West Science Social and Humanities Studies
Vol. 03, No. 11, November 2025, pp. 1582-1598

Bibliometric Analysis of International Collaboration on Sustainable Palm Oil Research

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Article Info

Article history:

Received Nov, 2025
Revised Nov, 2025
Accepted Nov, 2025

Keywords:

Sustainable Palm Oil
Bibliometric Analysis
International Collaboration
Scopus
Sustainability Science

ABSTRACT

This study conducts a comprehensive bibliometric analysis to examine the global research landscape and international collaboration patterns in sustainable palm oil research using Scopus-indexed publications from 2000 to 2025. Through co-authorship networks, institutional linkages, country collaborations, and keyword mapping, the analysis reveals an increasingly interdisciplinary field shaped by environmental science, engineering innovation, and sustainability governance. Results indicate that Malaysia and Indonesia serve as the principal research hubs, supported by strong collaborative networks with Europe, Asia, and emerging economies. Keyword co-occurrence and temporal evolution analyses show that early research was dominated by biofuel and life-cycle assessment themes, while recent studies have shifted toward environmental protection, climate impacts, circular economy strategies, and biomass valorization. Highly cited papers highlight critical contributions in renewable energy, biodiversity conservation, supply chain sustainability, and waste-to-resource innovation. Overall, the findings demonstrate that sustainable palm oil research is driven by diverse scientific perspectives and sustained international cooperation, emphasizing the need for integrated approaches to balance ecological integrity, technological advancement, and global sustainability objectives. This study contributes an empirical foundation for understanding thematic development, identifying collaboration hotspots, and guiding future research priorities in sustainable palm oil scholarship.

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1. INTRODUCTION

Sustainable palm oil has emerged as one of the most intensively discussed global issues due to its strategic role in the economic development of tropical countries and its simultaneous association with environmental and social challenges. Over the past two decades, the discourse surrounding sustainable palm oil has broadened from local agricultural practices toward a more integrated global sustainability agenda. Scholars have highlighted that palm oil functions not only as an agricultural commodity but also as a component of global value chains involving Europe, Asia, and North America [1]. As concerns about

deforestation, biodiversity loss, and community livelihood grow, research on sustainable palm oil has increasingly emphasized multi-country collaboration to ensure shared responsibility and knowledge exchange across producer and consumer nations [2].

International collaboration in sustainability-related fields is widely recognized as a catalyst for knowledge diffusion, methodological advancement, and policy harmonization. In the context of sustainable agriculture, collaborative networks allow scholars to merge scientific expertise, integrate socio-environmental perspectives, and accelerate the translation of research into policy [3]. Given that palm oil supply chains span multiple jurisdictions, from Southeast Asian producer countries to consumer markets in the West, cross-border cooperation has become essential. Such collaboration bridges disparities in research capacity, promotes transparency, and supports the monitoring of sustainability commitments across nations [4].

The global sustainability agenda reflected in frameworks such as the Sustainable Development Goals (SDGs) further underscores the importance of international cooperation in research. Sustainable palm oil connects directly with SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). The transnational nature of these goals means that no single country can tackle sustainability challenges alone, especially those embedded in global commodity systems (Koenig & Strauss, 2020). As a result, international academic networks have intensified, producing collaborative research outputs that seek to balance economic imperatives with environmental and social protections in palm oil-producing regions.

Bibliometric studies have become essential tools for mapping these collaborative efforts. Bibliometrics helps identify publication trends, influential authors, core journals, geographic collaboration patterns, and thematic evolutions across time [5]. In the context of sustainable palm oil research, bibliometric analysis enables scholars to observe the progression of debates from early environmental arguments to contemporary themes such as certification, traceability, and smallholder inclusion [6]. By providing a macro-level overview, bibliometrics supports evidence-based decision-making and highlights structural changes within the scientific landscape.

Despite the increasing complexity of palm oil research, there is still limited understanding of how international collaboration patterns have shaped the development of the knowledge base. Existing sustainability studies tend to focus either on environmental impacts, socio-economic factors, or certification schemes, but seldom on the underlying scholarly networks that generate this knowledge. Understanding patterns of co-authorship, country partnerships, and institutional linkages is essential because the credibility and dissemination of sustainability research often rely on the strength of these collaborative structures [7]. A structured bibliometric analysis therefore provides an empirical foundation to comprehend the evolution, direction, and leadership of global research efforts on sustainable palm oil.

Although sustainable palm oil has become a central topic in global sustainability discussions, there remains a critical gap in understanding how international collaboration networks have contributed to shaping its research landscape. Current literature tends to emphasize scientific outcomes, such as environmental assessments, plantation innovation, or certification impacts, without critically examining the collaborative structures behind these outputs. As a result, policymakers and researchers lack a comprehensive map of which countries, institutions, or co-authorship clusters have driven global knowledge production, how collaboration intensity has changed over time, and which thematic areas are most influenced by international partnerships. This gap limits the ability to optimize global cooperation, undermining efforts to align research

priorities with sustainability commitments across nations.

This study aims to conduct a comprehensive bibliometric analysis to map and evaluate international collaboration patterns in sustainable palm oil research using Scopus-indexed publications. Specifically, the study seeks to identify the most influential countries, leading institutions, dominant co-authorship networks, thematic clusters, and temporal evolution of global partnership structures.

2. METHODS

This study employed a quantitative bibliometric approach to map the structure, development, and international collaboration patterns in sustainable palm oil research. The Scopus database was selected as the primary data source because of its extensive coverage of high-quality peer-reviewed journals, standardized indexing practices, and robust citation metadata suitable for bibliometric analysis. The search query was constructed using a combination of controlled keywords such as *"sustainable palm oil," "sustainable palm-oil production," "palm oil sustainability," "RSPO,"* and *"sustainable agriculture palm oil"*. Boolean operators (*AND*, *OR*) were used to refine the retrieval process and ensure the inclusion of all relevant documents. The search was limited to the publication period 2000–2025 to capture the evolution of global sustainability discussions over the past 25 years. Only articles, conference papers, and reviews were included, while notes, editorials, and non-scholarly items were excluded to maintain analytical rigor.

After data retrieval, all metadata, titles, authors, affiliations, abstracts, keywords, publication years, source titles, citations, and country origins were exported in CSV and RIS formats for processing. A multi-step cleaning procedure was conducted to remove duplicate entries, unify author name variations, and consolidate institutional affiliations using manual verification and automated normalization techniques. Keyword harmonization was performed to merge synonymous terms (e.g., *"sustainable palm oil"*, *"palm oil sustainability"*) and eliminate generic or unrelated keywords. This preprocessing step ensured the accuracy of authorship networks, institutional mapping, and thematic clustering. The final dataset provided the foundation for co-authorship analysis, co-occurrence mapping, citation structure analysis, and country collaboration metrics.

Bibliometric analyses were conducted using VOSviewer, Bibliometrix R, and Microsoft Excel. VOSviewer was used to generate visualizations of co-authorship networks, country collaboration maps, institutional clusters, and keyword co-occurrence structures. Bibliometrix R was applied for performance analysis, including annual publication trends, influential authors, most productive institutions, citation counts, and thematic evolution over time. Excel supported descriptive statistics, dataset refinement, and tabulation of key indicators. Through this combination of tools, the study generated a comprehensive overview of the global collaboration landscape in sustainable palm oil research, revealing structural patterns, dominant research actors, and the thematic directions that characterize international scholarly cooperation in this field.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

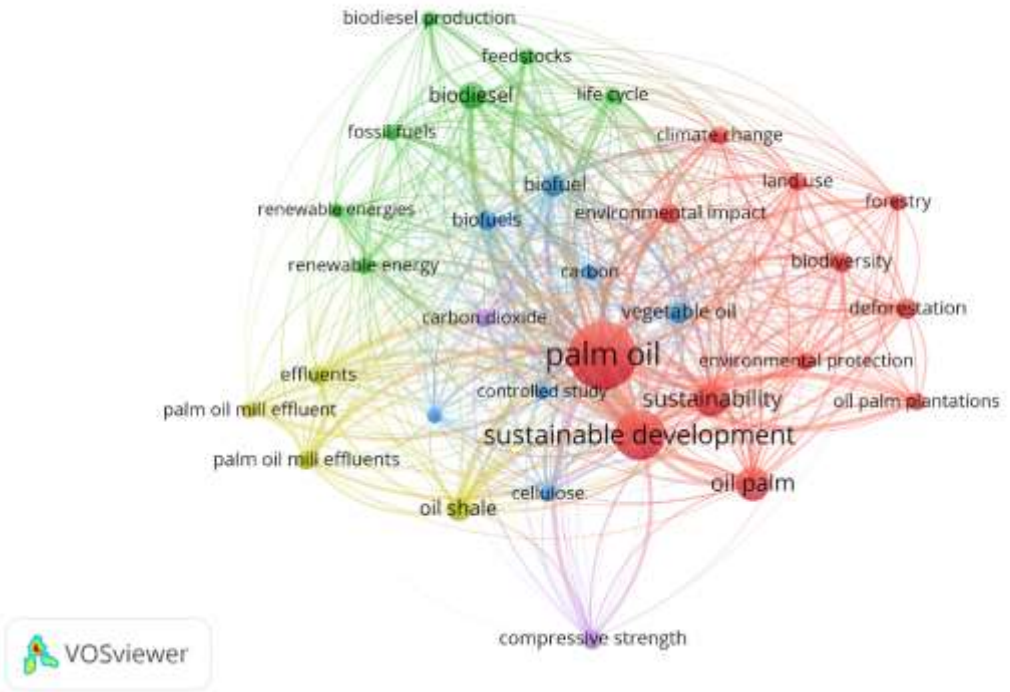

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

The VOSviewer map illustrates the intellectual structure of sustainable palm oil research by visualizing how frequently keywords co-appear within the same publications and how they cluster into thematic groups. The size of each node represents the frequency of keyword usage, while the colors represent distinct thematic clusters generated by VOSviewer. The thickness of the lines (links) indicates the strength of co-occurrence relationships between terms.

Central Themes: "Palm oil," "Sustainable development," and "Sustainability"

At the core of the map, the most prominent nodes "palm oil," "sustainable development," "sustainability," and "oil palm"serve as central anchors. Their large node size reflects their dominant presence across the literature. These keywords form the main intersection point where environmental, agricultural, and energy-related discussions converge. The dense web of connections around them shows that sustainable palm oil research is highly interdisciplinary, linking environmental science, renewable energy, agricultural systems, and climate policy.

Environmental Sustainability Cluster (Red Cluster)

The red cluster captures themes related to environmental impacts and land-based ecological concerns. Keywords such as "deforestation," "land use," "forestry," "biodiversity," "environmental protection," and "environmental impact" appear prominently. This cluster indicates that a substantial portion of the literature focuses on ecological risks associated with palm oil expansion. The strong connections between these keywords and "palm oil" suggest that environmental sustainability remains a global research priority, especially in the context of habitat loss, species decline, and ecosystem resilience.

Bioenergy and Renewable Energy Cluster (Green Cluster)

The green cluster focuses on palm oil's role in bioenergy and renewable fuels. Keywords like "biodiesel," "biodiesel production," "biofuel," "renewable energies,"

"feedstocks," "carbon," "carbon dioxide," and "fossil fuels" suggest a significant research stream exploring palm oil as an alternative energy source. The dense network connecting "biodiesel" to "palm oil" reflects the strong interest in reducing fossil fuel dependency, evaluating life-cycle emissions, and assessing palm-based bioenergy within climate mitigation strategies. This cluster highlights the technological and energy oriented dimensions of sustainable palm oil research.

Waste Management and Industrial Processes Cluster (Yellow Cluster)

The yellow cluster is associated with palm oil mill effluents, waste processing, and industrial by-products, represented by terms such as "palm oil mill effluents," "effluents," and "oil shale." This indicates a research stream focused on environmental engineering, waste treatment, and circular economy approaches. Studies in this cluster typically explore how to minimize pollution from palm oil mills, valorize waste streams, and adopt cleaner production methods.

Material Science and Engineering Cluster (Purple Cluster)

The purple cluster, represented by keywords like "cellulose" and "compressive strength," reflects a smaller but emerging body of research examining advanced material applications derived from palm biomass. These topics indicate work on converting palm oil by-products into novel materials, such as bio-composites, construction materials, and cellulose-based innovations.

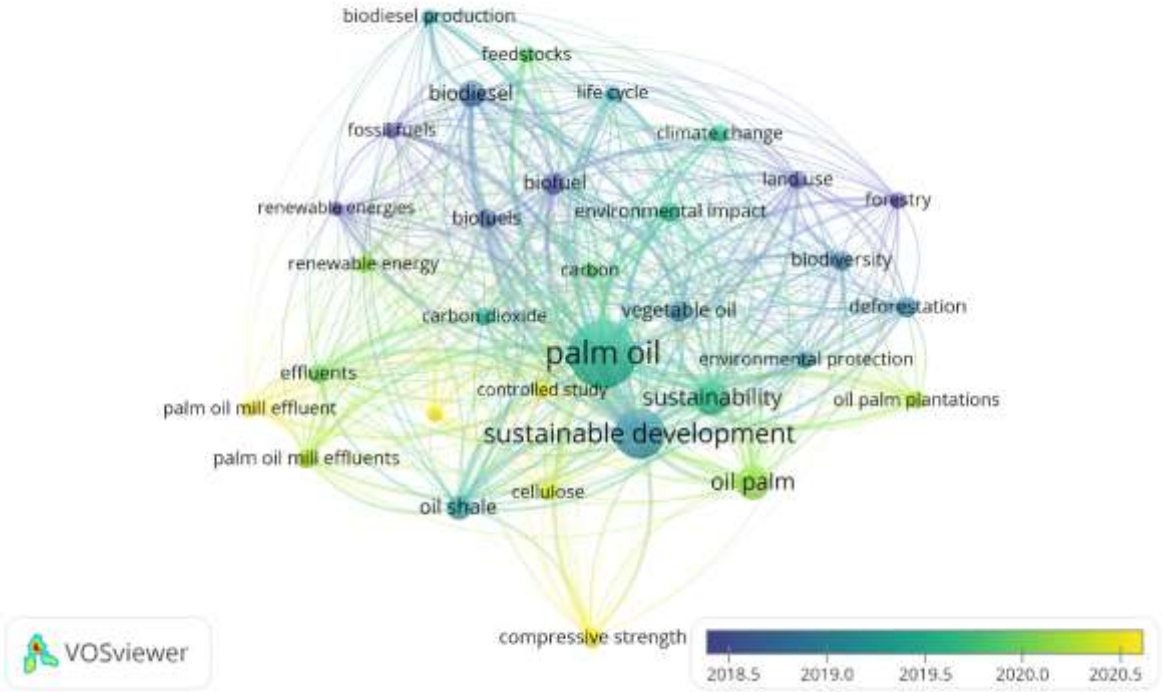

Figure 2. Overlay Visualization

Source: Data Analysis Result, 2025

The overlay visualization provides a temporal perspective on how sustainable palm oil research has evolved over the past several years. Using a color gradient ranging from purple to yellow, the map represents the average publication year associated with each keyword, allowing us to observe shifting research priorities over time. Keywords shaded in darker colors, particularly purple and blue, reflect themes that were more prominent in earlier publications around 2018–2019. These include "biodiesel,"

"biofuel," "renewable energy," "life cycle," "carbon dioxide," and "fossil fuels." The prominence of these earlier terms suggests that the initial focus of sustainable palm oil research was strongly tied to energy substitution and environmental performance assessment. During this period, scholars concentrated on examining palm oil as a biofuel feedstock, assessing the life-cycle emissions of biodiesel, and comparing its environmental impacts with conventional fossil fuels. This phase marks an era when the debate on palm oil was largely shaped by climate mitigation and renewable energy strategies.

As the timeline progresses toward 2019–2020, the visualization shifts into green tones, representing research themes that emerged during this transitional period. Keywords such as "climate change," "environmental impact," "biofuels," "vegetable oil," and "carbon" illustrate how the field expanded from energy-focused studies to broader environmental and ecological analyses. Instead of solely examining biofuel performance, researchers began integrating palm oil into wider discussions on global climate change, land-use emissions, and ecosystem impacts. This transition indicates a broadening of the sustainability discourse, moving from technical evaluations of bioenergy efficiency toward more holistic assessments of environmental degradation, climate risks, and resource management. During this stage, the literature reflects a diversification of perspectives that connect palm oil production with global sustainability commitments.

The most recent themes, represented by yellow-colored nodes corresponding to 2020–2021, highlight emerging research priorities centered on circular economy practices and biomass innovation. Terms such as "palm oil mill effluents," "effluents," "oil palm plantations," "cellulose," and "compressive strength" indicate growing scholarly interest in waste management, pollution control, and the valorization of palm biomass. Studies in this period increasingly explore how production residues such as palm oil mill effluent (POME) can be treated, recycled, or transformed into value-added materials. Research on cellulose and compressive strength demonstrates a shift toward engineering applications, where palm biomass is repurposed into construction materials, composites, and bio-based products. This recent attention reflects a strategic movement toward circular economic solutions that reduce waste and enhance resource efficiency within the palm oil industry.

Despite the variation across time, several core terms such as "palm oil," "sustainable development," "sustainability," and "oil palm" appear consistently across all color ranges. This indicates that these concepts form the central backbone of the research domain, maintaining relevance across earlier, transitional, and emerging phases. Their centrality suggests that regardless of shifts in specific topics, sustainable palm oil research continues to revolve around broader frameworks of sustainability science, development goals, and agricultural transformation. Overall, the overlay visualization reveals a dynamic and evolving research landscape: beginning with bioenergy-oriented analysis, expanding into climate and environmental considerations, and most recently progressing toward waste valorization and circular economy innovations. This progression underscores the field's increasing interdisciplinarity and its alignment with global environmental priorities.

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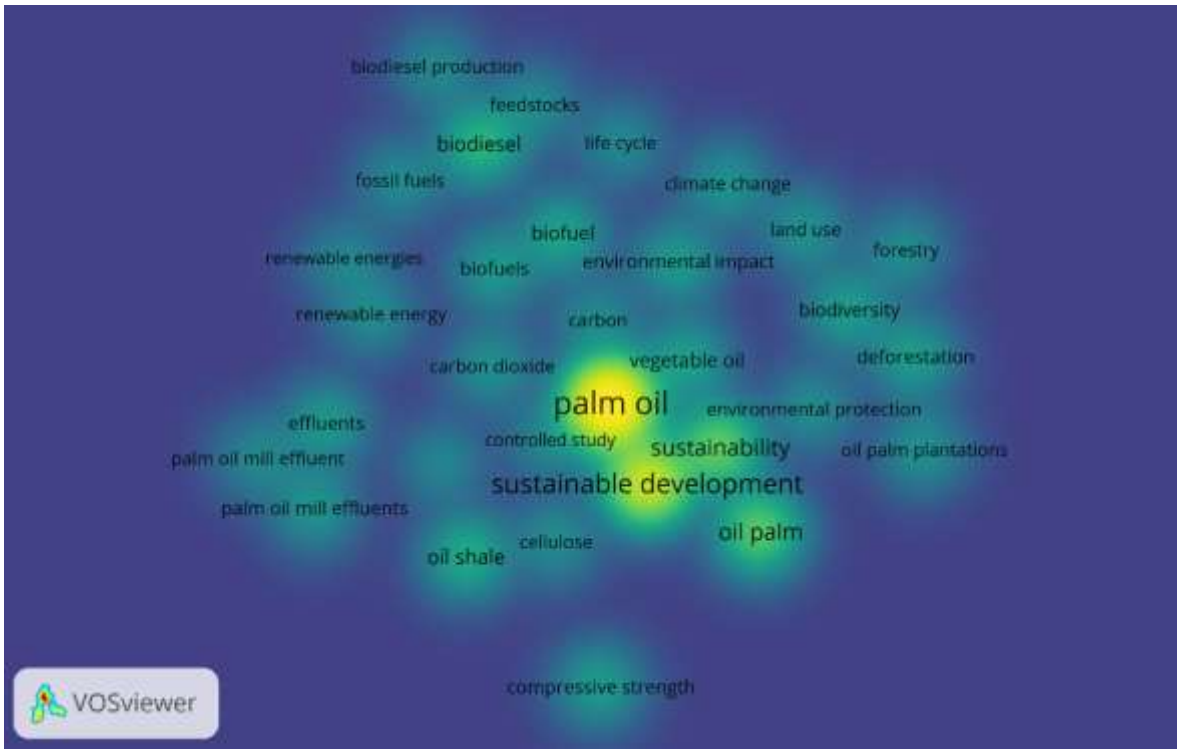

Figure 3. Density Visualization
Source: Data Analysis, 2025

The density visualization highlights the intensity and concentration of research attention within the sustainable palm oil literature. In this map, colors represent the density of keyword occurrences: yellow indicates very high frequency and centrality, green represents moderately high density, and blue/purple areas reflect lower density and less frequent research activity. This perspective allows us to identify the strongest conceptual centers within the field and the peripheral or emerging areas of study.

At the core of the visualization, the keywords "palm oil," "sustainable development," "sustainability," and "oil palm" appear in bright yellow, signifying that these terms are the most frequently used and heavily interconnected across publications. Their intense luminosity demonstrates that they form the conceptual backbone of sustainable palm oil research, anchoring both environmental and socio-economic discussions. The persistent prominence of these terms indicates that the field is fundamentally shaped by broad frameworks of sustainability science, development goals, and agricultural production systems.

Surrounding the central cluster, a moderately dense green zone includes keywords such as "environmental impact," "carbon," "vegetable oil," "climate change," "land use," and "biodiversity." This suggests that topics related to environmental quality, carbon emissions, and ecological consequences represent major thematic branches closely linked to the core concepts. Their density indicates strong and consistent research engagement, reflecting sustained global concern over deforestation, greenhouse gas emissions, and habitat loss associated with palm oil expansion. These topics represent well-established research fronts that continue to shape academic and policy debates.

Further from the center, the green-blue areas show keywords such as "biofuel," "biodiesel," "feedstocks," "life cycle," and "renewable energy." These terms reflect the energy-oriented dimension of palm oil research. Although still significantly connected, they are less dense compared to ecological terms, suggesting that research interest in palm oil as a bioenergy source, while important, is not as central as

sustainability and environmental impact themes. This may indicate a gradual shift from earlier biofuel-dominated discussions toward a more holistic appreciation of environmental and socio-political dimensions.

On the periphery, represented by cooler blue regions, appear keywords such as "palm oil mill effluent," "effluents," "oil shale," "cellulose," and "compressive strength." These terms represent smaller, specialized research areas, particularly in waste management, palm biomass utilization, and material science applications. Their lower density suggests that while these themes are emerging, they have not yet reached the same level of prominence as environmental or sustainability topics. Nonetheless, their presence in the density map reflects the growing academic interest in circular economy strategies, resource recovery, and innovative uses of palm oil by-products. Overall, the density visualization demonstrates that sustainable palm oil research is strongly anchored in global sustainability and environmental themes, with secondary emphasis on bioenergy and emerging attention to waste valorization and engineering applications.

3.2 Co-Authorship Network

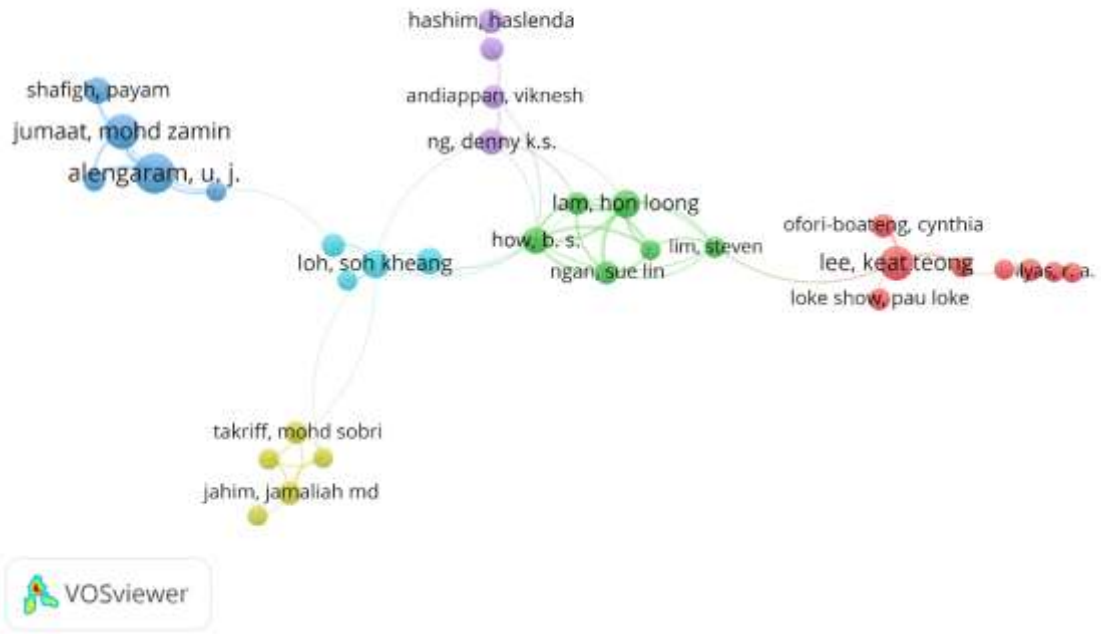

Figure 4. Author Collaboration Visualization
Source: Data Analysis, 2025

This VOSviewer co-authorship visualization maps the structure of scientific collaboration in sustainable palm oil research by showing how authors are connected through shared publications. Nodes (circles) represent individual authors, node size reflects publication volume or citation strength, and colors represent distinct collaboration clusters. The lines indicate co-authorship links, with thicker lines showing stronger or more frequent collaboration.

Blue Cluster – Engineering & Biodiesel Research Group

The blue cluster, led by authors such as Alengaram, U.J., Jumaat, Mohd Zamin, Shafigh, Payam, appears to focus on engineering applications and biodiesel-related studies. This group is closely

connected through strong co-authorship ties, suggesting a well-established, productive collaboration network. Their research likely emphasizes materials engineering, structural applications of palm biomass, or fuel properties, given the typical focus of these authors in the broader sustainability domain.

Cyan Cluster – Central Connector Authors

Authors such as Loh, Soh Kheang occupy a central position and act as a bridging node between multiple clusters. The strategic position of these nodes indicates that they play a key integrative role, linking engineering-focused studies with environmental science or management-oriented research groups. This suggests that these authors contribute to interdisciplinary work that connects palm oil engineering, energy, and sustainability fields.

Green Cluster – Environmental & Sustainability-Oriented Group

The green cluster includes authors like Lam, Hon Loong; How, B.S.; Ngan, Sue Lin; Lim, Steven, who work closely together. The density and connectivity of this cluster indicate strong collaboration in research themes related to environmental management, sustainability assessment, optimization, and possibly life-cycle analysis. Their links to the central authors indicate that they contribute significantly to cross-domain sustainability studies.

Purple Cluster – Policy & Management-Linked Researchers

The purple cluster, represented by authors such as Hashim, Haslenda; Andiappan, Viknesh; Ng, Denny K.S., is slightly more isolated but still connected to the main structure. These authors likely engage in decision-making models, sustainability policy, supply-chain analysis, or optimization frameworks, given their typical scholarly focus. Their distance indicates specialization, but their connections show engagement in collaborative, cross-disciplinary sustainability research.

Yellow Cluster – Biomass & Waste Management Group

This cluster, involving authors like Takriff, Mohd Sobri; Jahim, Jamaliah Md, appears to focus on bioprocessing, waste valorization, and biomass-based innovations. The cluster shape suggests a cohesive research team working on environmental processing technologies such as palm oil mill effluent treatment or biomass conversion.

Red Cluster – Independent Thematic Subgroup

The red cluster, consisting of authors like Lee, Keat Teong; Ofori-Boateng, Cynthia; Loke Show, Pau Loke, shows a smaller but distinct collaboration group focused likely on bioenergy systems, bioprocess engineering, or sustainable fuel technologies. The internal connectivity indicates strong collaboration within the group but limited cross-collaboration with other clusters.

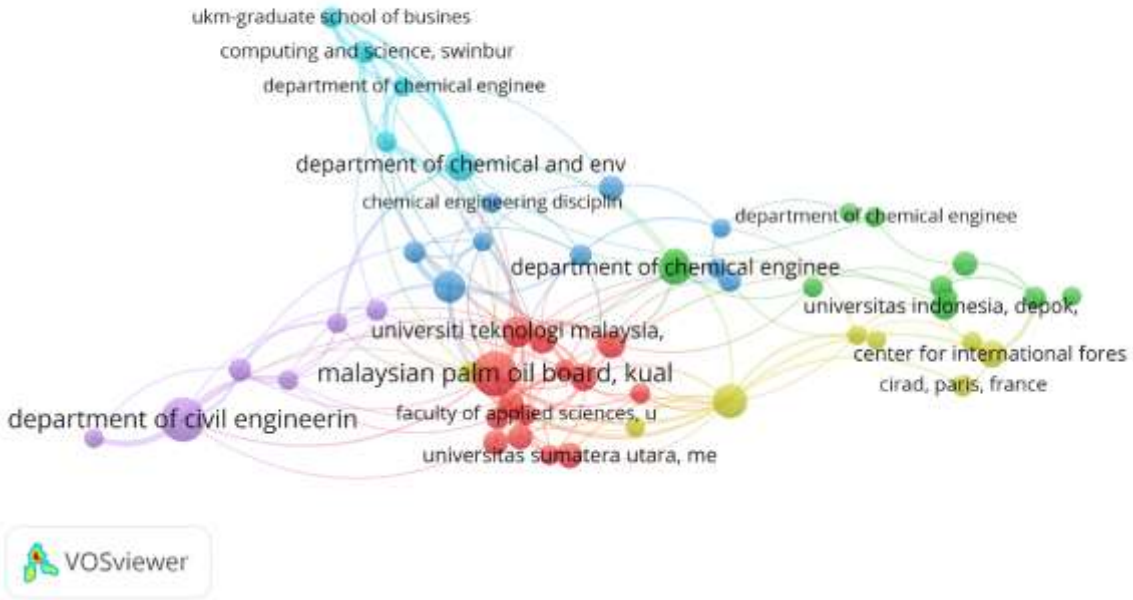

Figure 5. Affiliation Collaboration Visualization
Source: Data Analysis, 2025

This VOSviewer visualization depicts the structure of collaboration among research institutions involved in sustainable palm oil studies. Each node represents an institution or departmental affiliation, while colors indicate clusters of institutions that collaborate more intensively with one another. The lines connecting nodes show the strength of co-authorship ties: thicker or more numerous links represent more frequent cooperation in joint publications. Overall, the map illustrates a highly interconnected but cluster-diverse research landscape, dominated by Malaysian institutions and supported by international partners from Indonesia and Europe.

The central red cluster is anchored by the Malaysian Palm Oil Board (MPOB), which appears as one of the largest and most connected institutions in the network. Its central position demonstrates that MPOB is a core hub of sustainable palm oil research, engaging in collaborations with multiple universities, engineering departments, and applied sciences faculties. Nearby, institutions such as Universiti Teknologi Malaysia and Universitas Sumatera Utara connect strongly to MPOB, highlighting an academic–government research ecosystem focused on palm oil science, production technologies, and sustainability assessments. The density and connectivity of this cluster underscore MPOB's pivotal role in facilitating cross-institutional research partnerships both domestically and regionally.

The blue and turquoise clusters consist predominantly of chemical engineering departments, such as the Department of Chemical Engineering, Department of Chemical and Environmental Engineering, and specialized units from institutions like Swinburne University and UKM Graduate School of Business. These clusters indicate strong collaboration patterns in chemical processing, environmental engineering, and sustainable industrial technologies related to palm oil. Their proximity to the central cluster signifies that engineering research is closely integrated with the broader sustainability agenda, particularly in areas such as biofuel production, waste treatment, and optimization of palm oil processing systems.

On the left side of the network, the purple cluster, led by the Department of Civil Engineering, represents institutions that engage in more engineering-heavy or material-science-oriented research. Although slightly more peripheral, these institutions maintain connections with the core MPOB cluster, suggesting contributions in areas such as biomass utilization, construction materials from palm residues, or infrastructure-related sustainability topics.

The green and yellow clusters on the right reflect international collaboration networks, involving institutions such as Universitas Indonesia (Depok) and CIRAD (Paris, France). These groups are engaged in research related to environmental impact, forestry, sustainability policy, land-use studies, and socio-environmental assessments. Their distance from the engineering-heavy clusters indicates a disciplinary distinction—more aligned with environmental science, forest conservation, and agricultural sustainability rather than chemical or industrial engineering. However, the interlinkages between these clusters and the main network highlight the increasingly interdisciplinary nature of sustainable palm oil research, where ecological and socio-economic considerations interact with technological advancements. Across the map, the presence of multiple cross-cluster linkages demonstrates that sustainable palm oil research is not confined to isolated academic silos. Instead, it is built upon collaborative bridges between chemical engineering, environmental science, agricultural research, civil engineering, and sustainability governance.

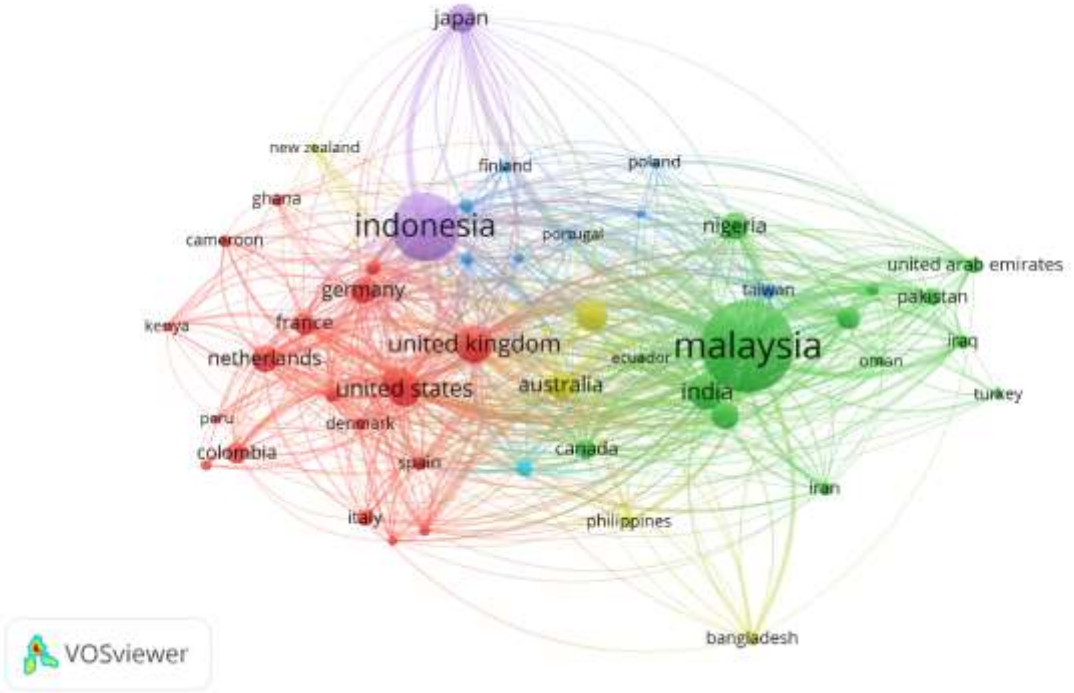

Figure 6. Country Collaboration Visualization
Source: Data Analysis, 2025

The VOSviewer country co-authorship visualization reveals the global structure of collaboration in sustainable palm oil research. Each node represents a country, with node size indicating publication volume and the thickness of lines representing the strength of collaborative ties. The different colors represent clusters of countries that frequently co-publish, reflecting regional research alliances and thematic focus areas. Overall, the map demonstrates a highly interconnected global research network, with

both producer countries and non-producer countries contributing significantly to the knowledge landscape.

At the center of the map, Malaysia emerges as the largest and most influential node, indicating its dominant role in sustainable palm oil research. This strong centrality reflects Malaysia's position as a major global palm oil producer and research hub, supported by extensive institutional capacity such as the Malaysian Palm Oil Board (MPOB) and multiple universities. Malaysia's dense network of links to countries such as India, Nigeria, Taiwan, Pakistan, Turkey, United Arab Emirates, and Iran reveals a broad and diversified collaborative environment. These partnerships emphasize shared interests in sustainable agriculture, bioenergy, environmental regulation, and industrial processing technologies.

Indonesia, the world's largest palm oil producer, also appears as a major node but occupies a slightly different position within the network. Its cluster, represented in purple, connects strongly with Japan, and to a lesser extent with European partners. This suggests that Indonesia's collaboration pattern is influenced by bilateral or regional partnerships, particularly in areas related to forestry, land use, climate mitigation, and environmental governance. The Indonesia–Japan cluster may reflect joint efforts in tropical agriculture, REDD+ programs, carbon accounting, and sustainable land-use planning.

The red cluster, dominated by the United Kingdom, United States, Netherlands, Germany, France, Italy, and Spain, represents a large and well established group of high-income countries collaborating primarily among themselves. This cluster is heavily interconnected, indicating strong research partnerships across Europe and North America. Although these countries are not major palm oil producers, their scientific engagement focuses on environmental impact assessments, global supply chain analysis, sustainable consumption, climate policy, biodiversity conservation, and life cycle studies. Their collaboration networks also link back to Malaysia and Indonesia, demonstrating the global concern surrounding palm oil sustainability issues.

In the green cluster, countries like India, Pakistan, Nigeria, UAE, Turkey, and Iraq maintain strong ties with Malaysia, reflecting South–South collaborations. Many of these countries are significant importers or processors of palm oil, which explains their active participation in research related to biofuel, food technology, industrial applications, and waste management. Nigeria's strong connectivity indicates emerging research capacity in West Africa, potentially driven by growing interest in adopting sustainable palm oil practices across African producer countries.

The blue cluster, including Poland, Finland, Portugal, and Australia, shows moderate but meaningful collaboration with both Western and Asian partners. These countries may contribute to methodological advancements, including modelling, technological innovation, environmental monitoring, and agricultural engineering. Australia's position between clusters suggests a bridging function, linking European research with Asian collaborators.

On the periphery, smaller nodes such as Kenya, Cameroon, Peru, Colombia, and New Zealand appear less connected but still linked to major research hubs. These countries may represent emerging interest in palm oil sustainability, either as developing producer regions (e.g., Colombia, Cameroon) or as contributors to global environmental and policy research (e.g., New Zealand).

3.3 Citation Analysis

The bibliometric data above identifies the ten most significant articles in the domain of Fear of.

Table 1. Top Cited Research

Citations	Authors and year	Title
1663	Wijffels, R.H., Barbosa, M.J. (2010) [8]	An outlook on microalgal biofuels
924	Ahmad, A.L., Yasin, N.H.M., Derek, C.J.C., Lim, J.K. (2011) [9]	Microalgae as a sustainable energy source for biodiesel production: A review
583	Raven, P.H., Wagner, D.L. (2021) [10]	Agricultural intensification and climate change are rapidly decreasing insect biodiversity
522	Sumathi, S., Chai, S.P., Mohamed, A.R. (2008) [11]	Utilization of oil palm as a source of renewable energy in Malaysia
496	Fernández Fernández, Y., Fernández López, M.A., Olmedillas Blanco, B. (2018) [12]	Innovation for sustainability: The impact of R&D spending on CO2 emissions
489	Janaun, J., Ellis, N. (2010) [13]	Perspectives on biodiesel as a sustainable fuel
477	Basiron, Y. (2007) [14]	Palm oil production through sustainable plantations
463	Aprianti, E., Shafigh, P., Bahri, S., Farahani, J.N. (2015) [15]	Supplementary cementitious materials origin from agricultural wastes - A review
457	Wolf, J. (2014) [16]	The Relationship Between Sustainable Supply Chain Management, Stakeholder Pressure and Corporate Sustainability Performance
446	Miettinen, J., Shi, C., Liew, S.C. (2016) [17]	Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990

Source: Scopus, 2025

The citation table presents a list of highly influential publications that shape the scientific landscape surrounding sustainable palm oil, bioenergy, environmental sustainability, and agricultural resource use. The high citation counts indicate that these studies have become foundational references in their respective research domains, providing conceptual, methodological, and policy-oriented contributions.

The most cited article, *Wijffels and Barbosa* [8] with 1663 citations, focuses on microalgal biofuels, highlighting the growing scientific interest in alternative renewable energy sources. Although not directly related to palm oil, its prominence in the citation network reflects the broader context in which sustainable palm oil research operates—namely, the global search for cleaner, more sustainable biofuel options. Similarly, *Ahmad et al.* [9] with 924 citations examines microalgae for biodiesel production, reinforcing the idea that comparative biofuel research provides an important benchmark against which palm oil's sustainability is evaluated.

Environmental sustainability concerns are further emphasized through *Raven and Wagner* [10] with 583 citations, which documents the rapid decline of insect biodiversity due to agricultural intensification and climate change. This study underscores

the ecological tensions surrounding large-scale plantation crops such as oil palm. Complementing this, *Miettinen et al.* [17] with 446 citations provides detailed insights into land cover distribution and peatland degradation across Malaysia, Sumatra, and Borneo—regions where palm oil expansion has been most pronounced. These highly cited environmental studies have become crucial references in debates about biodiversity loss, deforestation, and carbon emissions linked to palm oil production.

Several articles in the table directly address palm oil as a renewable energy source. *Sumathi et al.* [11] with 522 citations explores the potential of oil palm biomass for renewable energy in Malaysia, demonstrating the resource's versatility and value within a circular bioeconomy. *Janaun and Ellis* [13] with 489 citations and *Basiron* [14] with 477 citations also contribute substantially to the discourse on biodiesel sustainability and the development of sustainable palm oil plantations. These works help establish palm oil as a major biofuel feedstock while also stressing the need for sustainable production practices.

The table also includes studies addressing technological innovation and corporate sustainability. *Fernández Fernández et al.* [12] with 496 citations links R&D investment to reductions in CO_2 emissions, suggesting that innovation plays a vital role in enhancing environmental performance. In a related but broader context, *Wolf* [16] with 457 citations discusses the relationship between stakeholder pressure, sustainable supply chain management, and corporate sustainability performance—an issue highly relevant to global palm oil supply chains facing scrutiny from regulators, NGOs, and international markets. Finally, *Aprianti et al.* [15] with 463 citations demonstrates how agricultural waste—including oil palm residues—can be transformed into supplementary cementitious materials. This reflects a growing research trend focusing on value-added utilization of palm biomass, contributing to waste minimization and circular economy pathways.

Discussion

The findings of this bibliometric analysis reveal that sustainable palm oil research has evolved into an increasingly interdisciplinary and internationally collaborative field, shaped by environmental concerns, technological innovation, and shifts in global policy discourse. The keyword co-occurrence, temporal evolution, and density mapping demonstrate that sustainability-related themes stand at the core of research activities, while the author, institutional, and country networks highlight how global partnerships contribute to the field's intellectual development. Together, these results illustrate a maturing research landscape that integrates ecological science, engineering solutions, supply chain analysis, and renewable energy exploration.

The keyword co-occurrence map shows a well-defined clustering of thematic domains. The red cluster, dominated by terms such as *deforestation*, *biodiversity*, *environmental protection*, and *land use*, indicates the strong environmental framing of palm oil research. This aligns with the global debates surrounding the ecological impacts of palm oil plantations in Southeast Asia, particularly concerns about forest loss in Malaysia and Indonesia. The intensity of these connections shows that environmental science continues to serve as a major foundation of scholarly inquiry. In contrast, the green cluster revolves around *biodiesel*, *biofuel*, *renewable energy*, and *carbon dioxide*, demonstrating the technical and engineering-oriented dimension of the literature. These works explore palm oil not only as a plantation commodity but also as part of the broader energy transition and circular economy movement, especially in the context of biofuel adoption. The presence of these distinct but interconnected clusters suggests that sustainable palm oil has always been a hybrid topic, situated between ecological preservation and industrial innovation.

The temporal overlay visualization provides further insight into how research priorities have shifted over time. Earlier studies from 2018–2019 placed considerable emphasis on biodiesel production, feedstocks,

carbon emissions, and life-cycle assessment. This reflects a strong interest in positioning palm oil as a renewable energy resource capable of reducing dependence on fossil fuels. However, as the visualization transitions into 2019–2020, environmental and climate-related keywords become more prominent, indicating heightened scholarly attention to the broader consequences of agricultural intensification. During this period, detractors of palm oil gained visibility through media coverage and policy responses from consuming countries, encouraging researchers to deepen their examination of deforestation, peatland degradation, and biodiversity risks.

More recent research, emerging around 2020–2021, focuses increasingly on waste valorization, industrial ecology, and material innovation. Keywords such as *palm oil mill effluent*, *cellulose*, and *compressive strength* suggest that researchers have begun to explore how palm biomass waste can be converted into valuable materials, including bio-composites and construction applications. This evolution reflects a broader shift in sustainability science toward circular economy models, where waste and by-products are reimagined as resources. Collectively, these temporal changes confirm that sustainable palm oil research has moved from energy substitution toward a more holistic understanding of environmental, technological, and circular economy dynamics.

The density visualization reinforces this finding by highlighting the centrality of *sustainable development*, *sustainability*, *palm oil*, and *oil palm* as the most frequently occurring and interconnected keywords. Their bright yellow color visualizes the conceptual backbone of the field, demonstrating that almost all research strands—energy, environment, supply chain, biodiversity, waste management—ultimately converge on the overarching objective of achieving sustainable development. Meanwhile, the peripheral yet emerging keywords, appearing in cooler colors, represent specialized research niches that continue to grow, such as biofuel optimization, effluent treatment, biomass utilization, and environmental modeling.

The author co-authorship network reveals a complex yet well-connected structure composed of multiple research clusters operating across engineering, environmental science, and sustainability governance. The network highlights that sustainable palm oil research is not driven by isolated individuals but by collaborative groups of scholars, many of whom form long-lasting research partnerships. For instance, engineering-oriented clusters work closely on biodiesel, biomass processing, and chemical engineering issues, while environmental and policy-focused researchers contribute to land-use modeling, climate impacts, and ecological assessments. The presence of bridging authors such as Loh Soh Kheang demonstrates the integrative nature of this field, where interdisciplinary knowledge exchange strengthens the collective scientific output.

Institutional collaboration patterns paint a similar picture, with Malaysian institutions emerging as the most central contributors. The Malaysian Palm Oil Board (MPOB) occupies a strategic position at the network's core, reinforcing its role as a national and regional leader in palm oil research. MPOB's strong links with universities in Malaysia, Indonesia, and international partners reflect Malaysia's long-standing scientific commitment to improving palm oil production, processing technologies, and sustainability compliance. Engineering faculties, particularly departments of chemical and environmental engineering, play a primary role in research addressing energy, waste valorization, and industrial optimization. Meanwhile, European and Indonesian institutions contribute expertise in environmental modeling, forestry science, and socio-economic assessments. This diverse institutional ecosystem demonstrates that sustainable palm oil is a multifaceted field requiring collaborative knowledge generation.

The country collaboration network further emphasizes Malaysia's pivotal role in global sustainable palm oil research.

Malaysia's dominance in publication volume and collaborative links is unsurprising given its economic dependence on the industry and robust research infrastructure. Indonesia, while also a major producer, forms a slightly different network structure, collaborating closely with Japan and certain European countries. The red cluster of countries—including the United Kingdom, United States, Netherlands, and Germany—reflects the influence of global North actors in driving research on sustainability standards, supply chain governance, and corporate responsibility. These countries often shape global sustainability narratives, regulatory frameworks, and certification schemes such as RSPO, which have direct implications for producer nations. Meanwhile, emerging collaborations among India, Pakistan, Nigeria, and Middle Eastern countries highlight the South–South research ties shaped by shared economic interests and technological needs.

The analysis of highly cited papers shows that the intellectual drivers of the field span several domains: renewable energy research, environmental science, sustainable supply chain management, and innovative biomass utilization. The prominence of papers discussing microalgal biofuels and biodiesel indicates that palm oil research exists within a broader context of bioenergy innovation. Highly cited studies addressing deforestation, peatland changes, and biodiversity loss illustrate the global concern surrounding palm oil's ecological footprint. Finally, influential works on innovation, corporate sustainability, and agricultural waste valorization align with the shift toward eco-efficiency and circular resource use.

Overall, this study demonstrates that sustainable palm oil research is characterized by interdisciplinarity, international co-production of knowledge, and evolving research priorities driven by both environmental pressures and technological opportunities. While the field has increasingly diversified, its central objective remains consistent: navigating the complex balance Sbetween economic development, ecological protection, and responsible global resource use. As collaboration intensifies and emerging economies continue to invest in sustainability science, the global research landscape on palm oil is likely to become even more interconnected, innovative, and aligned with international sustainability goals.5

4. CONCLUSION

This bibliometric analysis provides a comprehensive understanding of the global research landscape on sustainable palm oil, revealing a field that has grown increasingly interdisciplinary, collaborative, and responsive to evolving sustainability challenges. The findings show that environmental concerns—particularly deforestation, biodiversity loss, and climate impacts—remain central to scholarly debates, while technological innovation in biodiesel production, waste valorization, and material engineering continues to expand the scientific frontier. Malaysia and Indonesia emerge as pivotal contributors, supported by extensive collaborations with institutions and countries across Asia, Europe, and North America. The strong presence of engineering, environmental science, and sustainability governance clusters illustrates that progress in sustainable palm oil requires integrated scientific perspectives and cross-border knowledge co-production. By mapping thematic evolution, co-authorship networks, and institutional linkages, this study highlights not only the maturity of the field but also the growing emphasis on circular economy solutions and global sustainability commitments. Overall, the results underscore the importance of sustained international collaboration and interdisciplinary research efforts in ensuring that palm oil development contributes meaningfully to ecological integrity, responsible production, and long-term sustainable development.

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