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Technological Innovation in Palm Oil Industry: A Bibliometric Analysis of AI, IoT, and Precision Agriculture Applications

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ABSTRACT

This study examines the representation of artificial intelligence (AI), the Internet of Things (IoT), and precision agriculture in the scholarly literature pertaining to the palm oil business. A bibliometric technique was employed to obtain literature indexed in major databases from 2000 to 2024, utilizing specific search strings that combined palm oil terminology with keywords related to AI, IoT, and smart farming. Following screening and data cleansing, performance analysis and science-mapping methodologies were employed using VOSviewer and Biblioshiny to investigate publication patterns, significant documents, collaboration networks, and keyword structures. The findings indicate a swiftly advancing research frontier centered on the intersection of IoT, palm oil, and sustainability, wherein sensor-based monitoring, intelligent platforms, and machine-learning technologies are utilized for plantation management and environmental supervision. Malaysia and Indonesia predominate in the national network, bolstered by interdisciplinary collaborations among engineering, computer science, and agriculture departments. Nonetheless, inclusive innovation and social factors are still inadequately examined, since the majority of research emphasizes technical feasibility and productivity over smallholder integration or governance concerns. The report finishes by delineating practical consequences for industry and policymakers, theoretical contributions to digital agriculture and innovation-ecosystem research, and objectives for future endeavors on sustainable, data-driven palm oil systems.

Keywords: *Palm Oil, Artificial Intelligence, Internet of Things, Precision Agriculture, Smart Farming, Bibliometric Analysis, Digital Agriculture, Sustainability.*

1. INTRODUCTION

Technological innovation has emerged as a pivotal element in transforming the global palm oil sector, a crucial supply of vegetable oil and a critical export commodity for numerous tropical economies. The sector is also subjected to ongoing scrutiny due to deforestation, greenhouse gas emissions, biodiversity depletion, labor concerns, and social unrest in production countries. These demands have compelled governments, corporations, and civil society entities to explore innovative methods for enhancing production while adhering to progressively rigorous environmental and social norms. Recent research on Industry 4.0 and digital technologies in palm oil indicates that sophisticated tools—specifically artificial intelligence (AI), remote sensing, the Internet of Things (IoT), and data-driven decision-support systems—can improve yield estimation, monitor land-use changes, and facilitate more transparent supply chains, thus paving the way for more sustainable palm oil production [1], [2], [3], [4].

Simultaneously, agriculture is experiencing a swift digital transition through artificial intelligence, the Internet of Things, and precision agriculture. Reviews indicate a significant increase in research on artificial intelligence and machine learning throughout the agricultural value chain, encompassing soil and crop management, pest and disease identification, yield forecasting, and decision support [5], [6], [7], [8]. Simultaneously, IoT-enabled precision agriculture is emerging as a pivotal paradigm wherein distributed sensors, communication networks, cloud platforms, and mobile interfaces produce continuous field-level data for the real-time management of irrigation, fertilization, and pest control [9], [10], [11].

Bibliometric analyses of precision agriculture technologies indicate a recent surge in research production, emphasizing big data analytics, smart farming, and cyber-physical systems aimed at improving productivity and sustainability [12], [13]. In the context of palm oil, these technical advancements are starting to manifest in tangible applications throughout the plantation and processing value chain. Remote sensing and geographic information systems (GIS) are utilized to identify oil palm plantations, monitor land clearing, distinguish plantations from natural forests, and evaluate their consequences for deforestation and habitat degradation [1], [14], [15], [16].

This spatial data can be integrated with AI-driven classification algorithms to identify illegal incursions, assess canopy conditions, or recognize illness symptoms. At more granular levels, GI- and sensor-based mapping of plantation blocks enhances estate planning and resource distribution [17]. Outside the field, Industry 4.0 technologies, including smart imaging, automated monitoring, and digital platforms, have been suggested to enhance mill operations, logistics, and supply-chain t raceability [2], [4].

The Internet of Things and precision agricultural technologies have significantly broadened the technical options accessible to oil palm producers. Sensor networks may, in principle, monitor soil moisture, microclimate, and tree growth, utilizing IoT-based platforms to transmit this data into AI and machine-learning models for yield prediction, stress identification, and site-specific management [9], [10]. Drones and autonomous ground vehicles, outfitted with cameras and sensors, are being investigated for automated scouting, mapping, and targeted spraying chores that may decrease labor demands and enhance the timeliness of agronomic operations [2], [3]. Nevertheless, adoption is inconsistent, especially among smallholders who have limitations regarding financing, digital infrastructure, and expertise. This raises worries that digital innovation in palm oil may worsen existing inequities unless the development and dissemination of technologies are inte ntionally planned to be inclusive [4], [16].

Concurrently, scientific literature about palm oil technologies and the broader applications of AI, IoT, and precision agriculture in agriculture is proliferating swiftly. Recent bibliometric studies delineate the progression of Precision Agriculture (PA), highlighting principal themes, prominent nations, and collaborative networks [12], [13]. Additional studies provide bibliometric assessments of smart agriculture and IoT-based irrigation, emphasizing research trends and knowledge clusters that span many crops and areas (Hendrawati, 2025; Hendrawati et al., 2025).

In addition to these general mappings, analyses of Industry 4.0 technologies in palm oil predominantly investigate mechanization, automation, and process optimization, whereas studies centered on remote sensing emphasize land-use monitoring and sustainability metrics ([1], [2], [4], [16]. However, these contributions frequently address AI, IoT, and PA as distinct subjects or as components of wider agricultural or industrial discussions, without methodically analyzing their interconnections within the particular ecological, economic, and governance framework of the palm oil sector.

Despite the expanding literature, consolidated understanding of the evolution of research on AI, IoT, and PA in the palm oil sector remains limited, including insights into significant contributors, dominant technological themes, and the identification of principal gaps and upcoming horizons. Current reviews on Industry 4.0 in palm oil are predominantly narrative and technology-centric [2], [3], [4], whereas studies centered on palm oil that employ remote sensing and GIS typically focus on land-use change, environmental repercussions, or spatial management, rather than comprehensive digital farming systems [1], [14], [15]. Conversely, global bibliometric analyses of AI, IoT, and PA seldom differentiate findings by commodity or examine the specific problems related to oil palm ecosystems and smallholder-centric supply chains [12], [18], [19].

This disjointed comprehension hinders researchers, policymakers, and industry stakeholders from pinpointing strategic research avenues, coordinating innovation initiatives, or formulating policies and capacity-building programs that correspond with the genuine trajectory of technological advancement in the palm oil sector. This work addresses the lack of a thorough bibliometric synthesis focused on technical advancement in palm oil, driven by AI, IoT, and precision agriculture. In the absence of such a synthesis, the knowledge framework of this swiftly advancing field remains unclear: the most significant publications, authors, institutions, and countries are not distinctly delineated; the prevailing and nascent thematic clusters are not systematically recognized; and the degree to which current research tackles critical sustainability, productivity, and inclusion issues in oil palm production is not thoroughly comprehended. This obstructs evidence-based agenda-setting, neglects duplication and fragmentation, and may impede the conversion of promising digital technologies into scalable solutions for both industrial estates and smallholder systems [2], [4], [12].

The aim of this study, entitled "Technological Innovation in Palm Oil Industry: A Bibliometric Analysis of AI, IoT, and Precision Agriculture Applications," is to comprehensively delineate and examine the scientific literature at the convergence of these technologies and the palm oil industry. The study specifically aims to: (1) quantify the temporal evolution of publications and identify the most influential articles, authors, institutions, journals, and countries; (2) elucidate the primary research themes and knowledge clusters through keyword co-occurrence and related bibliometric methodologies; and (3) underscore research gaps and prospective directions, particularly concerning sustainability, smallholder inclusion, and the governance of digital technologies in palm oil production. This bibliometric analysis offers a comprehensive overview of the area, intended to serve as a reference for researchers and decision-makers aiming to strategically enhance technological innovation in the palm oil business.

2. METHODS

This work employs a quantitative bibliometric approach to map and assess the scientific literature about technological innovation in the palm oil sector, specifically emphasizing applications of AI, IoT, and precision agriculture. Bibliometric analysis is extensively employed to investigate the structure and dynamics of scientific disciplines using publishing and citation data [20]. The principal data source for this research is the Scopus database, supplemented where needed by Web of Science to provide comprehensive coverage of high-quality, peer-reviewed publications [21]. The search strategy integrates agricultural keywords ("palm oil", "oil palm") with terminology related to digital and precision technologies ("artificial intelligence", "AI", "machine learning", "deep learning", "internet of things", "IoT", "precision agriculture", "smart farming", "remote sensing", "digital agriculture") employing Boolean operators. Searches are confined to journal articles, review papers, and conference proceedings published in English from 2000 to 2024, corresponding to the era when digital and Industry 4.0 technologies were systematically implemented in agriculture and palm oil research [22], [23].

The preliminary search results are exported in a standardized format, encompassing authors, title, abstract, keywords, journal, year, affiliations, citations, and references, and undergo a multi-phase screening and purification procedure. Initially, redundant entries across databases are eliminated. Secondly, titles, abstracts, and keywords are evaluated to confirm that each document explicitly pertains to both palm oil/oil palm and at least one of the specified technologies (AI, IoT, precision agriculture, smart farming, or closely associated digital tools), thereby excluding papers that reference these terms only superficially or concentrate on unrelated crops or sectors. Third, publications lacking enough bibliographic information or that are outside the designated scope (e.g ., policy reports, non-peer-reviewed materials) are eliminated. The residual corpus is subsequently refined by standardizing author names, institutional affiliations, country designations, and keyword variations (e.g., "oil-palm" versus "oil palm," "artificial intelligence" versus "AI," "Internet of Things" versus "IoT"). Synonymous or closely related terms are consolidated into cohesive groupings to enhance the robustness of co-occurrence analysis, adhering to established methodologies in bibliometric data preparation [22], [23].

The sanitized dataset is examined utilizing a blend of performance analysis and science-mapping methodologies. Performance analysis is executed utilizing Excel and R (employing the bibliometrix package and its web interface Biblioshiny) to produce descriptive metrics, including annual publication trends, the most prolific authors, institutions, countries, and journals, alongside citation-based impact assessments [22], [24]. Science mapping is conducted using VOSviewer and/or Biblioshiny to create and visualize networks of co-authorship (authors, institutions, nations), co-citation (documents, authors, journals), and keyword co-occurrence [25], [26]. Cluster analysis identifies key theme clusters within the discipline, whereas overlay and temporal visualizations illustrate the progression of topics across time, uncovering nascent research fronts. Network measures, such as link strength, density, and centrality, are analyzed to elucidate collaborative structures and intellectual connections. Every phase—from the formulation of search queries and screening criteria to the parameter settings for network construction—is meticulously recorded to improve transparency and replicability of the bibliometric process [20], [23].

3. RESULTS AND DISCUSSION

3.1 Network Visualization

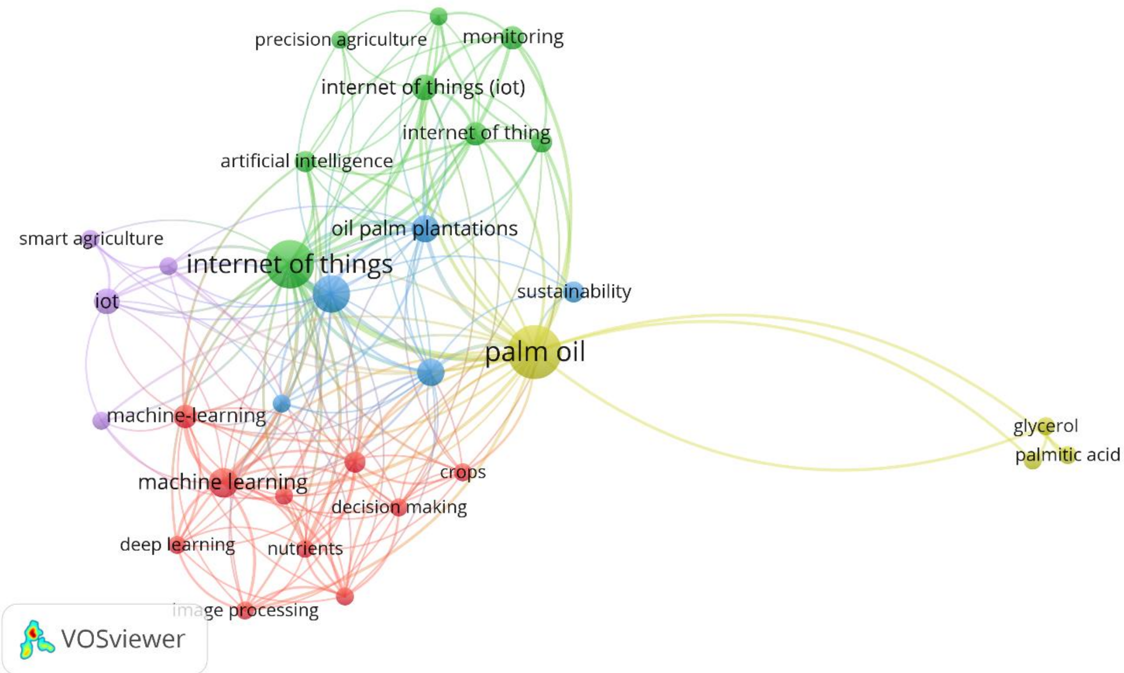

Figure 1. Network Visualization

Source: Data Analysis Result, 2025

The VOSviewer map keyword co-occurrence map identifies "palm oil" as the central hub of the network, characterized by a prominent node size and numerous connections. This suggests that the majority of the papers in your dataset expressly situate their research inside palm-oil contexts before extending to digital and precision technologies. The robust connections between palm oil and concepts such as the Internet of Things, machine learning, precision agriculture, decision-making, and sustainability indicate that the literature encompasses not only agronomic productivity but also data-driven management and sustainability governance within oil-palm systems. The extensive connections from palm oil to glycerol and palmitic acid on the right indicate a narrower, more specialized sub-stream concentrating on the biochemical or processing dimensions of palm oil products and by-products.

A notable cluster on the left side of the map is centered around "internet of things" and its derivatives (internet of things (IoT), internet of thing). The substantial scale of the Internet of Things node and the intricate green connections to monitoring, precision agriculture, oil palm plantations, and artificial intelligence underscore IoT as a significant technological issue within the corpus. This cluster encompasses research utilizing sensor networks and interconnected devices for field monitoring, plantation management, and real-time data acquisition. The strong association between the IoT cluster and palm oil suggests that numerous IoT applications are specifically evaluated or deliberated within oil-palm plantations, rather than solely in general agricultural contexts.

A significant cluster, characterized by "machine learning," "deep learning," and "image processing," is highlighted in red. The close connections within this cluster indicate a concentrated methodological emphasis on algorithmic tools for pattern identification and prediction. Connections from these nodes to crops, nutrients, and decision-making indicate that machine-learning applications are commonly employed for yield estimation, nutrient status assessment, disease or stress identification, and assistance in agronomic decisions. The links from this red cluster to palm oil and oil palm plantations indicate that these AI methodologies are being contextualized inside particular plantation systems, such as through remote-sensing images or sensor data analysis.

A diminutive yet significant cluster of nodes—such as "smart agriculture," "IoT" (abbreviation), and "monitoring"—constitutes a transitional area between the IoT and machine-learning domains. This indicates that several studies clearly contextualize their research within the overarching themes of "smart agriculture" or "smart farming," incorporating both IoT devices and AI/ML analytics. The interrelated links and hues in this area signify theme convergence: research is transitioning from discrete technology demonstrations to integrated cyber-physical systems that amalgamate sensing, connectivity, and intelligent analytics for palm oil production. This also signifies the shift from theoretical discourse to practical system-level implementations and case studies.

The network illustrates a close association between "sustainability," palm oil, and various technology nodes, but with a reduced node size. This trend indicates that sustainability is a significant, albeit not predominant, term in the technological innovation literature—frequently emerging as a consequence or contextual notion rather than as the primary technical emphasis. The periphery nodes of glycerol and palmitic acid suggest niche study in downstream processing and value-added goods, somewhat detached from the primary concerns of digital agriculture. The map illustrates a domain where palm-oil research is progressively converging with IoT and machine learning, systematically integrating them into precision and smart agricultural frameworks, while sustainability and by-product usage appear as associated yet subordinate elements.

3.2 Overlay Visualization

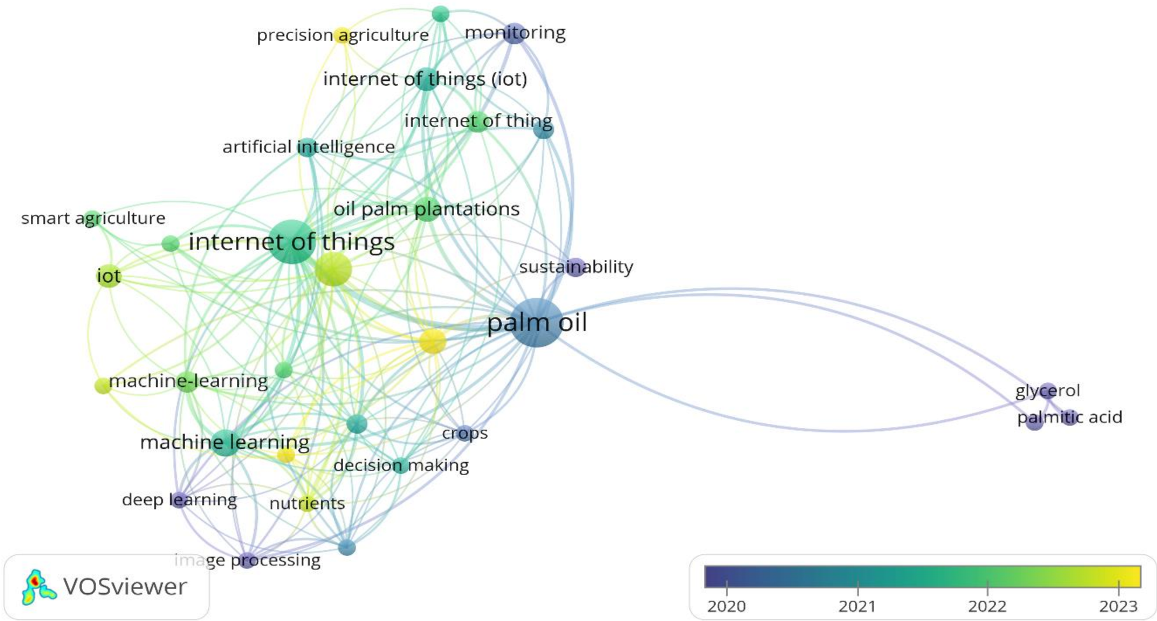

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2025

The overlay visualization image introduces a temporal aspect to the keyword network by color-coding nodes based on their average publication year (dark blue ≈ 2020, yellow ≈ 2023). "Palm oil" is centrally positioned in dark blue, signifying its status as a routinely utilized and very early keyword anchoring the field. The dark nodes "glycerol" and "palmitic acid" on the right pertain to the earlier literature, indicating a primary emphasis on palm oil chemistry, by-products, and processing rather than on digital technology. Similarly, "sustainability" is represented in bluish hues, indicating that environmental and social issues were introduced early in the discourse but had not yet been closely integrated with advanced AI/IoT terms.

The cluster associated with "internet of things," "IoT," and "smart agriculture" predominantly exhibits green to yellow hues, indicating a significant increase in IoT-focused research post-2021, particularly in 2022–2023. These nodes are intricately associated with "monitoring," "oil palm plantations," and "precision agriculture," which also exhibit more contemporary hues. This trend signifies that the latest publications are propelled by field-level sensing, real-time monitoring, and integrated precision agriculture systems for oil palm plantations. The substantial node size and recent coloration of the "internet of things" emphasize its emergence as a significant and quickly expanding research frontier at the convergence of digital technology and palm oil.

The machine-learning cluster, encompassing terms such as "machine learning," "deep learning," "image processing," "nutrients," and "decision making," exhibits a blend of turquoise-green hues, situating it between the established palm-oil/chemistry subjects and the recent surge in IoT/precision agriculture. This indicates that AI and machine learning techniques were embraced earlier (about 2021–2022), especially for image analysis, yield or nutrient forecasting, and decision assistance, and are now progressively linked with IoT and smart agriculture systems. The overlay map indicates a distinct temporal transition: the field has evolved from initial efforts in palm-oil processing and broad sustainability issues to a contemporary, technology-focused agenda centered on IoT-enabled monitoring, precision agriculture, and AI-driven analytics within oil-palm systems.

3.3 Citation Analysis

Table 1 delineates the 10 most-cited documents within the dataset pertaining to technol ogical innovation, artificial intelligence, the Internet of Things, and precision agriculture, specifically in relation to palm oil and bio-based systems. The table enumerates the citation counts, authors, publication years, and titles of each document, offering a comprehensive overview of the foundational works that influence contemporary discourse on smart monitoring, digital decision-support, biochemical processing of palm-oil derivatives, and sustainable biofuel production.

Table 1. The Most Impactful Literatures

Citations	Authors and year	Title
99	Shelare, S.D., Belkhode, P.N., Nikam, K.C., ... Nizami, A.-S., Rehan, M. (2023)	Biofuels for a sustainable future: Examining the role of nano-additives, economics, policy, internet of things, artificial intelligence and machine learning technology in biodiesel production
53	Wong, Y.J., Nakayama, R., Shimizu, Y., ... Muhammad Rashid, I.Z., Nik Sulaiman, N.M. (2021)	Toward industrial revolution 4.0: Development, validation, and application of 3D-printed IoT-based water quality monitoring system
40	Anderson, R.N. (2017)	'Petroleum Analytics Learning Machine' for optimizing the Internet of Things of today's digital oil field-to-refinery petroleum system
40	Jiménez, M.J., Esteban, L., Robles, A., ... Muñío, M.M., Molina, E. (2010)	Production of triacylglycerols rich in palmitic acid at sn-2 position by lipase-catalyzed acidolysis
33	Jiménez, M.J., Esteban, L., Robles, A., ... Muñío, M.M., Molina, E. (2010)	Production of triacylglycerols rich in palmitic acid at position 2 as intermediates for the synthesis of human milk fat substitutes by enzymatic acidolysis
21	Ruslan, A.A., Salleh, S.M., Hatta, S.F.W.M., Sajak, A.A.B. (2021)	IoT Soil Monitoring based on LoRa Module for Oil Palm Plantation
16	Mohd Basir Selvam, N.A., Ahmad, Z., Mohtar, I.A. (2021)	Real Time Ripe Palm Oil Bunch Detection using YOLO V3 Algorithm
15	Nugroho, L.E., Pratama, A.G.H., Mustika, I.W., Ferdiana, R. (2017)	Development of monitoring system for smart farming using Progressive Web App
13	Suhartini, S., Hidayat, N., Rohma, N.A., ... Nurika, I., Melville, L. (2022)	Sustainable strategies for anaerobic digestion of oil palm empty fruit bunches in Indonesia: a review

Citations	Authors and year	Title
13	Zulkifli, C.Z., Sulaiman, S., Ibrahim, A.B., ... Setiawan, M.I., Chiang, H.H. (2022)	Smart Platform for Water Quality Monitoring System using Embedded Sensor with GSM Technology

Source: Scopus, 2025

The distribution of highly cited publications indicates that the knowledge foundation for technical innovation in the palm oil sector is rooted in both plantation-level applications and interdisciplinary research in energy and digital technologies. [27] prioritize the integration of nano-additives, artificial intelligence, the Internet of Things, and machine learning in a holistic perspective on biodiesel production, demonstrating a significant focus on end-use energy systems and advanced process optimization rather than solely on plantation management. [28], [29], [30] examine IoT-based and sensor-driven water-quality monitoring and digital oil-field analytics, demonstrating that the generic Industry 4.0 infrastructure for monitoring and control serves as a crucial foundation for subsequent applications in palm-oil supply chains. Concurrently, numerous highly referenced publications are more explicitly associated with palm oil agronomy and processing. Jiménez et al. (2010a; 2010b) investigate the enzymatic synthesis of triacylglycerols abundant in palmitic acid as pr ecursors for useful fats, highlighting a significant biochemical aspect of palm oil research. [31], [32] implement IoT and computer vision methodologies in oil palm farms via soil-monitoring systems and real-time identification of ripe bunches utilizing YOLO V3, illustrating definitive applications of precision agriculture. [30], [33] further this trajectory by creating smart-farming and smart-platform solutions, whilst [34] concentrate on the sustainable anaerobic digestion of empty fruit bunches, connecting technical innovation to circular-economy initiatives. The table indicates that the citation core of the area is established at the convergence of generic digital technologies, energy and biofuel systems, and increasingly specialized palm-oil applications, highlighting the multidisciplinary nature of technical innovation in this sector.

3.4 Density Visualization

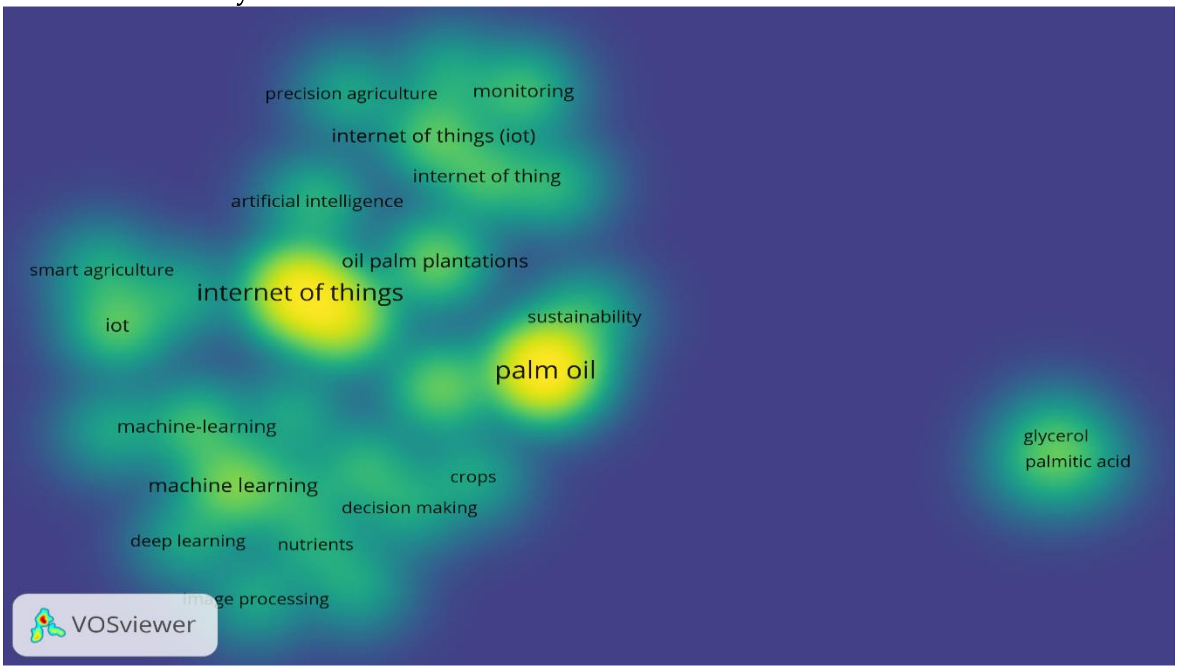

Figure 3. Density Visualization

Source: Data Analysis Result, 2025

The density graphic illustrates map identifies two primary "hot spots" in the literature: "internet of things" on the left and "palm oil" on the right. Their vivid yellow hue signifies that they are the most prevalent and strongly associated keywords in the corpus. The internet of things encompasses a plethora of associated terms—smart agriculture, IoT, precision agriculture, monitoring, artificial intelligence, and oil palm plantations—indicating that recent research predominantly focuses on sensor-based monitoring and interconnected systems for the management of oil palm fields. This indicates that IoT-enabled smart farming is a prevailing technical topic, serving as the primary conduit for the application of AI and precision agriculture concepts within the oil-palm sector.

A secondary core area, focused on palm oil and intricately associated with sustainability, constitutes another zone of high density, signifying that dialogues regarding technological innovation are deeply integrated into wider conversations on sustainable palm oil production and plantation management. Encompassing this are somewhat dense areas pertaining to machine learning, deep learning, image processing, nutrients, decision-making, and crops, indicative of an expanding still somewhat peripheral body of research employing AI and data analytics to facilitate agronomic decisions. Conversely, the distinct green area for glycerol and palmitic acid on the right illustrates a more specialized, less integrated research niche concentrating on biochemical process ing and by-products, somewhat isolated from the primary discussions on smart agriculture and sustainability. The density visualization indicates that the topic is organized around a nexus of IoT, palm oil, and sustainability, with AI and biochemical studies serving as significant yet more peripheral subdomains.

3.5 Co-Authorship Network

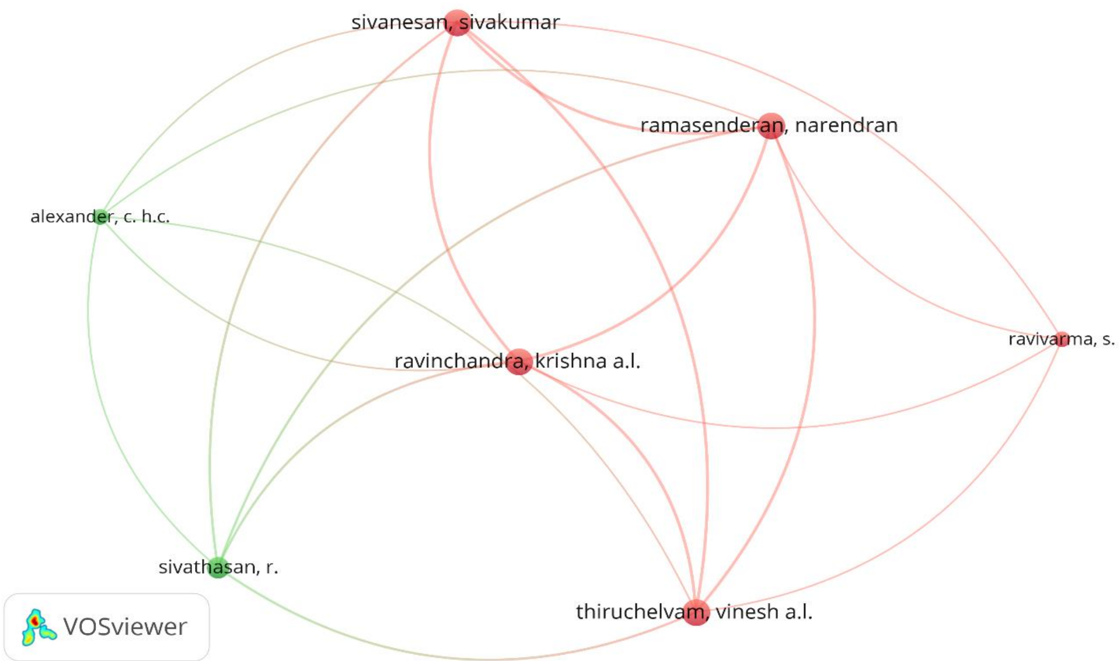

Figure 4. Author Visualization
Source: Data Analysis Result, 2025

The VOSviewer co-authorship map illustrates a compact yet cohesive collaboration network with two interrelated groups. The red cluster is mostly composed of Thiruchelvan Vinesh A.L., Sivanesan Sivakumar, Ramasenderan Narendran, Ravinchandra Krishna A.L., and Ravivarma S., who exhibit significant interconnections, suggesting frequent co-authorship and a cohesive research group. Thiruchelvan Vinesh A.L. serves as a pivotal node within this group, interconnected with all other authors in the cluster, so presumably functioning as the principal or coordinating researcher. Sivathasan R. and Alexander C.H.C. constitute a collaborative pair, with connections to the red cluster through joint publications, such as those with Ravinchandra Krishna A.L. The picture indicates that research on this topic is primarily propelled by a core group of authors engaged in intensive internal collaboration, supplemented by a smaller, partially interconnected cohort, rather than by numerous independent, loosely affiliated scholars.

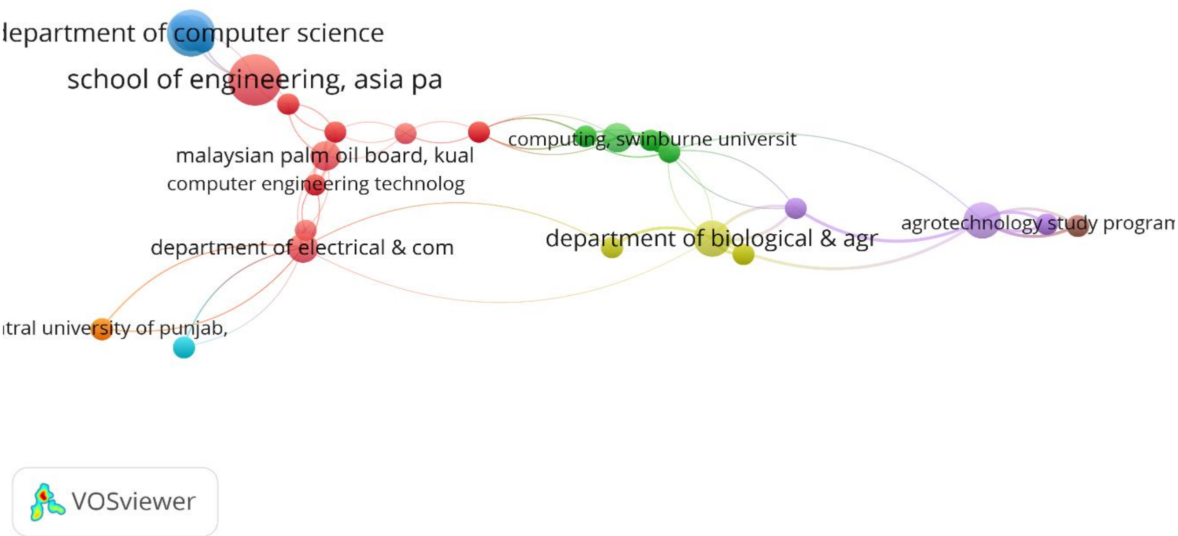

Figure 5. Affiliation Visualization
Source: Data Analysis Result, 2025

The affiliation network indicates that research on technological innovation in the palm-oil sector is propelled by multidisciplinary interactions between engineering/ICT units and agricultural/biological departments. On the left, the School of Engineering, Department of Computer Science, and associated units such as Computer Engineering Technology and the Department of Electrical & Communication constitute a dense red cluster, closely connected with the Malaysian Palm Oil Board—signifying robust affiliations between technical faculties and the principal sectoral agency in Malaysia. This engineering hub is linked to a green cluster surrounding Computing at Swinburne University, which subsequently connects to yellow and purple nodes, including the Department of Biological & Agricultural Sciences and the Agrotechnology Study Program, indicating the integration of computer science and data-driven expertise with agronomy and agrotechnology sectors. Peripheral nodes such as the Central University of Punjab indicate nascent or infrequent international cooperation. The map highlights that innovative efforts in AI, IoT, and precision agriculture for palm oil are rooted in interdisciplinary collaborations that integrate digital technology with specialized agricultural expertise.

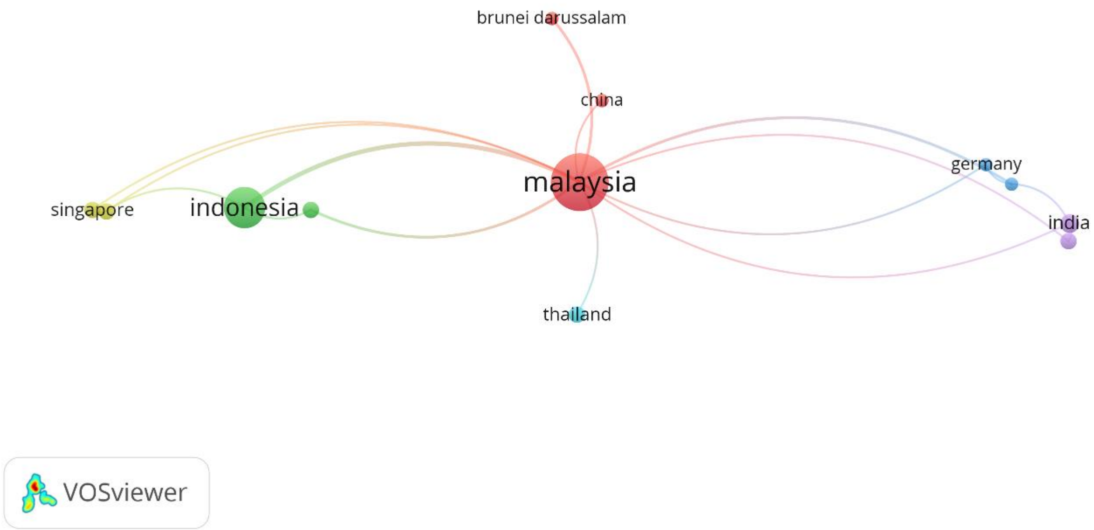

Figure 6. Country Visualization
Source: Data Analysis Result, 2025

The VOSviewer co-country collaboration map reveals that Malaysia serves as the primary center for research on technological innovation in the palm oil sector, exhibiting the highest node size and the most robust connections to other nations. Malaysia engages in extensive collaboration with Indonesia, underscoring their status as the foremost global producers of palm oil, and maintains significant connections with Singapore, presumably influenced by regional expertise in ICT and engineering. Conversely, links between Malaysia and India, as well as Germany, indicate the development of North–South collaborations, especially in engineering, environmental technology, and bioenergy. Subtle yet discernible connections to China, Brunei Darussalam, and Thailand indicate that these nations engage in the network primarily through collaborative projects with Malaysian institutions rather than functioning as autonomous centers of collaboration. The map illustrates a collaborative framework centered on Malaysia and dominated by Southeast Asia, featuring selective connections to prominent research economies beyond the area.

Discussions

Practical Implications

This bibliometric analysis offers a systematic overview of the applications of AI, IoT, and precision agriculture within the palm oil industry, serving as a direct resource for policymakers, corporations, and technology suppliers. The findings demonstrate that research hotspots concentrat e on IoT-based monitoring, smart sensors, and machine-learning image analysis, highlighting priority investment areas: field-level sensing (soil, water, and tree condition), yield and ripeness d etection, and digital platforms for real-time plantation management. Entities like the Malaysian Palm Oil Board, Indonesian ministries, and certification organizations can leverage these insights to formulate targeted funding strategies, pilot initiatives, and extension programs that expedite the dissemination of the most advanced technologies, rather than duplicating disjointed efforts. The pronounced regional concentration of production in Malaysia and Indonesia, coupled with developing connections to Germany, India, Singapore, and China, underscores significant op portunities for establishing international R&D consortia and capacity-building initiatives centered o n data infrastructure, open datasets, and interoperable standards for palm oil digitalization.

For practitioners and industry stakeholders, the mapping of keywords and highly cited articles provides a "menu" of validated technology solutions that may be tailored to specific local settings. Plantation enterprises and smallholder associations can pinpoint proven technologies—such as IoT soil-monitoring systems, water-quality sensors, and computer-vision tools for bunch detection—and utilize bibliometric evidence to collaborate with universities and startups for co-development. Sustainability officers and NGOs observe that the majority of digital innovation remains focused on productivity and monitoring, with comparatively limited efforts directly connecting AI/IoT to smallholder inclusion or social safeguards. This disparity indicates a pragmatic agenda: development pilot initiatives and commercial frameworks that integrate digital tools with training, collaborative arrangements, and financial strategies, enabling smallholders to engage in and gain from Industry 4.0 advancements, rather than being marginalized.

Theoretical Contributions

This study theoretically enhances the literature at the convergence of technical innovation, agricultural digitalization, and commodity-specific ecosystem analysis in multiple ways. This research enhances generic frameworks of smart agriculture and precision farming by illustrating the configuration of AI, IoT, and precision agriculture within the specific, high-impact commodity system of palm oil, which is marked by intricate land-use conflicts, global value chains, and a dual structure comprising large estates and smallholders. The co-occurrence and density analyses indicate that the "IoT–palm oil–sustainability" nexus is the predominant knowledge cluster, sugges ting that in this sector, digital technologies are seen not merely as efficiency aids but also as mechanisms for monitoring environmental performance and compliance. This enhances and refines current models of agricultural digitalization that are often crop-agnostic and mostly focused on productivity.

Secondly, the study enhances innovation-ecosystem and bibliometric theory by actually illustrating how technological trajectories within a commodity sector can be deduced from the configuration of scientific collaboration and keyword networks. Malaysia's centrality, combined with the engineering-computer science departments and their connections to biological and agrotechnology divisions, exemplifies how cross-disciplinary and cross-national networks facilitate the development of digital innovation niches in the Global South. The study provides a methodological framework for future sector-specific bibliometric analyses of digital transformation in other agricultural or resource-based industries by integrating performance indicators (most-cited works, productive institutions) with science-mapping techniques (co-authorship, co-citation, and keyword clusters).

Limitations and Future Research Directions

This study possesses multiple limitations that must be recognized when evaluating its resu lts. The analysis is predominantly based on documents indexed in major worldwide databases (e.g., Scopus, Web of Science) and limited to English-language publications. Consequently, significant technical publications, articles in local languages, theses, and industry white papers—especially those generated by regional research institutes, government entities, or private firms in producing nations—may be inadequately represented. This bias may result in an over focus on internationally prominent research, while undervaluing locally pertinent advances and grassroots experimentation with digital tools. Secondly, the bibliometric method identifies patterns in publication, citation, and co-occurrence; yet, it is incapable of thoroughly evaluating the real-world adoption, efficacy, or societal implications of technology. Extensively referenced articles and concentrated keyword groups may indicate scholarly interest rather than effective application in plantations or smallholder communities.

Furthermore, the selection of keywords and temporal parameters, along with the data cleaning and clustering settings in VOSviewer and Biblioshiny, inherently influences the resultant maps and clusters. While the study adheres to recognized bibliometric methodologies, varying parameter configurations or a broader search string (e.g., include terms related to robots, blockchain, or drones) could produce marginally distinct structures and thematic focuses. The approach is predominantly cross-sectional in its visual representations, providing a restricted dynamic perspective on the emergence and decrease of research fronts across time. Future research may integrate this bibliometric foundation with qualitative content analysis, expert interviews, or case studies of particular projects to enhance comprehension of the transition of digital technologies from experimental prototypes to mainstream applications, their interaction with governance and certification frameworks, and their impact on the livelihoods and negotiating power of smallholders and plantation workers within the palm-oil innovation ecosystem.

CONCLUSION

This bibliometric analysis delineated the scientific terrain of technological innovation within the palm oil sector, emphasizing the uses of artificial intelligence (AI), the Internet of Things (IoT), and precision agriculture. The data indicates that research output in this domain has significantly increased over the past decade, with palm oil becoming a pivotal element closely associated with keywords such as internet of things, machine learning, smart agriculture, and sustainability. The density and overlay visualizations illustrate a nexus of "IoT–palm oil–sustainability": the predominant research focus is on sensor-based monitoring, interconnected devices, and data-driven platforms employed to manage oil palm farms while concurrently addressing environmental issues. Machine learning and deep learning methodologies, especially in image processing and decision support, constitute a significant although rather ancillary component that is progressively merging with IoT frameworks. The network of authors, affiliations, and nations highlights the geographical and multidisciplinary characteristics of this research field. Malaysia and Indonesia, as prominent producing nations, serve as geographic hubs, with Malaysian institutions being particularly pivotal in cross-national partnerships. At the institutional level, engineering, computer science, and electrical/electronic departments closely collaborate with agricultural and biological sciences units, as well as with sectoral agencies like the Malaysian Palm Oil Board, demonstrating that digital transformation in palm oil is propelled by interdisciplinary partnerships that integrate domain knowledge and digital expertise. Simultaneously, the bibliometric evidence underscores other deficiencies. A significant portion of the extensively referenced research highlights technical feasibility and productivity, whereas there is a notable deficiency in focus on smallholder participation, social ramifications, and the governance of digital data. Research linking AI and IoT directly to certification frameworks, labor circumstances, or community-level advantages remains few. Moreover, a specialized yet somewhat insular group of papers concentrates on biochemical processing and its by-products (e.g., glycerol, palmitic acid), indicating that the integration between upstream digital agriculture and downstream processing technologies is insufficiently advanced. The study concludes that technological innovation in the palm oil sector is advancing swiftly but inconsistently: the scientific basis for IoT-based monitoring and AI-enabled analytics is robust, yet there are opportunities to integrate these advancements with an inclusive, sustainability-focused transformation of the wider palm oil ecosystem.

REFERENCES

[1] K. L. Chong, K. D. Kanniah, C. Pohl, and K. P. Tan, "A review of remote sensing applications for oil palm studies," *Geo-spatial Inf. Sci.*, vol. 20, no. 2, pp. 184–200, 2017.

[2] C. H. Lim *et al.*, "A review of industry 4.0 revolution potential in a sustainable and renewable palm oil industry: HAZOP approach," *Renew. Sustain. Energy Rev.*, vol. 135, p. 110223, 2021.

[3] L. Dahliani, S. Wirandayu, and M. Dewantara, "Implementation of technology 4.0 in achieving the effectivity and efficiency of the production process in palm oil plantation," in *E3S Web of Conferences*, EDP Sciences, 2022, p. 11.

[4] M. A. M. Zaki *et al.*, "Impact of industry 4.0 technologies on the oil palm industry: A literature review," *Smart Agric. Technol.*, vol. 10, p. 100685, 2025.

[5] N. C. Eli-Chukwu, "Applications of artificial intelligence in agriculture: A review.," *Eng. Technol. Appl. Sci. Res.*, vol. 9, no. 4, 2019.

[6] W. Syafitri, S. A. Prestianawati, M. Fawwaz, T. L. Imamia, and A. Rasli, "Factors Influencing Individuals to Be Involved in Informal Economic Sectors in Indonesia," *Int. J. Soc. Sci. Bus.*, vol. 8, no. 4, p. press-press, 2024.

[7] J. Botero-Valencia *et al.*, "Machine learning in sustainable agriculture: systematic review and research perspectives," *Agriculture*, vol. 15, no. 4, p. 377, 2025.

[8] M. Nautiyal, "The Intersection of Diversity, Equity, and Inclusion in Management Practices: A Descriptive Study," *PsychologyandEducation*, vol. 55, no. 1, pp. 608–615, 2023, doi: 10.48047/pne.2018.55.1.74.

[9] N. S. Abu *et al.*, "Internet of things applications in precision agriculture: A review," *J. Robot. Control*, vol. 3, no. 3, pp. 338–347, 2022.

[10] S. Malik *et al.*, "Deep learning based predictive analysis of energy consumption for smart homes," *Multimed. Tools Appl.*, vol. 84, no. 12, pp. 10665–10686, 2025.

[11] S. Sumarsono, N. Muflihah, and F. A. N. F. Afiatna, "The internet of things research in agriculture: A bibliometric analysis," *Int. J. Agric. Syst.*, pp. 1–20, 2024.

[12] A. Rejeb, K. Rejeb, A. Abdollahi, and A. Hassoun, "Precision agriculture: a bibliometric analysis and research agenda," *Smart Agric. Technol.*, p. 100684, 2024.

[13] V. K. D. Dagbelou, S. Bah, S. A. Adekambi, and J. A. Yabi, "Bibliometric and economic analysis in precision agriculture," *DAAfrica'2024 Data Sci. Agric. Africa*, p. 58, 2025.

[14] M. K. Rosyidy and E. Frimawaty, "Spatiotemporal analysis of oil palm land clearing," *Glob. J. Environ. Sci. Manag.*, vol. 10, no. 2, pp. 821–836, 2024.

[15] M. S. Ozigis, S. Wich, A. Descals, Z. Szantoi, and E. Meijaard, "Mapping oil palm plantations and their implications on forest and great ape habitat loss in Central Africa," *Remote Sens. Ecol. Conserv.*, vol. 11, no. 3, pp. 339–356, 2025.

[16] F. Granà, G. Achilli, E. Giovannoni, and C. Busco, "Towards a future-oriented accountability: accounting for the future through Earth Observation data," *Accounting, Audit. Account. J.*, vol. 37, no. 5, pp. 1487–1511, 2024.

[17] A. F. Gunawan, "The impact of entrepreneurial characteristics and competencies on business performance in the creative industry in Indonesia," *Asia Pacific J. Innov. Entrep.*, vol. 18, no. 3, pp. 300–317, 2024.

[18] H. Wulansari, D. D. Putri, and R. N. Gunawan, "Global Research Trends on AI and IoT in Precision Agriculture: A VOSviewer Analysis (2021–2024)," *J. Sci. Agrotechnology*, vol. 2, no. 2, pp. 1–11, 2024.

[19] T. D. Hendrawati, P. Narputro, F. A. Wicaksana, and A. Suryana, "Bibliometric Analysis of IoT-Driven Smart Agriculture and Irrigation Management Research: Trends, Topics, and Publication Patterns (2019-2024)," *Fidel. J. Tek. Elektro*, vol. 7, no. 2, pp. 130–140, 2025.

[20] I. Zupic and T. Čater, "Bibliometric methods in management and organization," *Organ. Res. methods*, vol. 18, no. 3, pp. 429–472, 2015.

[21] P. Mongeon and A. Paul-Hus, "The journal coverage of Web of Science and Scopus: a comparative analysis," *Scientometrics*, vol. 106, no. 1, pp. 213–228, 2016.

[22] M. Aria and C. Cuccurullo, "bibliometrix: An R-tool for comprehensive science mapping analysis," *J. Informetr.*, vol. 11, no. 4, pp. 959–975, 2017.

[23] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, 2021.

[24] J. A. Moral-Muñoz, E. Herrera-Viedma, A. Santisteban-Espejo, and M. J. Cobo, "Software tools for conducting bibliometric analysis in science: An up-to-date review," *Prof. la Inf.*, vol. 29, no. 1, 2020.

[25] N. Van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, 2010.

[26] N. J. Van Eck and L. Waltman, "Visualizing bibliometric networks," in *Measuring scholarly impact: Methods and practice*, Springer, 2014, pp. 285–320.

[27] S. D. Shelare *et al.*, "Biofuels for a sustainable future: Examining the role of nano-additives, economics, policy, internet of things, artificial intelligence and machine learning technology in biodiesel production," *Energy*, vol. 282, p. 128874, 2023.

[28] Y. J. Wong *et al.*, "Toward industrial revolution 4.0: Development, validation, and application of 3D-printed IoT-based water quality monitoring system," *J. Clean. Prod.*, vol. 324, p. 129230, 2021.

[29] R. N. Anderson, "'Petroleum Analytics Learning Machine'for optimizing the Internet of Things of today's digital oil field-to-refinery petroleum system," in *2017 IEEE International Conference on Big Data (Big Data)*, IEEE, 2017, pp. 4542–4545.

[30] C. Z. Zulkifli *et al.*, "Smart Platform for Water Quality Monitoring System using Embedded Sensor with GSM Technology," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 95, no. 1, pp. 54–63, 2022.

[31] A. A. Ruslan, S. M. Salleh, S. Hatta, and A. A. B. Sajak, "IoT soil monitoring based on LoRa module for oil palm plantation," *Int. J. Adv. Comput. Sci. Appl.*, vol. 12, no. 5, pp. 215–220, 2021.

[32] N. A. M. B. Selvam, Z. Ahmad, and I. A. Mohtar, "Real time ripe palm oil bunch detection using YOLO V3 algorithm," in *2021 IEEE 19th Student Conference on Research and Development (SCOReD)*, IEEE, 2021, pp. 323–328.

[33] L. E. Nugroho, A. G. H. Pratama, I. W. Mustika, and R. Ferdiana, "Development of monitoring system for smart farming using Progressive Web App," in *2017 9th International Conference on Information Technology and Electrical*

Engineering (ICITEE), IEEE, 2017, pp. 1–5.

[34] S. Suhartini *et al.*, "Sustainable strategies for anaerobic digestion of oil palm empty fruit bunches in Indonesia: a review," *Int. J. Sustain. Energy*, vol. 41, no. 11, pp. 2044–2096, 2022.