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Palm Derived Products: A Bibliometric Analysis of Industrial Downstreaming

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ABSTRACT

This study presents a comprehensive bibliometric analysis of global research on palm-derived products with a focus on industrial downstreaming. Using data extracted from the Scopus database and visualized through VOSviewer, the analysis maps the intellectual structure, thematic evolution, and collaborative patterns within the domain. Results reveal that "palm oil" is the most central keyword, with strong research clusters surrounding biodiesel, oleochemicals, biomass utilization, and emerging themes such as pyrolysis and biochar. Temporal analysis indicates a shift from conventional processing techniques to sustainability-driven innovations, particularly in waste valorization. Malaysia and Indonesia are identified as the leading contributors, with increasing global collaboration involving countries like China, India, the United States, and Nigeria. Co-authorship networks show concentrated but gradually integrating research communities. The study underscores the importance of interdisciplinary approaches, policy alignment, and sustainable industrial strategies in enhancing the economic and environmental impact of palm-based downstream industries. Recommendations for future research include focusing on life-cycle assessment, digitalization, and high-value derivative product development.

Keywords: *Palm Oil, Industrial Downstreaming, Biomass Valorization, Biodiesel, Bibliometric Analysis*

1. INTRODUCTION

The palm oil industry has long played a central role in the economies of many tropical countries, especially in Southeast Asia, where Indonesia and Malaysia dominate global production. Traditionally seen as a raw material exporter, the palm oil sector has increasingly gained attention for its potential in downstream industrial applications. Palm-derived products now extend far beyond cooking oil and basic commodities, they include processed goods such as oleochemicals, biodiesel, cosmetics, and even pharmaceuticals [1]. This transformation is not merely an economic trend but also a strategic necessity, driven by global market pressures, sustainability challenges, and national development agendas.

Industrial downstreaming—the process of increasing value-added activities within a resource-based sector—has become a key strategy for countries looking to maximize economic benefits from their natural resources [2]. In the context of palm oil, downstreaming includes refining crude palm oil (CPO) into higher-value derivatives such as fatty acids, glycerin, soap noodles, and industrial lubricants. These products not only fetch higher prices in the international market but also support the development of domestic industries, job creation, and technology transfer [3], [4]. Governments in producing countries have implemented policies such as export taxes on crude products and incentives for refined goods to stimulate this value-adding process [5].

The global demand for sustainable and traceable products has further accelerated the evolution of palm-derived industrial outputs. The emergence of green chemistry, clean energy mandates, and circular economy principles has opened new pathways for innovation in palm oil derivatives. Biodiesel, for example, has gained traction as an alternative to fossil fuel, while biodegradable plastics and surfactants from palm feedstock are gradually replacing petroleum-

based counterparts [6]. As environmental concerns rise, integrating sustainability into palm-based downstream products has become an imperative rather than an option. The industry's response is reflected in the growing number of certification schemes, green product labeling, and R&D investment in eco-friendly solutions.

Academically, the transformation of palm oil from a commodity to a diversified industrial base has spurred a significant body of research. Scholars have explored topics such as supply chain dynamics, policy impacts, environmental consequences, technological innovation, and market behavior related to downstream palm products. Bibliometric analysis enables researchers to map these intellectual developments systematically. By tracking publication trends, influential authors, research clusters, and emerging themes, bibliometric methods offer insights into the trajectory and structure of knowledge in this evolving domain [7]. Given the importance of palm downstreaming in both policy and practice, a systematic analysis of the literature is warranted.

Despite the expanding role of palm-based derivatives in global markets, fragmentation still characterizes the academic landscape on industrial downstreaming in this sector. Research tends to be dispersed across different disciplines—agriculture, engineering, environmental science, economics—each using varied methodologies and terminologies. As a result, there is limited synthesis of knowledge that brings together the economic, technological, and sustainability dimensions of palm-based downstream industries. Bibliometric analysis offers a holistic perspective by visualizing patterns, networks, and gaps in the literature. It can guide future studies, inform policy decisions, and highlight collaborative opportunities between academia and industry stakeholders.

Although numerous studies have addressed various aspects of the palm oil industry, there remains a paucity of systematic reviews focusing specifically on the downstream segment of palm-derived industrial products. Existing literature reviews often center on environmental impacts, smallholder livelihoods, or bioenergy policies, while overlooking the complex innovation ecosystem that supports downstream industrialization. Without a comprehensive bibliometric overview, researchers and policymakers lack a unified understanding of the trends, influential actors, and thematic foci shaping the field of palm-based industrial downstreaming. This study aims to conduct a bibliometric analysis of global research on palm-derived products with a specific focus on industrial downstreaming.

2. METHODS

This study employs a bibliometric analysis to map the intellectual landscape and research evolution surrounding palm-derived products with a specific emphasis on industrial downstreaming. Bibliometric analysis is a quantitative method used to evaluate scientific publications and uncover patterns, trends, and relationships within a research domain [7]. The method is particularly suited for capturing the structure and dynamics of academic output across time and disciplines. This study utilizes data extracted from the Scopus database, which offers comprehensive indexing of peer-reviewed literature across various fields relevant to palm oil research, including agriculture, engineering, environmental science, and industrial applications.

The search strategy was constructed using a combination of keywords related to palm oil and downstream products. Terms such as "palm oil," "palm-based," "oleochemical," "biodiesel," "palm derivative," "downstream industry," and "value-added products" were used in the article title, abstract, and keyword fields. The search was restricted to publications between the years 2000 and 2024 to capture contemporary research trends. Only journal articles, conference papers, and reviews

published in English were included to ensure academic rigor and relevance. After the initial search, duplicate entries, irrelevant topics (e.g., palm tree botany or non-industrial usage), and inaccessible records were removed through manual screening.

The final dataset was exported in RIS and CSV formats and analyzed using VOSviewer, a visualization tool designed for constructing and viewing bibliometric maps. Co-authorship analysis was conducted to explore collaboration networks among authors and institutions, while co-occurrence analysis of keywords was used to identify research hotspots and thematic clusters. Citation analysis helped determine influential publications and journals. The results were interpreted to provide insights into the development, fragmentation, and convergence of research themes within the downstream palm-based product domain.

3. RESULTS AND DISCUSSION

3.1 Network Visualization

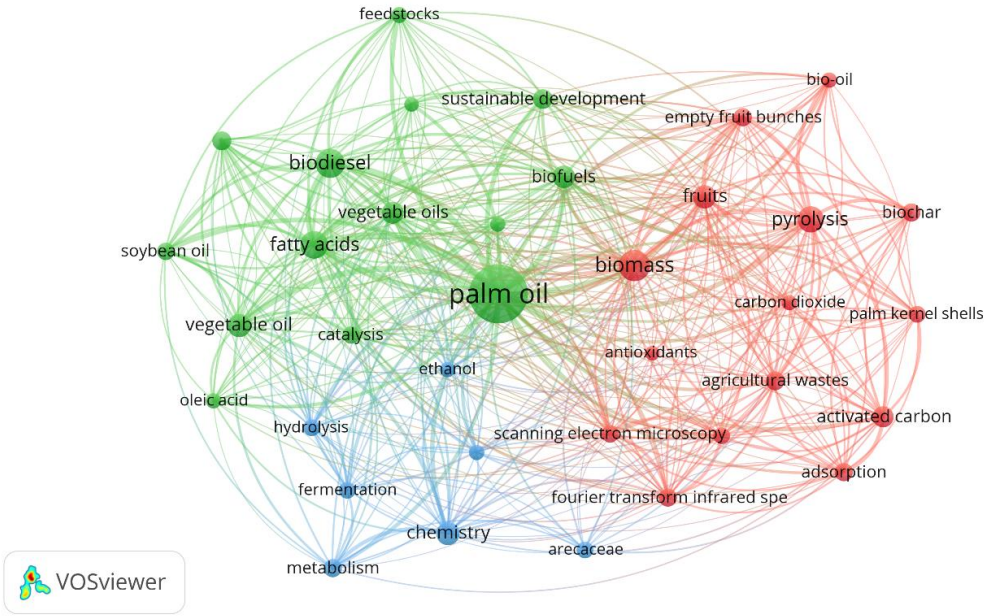

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

Figure 1 highlights the thematic structure of palm-derived product research related to industrial downstreaming. The keyword "palm oil" appears as the most central and dominant node, indicating its pivotal role as the primary research focus. Surrounding it are three major clusters: green, red, and blue, each representing distinct thematic groupings within the bibliometric landscape. The thickness and density of the connecting lines suggest a high degree of interconnectivity among research areas, pointing to an interdisciplinary nature in this field.

The green cluster, primarily positioned to the left, reflects a strong emphasis on biofuels and oleochemical derivatives. Keywords such as biodiesel, biofuels, fatty acids, vegetable oils, catalysis, and sustainable development dominate this group. This indicates a large body of research dedicated to transforming palm oil and other vegetable oils into renewable energy sources and chemicals. The presence of feedstocks, soybean oil, and oleic acid also suggests comparative studies and process innovations that extend to non-palm sources, emphasizing the broader context of bio-based product development.

On the right, the red cluster centers around biomass, pyrolysis, biochar, and activated carbon. These keywords indicate a focus on waste valorization and thermal conversion processes

using by-products of palm oil such as empty fruit bunches and palm kernel shells. Studies in this cluster typically explore how agricultural waste materials can be transformed into energy-dense and carbon-rich substances, reinforcing the role of palm biomass in circular economy initiatives. The inclusion of carbon dioxide, adsorption, and antioxidants further points to research on environmental mitigation and material science applications.

The blue cluster at the bottom is more technically oriented, comprising terms like chemistry, fermentation, metabolism, hydrolysis, ethanol, and scanning electron microscopy. This cluster represents the biochemical and molecular approaches to palm-based research. It suggests ongoing efforts to understand the metabolic pathways, microscopic structures, and chemical transformations involved in producing downstream products. The presence of arecaceae (the palm family) links biological taxonomy with industrial research, while Fourier transform infrared spectroscopy indicates advanced characterization techniques in use.

3.2 Overlay Visualization

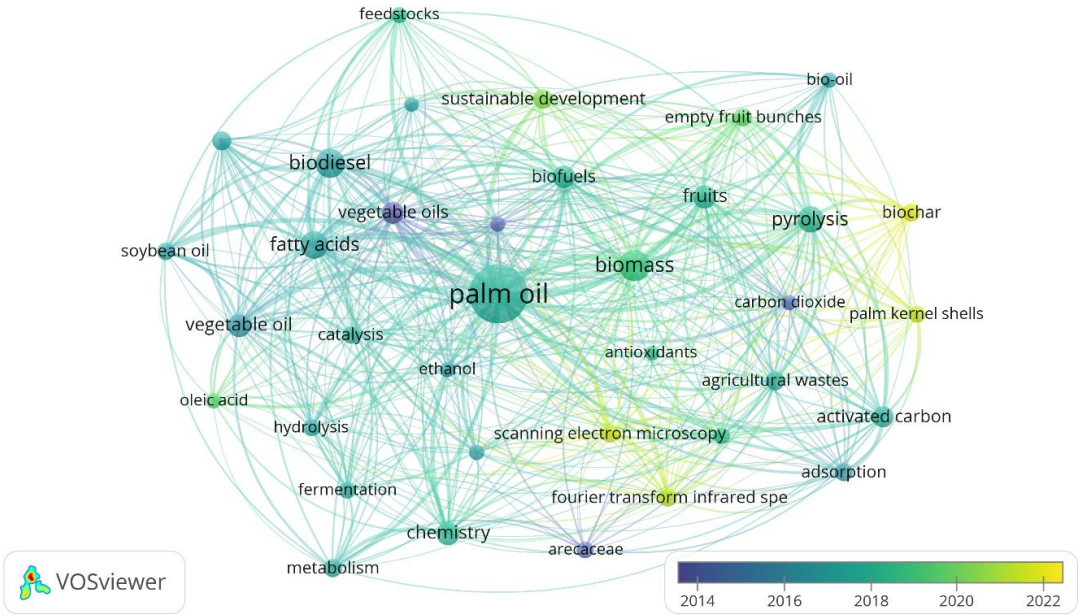

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2025

Figure 2 displays the temporal evolution of research themes in palm-derived products and downstream industrial applications. The color gradient from dark blue (older) to yellow (more recent) represents the average publication year associated with each keyword. Central terms such as "palm oil", "biomass", and "biodiesel" appear in greenish hues, indicating their sustained attention and consistent research activity from around 2016 to 2019. These keywords signify mature themes that have formed the backbone of palm-related downstream studies, particularly in energy conversion and resource utilization.

Recent research trends are revealed in the yellow-tinted keywords, concentrated primarily in the pyrolysis and waste valorization domain. Terms such as *"biochar," "pyrolysis," "activated carbon,"* and *"palm kernel shells"* are positioned toward the right and are among the most recent focus areas, with average publication years nearing 2021–2022. This suggests a growing scholarly interest in converting agricultural residues from palm oil production into value-added materials, aligning with global shifts toward circular economy and sustainable waste management strategies. In contrast, earlier studies, represented by darker shades (blue and purple), cluster around *"fatty acids," "vegetable oils," "catalysis,"* and *"hydrolysis."* These represent foundational biochemical and process-

oriented research that dominated the early 2010s. Such keywords reflect efforts in chemical modification, oleochemical production, and biodiesel conversion, laying the groundwork for subsequent advancements in the field.

3.3 Citation Analysis

Table 1. The Most Impactful Literatures

Citations	Authors and year	Title
1761	[8]	Biodiesel from microalgae beats bioethanol
1205	[9]	Natural fibers, biopolymers, and biocomposites
484	[10]	Perspectives on biodiesel as a sustainable fuel
336	[11]	Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils
298	[1]	Palm oil: Addressing issues and towards sustainable development
276	[12]	A review of the potentials, challenges and current status of microalgae biomass applications in industrial wastewater treatment
270	[13]	Carboxylic acid reductase is a versatile enzyme for the conversion of fatty acids into fuels and chemical commodities
245	[14]	Date palm tree (Phoenix dactylifera L.): Natural products and therapeutic options
245	[15]	Biodiesel production from non-edible plant oils
243	[16]	N-Butanol derived from biochemical and chemical routes: A review

Source: Scopus, 2025

3.4 Density Visualization

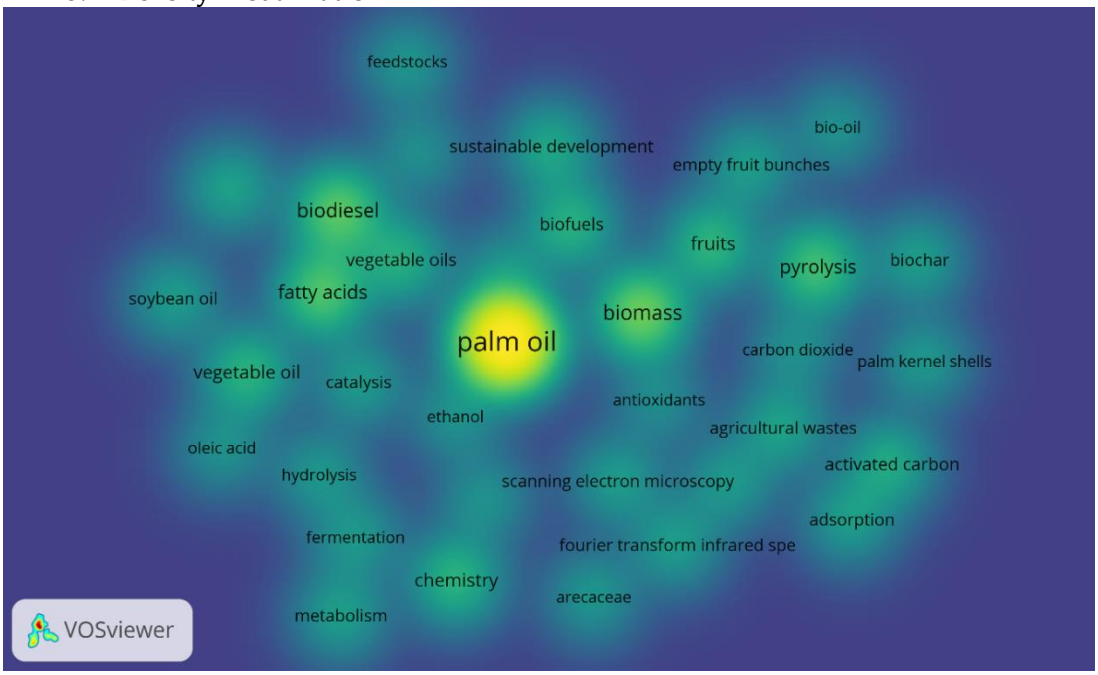

Figure 3. Density Visualization

Source: Data Analysis Result, 2025

Figure 3 presents the concentration and intensity of keyword usage in research related to palm-derived products and downstream industries. The term "palm oil" is depicted in bright yellow, indicating it is the most frequently occurring and central concept in the dataset. This confirms its role as the foundational topic across various studies. Surrounding this core, keywords such as "biomass," "biodiesel," "fatty acids," and "biofuels" appear in lighter green, signifying relatively high but secondary levels of research focus. These terms represent key application areas and processing outputs, suggesting that much of the downstream research remains concentrated on energy conversion and oleochemical processing. On the periphery, keywords such as "adsorption," "activated carbon," "scanning electron microscopy," and "fermentation" are shown in darker green to blue shades, indicating lower research density. These areas, while less dominant, reflect specialized and emerging themes like material science applications and analytical techniques. Similarly, topics related to "biochar," "palm kernel shells," and "pyrolysis" also suggest growing interest in biomass valorization and circular economy approaches, albeit with less saturation in the literature.

3.5 Co-Authorship Network

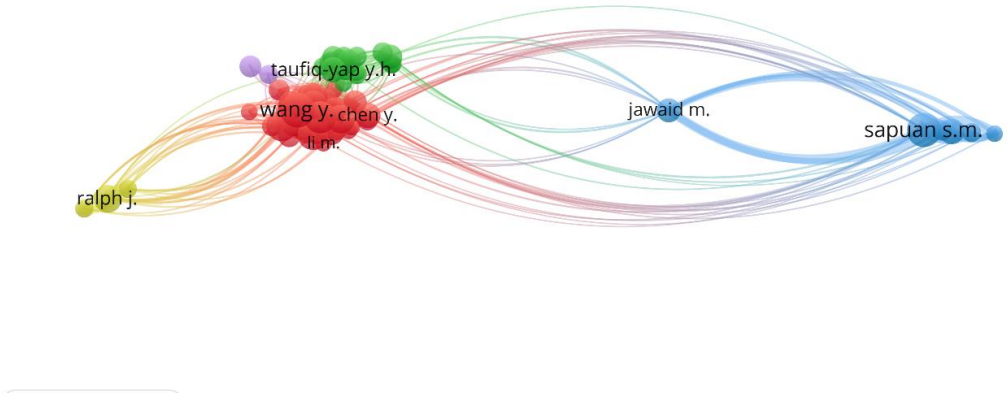

Figure 4. Author Visualization
Source: Data Analysis Result, 2025

Figure 4 illustrates clusters of researchers who are actively publishing in the field of palm-derived products and industrial downstreaming. The network is composed of several distinct groups, with Sapuan S.M. and Jawaid M. forming a prominent collaboration cluster on the right, signifying their central role and strong partnership in this domain. The thick lines connecting them denote high-frequency co-authorship, indicating sustained joint research output. In the central region, another dense cluster centers around Wang Y., Cheng Y., and Li M., reflecting a tightly knit research community, likely focused on chemical or process engineering aspects. Ralph J., located on the left in yellow, appears more peripheral but still linked to others, suggesting contributions from a different subdiscipline or early collaboration links.

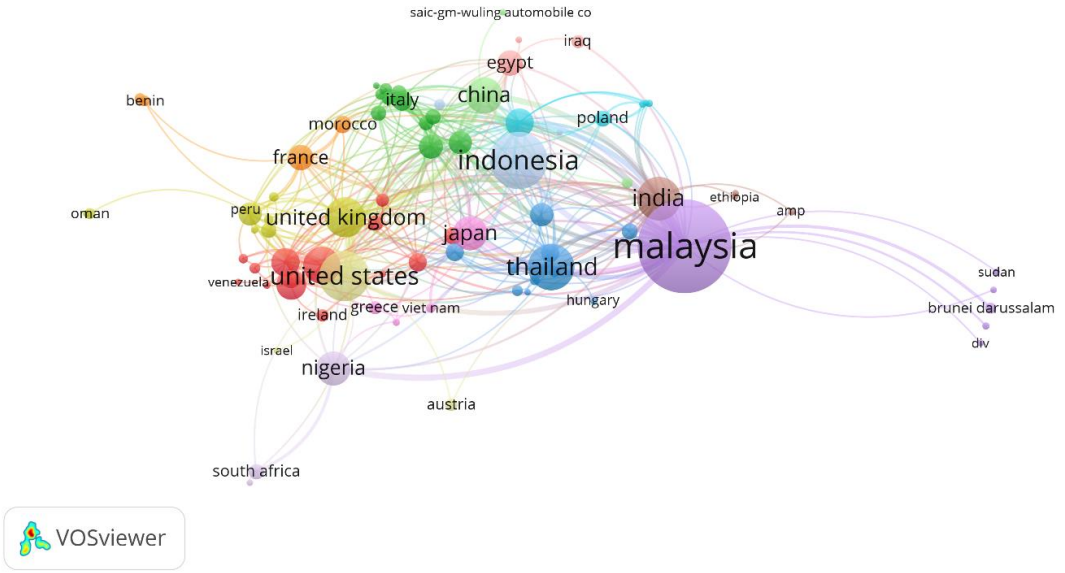

Figure 5. Country Visualization
Source: Data Analysis Result, 2025

Figure 5 map shows the global distribution and interconnectedness of research contributions related to palm-derived products and industrial downstreaming. Indonesia and Malaysia are the dominant central nodes in the network, highlighted in purple and blue, respectively, signifying their leading roles in the research field. Other notable countries include the United States, China, India, and Thailand, with strong interconnections indicating international collaboration. The density of connections between these countries suggests an active global research network, especially in Southeast Asia and major developed nations. Additionally, countries like Nigeria, South Africa, and Ethiopia on the outer periphery show more isolated connections, suggesting emerging or less frequent involvement in the research network.

Discussion

1. Evolving Research Focus in Palm-Based Downstream Industries

The keyword co-occurrence map clearly indicates that "palm oil" remains the most dominant and central term in the literature, reflecting its foundational role as the primary raw material for a wide range of downstream products. The presence of strong clusters around terms like *"biodiesel," "fatty acids," "vegetable oils,"* and *"biofuels"* points to a sustained emphasis on renewable energy and oleochemical development. These clusters confirm the prioritization of palm oil as a feedstock for energy transition efforts, particularly in biodiesel production—an area that has received strong policy and industrial support in countries such as Malaysia and Indonesia [17]–[19]. In parallel, the emergence of clusters related to *"pyrolysis," "biochar," "activated carbon,"* and *"agricultural wastes"* suggests that biomass valorization is gaining research momentum. These terms are tied to converting palm oil industry by-products, such as empty fruit bunches and palm kernel shells, into valuable secondary products. This trend aligns with the global shift toward circular economy practices, where waste is reimagined as a resource for energy, soil enhancement, or industrial raw materials. Such developments highlight a diversification in downstream pathways, from conventional fuel production to innovative material recovery. The increasing attention to *"sustainable development"* within the green cluster signifies a growing awareness of environmental considerations in downstream industrialization. Researchers are no longer solely focused on technological yield or efficiency but are also examining life-cycle impacts, carbon emissions, and the

integration of palm oil by-products into sustainable production chains [20]. This shift marks a critical evolution in the research agenda, from linear exploitation to more responsible industrial ecosystems.

2. Temporal Trends and Research Maturity

The overlay visualization adds a temporal layer to the keyword analysis, revealing the progression of research themes over time. Foundational themes like *"fatty acids," "hydrolysis," "catalysis,"* and *"fermentation"* appear in darker hues, suggesting that these topics dominated earlier research efforts, particularly in the early 2010s. These themes reflect early interest in the chemical and biochemical processing of palm oil, laying the groundwork for the broader development of palm-derived value chains. Conversely, more recent interest, shown in yellow hues, centers around *"biochar," "pyrolysis,"* and *"activated carbon,"* indicating an uptick in thermal conversion technologies and waste-to-resource strategies post-2020. This development is timely, given the increasing pressure on palm oil-producing countries to reduce emissions and improve waste management practices. The evolution also suggests that the field is maturing, with newer research building on established processing techniques to explore sustainability and innovation frontiers. This chronological shift also reflects the impact of global sustainability agendas—such as the United Nations Sustainable Development Goals (SDGs)—on research directions. The transition from high-emission, high-waste industrial models to low-carbon, resource-efficient systems is influencing research funding, publication focus, and collaboration patterns globally.

3. Intellectual Structure and Leading Contributors

The author co-authorship map reveals a fragmented yet evolving network of researchers. On one end, we observe concentrated clusters of scholars such as Wang Y., Chen Y., Li M., who dominate the central research network, possibly focused on chemical or materials engineering. On the other, authors like Sapuan S.M. and Jawaid M. are leading contributors in composite materials and sustainable industrial applications, frequently collaborating and contributing to knowledge diffusion within the domain. Their prominence indicates the importance of academic leadership and research hubs in advancing specialized areas of downstream palm research. Interestingly, while many authors operate in tight-knit groups, there is growing cross-cluster collaboration, especially among Southeast Asian scholars and their international peers. This trend signifies increasing internationalization of the field and reflects the shared interest in palm oil as both a commercial and scientific resource. However, the fragmentation also suggests that more efforts are needed to integrate disparate research clusters and foster interdisciplinary collaboration, especially between chemical engineers, environmental scientists, and policy researchers.

4. Geographical Contributions and Collaborations

The country collaboration map shows Malaysia and Indonesia as the two most influential contributors to palm oil downstream research. Their dominance is expected, given their status as the world's top producers of palm oil. Both countries have actively invested in palm-based R&D infrastructure, national policies promoting downstream industries, and public-private partnerships to scale industrial applications [21], [22]. The proximity of keywords like *"biodiesel," "sustainable development,"* and *"biomass"* to these countries further illustrates their comprehensive involvement in the domain—from production to innovation to sustainability. Other significant contributors include India, China, Thailand, and the United States, which are either major importers or developers of technologies related to palm oil derivatives. For instance, China's interest may lie in oleochemical applications, while the United States and Europe contribute through sustainability analysis, policy research, and industrial process innovation. Countries like Nigeria, Egypt, and South Africa show emerging involvement, indicating that palm oil downstream research is becoming increasingly globalized.

5. Implications for Policy and Practice

The bibliometric insights have practical implications for policy development and industrial planning. Policymakers in palm oil-producing countries should recognize that downstream industrialization is not just a technical issue but a multidimensional agenda involving environmental stewardship, international competitiveness, and inclusive growth. For instance, the growing interest in *waste valorization* and *biochar* research implies potential regulatory support for biomass recycling incentives and carbon offset programs. Industrial stakeholders, on the other hand, can utilize the thematic trends to align their R&D investments with global research directions. Areas such as *activated carbon production*, *biodegradable polymers*, and *green oleochemicals* are likely to see increased demand, making them attractive targets for commercialization. Collaboration with academic institutions will be crucial to reduce the time from research to market and ensure sustainability compliance. Furthermore, the academic community can benefit from this bibliometric mapping by identifying underexplored areas such as *life-cycle assessment*, *techno-economic modeling*, and *supply chain optimization* in palm downstreaming. Interdisciplinary work involving data science, environmental economics, and industrial ecology could enrich the existing knowledge base and expand its applicability to real-world problems.

CONCLUSION

This bibliometric analysis reveals the dynamic and evolving landscape of research on palm-derived products and industrial downstreaming, with palm oil serving as a central focus across diverse thematic clusters such as biodiesel production, biomass valorization, and sustainable development. The study highlights a chronological shift from early research centered on oleochemical and biochemical processes toward more recent explorations into circular economy practices, including pyrolysis and the transformation of palm oil waste into value-added materials. Collaborative networks are notably strong in Southeast Asia, particularly in Malaysia and Indonesia, reflecting their global leadership in palm oil production and innovation. However, emerging participation from countries in Africa, the Middle East, and South America indicates expanding global interest. Despite some fragmentation in author networks, the growing interdisciplinary and international collaboration presents significant opportunities for future research. To advance the field further, stakeholders must integrate sustainability, technological innovation, and policy support to enhance the value chain of palm-derived products and promote more inclusive and responsible industrial development.

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