility and perceived impact of region-specific studies, particularly those addressing grassroots-level practices or local policy nuances within Indonesia's POSC. As a result, the global discourse may be disproportionately shaped by perspectives aligned with English-speaking academia, potentially overlooking localized insights that are crucial for comprehensive understanding and policy development.

In addition, journal indexing practices may introduce another layer of bias. Prestigious international journals, which are more likely to be indexed in databases used for

bibliometric studies, often favor topics or methodologies that align with global research agendas, potentially marginalizing indigenous knowledge systems or applied research with direct policy relevance in producing countries. This raises critical questions about whose knowledge is being amplified in the academic debate and how that may influence sustainability strategies within the POSC. Acknowledging these biases not only enhances the rigor of bibliometric interpretations but also calls for more inclusive indexing and data collection practices in future bibliometric research.

From a policy perspective, governments can leverage these insights to develop more effective regulatory frameworks that balance economic growth with sustainability. The study's findings underscore the need for policies that support smallholder farmers, who play a crucial role in the POSC but often lack access to resources for certification and sustainable practices (Abideen et al., 2023; Nupueng et al., 2023). By using bibliometric data to identify research trends, policymakers can prioritize funding for research that addresses knowledge gaps in areas such as deforestation mitigation, biodiversity conservation, and alternative energy applications of palm oil. The evidence from this study suggests that government agencies should also strengthen international collaborations to align domestic policies with global sustainability standards, fostering a more integrated approach to palm oil governance.

On a broader scale, these results have global implications for other biomass-based industries facing similar challenges. As seen in the analysis, trends in palm oil research often align with global concerns such as climate change, trade policies, and supply chain resilience. By applying similar bibliometric methodologies, stakeholders in industries such as soybean, timber, and sugarcane can identify key research areas and adapt best practices from the palm oil sector. This reinforces the importance of knowledge exchange across biomass supply chains, where lessons learned from one industry can inform strategies for sustainable management in others. Ultimately, the growing research interest in POSC highlights the critical role of scientific knowledge in shaping policy decisions and business strategies that promote sustainability on a global scale.

3.7. Future implications & recommendations

The findings from this bibliometric analysis have several implications for future research and policy-making in the palm oil industry. First, the increasing volume of POSC research highlights the growing awareness of the need for sustainable practices within the industry. As more studies focus on sustainability, deforestation, and smallholder involvement, it is clear that there is a shift toward addressing the social and environmental impacts of palm oil production. This shift in focus should inform policy frameworks aimed at improving sustainability standards and promoting certification schemes like RSPO.

Future trends in POSC research are likely to continue focusing on sustainable development, with a particular emphasis on smallholders and the social dimensions of palm oil production. As smallholders account for a significant portion of global palm oil production, ensuring that they are included in sustainability initiatives will be crucial. Research into certification schemes and their impact on smallholder livelihoods will be critical to addressing the challenges of balancing economic development with environmental stewardship.

Technological advancements, such as precision agriculture, blockchain for supply chain transparency, and renewable energy integration, are also likely to feature prominently in future research. These technologies offer potential solutions to many of the challenges facing the palm oil industry, from deforestation to carbon emissions. Scholars should focus on how these technologies can be applied in the context of palm oil production, particularly in regions where infrastructure and resources are limited.

The ongoing geopolitical shifts, such as the Ukraine conflict and changes in global energy policies, will continue to influence research on alternative energy sources, including palm oil-based biofuels. As countries reassess their energy security strategies, research into the role of palm oil as a biofuel feedstock is likely to increase. However, future research

should also critically examine the trade-offs between biofuel production and food security, biodiversity conservation, and land use change.

Given the multidisciplinary nature of palm oil research, fostering collaborations across disciplines and regions will be essential. Policymakers and researchers should work together to create integrated solutions that address the environmental, economic, and social dimensions of palm oil production. Strengthening international partnerships, particularly between producing and consuming countries, will be key to advancing the global sustainability agenda.

Figure 6. Call for actions regarding palm oil supply chain and sustainability.

4. Conclusion

This bibliometric analysis of POSC research from 2007 to 2024 highlights a marked increase in scholarly attention, especially after 2016, driven by growing global concerns over sustainability, climate change, and environmental governance. The results indicate that Indonesia plays a pivotal role in this research landscape, not only due to its dominance in global palm oil production but also through strong international collaborations with countries like Malaysia and the United States. The research reflects a multidisciplinary approach, with contributions from environmental science, economics, and development studies, and emphasizes the need to balance economic development with environmental and social considerations. Moreover, the high citation impact of research from countries with relatively lower publication volumes suggests that targeted, high-quality research can significantly influence global sustainability discourse.

The analysis underscores the multidisciplinary nature of POSC research, with contributions spanning environmental science, economics, and development studies. As the field matures, future research will need to focus on sustainable practices, technological innovations, and the role of smallholders in promoting a more sustainable palm oil industry. Strengthening international collaborations and policy frameworks will be critical to achieving these goals, ensuring that palm oil can contribute to sustainable development without compromising environmental and social integrity. Additionally, the findings suggest that POSC research is highly dynamic, influenced by global events such as the COVID-19 pandemic and geopolitical shifts, which affect research priorities and funding allocations. The increasing attention to traceability, circular economy principles, and digital transformation in supply chain management further highlights the evolving nature of this research area.

The implications of these findings suggest that future research will increasingly focus on sustainability, smallholder inclusion, and the application of new technologies to address palm oil's environmental and social challenges. As geopolitical shifts, such as the Ukraine conflict, and global climate commitments influence research directions, the role of palm oil in energy security and biofuel production is likely to grow. However, this study has some limitations, including its reliance on bibliometric data from specific databases, which may exclude relevant non-indexed research. Additionally, while this study identifies key trends and collaboration networks, it does not provide an in-depth content analysis of emerging theoretical frameworks or policy impacts. Future research should address these gaps by integrating qualitative analyses and expanding comparisons with other biomass-based supply chains, such as soybean or timber. Moving forward, fostering stronger interdisciplinary collaborations and promoting policy frameworks that align with sustainability goals will be crucial. International partnerships, especially between palm oil-producing and consuming countries, will be essential to ensuring the industry's transition to more sustainable practices. As research on the POSC continues to evolve, it will play a key role in shaping global strategies for sustainable development.

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Biography of Author

William Ben Gunawan. A master of management student at PPM School of Management, Indonesia, while also a master of business administration student at INTI International University, Malaysia.

- Email: wbwilliambenwb@gmail.com
- ORCID: 0000-0003-0633-4477
- Web of Science ResearcherID: GRN-9396-2022
- Scopus Author ID: 57722976700
- Homepage: William Ben Gunawan-Google Scholar